Geology and Mineral Resources

of

Box Elder County, Utah

by Hellmut H. Doelling

with

Jock A. Campbell

J. Wallace Gwynn

Lee I. Perry

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of the
UTAH DEPARTMENT OF NATURAL RESOURCES

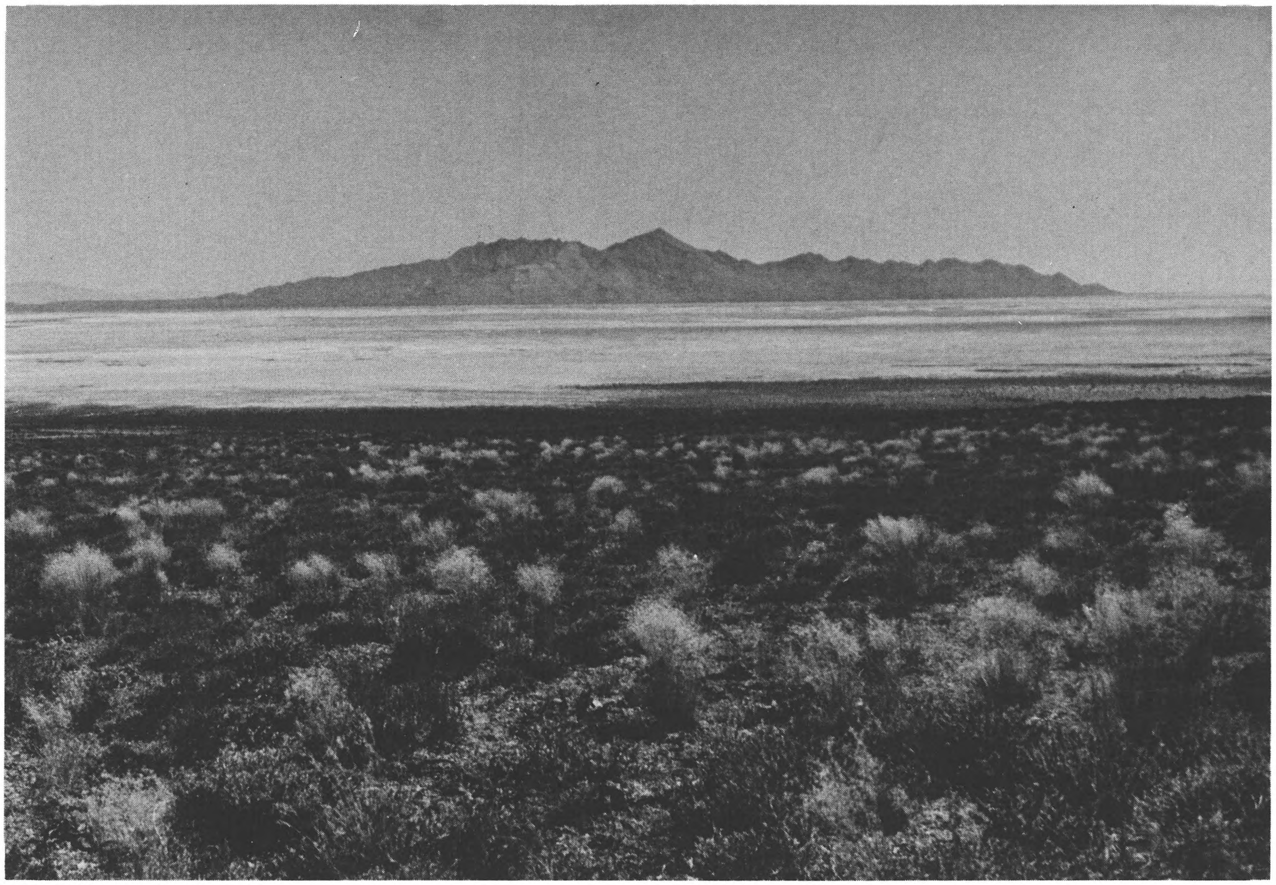
BULLETIN 115, 1980

Geology and Mineral Resources of Box Elder County, Utah

by Hellmut H. Doelling

Part 1

Geology



The Newfoundland Mountains are surrounded by the mudflat of the Great Salt Lake Desert and typically illustrate mountain ranges of the "western desert". Note the desert shrubbery in the foreground.

CONTENTS

ILLUSTRATIONS

Part 1

Part 2

TABLES

Part 1

Part 2

PHOTOGRAPHS

Part 1

Part 2

PLATES

GEOLOGY AND MINERAL RESOURCES OF BOX ELDER COUNTY, UTAH

by Hellmut H. Doelling[1]

INTRODUCTION

Box Elder County is situated in the northwest corner of Utah bordering with Idaho on the north, Nevada on the west, Tooele and Weber counties on the south and Cache County on the east. It comprises a land area of 5,594 square miles and a large part of the Great Salt Lake (approximately an additional 800 square miles). It is the fourth largest county in Utah and for comparison is a little larger than Connecticut (4,862 square miles) and a little smaller than Hawaii (6,425 square miles).

Physiography

The elevation ranges from a low of 4,200 feet (Great Salt Lake) to a maximum of nearly 10,000 feet. Three physiographic types make up Box Elder County and each shares a nearly equal area.

The first consists of the mud flats of the Great Salt Lake Desert and the shorelines of the Great Salt Lake, a very flat, gray expanse with a very shallow water table. Its surface is mostly devoid of plant life because of the highly saline nature of the ground water and the impermeable surface mud. Small areas of gypsite, oolite or sand dunes are found in places near the edges of the mud flat.

The mountainous land makes up the second physiographic type and stands in contrast with the featureless mud flat. Several mountain ranges with a rough north-south alignment are scattered across the area. There is one notable east-west aligned range near the north boundary of the county. The mountainous land consists mainly of hard consolidated bedrock and its weathered products. The dominant rock types are limestone, dolomite, quartzite, and igneous rock. Prominent mountain ranges include the Goose Creek, Pilot, Newfoundland, Grouse Creek, Raft River, Hogup, Terrace, Lakeside, Hansel (Summer Ranch), Promontory, North Promontory, West Hills, Clarkston Mountain and Wasatch ranges.

Surrounding the mountains and extending to the edges of the mudflat is a broad slope that constitutes the third physiographic type. Alluvial fans, bajadas, pediments, lake terraces, and other fluvial and lacustrine landforms dominate this area. Most of the surface is naturally vegetated by sagebrush, shadscale, and other desert shrubbery and grasses while the higher areas support a pinion-juniper woodland. From a distance the slope appears smooth and uninterrupted, but close examination often reveals deep gullies of intermittent washes and drainages. The materials which make up this slope are mainly clastics, from the finest particulate matter to boulders, mostly unconsolidated or partly consolidated. Physiographic and topographic maps showing the more important drainages and the larger physical features are given as figures 1a and 1b.

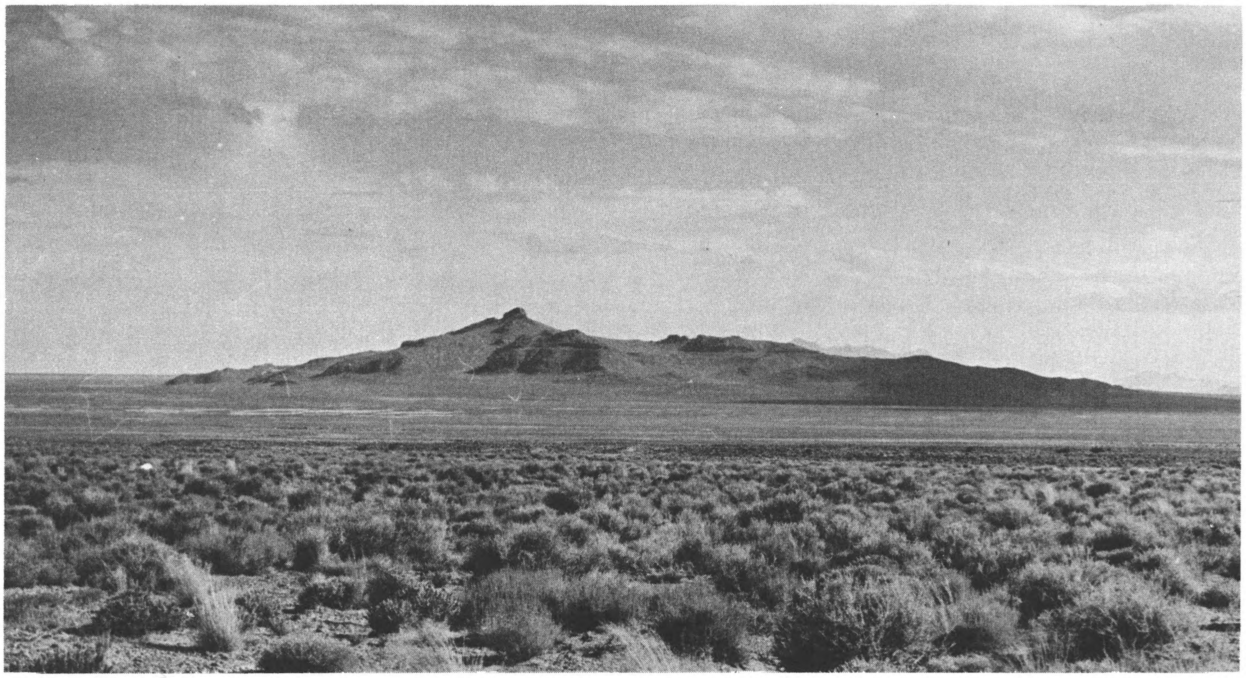
Climate

Three climates are present in Box Elder County; mid-latitude desert, mid-latitude steppe, and mountain. Desert conditions prevail over the mud flat areas and on the lower half of the slope. Annual precipitation ranges from 4 to 8 inches; the mean January temperature is in the low 20s (degrees F) and the mean July temperature is in the 70s. Minimum winter temperatures can dip below zero and maximum summer temperatures occasionally exceed 100 degrees F. Precipitation is irregular but distributed equally throughout the year. Desert recording stations are at Lemay and Lucin (figure 2).

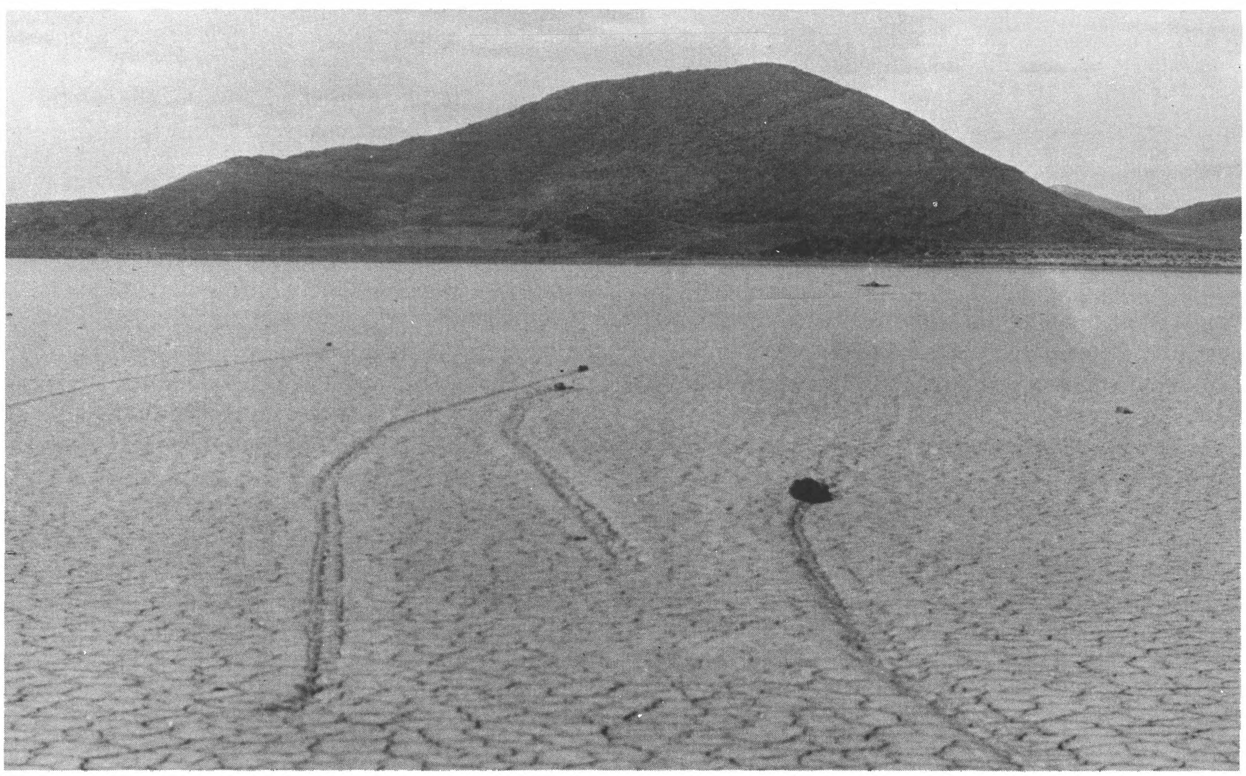
A steppe climate affects the remainder of the slope and extends into the mountains to an elevation of about 7,500 feet. The lower mountain ranges are completely in this climatic zone. The annual precipitation ranges from 8 to 16 inches with the higher elevations receiving the greater amount (figure 3). The mean January temperature ranges from the teens to the low 20s and is dependent upon local conditions. The mean July temperature ranges from the high 60s into the low 70s. Generally temperatures are slightly lower than in the desert area. Somewhat milder conditions prevail in desert and steppe areas adjacent to the Great Salt Lake. Grouse Creek, Park Valley, Snowville, Tremonton, and Brigham City are steppe stations. Climographs for Grouse Creek and Park Valley are given in figure 2.

Mountain climates prevail above 7,500 feet, the largest areas of which are located in the northern and eastern parts of the county. The greatest amount of precipitation occurs in the Raft River Mountains and

[1] Chief, Economic Geology Section, Utah Geological and Mineral Survey.



P 1. Numerous isolated knolls and mountains are scattered in and around the Great Salt Lake Desert in the western part of Box Elder County. This one is known as Pigeon Mountain and is mostly Permian Rex Chert.



P 2. Mud-cracked surface east of the Lakeside Mountains showing rock trails. The knoll in the background consists of Upper Cambrian dolomite. Friction is reduced to almost nothing when the surface is wet, and winds are able to push rocks up to a few feet in diameter for distances of many yards.

P 3. Shoreline of the Great Salt Lake near Rozel Point. Basalt outcrops project as peninsulas into the lake. Much of Great Salt Lake is in Box Elder County.

P 4. View of a segment of the Raft River Mountains (south side). The white outcrops are of the Elba Quartzite. The Elba (Precambrian Z) rests unconformably upon the Older Schist and Adamellite Gneiss making up the core of the range. The latter two units are Precambrian X in age.

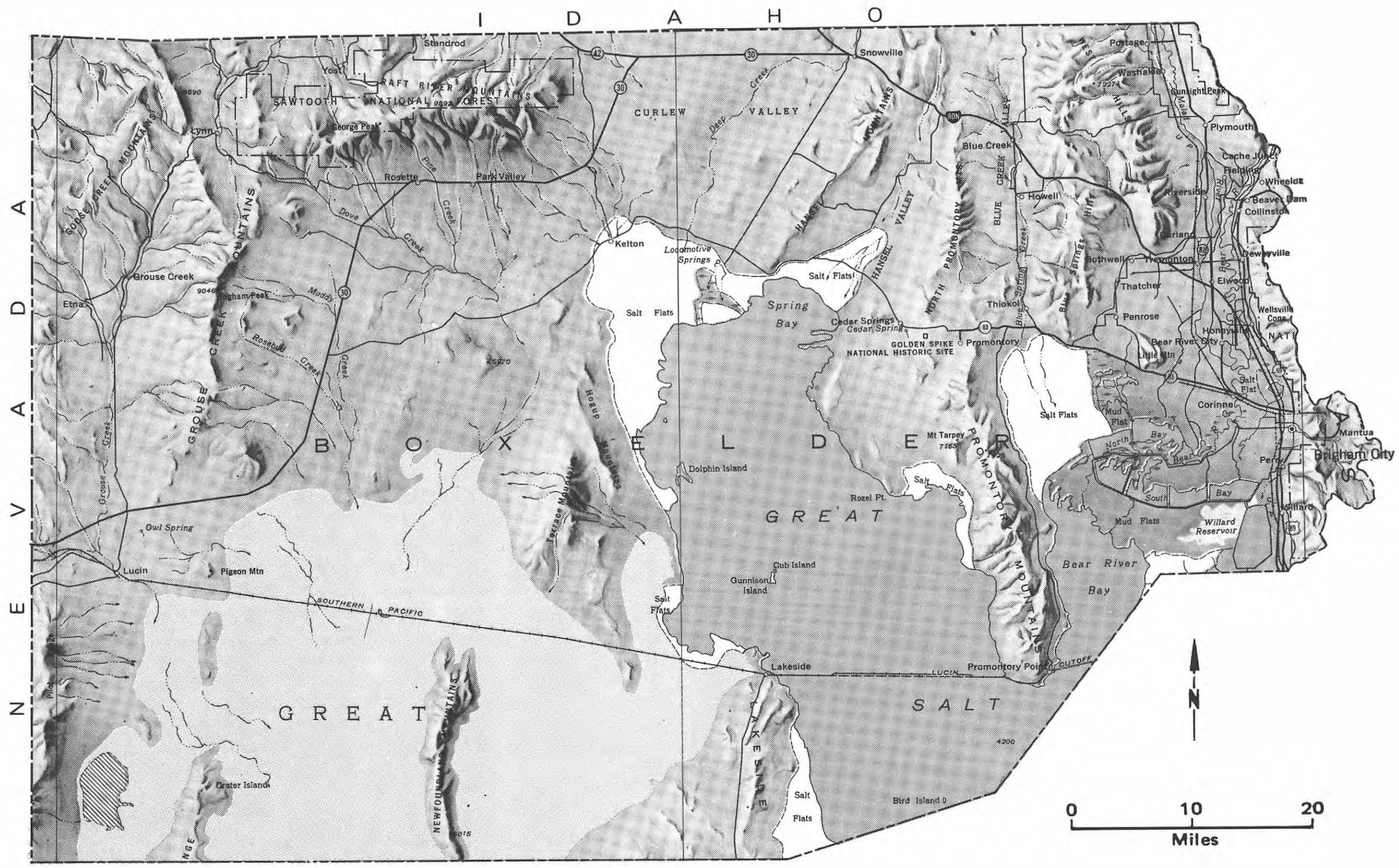


Figure 1a. Physiographic map of Box Elder County, Utah

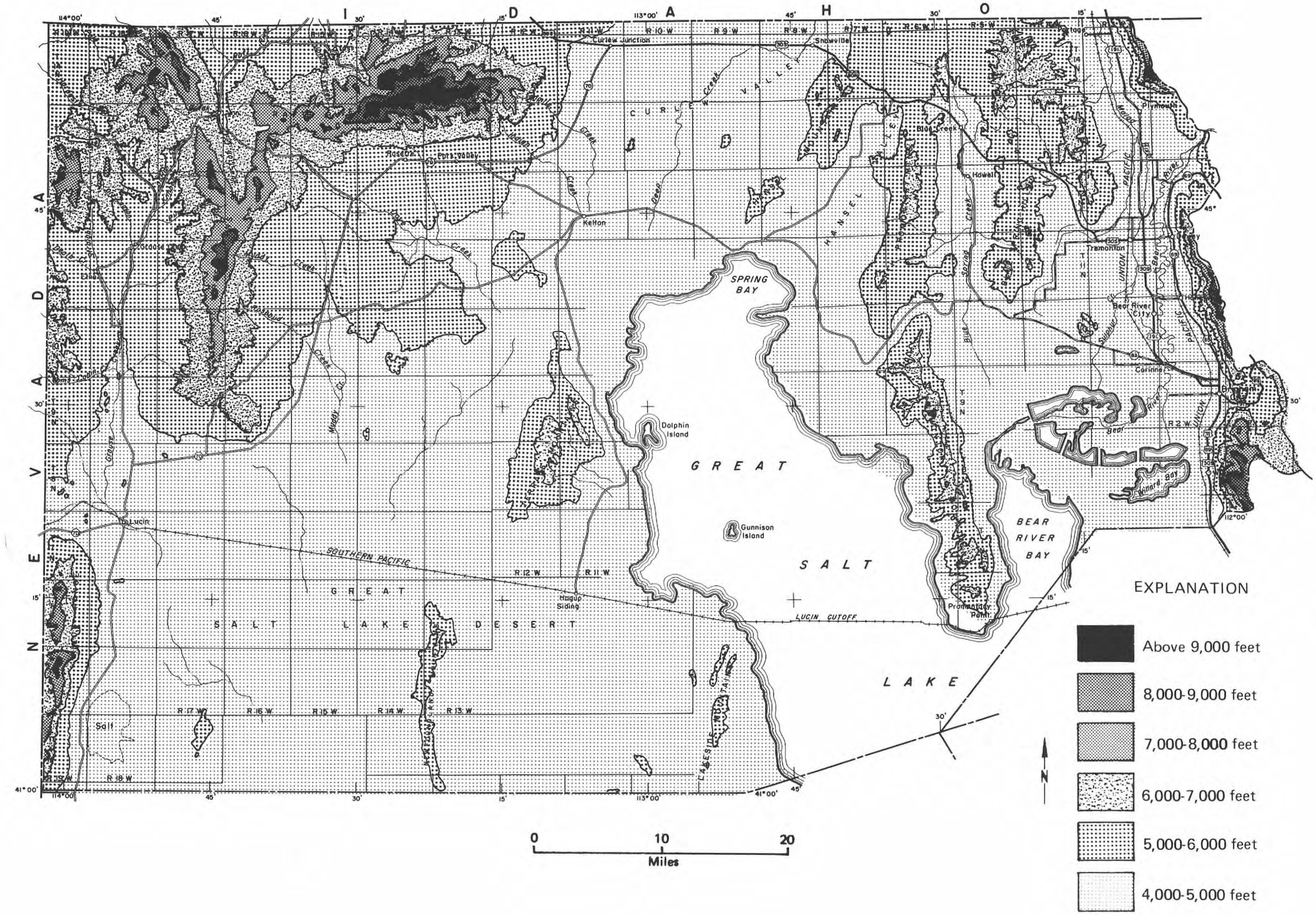


Figure 1b. Generalized topographic map of Box Elder County, Utah

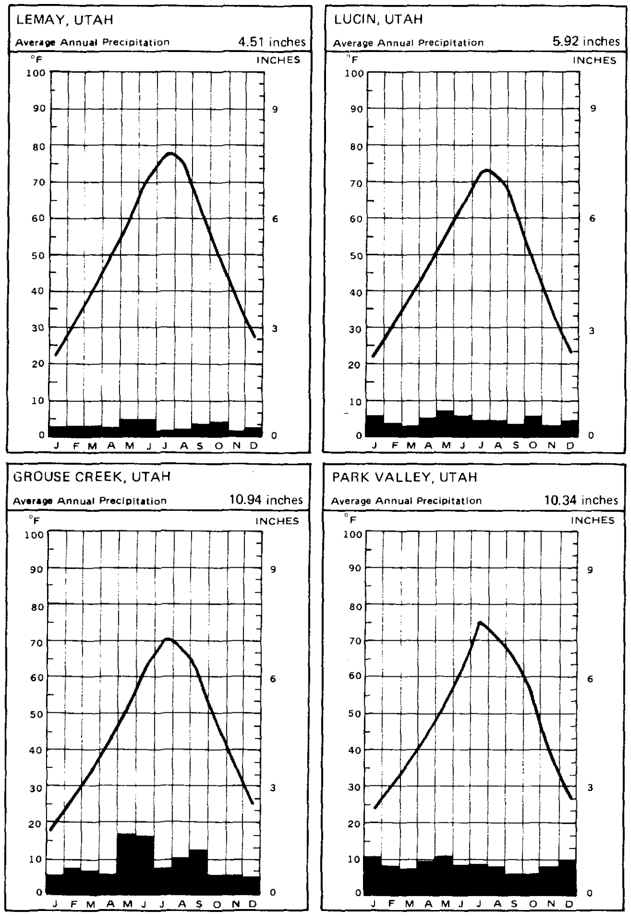


Figure 2. Climographs of Middle Latitude Dry stations. Lines show temperatures; bars show rainfall.

in the Wasatch Range, both areas exceeding 30 inches. The climatic variations as found in these mountains are the results of local conditions and local physiography. The temperature range is as wide as that found in the desert and steppe areas; however, the average drops with increased altitude. Precipitation is highest during winter and summer months, the first in response to cyclonic storms, the latter to convection. Areas above 8,500 feet are generally inaccessible during the winter months because of heavy snow accumulation.

Land Use

The principal land use is for agricultural purposes. In the area west of Great Salt Lake the mountainous and slope lands are primarily used for grazing; choice areas with available water are used to produce hay and forage. The larger of such areas are found at the base of the higher mountain ranges that are the source of permanent streams (Raft River, Grouse Creek, and Goose Creek ranges). Little use is made of the mud flat; the U. S. Air Force (Hill Air Force Range) occasionally uses part of it for its military testing activities. It maintains a small permanent force south of Lakeside on the west side of Great Salt Lake.

In the area between Curlew Valley and the West Hills north of Great Salt Lake both dry and irrigated farming is carried out. A greater percentage of the land in this area is cropped, and in addition to hay and forage crops, dry-farm wheat is important. As in the western part of the county very few permanent streams or springs are available and well water is used for irrigation.

Easternmost Bear River Valley is an area of intensive farming. Irrigation water is provided by the Bear River, Malad River and numerous streams originating in the high bordering Wasatch Range to the east. A great variety of vegetables, fruit, sugar beets, corn, potatoes and wheat, along with hay and forage, are produced in the valley.

Population

The population of Box Elder County is 28,129 (1970 census) with most people living in and around the Bear River Valley. Only one or two percent of the people make their home in the region west of Great Salt Lake. The population of the various communities is given in table 1.

Industry

The principal industries in the more populated Bear River Valley are agriculture, manufacturing, government and trade services. Brigham City, the largest community, is the county seat. In areas west and north of the Great Salt Lake the principal industry is agriculture. A large manufacturing plant (Thiokol Chemicals) located south of Howell along the Blue Springs Hills produces rocket fuels and related products, some of which are tested and stored here. Most of the work force lives in the Bear River Valley. A salt plant harvests and packages at the southern tip of the Promontory peninsula at Saline, and the Southern Pacific Railroad traverses east-west across the southern third of the west half of the county. The railroad intermittently operates rock quarries at various locations along the line, especially at Lakeside. Both salt plant and railroad workers maintain their homes out of the area. The U. S. Air Force (Hill Air Force Range) maintains a small force south of Lakeside. Mining activity is scattered throughout the county, but primarily in the mountain areas or

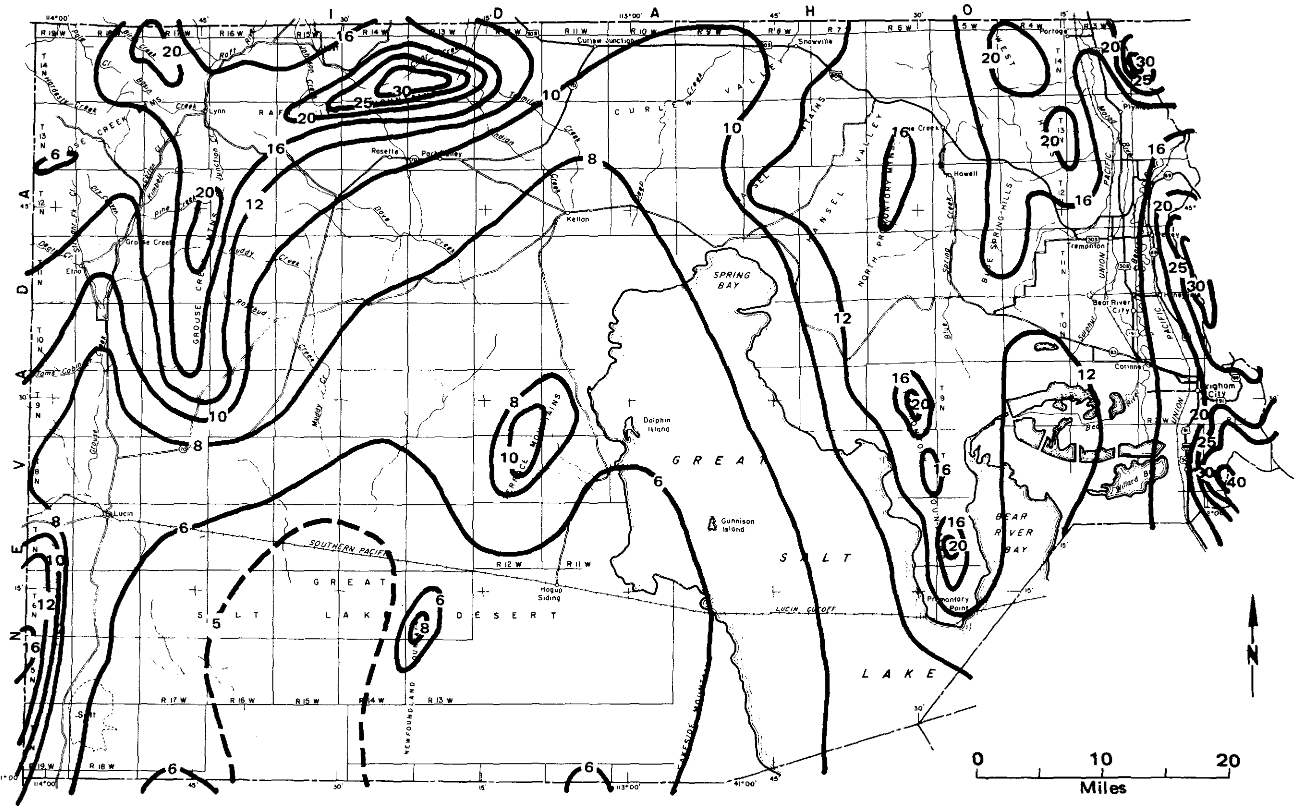


Figure 3. Normal annual precipitation (in inches) Box Elder County, Utah.

upper parts of the slope. In 1975 most mines and quarries were inactive.

Access

Accessibility is primarily by highways and roads that are confined to the slope country. Numerous paved roads provide access to most parts of the Bear River Valley and there are many good secondary roads leading to the high mountains. Access is provided to the edges of the mud flat only where waterfowl management areas have been developed. Box Elder County has five such areas, of which four are in the Bear River Bay area. These include Salt Creek, Public Shooting Grounds, Bear River Migratory Refuge, and Harold S. Crane waterfowl management areas. The Union Pacific Railroad has two north-south lines through Bear River Valley.

North of the Great Salt Lake good access is available into the slope areas that surround the mountain ranges. However, the secondary gravel and dirt roads that lead into the mountain ranges are often in disrepair. Many roads are private and are locked with gates. The Locomotive Springs Waterfowl Management Area is located here.

In the area west of Great Salt Lake the Southern Pacific Railroad traverses the mudflat across the southern third of the county. The railroad maintains a paralleling gravel road which is the only access to the Newfoundland Mountains, and permission for use is necessary. The only paved road is Utah Highway 30, connecting Snowville with Montello, Nevada. The county maintains good gravel roads in the principal valleys between mountain ranges. Mountain roads are often in poor repair.

Land Ownership

Omitting the Great Salt Lake and its relict lands (which belongs to the state of Utah), the ownership of Box Elder County lands is given in table 2 and illustrated on figure 4. In the west the Federal Government is the chief landowner; in the east more than 86 percent is held privately. In the western part of the county the privately owned land is concentrated in the better watered areas at the base of the Grouse Creek and Raft River Mountains and in Curlew Valley. Many of the alternating sections surrounding the old Central Pacific railroad grade in a 36-mile swath from Kelton to Lucin and the Nevada border are the private property of the Southern

Table 1. Population of Box Elder County and its communities, 1970 census.

Bear River Valley and vicinity	Population	
Bear River City	445	
Beaver Dam	65	
Bothwell	302	
Brigham City	14,007	
Collinston	15	
Corinne	471	
Deweyville	248	
Elwood	294	
Fielding	254	
Garland	1,187	
Honeyville	640	
Mantua	413	
Perry	909	
Plymouth	203	
Portage	144	
Riverside	200	
Tremonton	2,794	
Willard	1,045	
Rural and unincorporated	3,912	
Total and percent of county	27,548	(97.9%)
Area north of Great Salt Lake		
Blue Creek	35	
Howell	146	
Snowville	174	
Rural and unincorporated	59	
Total and percent of county	414	(1.5%)
Area west of Great Salt Lake		
Grouse Creek	100	
Park Valley	25	
Yost	51	
Rural and unincorporated	29	
Total and percent of county	205	(0.6%)
Total Box Elder County	28,129	

Pacific Railroad or have been sold by them to private individuals. The railroad extracts rentals for various usages much as does the Bureau of Land Management. Military land is located between the Great Salt Lake and the Newfoundland Mountains south of the Southern Pacific railroad tracks and is used for many kinds of military testing. The area is controlled by Hill Air Force Base and is called the Hill Air Force Range; it includes mountain, slope, and mud flat lands.

State-owned lands show no areas of agglomeration (except Great Salt Lake), and follow the normal arrangement of sections 2, 16, 32, and 36 of every township. State lands have been preempted on the military, forest, and wildlife areas and have been sold in the better watered northern and eastern areas of the county. The National Forest Service lands are a part of the Sawtooth National Forest and are located in the Raft River Mountains. The Locomotive Springs Waterfowl Management Area is located on the north shore of the Great Salt Lake southeast of Kelton.

The eastern part of the county is principally privately owned land and is developed into farms and ranches or is occupied by communities. Several waterfowl management areas are located around Bear River Bay and Willard Bay. The Wasatch National Forest is located in the Wasatch Range along the east boundary of the county. Bureau of Land Management and Utah lands are irregularly scattered and most are found in areas of rocky hills, ridges, or other rough lands.

Table 2. Percentage ownership of lands, Box Elder County, Utah

Ownership (1975)	West (3,937 sq. mi.)	East (1,657 sq. mi.)	Total County (5,594 sq. mi.)
Federal Government land			
Bureau of Land Manage-land	41.5%	3.2%	30.1%
Military (Air Force)	8.2	---	5.8
National Forest Sv.	2.8	1.3	2.4
Waterfowl Management	0.6	7.3	2.6
Total	53.1	11.8	40.9
State of Utah land	6.2	1.8	4.9
Private land	40.7	86.4	54.2

GEOLOGY

Box Elder County displays a variety of lithologic types in each of the major rock divisions: sedimentary, igneous, and metamorphic, in a typical Basin and Range setting. True to the basic structure most of its mountain ranges generally trend north-south, but the Raft River Range trends east-west. Each mountain range exhibits a variety of structural situations; most stratigraphic units are folded and faulted, and many are intruded by igneous rocks (figure 5). A generalized section of rock units for Box Elder County is given in table 3.

Stratigraphy

Exposed stratigraphic units range in age from Precambrian to Triassic for the more consolidated units and from Tertiary to Quaternary for mostly non-consolidated or partially consolidated units. Jurassic and Cretaceous stratigraphic units are not present. The consolidated units are mostly exposed in the mountain ranges, whereas the non-consolidated or partially consolidated units are usually exposed in the basins or

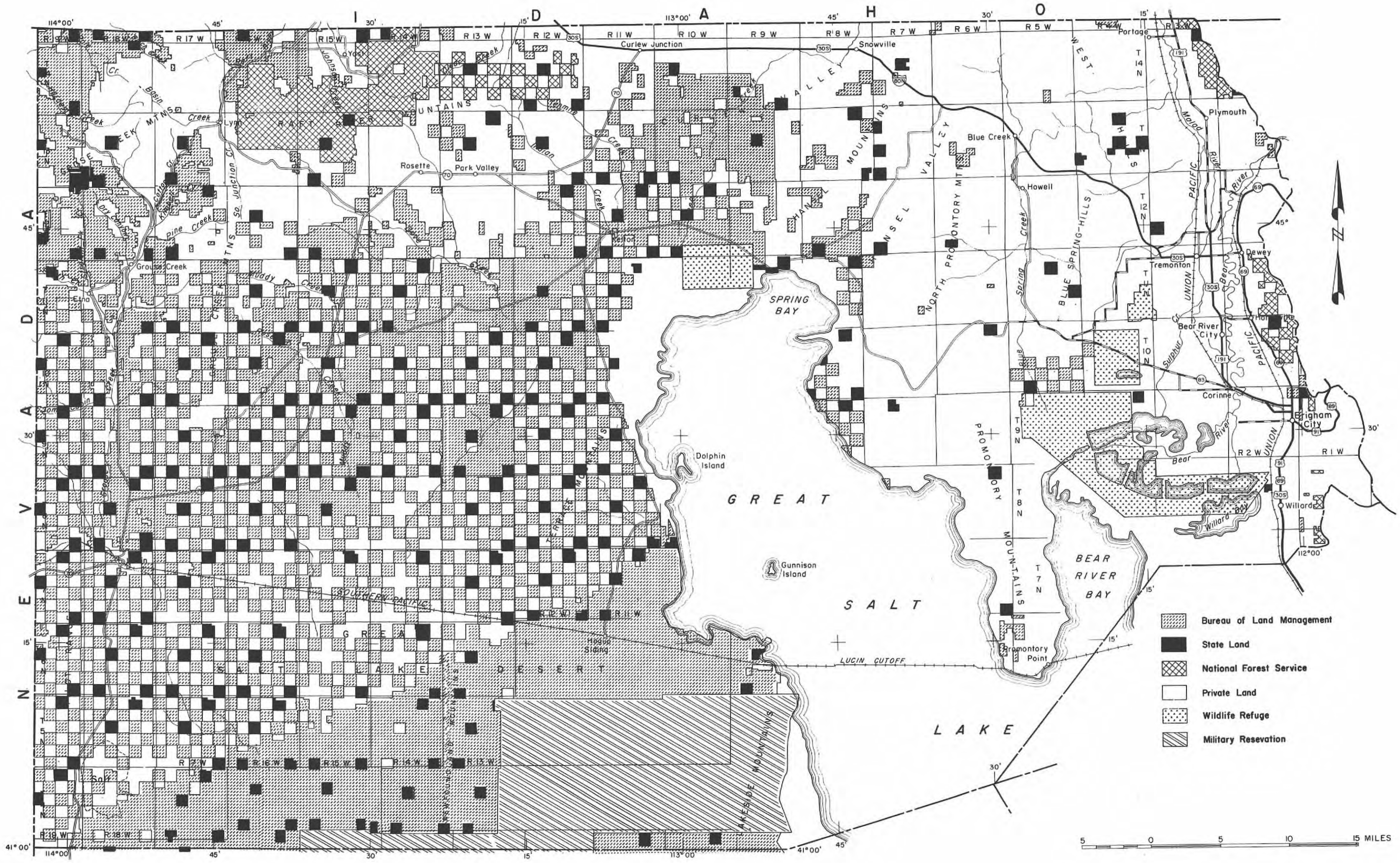


Figure 4. Land ownership map, Box Elder County, Utah (1975)

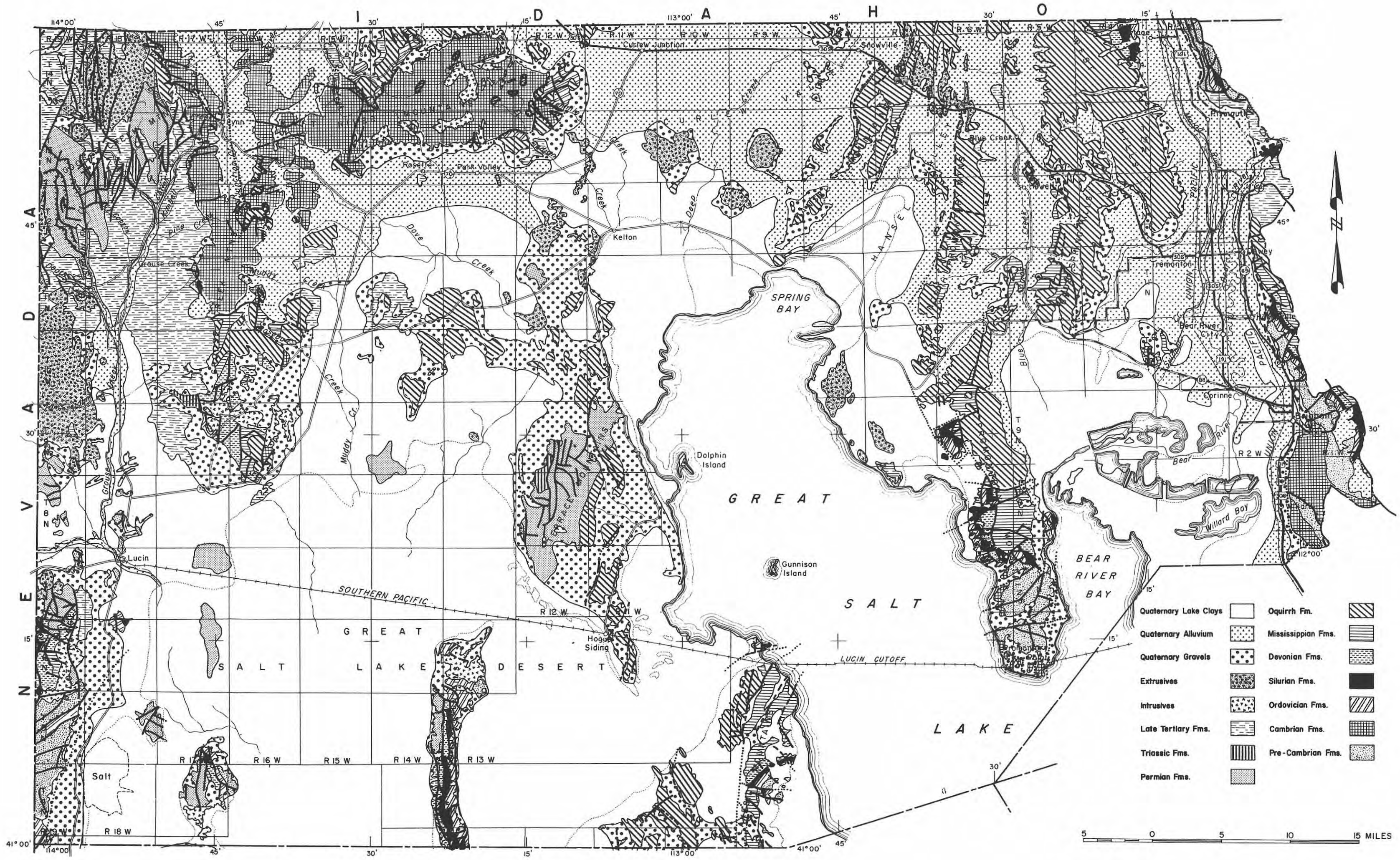


Figure 5. Generalized geology of Box Elder County, Utah

Table 3. Generalized Section of Rock Units, Box Elder County, Utah

GEOLOGIC AGE		NAME	DESCRIPTION	POSSIBLE ECONOMIC VALUE
Quaternary		Post Bonneville basinal deposits	Surface accumulations, especially on playas and mud flats; deposited by wind and water; includes mostly light-colored argillaceous material - clays, silts, but also sands, minor gravel, efflorescences of alkali salts and crystalline salt crusts; usually very thin	Sodium or potash salts
		Gravity deposits	Talus, scree, landslides, rock rivers, lag gravels, etc., usually found in mountainous areas	Minor gravel, riprap, landslides usually unsuitable for road gravel
		Glacial deposits	Poorly sorted morainal materials confined to Raft River Mountains	Minor fill material
		Alluvium; fans, channel deposits, floodplain deposits and colluvium	Unconsolidated gravel, sand, silt and clay	Gravel, borrow material
		Eolian deposits	Dunes of sand, oolite, gypsite	Soil conditioners, minor sources of sand, fluxing material
	LAKE BONNEVILLE DEPOSITS	Tufa-cemented conglomerate	Well-indurated conglomerate usually plastered along a prominent lake level	Ornamental garden stones
	LAKE BONNEVILLE DEPOSITS	Gravels	Primarily well-rounded pebbles to cobbles in a loamy matrix; deposited as beaches, gravel bars and deltas, sometimes extremely well sorted.	Gravel, construction material
	LAKE BONNEVILLE DEPOSITS	Diatomaceous marl	Pale-buff to white stratified siliceous marl	Diatomaceous earth
	LAKE BONNEVILLE DEPOSITS	Ice-rafted deposits	Boulders to immense blocks of consolidated rock lodged against a prominent shoreline	
	LAKE BONNEVILLE DEPOSITS	Clay and mud	Thick accumulations of stratified clay and mud with some coarser material and interstratified chemicals; occurs as mud flats and in intermontane plains of the Great Salt Lake Desert, often calcareous and with high salt content.	Contains sodium and potash brines, unsuitable for highway fill.
Tertiary		Salt Lake Group and ?Payette Formation	Stratified tuffaceous units, sandstone, conglomerate, siltstone, shale, often interbedded with rhyolitic flows, vitrophyres; lesser amounts of limestone, carbonaceous shale and lignite	Fill material, soil conditioners decorative stone, lignite, bentonite, volcanic ash, soft abrasives, common clay, gemstones
Triassic		Thaynes and Dinwoody Formations Undifferentiated	Thin-bedded to shaly silty limestone, thin to medium-bedded bioclastic limestone, calcareous shale and brown sandstone.	

(Continued)

Table 3 : Generalized Section of Rock Units, Box Elder County (continued)

GEOLOGIC AGE		NAME	DESCRIPTION	POSSIBLE ECONOMIC VALUE
Permian	Phosphoria	Gerster Formation	Crystalline and bioclastic limestone with lesser amounts of chert	Riprap, etc.
	Phosphoria	Rex Chert	Bedded chert, cherty siltstone and mudstone, with minor limestone and dolomite	Host for Lucin variscite
	Phosphoria	Meade Peak Formation	Mudstone, silty and cherty carbonate rock and shale	Contains phosphatic shale
	Park City	Grandeur Formation	Dolomite, silty dolomite, silty limestone, sandstone, cherty	Riprap, railroad ballast, crushed stone
		Loray Formation	Yellow to gray fine-grained calcareous sandstone and silty cherty limestone and dolomite	
		Diamond Creek Sandstone	Calcareous sandstone and orthoquartzite, fine to coarse-grained, well-rounded quartz sand	Possible source of sand
Pennsylvanian		Oquirrh Formation Penn-Permian Undifferentiated	Sandy and silty and bioclastic thin-bedded to massive limestones, calcareous shales and sandstones, orthoquartzites	Some beds suitable for riprap, railroad ballast, crushed stone, host for variscite, tungsten
Mississippian		Diamond Peak-Chainman-Manning Canyon	Purplish gray to brown fissile siltstone, becoming coarse, sandy and conglomeratic toward top	
		Great Blue Limestone	Thickbedded to massive, dark gray limestones, cherty and fossiliferous, subordinate shaly bioclastic limestone, sandstone and shale	Some beds suitable for riprap, railroad ballast, crushed stone, high purity limestone.
		Humbug Formation	Tan-gray fine-grained calcareous sandstone and platy weathering shaly sandy limestone	
		Deseret Formation	Dark gray to black, medium to thick-bedded limestone with minor chert	Some beds suitable for riprap, crushed stone
		Joana Limestone, Lodgepole Formation	Black to dark gray limestone, medium bedded to massive with some chert, lower beds thin-bedded limestone	Some beds suitable for riprap, crushed stone
Devonian	Jefferson Formation	Three Forks Shale	Gray calcareous fissile shale, some intercalated silty limestone beds	
	Jefferson Formation	Guilmette Formation	Mostly gray to blue-black limestone in thick beds but shaly limestone and quartzite beds are locally common. Becomes dolomitic eastwardly, resistant	Ore host, riprap, crushed stone, railroad ballast
	Jefferson Formation	Simonson Dolomite	Alternating light and dark gray banded dolomite, some limestone in western sections, thin to thick beds	Riprap, crushed stone, refractories, dolomite.
		Water Canyon Dolomite	Less resistant aphanic light to mouse-gray dolomite, medium to thick-bedded	Refractories, dolomite.

(Continued)

Table 3: Generalized Section of Rock Units, Box Elder County, Utah (continued)

GEOLOGIC AGE	NAME	DESCRIPTION	POSSIBLE ECONOMIC VALUE
Silurian	Laketown Dolomite	Chiefly light to dark-gray dolomite with minor cherty intervals, sugary weathering, thick-bedded to massive	Ore host, riprap, crushed stone, dolomite
Ordovician	Fish Haven Dolomite	Thick-bedded to massive dark gray crystalline dolomite, usually cherty near base, less so above	Ore host, riprap, crushed stone, dolomite
	Eureka Quartzite	Light gray-white vitreous, fine to medium-grained quartzite, mostly massive and resistant	Possible source of blasting, engine sands, high silica sands.
	Crystal Peak Dolomite	Dark gray to black silty dolomite	
	Swan Peak Quartzite	Grayish white quartzite and sandstone thick-bedded to massive, resistant	Possible source of blasting, engine sands, high silica sands
	Pogonip-Lehman-Kanosh Formations	Reddish brown siltstones and argillites with minor thin-bedded argillaceous limestones to east; thin-bedded platy weathering light bluish limestone with minor argillite to west	
	Garden City Limestone	Interbedded complex of intraformational limestone conglomerate, thin-bedded silty limestones and thick-bedded crystalline limestone, silt increases toward top, often contains chert	Riprap, crushed stone, host for tungsten
Cambrian	Upper Cambrian carbonates	Mostly thick-bedded to massive, light to dark gray dolomite, cherty at some localities, contains subordinate limestone, especially to west	Riprap, crushed stone, dolomite
	Middle Cambrian undifferentiated	Mostly bluish gray limestone, with some dolomite and shale	Parts for riprap and crushed stone, ore host
	Prospect Mountain Quartzite Brigham Group Quartzite of Clarks Basin	Mostly quartzite, white, gray, pink, brown, tan or green, massive, blocky or slabby, with intercalated units of schist, limestone, phyllite, slate, argillite, pebble conglomerate, meta-volcanics and siltstone.	Crushed stone, dimension stone, ornamental stone, mica, riprap, and possibly blasting and engine sands and silica
Precambrian	Precambrian Z units		
	Farmington Canyon Complex	Medium to coarse-grained gneiss intruded by pegmatite	Ore host, pegmatite minerals
	Older schist	Brown and silvery mica rich schist intruded by pegmatite and adamellite	Ore host, kyanite?

valleys. As much as 70,000 feet of sediment were deposited within the county boundaries between Precambrian and Triassic time. Mostly shallow-water marine deposits were laid down in areas of subsidence (geosynclines). Correlations of units are often difficult because of facies changes and the wide separation between outcrops from mountain range to mountain range. A tentative correlation diagram is given as figure 6. Deposition was not continuous during this interval and several unconformities interrupt the depositional sequence.

Marine deposition ceased after Triassic time and the area experienced erosion and tectonic disturbances. In Middle Tertiary time the area again began to accumulate sediments, this time under continental fluvial or lacustrine environments. These deposits are mostly in the basins between the presently existing mountain ranges and in places exceed 12,000 feet in thickness.

Precambrian

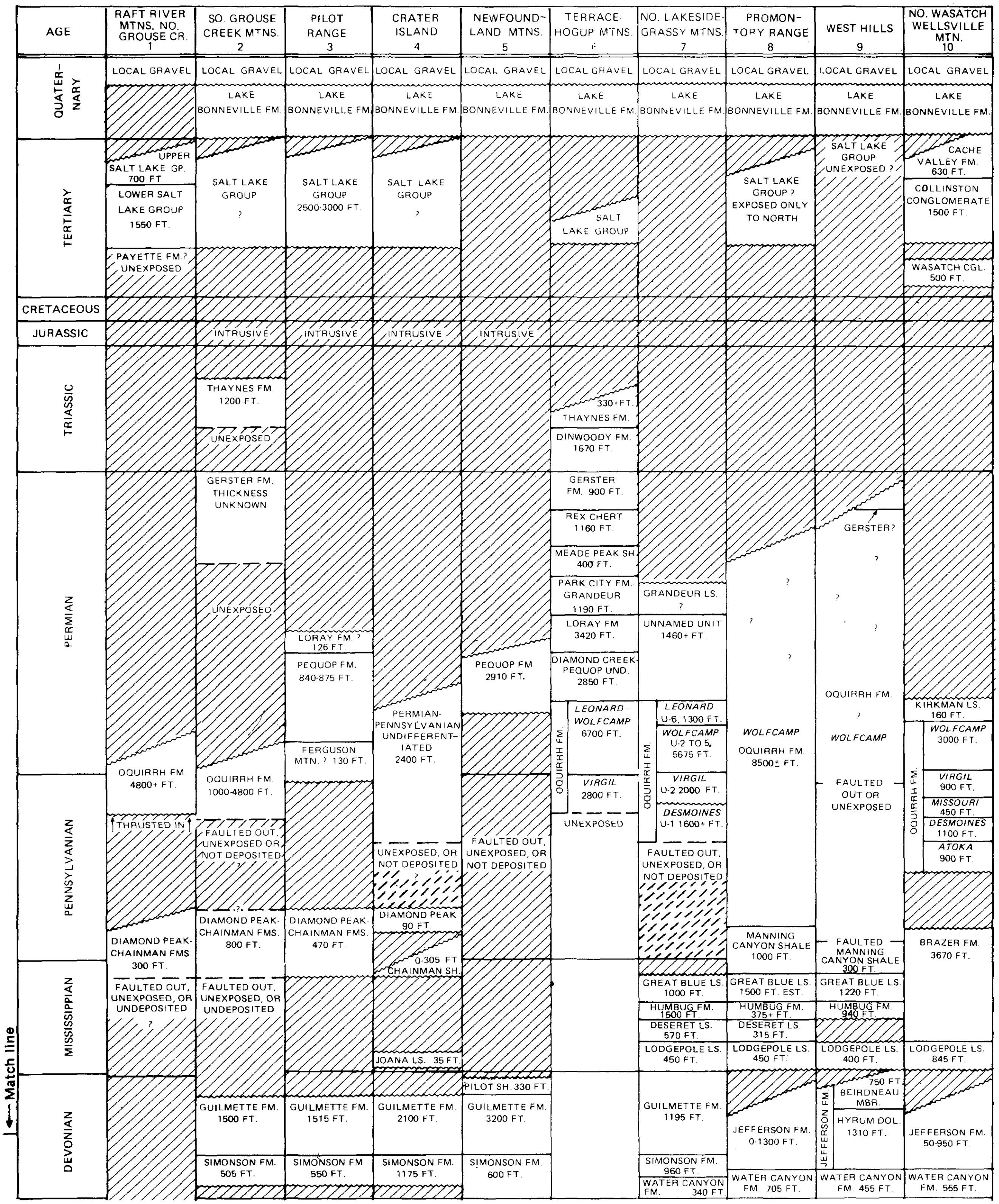
Precambrian rocks are exposed in the Grouse Creek, Raft River, Promontory, Wasatch, and Pilot mountain ranges (figure 7). On the basis of radiometric dating the oldest rocks are 2.2 to 2.5 billion years old and are exposed in the Raft River and Grouse Creek Mountains. Condie (1969) places these rocks in the outer belt of the Wyoming Province. Wyoming Province rocks are related to the Kenoran Orogeny that occurred 2.5-2.7 billion years ago. He gives two explanations for the younger age of rocks in Box Elder County: (1) the granitic plutonism of the Kenoran Orogeny progressively moved outward from the center of the province to the outer belt over several hundred million years or (2) the radiogenic Sr and Pb were redistributed and partly lost in the peripheral parts of the province during the later Hudsonian Orogeny (1.6-1.8 b.y. ago). These oldest rocks have been named the Older Schist. They are exposed in the deeper canyons at several localities in the two mountain ranges. The largest and thickest exposures are in the east half of the Raft River Range; 1,300 feet have been measured in Indian Creek Canyon. The Older Schist is described as dark, drab, brown and silvery mica-rich schist. In precise terms there is muscovite-biotite-quartz schist, mica-plagioclase-microcline-quartz schist, and muscovite-quartz schist. These rocks are thought to originally have been shale, argillaceous and feldspathic sandstone and siltstone, and pebbly and cobbly mudstone. In the vicinity of Clear Creek, in the northeastern part of the Raft River Range, there are 200 feet of semi-schistose crossbedded metasandstone at the lowermost exposures overlain by 200 feet of metamorphosed mudstone with intercalations of pebbly and cobbly mudstone, finally overlain by 600 feet of metamorphosed mudstone with occasional interbeds of siltstone and sandy shale. In the central Grouse Creek Mountains the Older Schist has been intruded by granitic rocks that are gneissose and grade upward into schist. Normally the Older Schist borders these plutons or is found as remnants within them, as it does in the Raft River Mountains. The granitic rocks have been dated to be about 2.5 billion years old (Compton and others, 1977, p. 1237).

The next older rocks in Box Elder County are associated with the Churchill Province (Condie, 1969) and related to the Hudsonian Orogeny that occurred 1.6 to 1.8 billion years ago. Rocks of this age are exposed in the Wasatch Range east and south of Willard and are represented by the Farmington Canyon Complex. More than 6000 feet of medium- to coarse-grained gneissic quartz monzonite with occasional plagioclase-hornblende amphiobolite layers and minor ptygmatic quartz veins are present. Cambrian sediments unconformably overlie the Farmington Canyon Complex. The Cambrian units have been overridden by a thrust sheet in which is a thick sequence of younger Precambrian units.

James (1972), has recently developed an interim scheme of subdividing the Precambrian, which the U. S. Geological Survey intends to use. Time boundaries are set at 800, 1600 and 2500 million years ago. Rocks older than 2.5 billion years are designated with a W, 1.6 to 2.5 by an X, 0.8 to 1.6 by Y, and 0.6 to 0.8 billion years by Z.

The oldest unit exposed in the Willard thrust sheet has been named the metaquartzite and schist of Facer Creek and is assigned to the X interval by Sorensen and Crittenden (1976). The unit is 0 to 2,000 feet thick in the county and is described as a medium- to fine-grained, white to buff, buff-weathering, medium-bedded to massive quartzite; white to tan-weathering, fine- to coarse-grained muscovite and quartz-muscovite schist; green, blue, and purple slate and phyllite; with minor amphibolite sills, hematite-quartz schist, and apple-green fuchsitic quartzite. An unconformity separates this unit from younger Precambrian units designated by a Z. Exposures of the metaquartzite and schist of Facer Creek extend southward from Perry Canyon into Weber County. The unit is well-exposed along the crest of the Wasatch Range south of Grizzly Peak. Precambrian stratigraphic columns are given on figure 8.

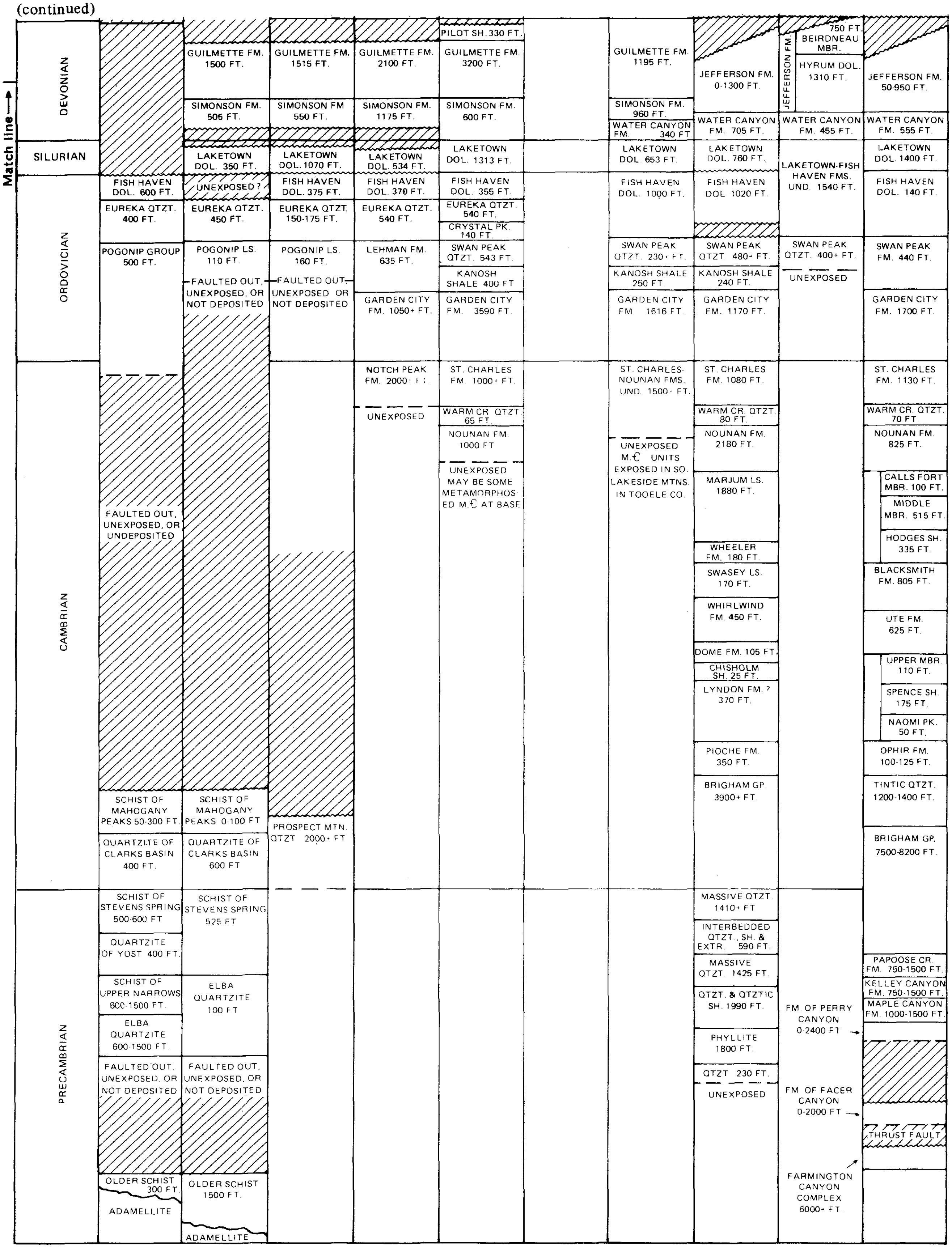
The Older schist of the Grouse Creek and Raft



(continued)

Figure 6. Correlation of stratigraphic units in Box Elder County.

(continued)


Match line
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRECAMBRIAN
FISH HAVEN DOL. 600 FT.
EUREKA QTZT. 400 FT.
POGONIP GROUP 500 FT.
FAULTED OUT, UNEXPOSED, OR UNDEPOSITED
SCHIST OF MAHOGANY PEAKS 50-300 FT.
QUARTZITE OF CLARKS BASIN 400 FT.
SCHIST OF STEVENS SPRING 500-600 FT
QUARTZITE OF YOST 400 FT.
SCHIST OF UPPER NARROWS 600-1500 FT.
ELBA QUARTZITE 600-1500 FT.
FAULTED OUT, UNEXPOSED, OR NOT DEPOSITED
OLDER SCHIST 300 FT.
ADAMELLITE
GUILMETTE FM. 1500 FT.
SIMONSON FM. 505 FT.
LAKETOWN DOL. 350 FT.
UNEXPOSED ?
EUREKA QTZT. 450 FT.
POGONIP LS. 110 FT.
FAULTED OUT, UNEXPOSED, OR NOT DEPOSITED
SCHIST OF MAHOGANY PEAKS 0-100 FT
QUARTZITE OF CLARKS BASIN 600 FT
SCHIST OF STEVENS SPRING 525 FT
ELBA QUARTZITE 100 FT
FAULTED OUT, UNEXPOSED, OR NOT DEPOSITED
OLDER SCHIST 1500 FT.
ADAMELLITE
GUILMETTE FM. 1515 FT.
SIMONSON FM 550 FT.
LAKETOWN DOL. 1070 FT.
FISH HAVEN DOL. 375 FT.
EUREKA QTZT. 150-175 FT.
POGONIP LS. 160 FT.
FAULTED OUT, UNEXPOSED OR NOT DEPOSITED
PROSPECT MTN. QTZT 2000+ FT
GUILMETTE FM. 2100 FT.
SIMONSON FM. 1175 FT.
LAKETOWN DOL. 534 FT.
FISH HAVEN DOL. 370 FT.
EUREKA QTZT. 540 FT.
LEHMAN FM. 635 FT.
GARDEN CITY FM. 1050+ FT.
NOTCH PEAK FM. 2000+ FT.
UNEXPOSED
PILOT SH. 330 FT.
GUILMETTE FM. 3200 FT.
SIMONSON FM. 600 FT.
LAKETOWN DOL. 1313 FT.
FISH HAVEN DOL. 355 FT.
EUREKA QTZT. 540 FT.
CRYSTAL PK. 140 FT.
SWAN PEAK QTZT. 543 FT.
KANOSH SHALE 400 FT
GARDEN CITY FM. 3590 FT.
ST. CHARLES FM. 1000+ FT.
WARM CR. QTZT. 65 FT.
NOUNAN FM. 1000 FT
UNEXPOSED MAY BE SOME METAMORPHOSED M.€ AT BASE
GUILMETTE FM. 1195 FT.
SIMONSON FM. 960 FT.
WATER CANYON FM. 340 FT
LAKETOWN DOL. 653 FT.
FISH HAVEN DOL. 1000 FT.
SWAN PEAK QTZT. 230+ FT.
KANOSH SHALE 250 FT.
GARDEN CITY FM. 1616 FT.
ST. CHARLES-NOUNAN FMS. UND. 1500+ FT.
UNEXPOSED M.€ UNITS EXPOSED IN SO. LAKESIDE MTNS. IN TOOELE CO.
JEFFERSON FM. 0-1300 FT.
WATER CANYON FM. 705 FT.
LAKETOWN DOL. 760 FT.
FISH HAVEN DOL 1020 FT.
SWAN PEAK QTZT. 480+ FT
KANOSH SHALE 240 FT.
GARDEN CITY FM. 1170 FT.
ST. CHARLES FM. 1080 FT.
WARM CR. QTZT. 80 FT.
NOUNAN FM. 2180 FT.
MARJUM LS. 1880 FT.
WHEELER FM. 180 FT.
SWASEY LS. 170 FT.
WHIRLWIND FM. 450 FT.
DOME FM. 105 FT.
CHISHOLM SH. 25 FT.
LYNDON FM. ? 370 FT.
PIOCHE FM. 350 FT.
BRIGHAM GP. 3900+ FT.
MASSIVE QTZT. 1410+ FT
INTERBEDDED QTZT., SH. & EXTR. 590 FT.
MASSIVE QTZT. 1425 FT.
QTZT. & QTZTIC SH. 1990 FT.
PHYLLITE 1800 FT.
QTZT 230 FT.
UNEXPOSED
JEFFERSON FM.
750 FT.
BEIRDNEAU MBR.
HYRUM DOL. 1310 FT.
WATER CANYON FM. 455 FT.
LAKETOWN-FISH HAVEN FMS. UND. 1540 FT.
SWAN PEAK QTZT. 400+ FT.
UNEXPOSED
FM. OF PERRY CANYON 0-2400 FT
FM. OF FACER CANYON 0-2000 FT
FARMINGTON CANYON COMPLEX 6000+ FT.
JEFFERSON FM. 50-950 FT.
WATER CANYON FM. 555 FT.
LAKETOWN DOL. 1400 FT.
FISH HAVEN DOL. 140 FT.
SWAN PEAK FM. 440 FT.
GARDEN CITY FM. 1700 FT.
ST. CHARLES FM. 1130 FT.
WARM CR. QTZT. 70 FT.
NOUNAN FM. 825 FT.
CALLS FORT MBR. 100 FT.
MIDDLE MBR. 515 FT.
HODGES SH. 335 FT.
BLACKSMITH FM. 805 FT.
UTE FM. 625 FT.
UPPER MBR. 110 FT.
SPENCE SH. 175 FT.
NAOMI PK. 50 FT.
OPHIR FM. 100-125 FT.
TINTIC QTZT. 1200-1400 FT.
BRIGHAM GP. 7500-8200 FT.
PAPOOSE CR. FM. 750-1500 FT.
KELLEY CANYON FM. 750-1500 FT.
MAPLE CANYON FM. 1000-1500 FT.
THRUST FAULT

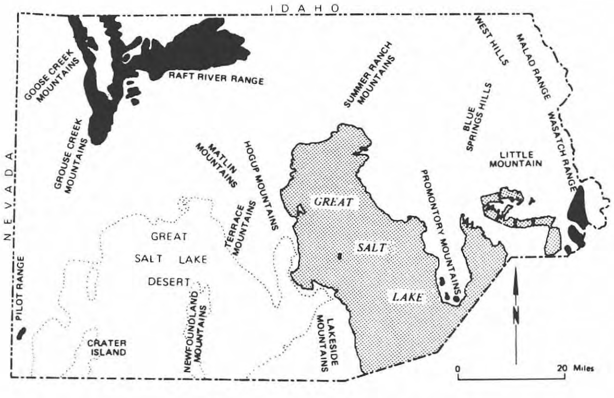


Figure 7. Precambrian outcrops of Box Elder County.

River mountain ranges is unconformably overlain by a sequence of four formations that are tentatively assigned to the Precambrian by Compton (1972, 1975). Hintze (1973) cites a personal communication with Compton in 1972 in which these four units were believed to be best assigned to the Precambrian X interval because of distinctive rock types comparable to those found in the metaquartzite and schist of Facer Creek. Hintze also cites Armstrong in a 1973 personal communication as believing the four formations to be latest Precambrian or early Paleozoic in age. Armstrong has worked in the Albion Range in Idaho with similar units to those found in the Raft River area (1968). In a discussion about the Huntsville area in Weber County, Crittenden and others (1971), note that in the Precambrian Z Maple Canyon Formation there is a pale-green quartzite containing chromian mica that resembles the green quartzite found in the lowermost of the four units exposed in the Raft River Range. The Maple Canyon Formation is also exposed in the Wasatch Range near Willard. Compton (1972) states,

> "A probable late Precambrian age is indicated for these four formations by certain distinctive rocks that are not known to occur in the Cambrian and Ordovician formations of the region, specifically: green quartzite, magnetite-rich and hematite-rich rocks, metadiabase, metamorphosed granite porphyry, and metamorphosed silicic tuffs and tuffaceous sedimentary rocks."

Further, Compton (1975) indicates that the uppermost unit is interlayered with the lowest Cambrian unit and that the four units have the same kind of contacts and he cannot place a major unconformity within the sequence. For purposes of this report the four units are assigned to the Precambrian Z interval.

Precambrian Z rocks are present in the Wasatch, Promontory, Raft River, and Grouse Creek mountain ranges and in the Pilot Range along the Nevada border. Although they bear similar lithologies, correlation between the ranges (except for the Raft River-Grouse Creek area) has not been possible. The four units of the Raft River Grouse Creek area are named, in ascending order; Elba Quartzite, schist of the Upper Narrows, quartzite of Yost, and the schist of Stevens Spring.

The Elba Quartzite has the most conspicuous outcrops in the Raft River Range and has prominent exposures in the Grouse Creek Mountains. The unit is lenticular and variable in lithology and ranges in thickness from 50 to 1500 feet, averaging 500 feet. Typically the unit is a white, tan, or in places green micaceous quartzite that is especially well displayed on the flanks of the Raft River Range. The bedding is thin to thick, some beds are cross-bedded, and muscovite-quartz schist forms thin partings between some of the beds. There are a number of quartzite pebble conglomerate beds as well. In the eastern part of the Raft River Mountains the Elba Quartzite has a lens-shaped, fine-grained mica-feldspar-quartz schist member up to 600 feet thick in the middle.

The schist of the Upper Narrows overlies the Elba Quartzite with a gradational contact of quartz-rich schists up to 100 feet thick. In some places the contact is sharp, but in most places it is about 10 feet thick. The make-up of the schist varies considerably from place to place, all in lenticular fashion. The rock is generally dark-brown or gray and weathers slabby. The most abundant rock types are biotitic fine- to medium-grained schist and muscovite-quartz schist. In addition there are lenses of fine-grained feldspathic muscovite-gneiss, phyllite, and chloritic schist. In the eastern part of the Raft River Range the schist of the Upper Narrows can be subdivided into a lower biotitic and feldspathic fine-grained gneiss and schist and an upper muscovite-quartz schist. The contact between the two members is gradational. In the Dove Creek Mountains (eastern arm of Grouse Creek Mountains) the muscovite-quartz schist member is an extensive lens in the middle of the formation.

Outcrops of the quartzite of Yost are restricted to smaller areas in the western Raft River Range and in the Dove Creek Mountains. The formation ranges from 0 to 400 feet in thickness and pinches to the southwest. The quartzite is mostly white, thin-bedded, and contains sparse to moderate amounts of muscovite mica. In local areas, such as in the Upper Narrows of the Raft River in the Dove Creek Mountains, there are beds of green chromium mica-bearing quartzites. In some areas the quartzite contains up to 10 percent feldspar and small quartzite pebbles.

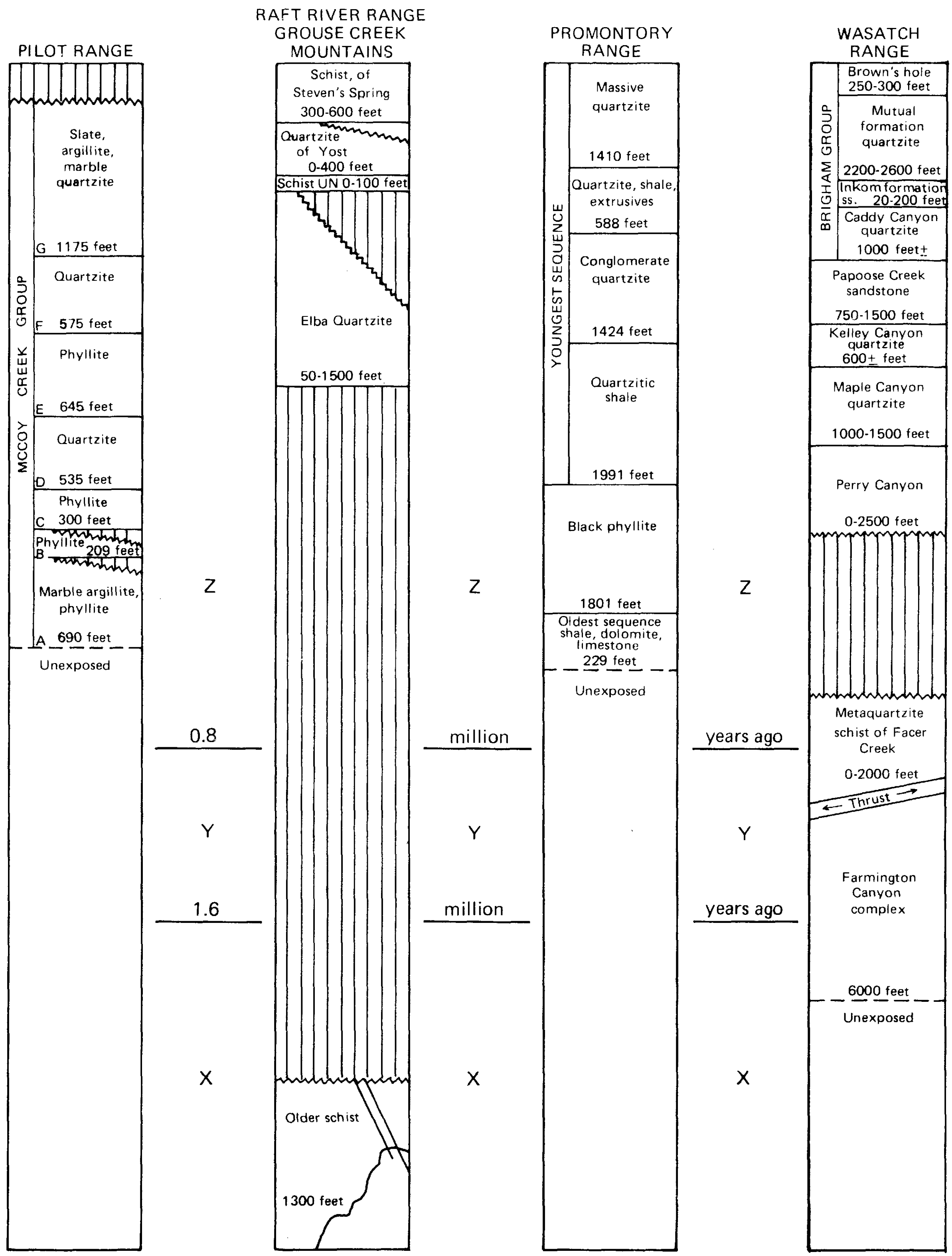


Figure 8. Precambrian columns in Box Elder County.

The youngest Precambrian Z unit is the schist of Stevens Spring and is 300 to 600 feet thick. The formation is usually poorly exposed and is mostly fine-grained muscovite-quartz-schist with abundant lentils of graphitic phyllite. Occasionally there are lenses of feldspathic muscovite-quartzite, each a few feet thick, and lenses of dark green epidote- or plagioclase-hornblende schist. Locally the rock contains garnet, chloritoid, and biotite porphyroblasts. The largest exposures are in the western Raft River Range and in the southern Dove Creek Mountains. The lower contact with the quartzite of Yost is sharp or grades rapidly. At least part of the schist of Stevens Spring was caught in thrust-faulting that is demonstrable in the region; part of the unit is found beneath the thrust and part above. At Bald Knoll, in the southeastern part of the Raft River Range, the schist of Stevens Spring overlies the schist of Upper Narrows in a thrusted relationship. In the western Raft River Range the schist of Stevens Spring is conformably overlain by Cambrian units and is thrust over itself and the lowermost Cambrian units.

Recognized Precambrian Z units in the central Grouse Creek Mountains include the Elba Quartzite and the schist of Stevens Spring. These units lie unconformably on a Precambrian adamellite gneiss or on the Older Schist (Precambrian X). The Elba Quartzite is described as well-bedded, white metaquartzite with minor muscovite, mostly in 1½-inch beds. The schist of Stevens Spring is dark bluish biotite-chlorite-muscovite-quartz schist for the most part, with lenses of hornblende schist or fine-grained hornblende-plagioclase near its base. Locally red-brown garnets to 3/4-inch are found in it. A thickness of about 525 feet are assigned to this uppermost Precambrian unit.

Seven Precambrian Z units aggregating more than 4,775 feet in thickness have been recognized in the southern Pilot Range by O'Neill (1968, figure 2). These are identified as units A to G in ascending order. The lower part of Unit A consists of 500 or more feet of light tan to medium gray, medium-grained, resistant quartzite and the upper 190 feet or more consist of thin-bedded slope-forming, finely-crystalline gray laminated marble with black to green argillite near the base. Unit B, as much as 200 feet thick, is also thin-bedded marble, but is medium crystalline and has 40 feet of brown and green phyllite and micaceous schist in the middle. Unit C is up to 300 feet thick and is non-resistant platy, green and gray spotted phyllite with fine-grained quartzite intercalations. Unit D lies conformably on Unit C and has a lower member consisting of 410 feet of massive, resistant, medium-grained to gritty, cross-bedded quartzite and a 125-foot upper member of green grit, slate, and phyllite. The grit forms cliffs, and the slate and phyllite form benches. Unit E is about 645 feet thick and its lower contact is gradational. The unit is mostly soft green to blue gray slate, argillite, and phyllite having minor interbeds of quartzite, conglomerate, and gritstone. There is a sharp contact between Unit E and F, which is marked by a sudden change in slope. Unit F is mostly thick-bedded cliff-forming, coarse-grained tan to brown quartzite. The upper contact is again sharp; Unit G comprises 1175 feet of soft slates, argillites, and siltstones with occasional interbeds of marble and quartzite. The top of Precambrian Z rocks in the Pilot Range is marked by a disconformity and is overlain by the Cambrian Prospect Mountain Quartzite.

The Precambrian Z rocks of the Promontory Range are also exposed at the southern-most tip of the Promontory peninsula of the Great Salt Lake. The area is strongly faulted, interrupting the normal sequences so much that correlation from fault block to fault block is difficult. The very oldest rocks, labelled the "oldest sequence" are exposed in a few acres with 229 feet of strata. The rocks are mostly quartzite with minor metamorphosed mafic extrusives, shale, argillite, silicified dolomite and limestone. All but a limestone sequence at the top have been subjected to low-grade regional metamorphism. The "intermediate sequence" consists of 1,801 feet of black phyllite, minor amounts of interbedded shale, metamorphosed mafic extrusives and metamorphosed calcareous strata. The "youngest sequence" measures 5,413 feet and is a ledge and slope-former. It can be subdivided into four units; the lowermost is 1,991 feet thick, mostly consisting of light greenish gray, silty to very fine-grained quartzitic shale interbedded with green gray, light gray or tan, blocky quartzite and metamorphosed basic extrusives and sills. Above this is a 1,424-foot massive quartzite of which the basal 990 feet and the upper 170 feet are conglomeratic. The conglomeratic units weather to a lighter color than the dark brown quartzite between. The third unit consists of interbedded quartzite, shale and metamorphosed basic extrusives and is 588 feet thick. Finally, at the top, is 1,410 feet of massive quartzite containing conglomerate lenses. Crittenden (in Hintze, 1973, p. 123) believes these are equivalent to the Late Precambrian rocks near Huntsville (Weber County) and near Willard in the Wasatch Range of Box Elder County.

Eight formations are described by Sorensen and Crittenden (1976) as making up the Precambrian Z interval in the Wasatch Range near Willard. The thickness of the sequence ranges from 5,820 to more than

10,000 feet. These units are listed and described in table 4 and in ascending order include the formation of Perry Canyon, Maple Canyon Formation, Kelley Canyon Formation, Papoose Creek Formation, Caddy Canyon Quartzite, Inkom Formation, Mutual Formation, and the Browns Hole Formation. These formations are best exposed in the Wasatch Range from Brigham City southward into Weber County. The units are considerably faulted, thrusted and folded, but the strike is generally northwesterly. Sorensen and Crittenden indicate that deposition of Precambrian Z units did not take place or they were eroded from the Farmington Canyon Complex in the autochthonous block of the Willard thrust. The Complex is unconformably overlain by Cambrian formations. The Precambrian Z units were deposited on the metaquartzite and schist of Facer Creek wherever the allochthonous block originated (to the west) and were later thrusted into the area. The thick Precambrian quartzites were previously known as the Brigham Quartzite or Formation; five formations now make up the Brigham Group; the lower four formations (3,500+ feet thick) are assigned to the Precambrian Z and the upper formation (4,000+ feet thick) is assigned to the Cambrian.

Cambrian

Rocks of Cambrian age in western Utah consist of an upper group of dolomitic units, a middle sequence of alternating limestone and shale formations, and a lower, mostly quartzitic sequence. In the western part of Box Elder County the three groups are not exposed together in a single mountain range. To the east, more complete sections are present. Roughly, the upper dolomitic units are Upper Cambrian, the middle sequence is Middle Cambrian, and the lower quartzites are Lower Cambrian. The exact positions of the time lines vary from place to place, but the grouping is useful for general discussion. Cambrian rocks are exposed in the Pilot Range, Crater Island, Newfoundland Mountains, Lakeside Mountains, Grouse Creek Mountains, Raft River Range, Promontory Range, Malad Range, and in the Wasatch Range (figures 9 and 10).

The Promontory Range boasts one of the more complete Cambrian sections in Box Elder County. The thickness of strata totals 10,762 feet and involves twelve formations dated Lower, Middle, and Upper. These units are principally exposed in the southern half of the Promontory peninsula. The Lower Cambrian is represented by the Prospect Mountain Quartzite which has been measured at 3,884 feet. It is very homogeneous unit, and with the exception of some shaly beds near the

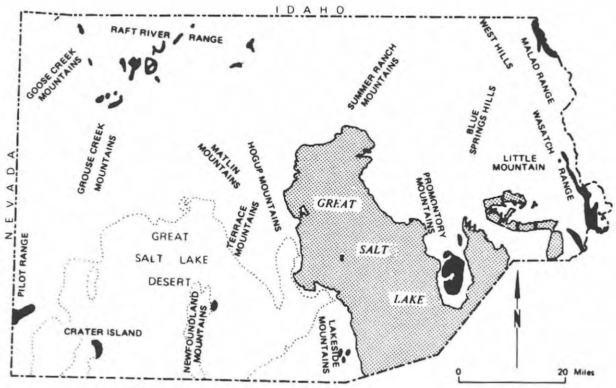


Figure 9. Cambrian outcrops of Box Elder County.

top, consists of mostly tan to white, very fine- to very coarse-grained quartzite. There are brown, pink, and light green quartzites as well, but these appear fewer times in the column. The Prospect Mountain Quartzite forms smooth, even slopes in outcrop.

Middle Cambrian stratigraphy has been undergoing revision and the names and boundaries as mapped by the earlier investigator (Olson, 1960) are being changed. A comparison chart of the old and new units (as listed in Hintze, 1973, p. 123) is shown as table 5. The initial unit of Olson's Middle Cambrian of the Promontory Range is the Pioche "Shale". It is 307 feet thick in the most reliable measured section and is mostly green quartzite that is fine-grained and weathers purple to dark brown. The minor shale is dull green to olive, micaceous and quartzitic. It is less resistant than the underlying Prospect Mountain Quartzite and forms a steep slope. The Busby Quartzite lies upon the Pioche "Shale" and averages 45 feet in thickness. It has three parts; a lower fine-grained calcareous quartzite that weathers tan to light brown, a middle pearly, dark gray, medium crystalline limestone which weathers tan to brown, and an upper gray, silty, micaceous shale which is commonly concealed and less resistant to erosion than the unit below. In the revision, the Pioche "Shale" and Busby Quartzite of Olson are combined to form the new Pioche Formation, about 350 feet thick.

The Millard Limestone overlies the Busby Quartzite and is 200 feet thick and is a slope-former. It is a dark gray, very finely crystalline, silty limestone and characterized by orange to tan, silty laminae parallel to the bedding. Intervals lacking siltstone partings rarely exceed six inches and are usually less than 1/6-inch thick. The Millard Limestone contains fossils, identified as the *Ptarmigania* assemblage, which positively identifies these rocks as Middle Cambrian.

Table 4. Chart listing Precambrian Z formations and their descriptions in the Wasatch Range of Box Elder County.

Group	Formation	Thickness, Feet	Description
	Geertsen Canyon Quartzite		CAMBRIAN ROCKS
Brigham Group	Browns Hole Formation	250-350	(Precambrian Z) Medium-bedded, medium-to fine-grained, well-sorted, white- to terra cotta-colored quartzite. Locally underlain by red to black, scoriaceous to amygdaloidal volcanic breccias, or volcanically derived conglomerates
Brigham Group	Mutual Formation	2200-2600	(Precambrian Z) Medium- to thick-bedded, medium- to coarse-grained, locally pebbly, locally feldspathic quartzite, in dark shades of purple, red, green, and brown
Brigham Group	Inkom Formation	20-200	(Precambrian Z) upper part very fine-grained, dark-green sandstone, underlain by laminated dark-green to olive-drab siltstone; lower part silver- to gray-weathering tuff, commonly with abundant rounded sand grains
Brigham Group	Caddy Canyon Quartzite	1000±	(Precambrian Z) Medium-grained, medium-to thick-bedded, vitreous quartzite; parts of unit may be light-gray to white, but rocks are generally tan, gray, green, blue-green, or purple. Upper contact commonly marked by 15-20 foot (5-6 m) zone of rusty-weathering cliff-forming brecciated white quartzite
	Papoose Creek Formation	750-1500	(Precambrian Z) Predominantly dark-gray to olive-drab siltstone, with inter-bedded light-gray to greenish-gray, fine-grained quartzitic sandstone; bedding is characteristically thin, wavy, and discontinuous. North of Perry Canyon, unit includes medium-bedded brown-weathering medium- to coarse-grained quartzite
	Kelley Canyon Formation	600±	(Precambrian Z) Thin-bedded, dark-gray to black argillite, weathering to tan, dark-gray, greenish-gray, and silver; commonly has alternating dark-gray and greenish-gray interbeds. Brown-weathering, chloritic, chloritic, carbonatic lamprophyre dikes common throughout unit
	Maple Canyon Formation	1000-1500	(Precambrian Z) Medium-bedded, coarse-grained, pale-green to greenish-gray arkosic quartzite, locally gritty to conglomeratic; minor purple to maroon gritty arkosic quartzite; thick-bedded, medium- to coarse-grained, buff-weathering white quartzite; tan, olive-drab, and green laminated siltstone; includes thin bed of mottled light- and dark-gray limestone near Perry Basin and tan-weathering stromatolitic limestone in Perry Canyon
	Formation of Perry Canyon	0-2500	(Precambrian Z) Upper part mainly olive-drab to brown siltstone and fine-grained quartzitic sandstone. Underlain by or grades laterally into massive, black, carbonaceous mudstone and gray to dark-green, tan-weathering micaceous argillite. Lower part gray to black, tan- to gray-weathering diamictite (indicated on map by dotted pattern and symbol Zpd), with boulder- to pebble-size quartzitic and granitic clasts set in a black, medium- to fine-grained, sandy matrix; grades laterally into black chloritoid slate and black, medium- to fine-grained sandy mudstone. Minor pillow lava and limestone near base. Scattered exposures of coarse arkosic quartzitic grit at base of unit
	Metaquartzite and schist of Facer Creek		PRECAMBRIAN X ROCKS

After Sorensen and Crittenden (1976)

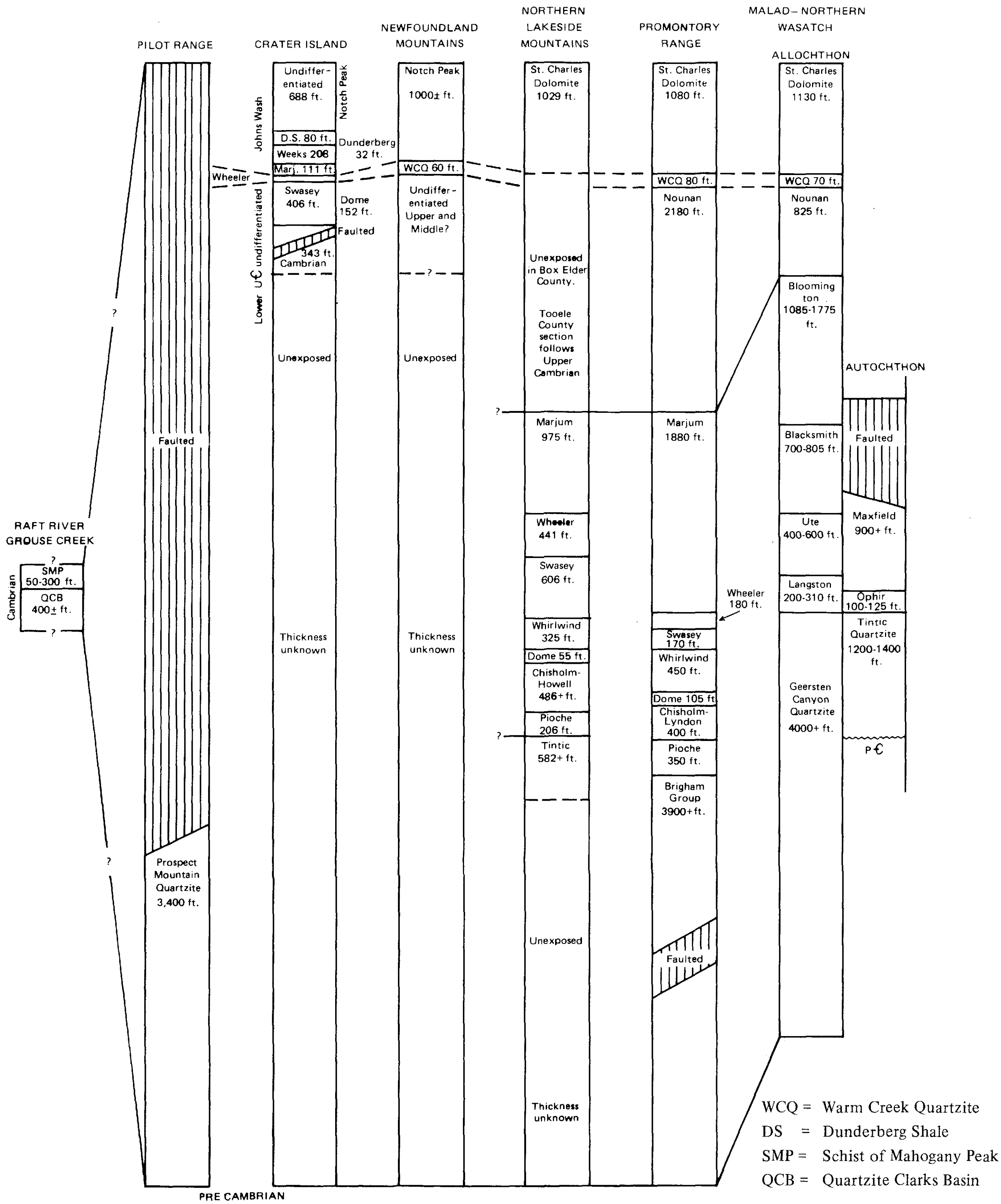


Figure 10. Correlations of Cambrian units in Box Elder County.

Table 5. Comparison of Middle Cambrian formations as mapped by Olson and modified by Hintze.

Olson, 1960	feet	feet	Hintze, 1973, Chart 6
Marjum Limestone	1878	1880	"Marjum" Limestone
Wheeler Formation	180	180	"Wheeler" Formation
		170	"Swasey" Limestone
Swasey Limestone	494	450	Whirlwind equivalent
Dome Limestone (39)			
Burnt Canyon Ls.	91		
		105	Dome equivalent
Burrows Limestone	301		Chisholm equivalent (26)
		370	Lyndon equivalent
Millard Limestone	202		
Busby Quartzite (45)			
Pioche "Shale"	307	350	Pioche Formation
Prospect Mountain Quartzite	3,884	3,900	Brigham Group

The overlying Burrows Limestone is 300 feet thick. It is mostly dolomite interbedded with limestone with subordinate shale. In the Promontory Range the dolomite is gray, medium- to coarsely-crystalline, and weathers uniformly to brown or dark brown. In contrast the limestones are microcrystalline, silty, and weather light gray. Starting at about 130 feet below the top of the Burrows Limestone is a green, slightly micaceous shale that is 26 feet thick and fossiliferous. Above is mostly light-gray limestone that is locally quite resistant. The shale contains fossils of the *Glossopleura* zone and in the revision is called the Chisholm equivalent. The limestone that overlies it is called the Dome equivalent and the dolomite and limestone beds that lie beneath it are termed the Lyndon equivalent, and include the Millard Limestone.

Ascending further in the section, the next unit mapped by Olson (1960) is the Burnt Canyon Limestone, a gentle slope-former about 90 feet thick, consisting of interbedded limestone and shale. The dark gray limestone is very finely crystalline and the shale is green to olive and micaceous. It also contains part of the *Glossopleura* zone. Above is 40 feet of cliff-forming, dark gray, very finely crystalline, oolitic limestone which was assigned to the Dome Limestone. Above the Dome is the 494-foot Swasey Limestone with a 322-foot Condor Member at its base. In the revised sequence the Burnt Canyon Limestone, Dome Limestone, and Condor Member are combined and termed the Whirlwind equivalent. The upper 170 feet of the Swasey Limestone of Olson become the " Swasey" Limestone of the revision. The Condor Member consists of limestone interbedded with shale; the limestone is gray to dark-gray, microcrystalline to finely crystalline, very thin-bedded, and has orange silty partings along bedding surfaces, the shale is green gray to silvery tan and talcose. The upper "Swasey" Limestone is like the limestone of the Condor Member, except that the upper part becomes thick-bedded and the silty partings disappear (figure 11).

The succeeding Middle Cambrian units and the Upper Cambrian units were not revised. The Wheeler Formation is 180 feet thick and is mostly blackish-gray to whitish-gray, silty and calcareous. There is some minor dark-gray, tan-weathering, medium-crystalline limestone as well. The uppermost Middle Cambrian formation is the Marjum Limestone, 1,878 feet thick. The lower half forms slopes and the upper half forms vertical cliffs. It has a lithology consisting of limestone, shale, "concretionary limestone in shale", siltstone and dolomite. Limestone is the most abundant rock type and is dark gray and microcrystalline. Fossils are few, but enough have been identified to verify a Middle Cambrian age.

There are two Upper Cambrian units which are separated by an 80-foot quartzitic member assigned to the base of the uppermost formation. The lower Nounan Formation is 2,180 feet thick, a ledge-former, mostly of alternating limestone and dolomite. There are subordinate interbeds of siltstone and mudstone. Dolomite makes up 70 percent of the unit and generally is a lighter shade of gray than the limestone. The uppermost Cambrian unit in the Promontory Range is the 1,160-foot St. Charles Dolomite. Most of the St. Charles consists of ledge and slope-forming, light-gray, thick-bedded dolomite.

Along the east boundary of Box Elder County another "good" Cambrian section crops out; the total exposed rock has a thickness of approximately 6,650 feet. The dividing mountain range separating Box Elder from Cache County south of Utah Highway 30 is known as the Wasatch Range and includes Willard Peak, the Pisgah Hills, and Wellsville Mountain. North of Utah Highway 30 the mountains are a part of the southern Malad Range which in Utah includes the Junction Hills and Clarkston Mountain. The Cambrian units exposed in both ranges are the same but are more complete in the Wasatch Range.

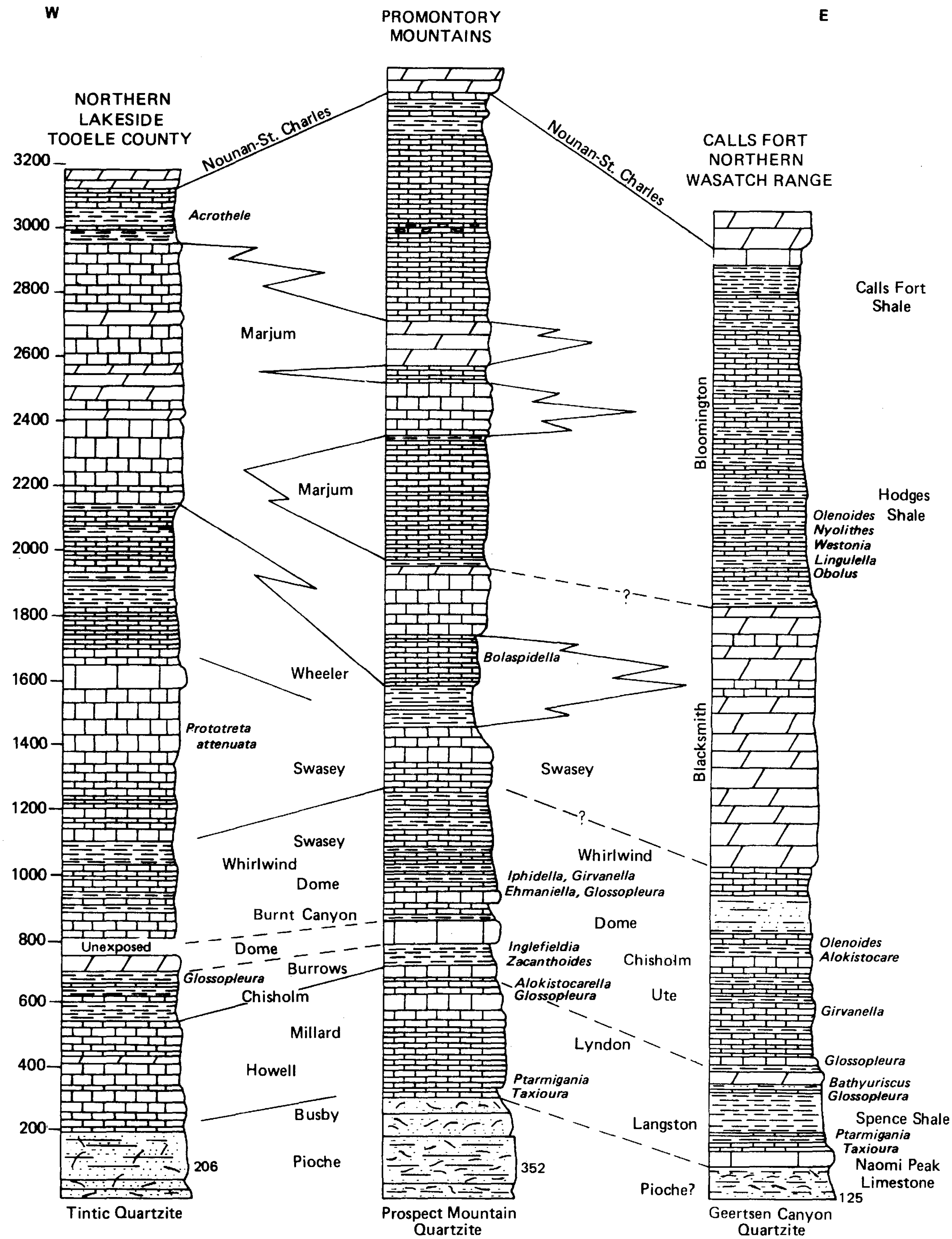
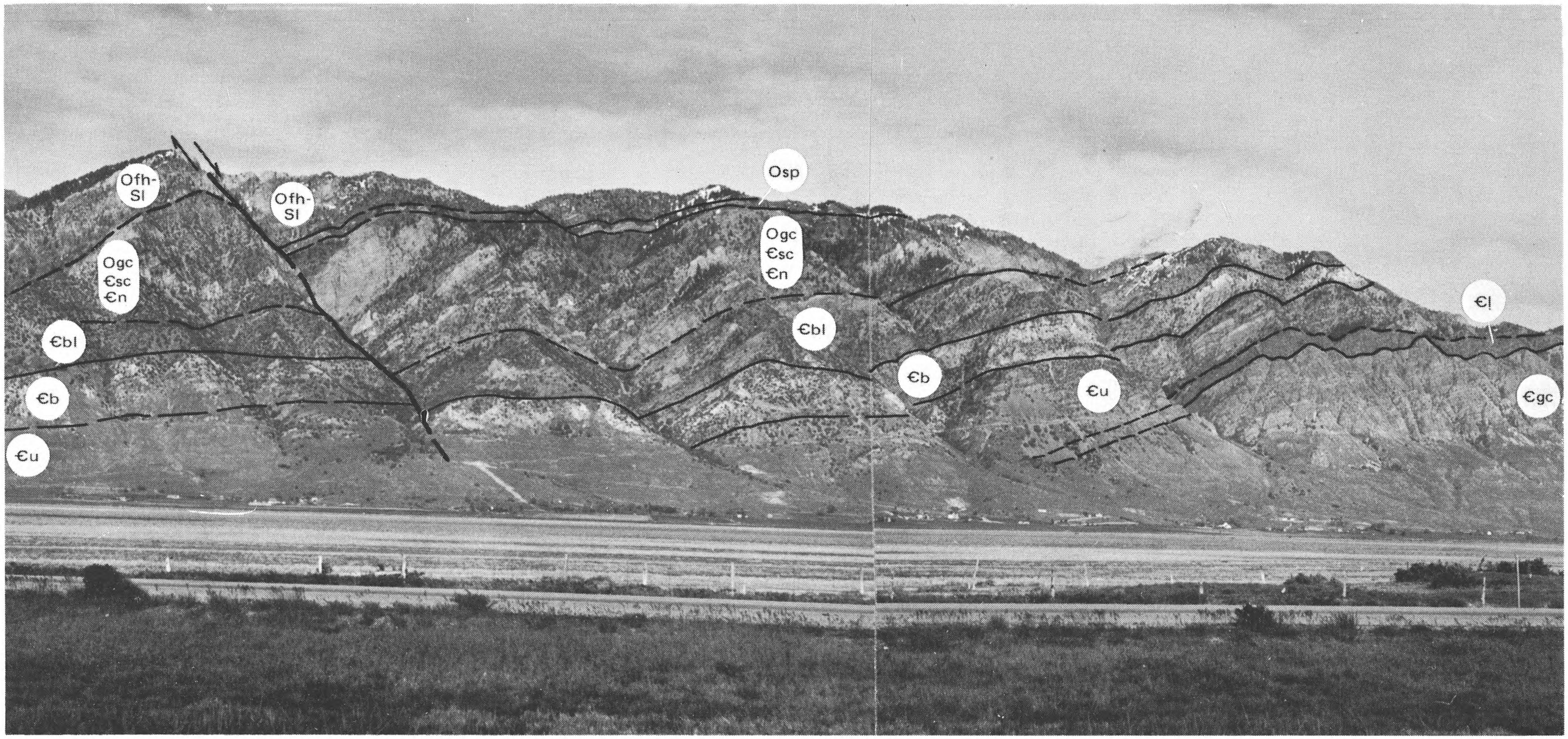
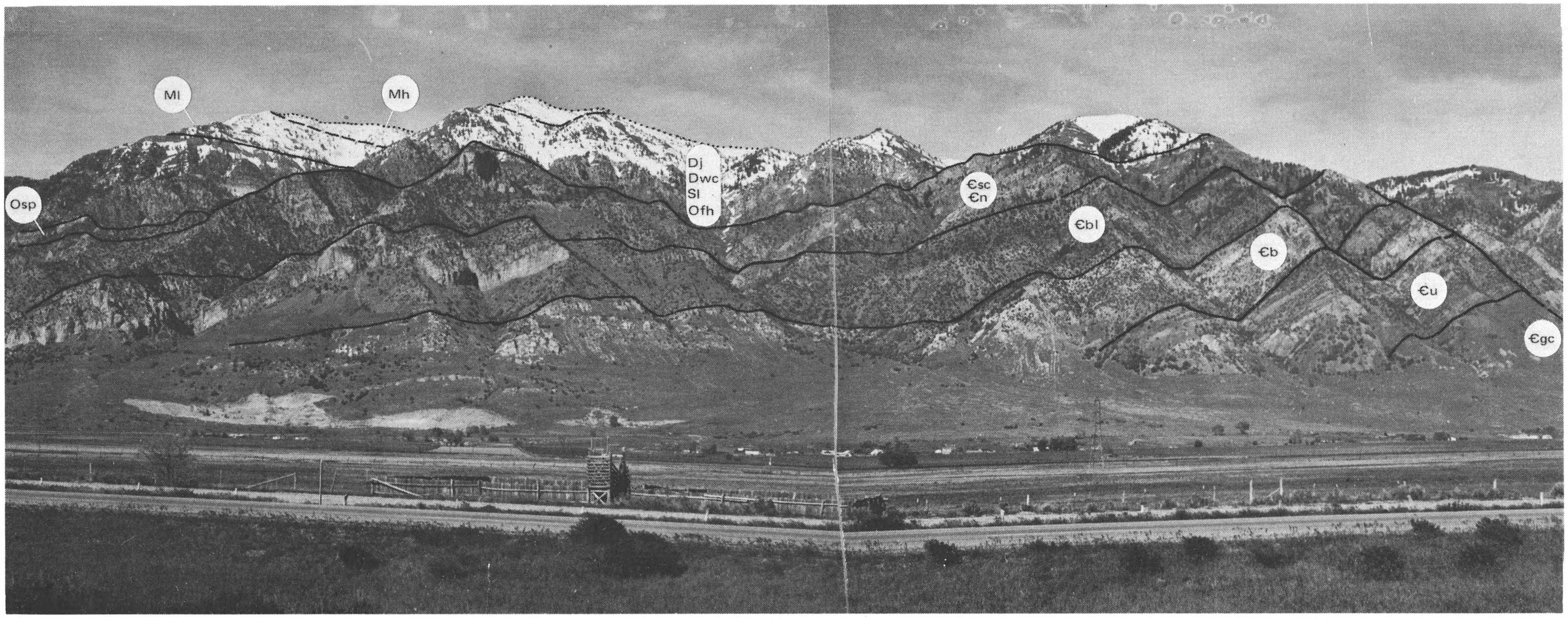


Figure 11. Correlation and lithologic diagrams of Middle Cambrian rocks at selected locations in Box Elder County.



P 5. View of western front of southern half of Wellsville Mountain, north of Brigham City, showing exposures of Cambrian units: Cgc = Geertsen Canyon Quartzite, Cl = Langston Formation, Cu = Ute Formation, Cb = Blacksmith Formation, Cbl = Bloomington Formation, Cn = Nounan Formation, Csc = St. Charles Formation. Ordovician units are also exposed high on the mountain: Ogc = Garden City Formation, Osp = Swan Peak Formation, Ofh-Sl = Fish Haven Dolomite and Laketown Dolomite (Silurian).



P 6. Wellsville Mountain in the Honeyville area where Lower Paleozoic rocks are well exposed. Cambrian units include the Geertsen Canyon Quartzite (Cgc), Langston Formation (Cl), Ute Formation (Cu), Blacksmith Formation (Cb), Bloomington Formation (Cbl), Nounan Formation (Cn), St. Charles Formation (Csc). Ordovician units include the Garden City Formation (Ogc), Swan Peak Formation (Osp), Fish Haven Dolomite and Devonian units include the Water Canyon Formation (Dwc) and Jefferson Dolomite (Dj). Mississippian units are exposed at the very tops of the peaks; Lodgepole Formation (Ml) and Humbug Formation (Mh).

In the Wasatch Range the Cambrian formations are complexly folded, faulted. and thrusted. The strata indicate that the allochthonous block of the Willard thrust fault was pushed over the autochthonous block for a considerable distance from the west. The very oldest rocks of the Willard Peak area are represented by the Precambrian Farmington Canyon Complex in the autochthon. Unconformably overlying this unit is an assemblage of three Cambrian formations, the Tintic Quartzite, Ophir Shale, and Maxfield Limestone.

The Tintic Quartzite is 1200 to 1400 feet thick and the lower part is considered Lower Cambrian in age. The lower portion is generally maroon or purple, medium- to coarse-grained, medium- to thick-bedded arkosic quartzite. The upper part is lighter in color; white, buff, or tan, but otherwise has the same description. The formation is locally cross-bedded and the base may have a thin horizon of red conglomerate. The Tintic grades upward into the Ophir Formation. The Middle Cambrian Ophir is 100 to 125 feet thick and is mostly drab light brown to olive shale and siltstone. The lower half may contain beds of brown-weathering silty sandstone and iron-stained dolomite. The Middle Cambrian Maxfield Limestone is the uppermost exposed unit in the autochthonous block and is estimated to be 900 feet thick. The principal lithology is medium to dark gray dolomite. The rock is finely crystalline and thin- to medium-bedded with thin intercalations of greenish brown shale and shaly or silty limestone. The Maxfield is a ledge-former.

The allochthonous block contains seven Cambrian formations, listed in ascending order: Geertsen Canyon Quartzite, Langston Formation, Ute Formation, Blacksmith Limestone, Bloomington Formation, Nounan Formation, and the St. Charles Formation. The Geertsen Canyon Quartzite is the uppermost unit of the Brigham Group and is dated Lower Cambrian on the basis of K/Ar dating of 570 ± 7 million years of hornblende from volcanic rocks in the underlying Precambrian (Browns Hole Formation) with which it is conformable. As in the Tintic Quartzite the lower part is maroon, purple, green, and generally arkosic. The Geertsen Canyon is much thicker, more than 4000 feet, and is medium- to coarse-grained quartzite; the beds are medium to thick, and there are scattered zones of small pebbles. The upper part is lighter in color; white, gray, or light gray-green; worm borings (*Scolithus*) are abundant.

Before proceeding with descriptions of the Middle and Upper Cambrian units it is well to discuss correlations between the western assemblage as exposed in the Promontory Range and the assemblages of the allochthon and autochthon of the Willard thrust. Rigo (1968, p. 59) has reconstructed the Cambrian section as it would have appeared prior to thrusting, as is shown in figure 12. Thicknesses are not considered in this sketch: in the Promontory Range the Middle and Upper Cambrian units are not quite 7000 feet thick; in the allochthon they are about 5000 feet thick, and in the complete autochthon may be 2000 feet thick.

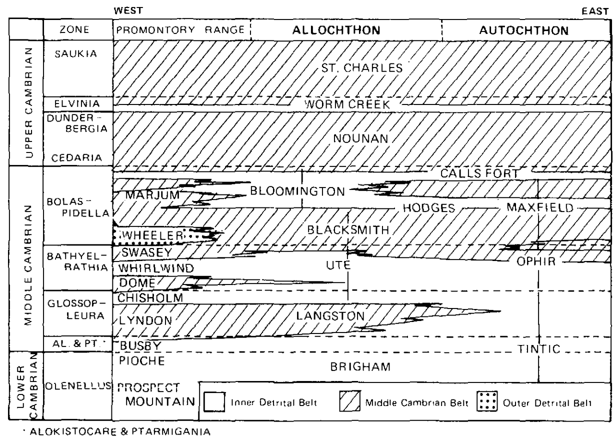


Figure 12. East-West palinspastic diagrammatic sketch across eastern Box Elder County indicating Cambrian lithofacies changes as modified from Rigo (1968, p. 59). The sketch does not consider thickness of rock units.

Overlying the Geertsen Canyon Formation (Brigham Group) at Wellsville Mountain is the Langston Formation, of Middle Cambrian age, 310 feet thick. At the base of this unit are 50 feet of light to medium gray, finely crystalline, sandy limestone beds with a few thin beds of calcareous sandstone at the bottom. This subunit is called the *Ptarmigania* Limestone Member or the Naomi Peak Member. Locally, there is a red to dark brown, coarsely crystalline dolomite at the base up to 25 feet thick. The next 175 feet make up the Spence Shale Member, a black, green, and neutral gray shale and siltstone that is normally fossiliferous. The uppermost Langston (110 feet) consists of tan-weathering dolomite and silty gray limestone. The dolomite is fine- to coarse-grained and thick-bedded to massive; the limestone is generally darker in color, fine-grained, thin-bedded with uneven bedding planes. Prominent brown mottles and stripes are common in the limestone and there is occasional intraformational conglomerate.

The overlying Ute Formation is 625 feet thick and consists of blue gray, very finely grained, thin-bedded limestone and green brown shale. It is in part oolitic, stromatolitic, sandy and silty. Colorfully striped silty and sandy limestone beds are characteristic; the unit is generally less resistant than the upper member of the Langston below and the Blacksmith Formation above.

Above the Ute, the Blacksmith Formation is mostly light to dark gray, fine to medium crystalline, massive dolomite and dolomitic limestone. It tends to be oolitic, especially near the base and top. It is a resistant cliff-former and has orange or tan silt horizons as if the bedding were thin to medium. The Blacksmith Formation is 805 feet thick at Wellsville Mountain.

The overlying Bloomington Formation is divisible into three members. At the base is the 335-foot Hodges Shale, olive brown with a few thin light to dark gray limestone beds; in the middle is a 515-foot sequence of platy-weathering, light to dark gray, slope-forming limestone, and at the top is a 235-foot section of light to dark gray oolitic limestone and intraformational conglomerate. This upper member is known as the Calls Fort Shale Member. Near Willard Peak the Calls Fort Member is 400 to 600 feet thick and contains a significant amount of tan to olive shale with egg-shaped lenses of light gray limestone. Orange and brown-weathering silty limestone alternates with gray-weathering limestone beds. The bedding is generally thin.

The Upper Cambrian at Wellsville Mountain is made-up of the Nounan and St. Charles Formations, as it does in the Promontory Range. The Nounan Formation is 825 feet thick and the St. Charles is 1,200 feet thick. The lower two-thirds of the Nounan is light-gray, microcrystalline, thin-bedded, resistant dolomite. The upper part is inter-bedded dolomite and dark-gray argillaceous, thin-bedded limestone. The uppermost of these limestone beds are very sandy. The Worm Creek Member of the St. Charles Formation separates the two formations and is 70 feet thick. The Worm Creek is light gray, fine-grained, medium-bedded, sugary weathering limonitic quartzite. The remainder of the St. Charles consists of a lower part of dark to light gray, thin-bedded, sometimes silty or sandy limestone and dolomite. The upper portion consists of dark gray and massive cherty dolomite.

On the west side of Great Salt Lake, in the northern Lakeside Mountains, more than 1000 feet of Upper Cambrian dolomite is exposed, all of which may be assigned to the St. Charles Formation. These Upper Cambrian beds are light to medium gray, mostly thick-bedded and form rounded hills and knolls. Some beds contain abundant algal spheres and siliceous bodies often called "twiggy" bodies. In the southern Lakeside Mountains, Tooele County, a more complete Cambrian section is exposed. Part of this section is shown on figure 11 in comparison with other Box Elder County sections. Its thickness compares favorably with that in the Promontory Range (figure 13).

In the Newfoundland Mountains the oldest exposed strata are the Upper Cambrian dolomites, but many of the beds have been metamorphosed or altered. About seven subunits are discernible. The third subunit from the bottom is a conspicuous 63-foot brownish tan-weathering quartzite that may correspond to the Worm Creek Quartzite Member of the St. Charles Formation as exposed in the mountain ranges to the east. This marker divides the exposed Cambrian of the Newfoundland Mountains in half, roughly 1,000 feet of strata above and 1,000 feet of strata below it. Immediately below the marker is 250 feet of dark gray limestone. The lowermost subunit consists of thick-bedded, light to dark gray, sugary-weathering dolomite. Above the Worm Creek (?) is a subunit of alternating grayish white quartzite and medium to light gray limestone, 120 feet thick. The lower part of this subunit is mostly limestone. Overlying is a 45-foot section of slate gray spotted phyllite. The phyllite is overlain by brown-weathering, thick-bedded and recrystallized limestone. The uppermost subunit is thick-bedded dolomite that forms rounded hills and contains occasional limestone beds. It weathers sugary and some of the rock is tremolitized. The Cambrian outcrops are situated near a quartz-monzonite stock (Newfoundland stock) and many of the beds have been bleached and marbleized.

Upper Cambrian rocks are present on Crater Island, the northernmost mass of the Silver Island Mountains. In recent paleontologic work by Robison and Palmer (1968, p. 168) the available mapped data was revised in age for rocks exposed in the Tooele County portion of the Silver Island Mountains. They showed that much of the "middle sequence" of alternating shale and limestone in that mountain range is Upper Cambrian in age. Schaeffer (1960) considered his assignment of names to correlate directly with the rocks mapped by Anderson (1957) in Crater Island in his discussions of the various units. If Anderson's units do correlate with Schaeffer's units bearing the same names then the comparison made in figure 14 is valid.

The Wheeler Shale of Anderson is represented by a sandstone and is found less than 1100 feet below the top of the Cambrian section. This compares almost directly with the thickness of strata above the Worm Creek

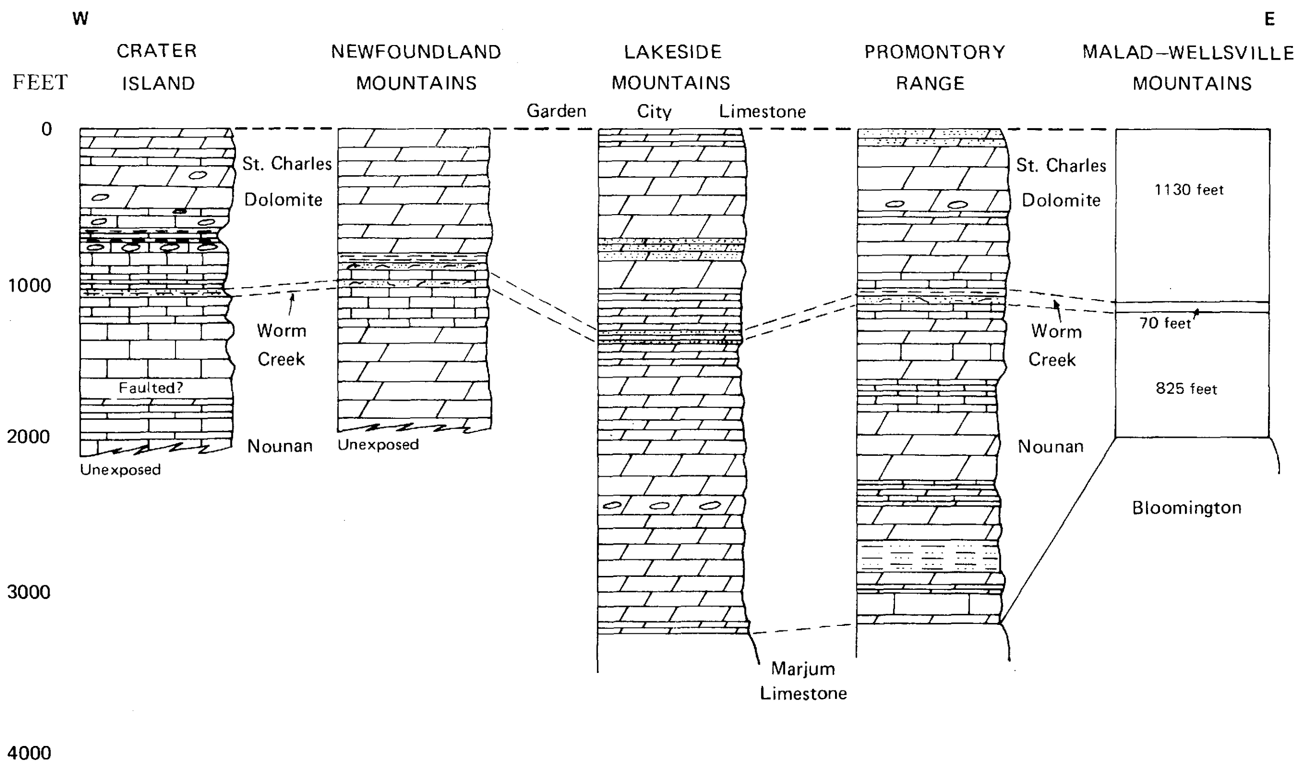


Figure 13. Upper Cambrian correlation across Box Elder County.

Quartzite Member of the St. Charles Formation in the Wasatch Range, Promontory Range, Lakeside Mountains, and the Newfoundland Mountains. The lower-most 343 feet are simply labelled Cambrian? and are described as medium- to dark-gray, thin-bedded to massive limestone. The uppermost beds are dolomite and in fault contact with the overlying Dome Limestone. The Dome consists of 157 feet of light gray, medium to coarsely crystalline, massive dolomitic limestone. It is overlain by 406 feet of gray, finely crystalline, thin-bedded to massive, ledge and slope-forming limestone, that are assigned to the Swasey Limestone. The Wheeler Shale is 32 feet thick and described as interbedded gray limestone and red to yellow brown sandy shale or shaly sandstone. The Marjum Limestone is 111 feet of light-gray limestone that forms slopes and ledges. There are silty orange or light brown bands. The Weeks Limestone has a similar description, but is thicker-bedded and contains some chert and secondary dolomite. These two units are combined to form the Johns Wash Limestone of Robison and Palmer. The Dunderberg Shale of Anderson is the Corset Springs Shale of Robison and Palmer, and in Crater Island is 80 feet thick, where it consists of thin, interbedded light gray to red brown limestone, shale, and chert. The remaining Upper Cambrian section is 688 feet thick and is mostly alternating thin to massive beds of dolomite and limestone. The rocks are generally a shade of gray and often laminated. The white siliceous "twiggy" bodies are common and the unit forms ledges and slopes in outcrop. Robison and Palmer refer this section to the Notch Peak Formation.

The Pilot Range in Utah has a single Cambrian formation, the Prospect Mountain Quartzite, which is estimated to be about 3,400 feet thick. Presently it is considered to be entirely Lower Cambrian in age. The Prospect Mountain Quartzite is mainly light in color, but in places is dark brown, maroon, purple, and even green. Weathering alters the exposed surfaces into brownish hues and the grain size is fine to coarse. Low in the section darker quartzites become more common, and limestone, phyllite, slate, argillite and pebble conglomerate are present. Possibly some of these lower beds are Precambrian. It is a highly resistant unit and conducive to the formation of rugged terrain, talus, rock rivers, and other accumulations of coarse rubble. Upper Cambrian units are present in the southern Pilot Range of Nevada and are tentatively thought to be present in Gartney Mountain along with the Ordovician Pogonip Group. Gartney Mountain is an elongate knoll near the north end of the Pilot Range near the Southern Pacific railroad tracks. The Gartney Mountain outcrops are medium to massively bedded dolomitic limestones and dolomite.

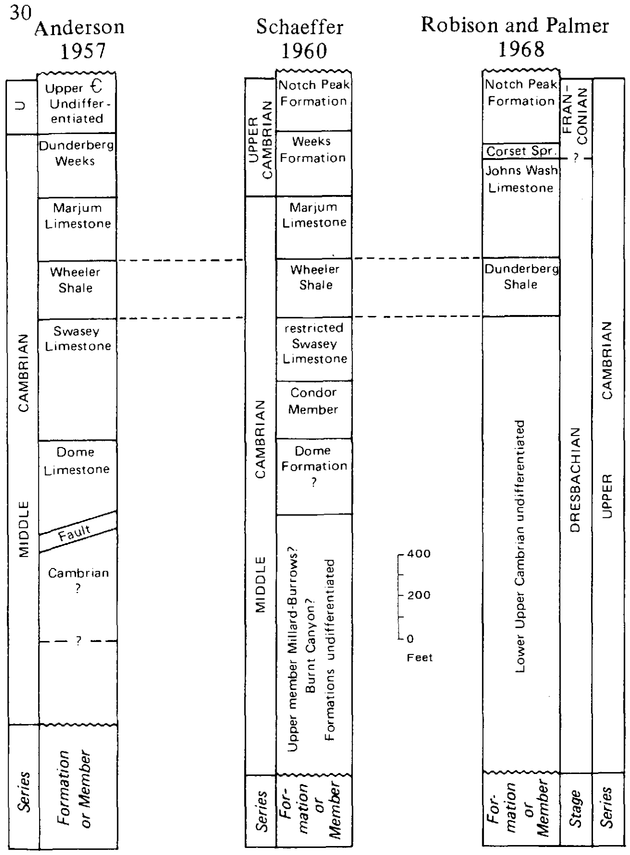


Figure 14. Comparison of Anderson's (1957) and Schaeffer's (1960) mapped units as revised by Robison and Palmer (1968).

Cambrian rocks are present in the northern Grouse Creek Mountains (Vipont Mountains), in the Dove Creek Mountains (northeastern arm of the Grouse Creek Mountains), and in the Raft River Range. There are two units; the schist of Mahogany Peaks and the quartzite of Clarks Basin. The lower quartzite of Clarks Basin is about 400 to 600 feet thick, mostly thinbedded with white micaceous partings. The lowermost strata appear to interfinger with Precambrian rocks (figure 15). The schist of Mahogany Peaks is 0 to 300 feet thick and is mostly dark brown, micaceous schist. It exhibits a lack of bedding and has an abundance of mica, garnet, and staurolite. The unit locally interfingers with overlying fossiliferous Ordovician strata. There is no data which allows the assignment of these units to the Lower, Middle, or Upper Cambrian, and they are too metamorphosed to compare with neighboring sections lithologically. The Grouse Creek-Raft River Cambrian? section is much thinner than the Cambrian of the other mountain ranges in the county.

Ordovician

The Ordovician sections in Box Elder County are

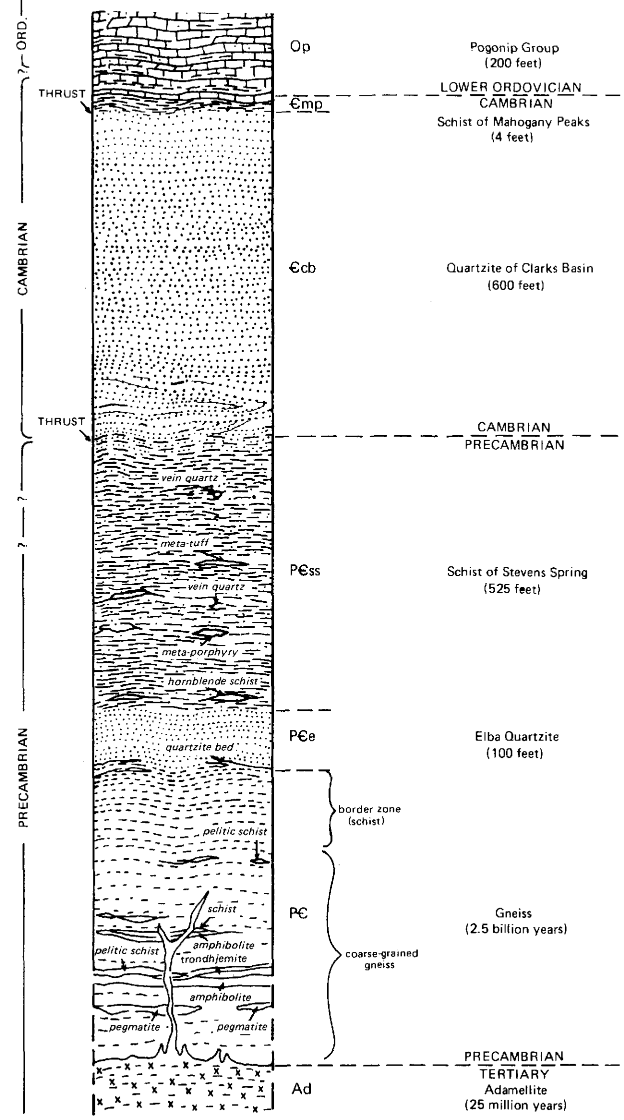
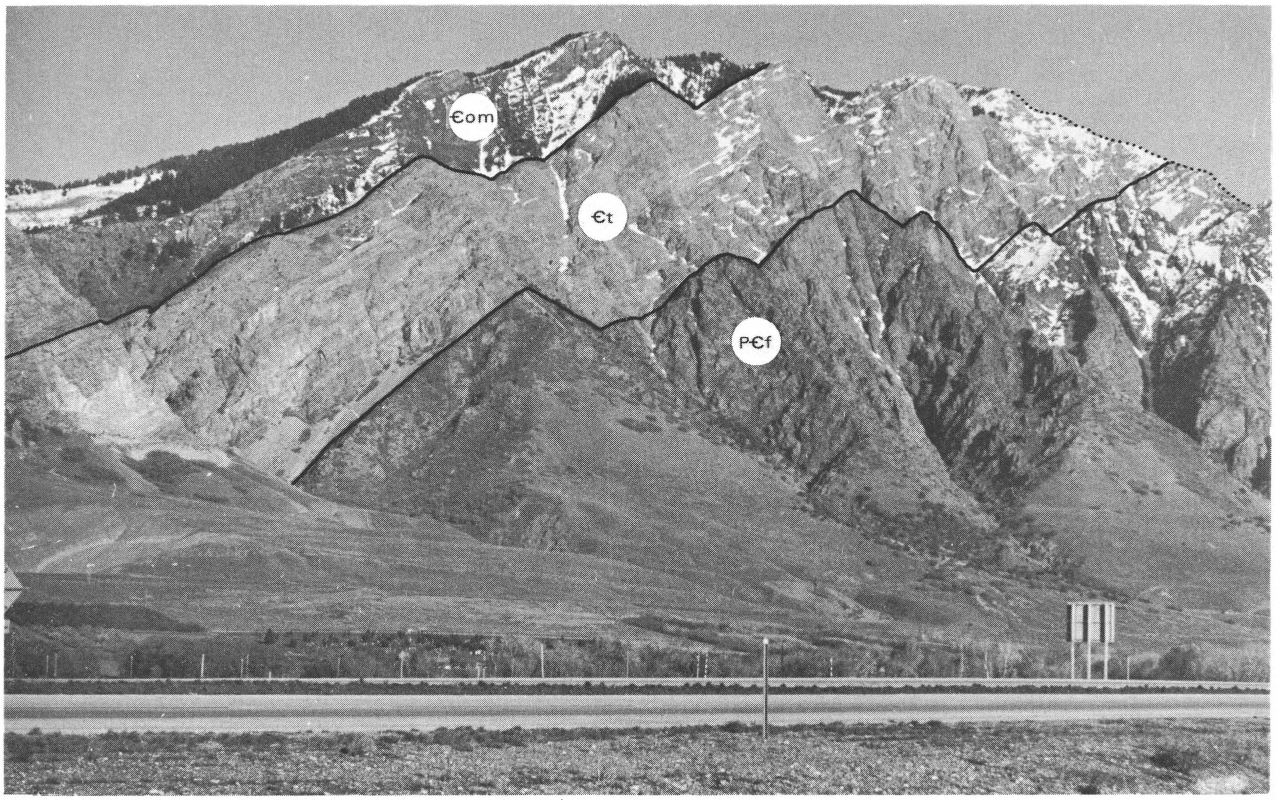
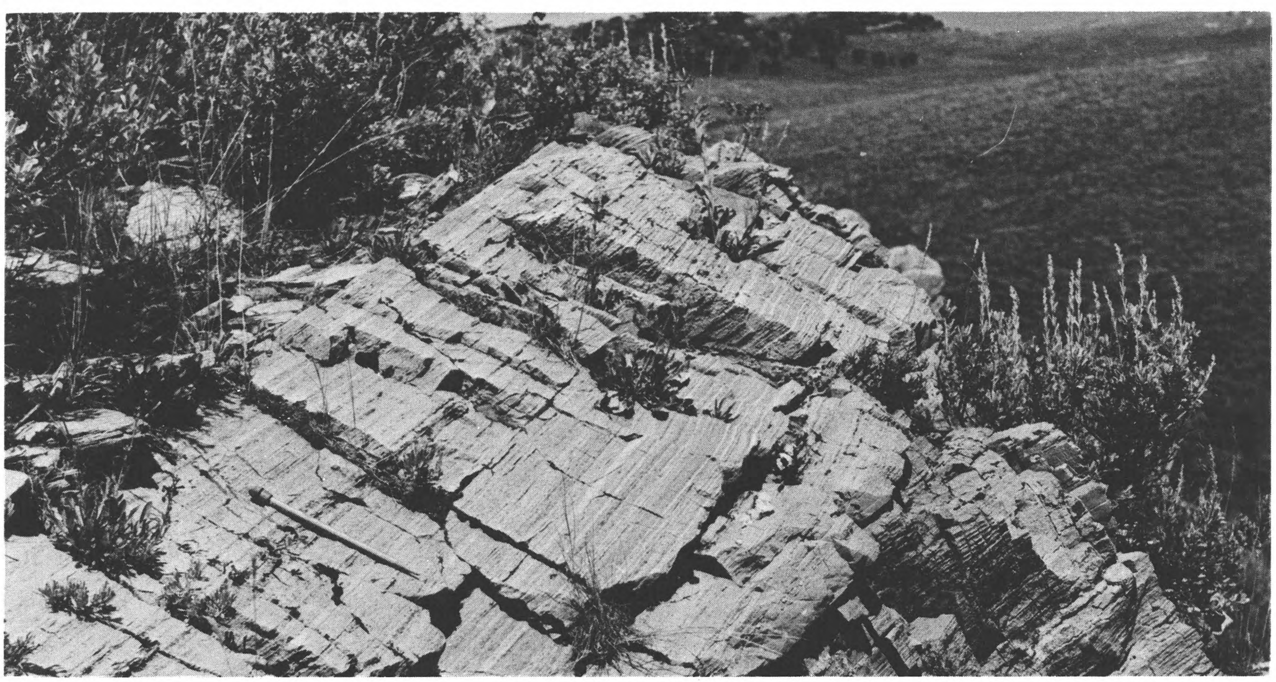


Figure 15. Precambrian and Cambrian units in the Grouse Creek Mountains (after Todd, 1973, p. 22).

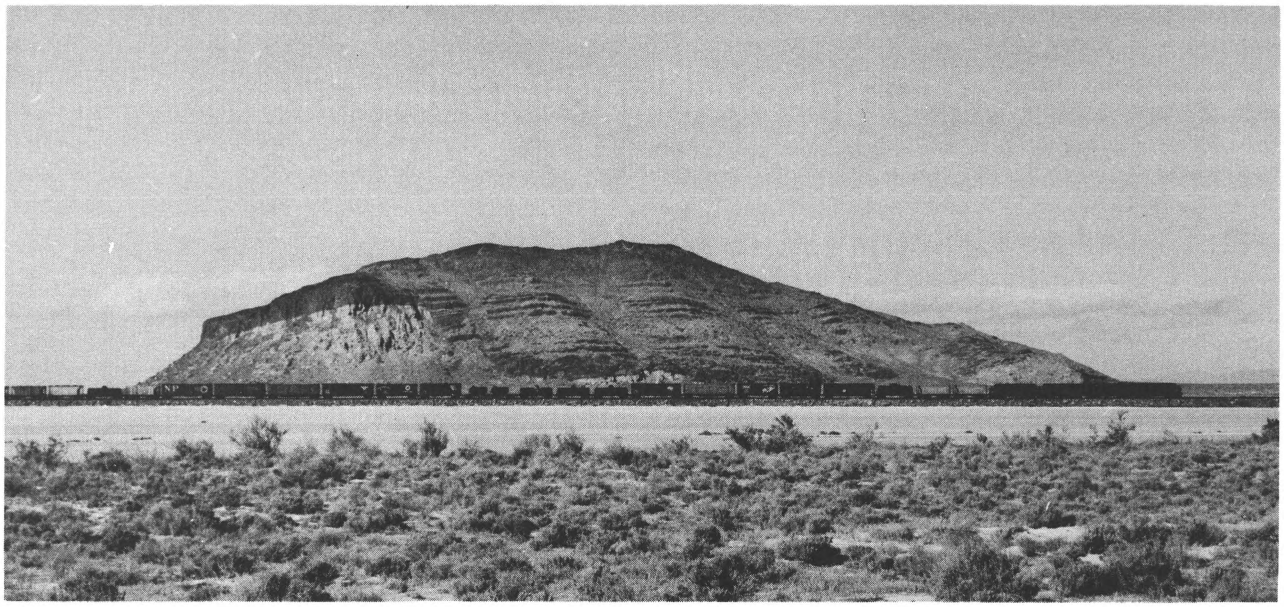
essentially composed of four units or formations: a lower interbedded complex of intraformational limestone conglomerate, silty limestone, and thick-bedded crystalline limestone known as the Garden City Formation; a soft, slope-forming reddish brown siltstone or argillite with thin-bedded, platy weathering, light blue limestone known as the Kanosh, Lehman or Swan Peak Shale; a quartzitic unit, light gray but weathering to tan and brown hues, massive and resistant, known as the Eureka and Swan Peak Quartzites; and an upper dark gray to black, thick-bedded to massive dolomite containing significant amounts of chert, known as the Fish Haven Dolomite. In western Utah the Pogonip Group includes all Ordovician units older than the quartzitic unit (Lower and part of Middle Ordovician) (figures 16 to 18).



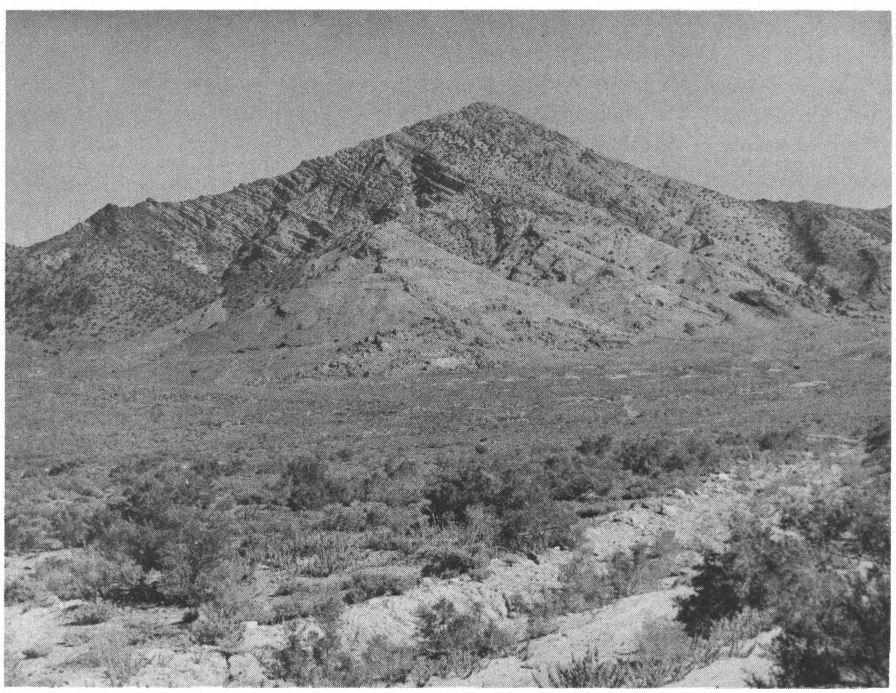
P 7. View of the Wasatch Range near Willard, Utah. The exposed rocks include the Farmington Canyon Complex (p€f), the Tintic Quartzite (€t) and the Ophir Shale and Maxfield Limestone (€om). These are the autochthonous units associated with the Willard thrust fault.



P 8. A good exposure of Pogonip Group? rocks in the Grouse Creek Mountains. The Pogonip is thrust over older (Cambrian? and Precambrian) rocks in the Pilot, Grouse Creek, and Raft River ranges in Box Elder County.



P 9. Strong Knob is a prominent knoll at the north end of the Lakeside Mountains exposing Ordovician units. The light outcrop is the Swan Peak Quartzite and the overlying dark unit is the Fish Haven Dolomite. The Southern Pacific Railroad is an important transportation link crossing Box Elder County.



P 10. Desert Peak is the highest in the Newfoundland Mountains and consists of the Ordovician Fish Haven Dolomite and the Silurian Laketown Dolomite.

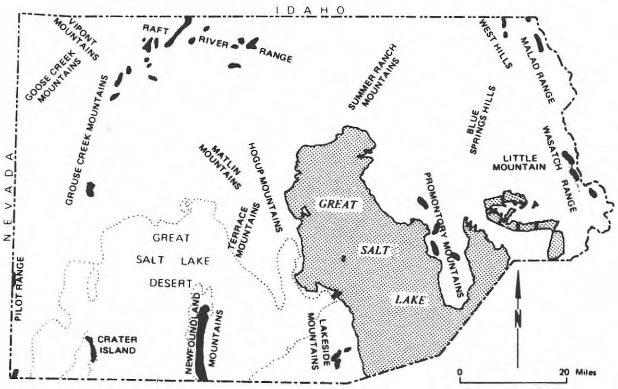


Figure 16. Ordovician outcrops of Box Elder County.

At Wellsville Mountain (northern Wasatch Range) the Ordovician is 2,225 feet thick. The Garden City Limestone forms cliffs of medium gray, finely crystalline, thick- to medium-bedded limestone, dolomitic limestone, and intraformational limestone conglomerate. The lower part is banded with muddy limestone and silt partings that weather in relief. Most of the unit is rhythmically banded with 18-inch layers of finely crystalline medium gray limestone and shaly limestone containing silt partings or laminae. The upper 150 to 175 feet of the 1700-foot unit contain black chert nodules and stringers and become increasingly dolomitic. The Swan Peak Quartzite shale member is 165 feet thick and consists of black shales and silty sandstones and is usually fossiliferous. The quartzite member is 270 feet thick and the lower 80 feet consist of brown to gray green quartzite, whereas the remainder is the typical massive, cream to orange pink ripple-marked quartzite. Only 140 feet of the Fish Haven Dolomite are found at the top of the Ordovician section; it is a dark gray, coarsely crystalline, fossiliferous massive dolomite. The thin 140-foot Fish Haven of Wellsville Mountain stands in contrast to the 1,020-foot upper dolomite in the Promontory Range and Lakeside Mountains. It is difficult to separate the Fish Haven from the overlying Laketown Dolomite of Silurian age as the two grade into each other without conspicuous lithologic change (figure 17).

Ordovician rocks are exposed on West Mountain near Portage on the west side of Bear River Valley. The oldest exposed unit is the Swan Peak Quartzite, which is estimated to be more than 400 feet thick. Overlying this is a 1540-foot section of dark to light gray dolomite that includes both Fish Haven Dolomite and the Silurian Laketown Dolomite. The exact dividing line between the upper two units is not defined but is inferred to be 300 feet above the base.

In the Promontory Range the four typical units are exposed, totalling 2,910 feet of strata. The Garden City is a slope-former with locally resistant beds forming prominent cuestas. The formation may be divided into three subunits: (1) a 560-750-foot basal unit consisting of light blue gray weathering limestone with very thin light brown seams of well-indurated muddy limestone giving the member a banded appearance: (2) a middle 230-345 foot-thick massive limestone with black nodular chert that weathers to a dark blue gray, and (3) an upper 200-foot unit of massive, dark gray to dark bluish gray, finely crystalline dolomite that weathers to shades of gray. The shale member of the Swan Peak Quartzite is about 240 feet thick and is normally poorly exposed because of the covering quartzite rubble from the upper member. The quartzite member is about 480 feet thick, is white to tan or light brown and very fine-grained to fine-grained. Weathered colors are generally reddish brown to orange, but locally the uppermost 2/5ths of the unit weathers white. The unit is rarely crossbedded and is quite massive. The Fish Haven or Ely Springs Dolomite, the uppermost Ordovician unit, is 1,019 feet thick in the Promontory Range and forms gentle to steep slopes above the cliffy Swan Peak Quartzite. There is a distinctive unit of dark gray to black, very finely crystalline dense dolomite 120 feet thick with abundant black chert in the upper half. The upper strata, other than the black unit, consist of alternating dark gray and light gray, blocky to massive dolomite. Chert is uncommon, but vugs lined with quartz crystals are locally abundant.

The Ordovician in the Lakeside Mountains is composed of the Garden City Limestone (1616 feet), the Swan Peak Quartzite shale member (252 feet), the Swan Peak Quartzite (230 feet) and the Fish Haven Dolomite (1000 feet). The lower two-thirds of the Garden City Formation is slope-forming, while the upper third is highly resistant, forming precipitous cliffs. The lower two-thirds of the formation consists of an interbedded complex of intraformational limestone conglomerate, thin-bedded silty limestones, and thick-bedded to massive crystalline limestones. Generally, fine- to medium-grained textures prevail. Silty partings, which weather to a tan color, are common in the thin-bedded varieties. Intraformational conglomerates contain pebble- to cobble-sized fragments. The upper third of the formation consists of generally massive, dark blue or dark gray limestone with considerable silt. One thin olive green shale bed was observed in this part of the formation. The unit also contains many scattered trilobite-debris beds, and minor black chert is found in the upper resistant beds. Toward the top of the formation the beds

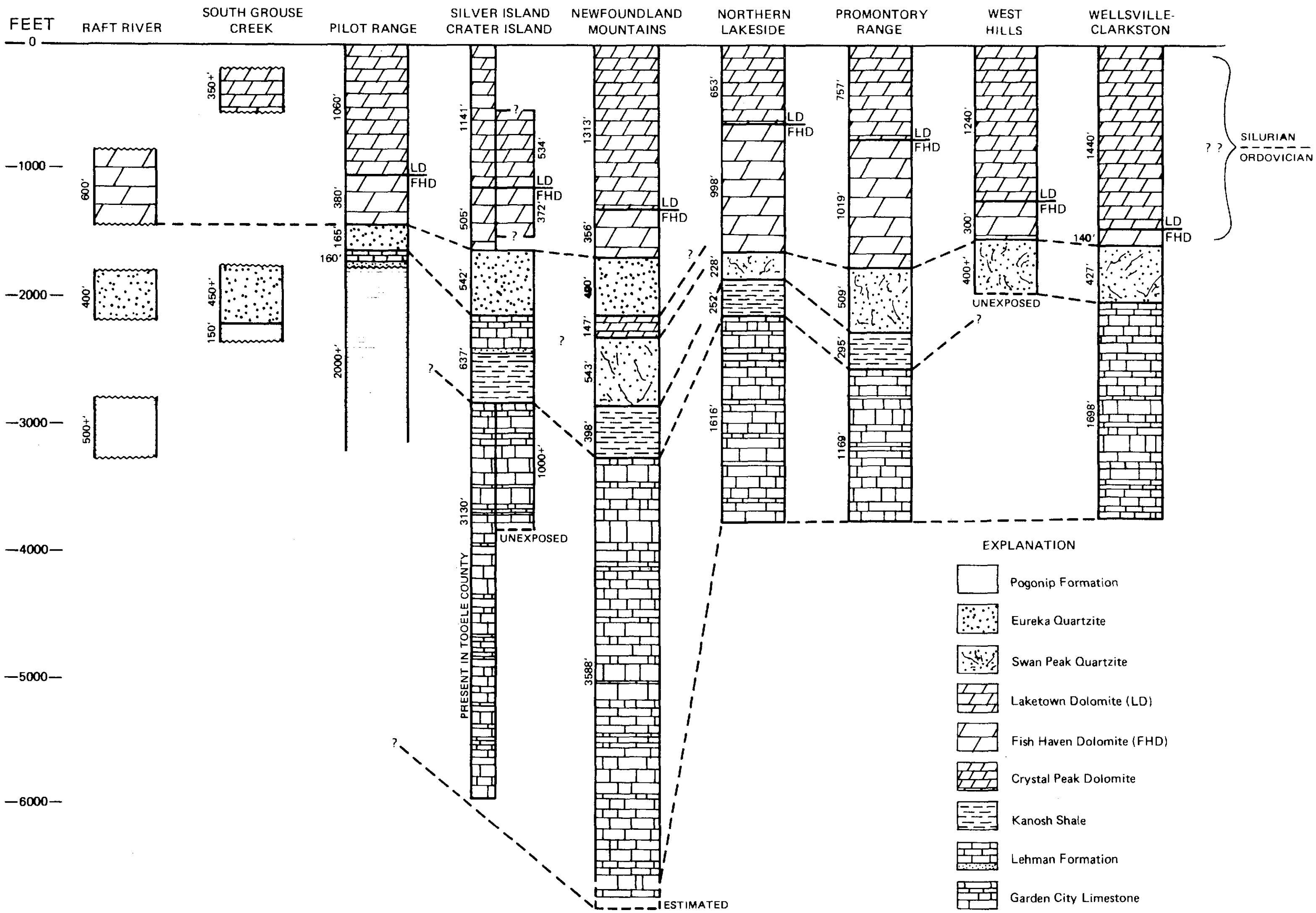


Figure 17. Correlations of Ordovician and Silurian units in Box Elder County.

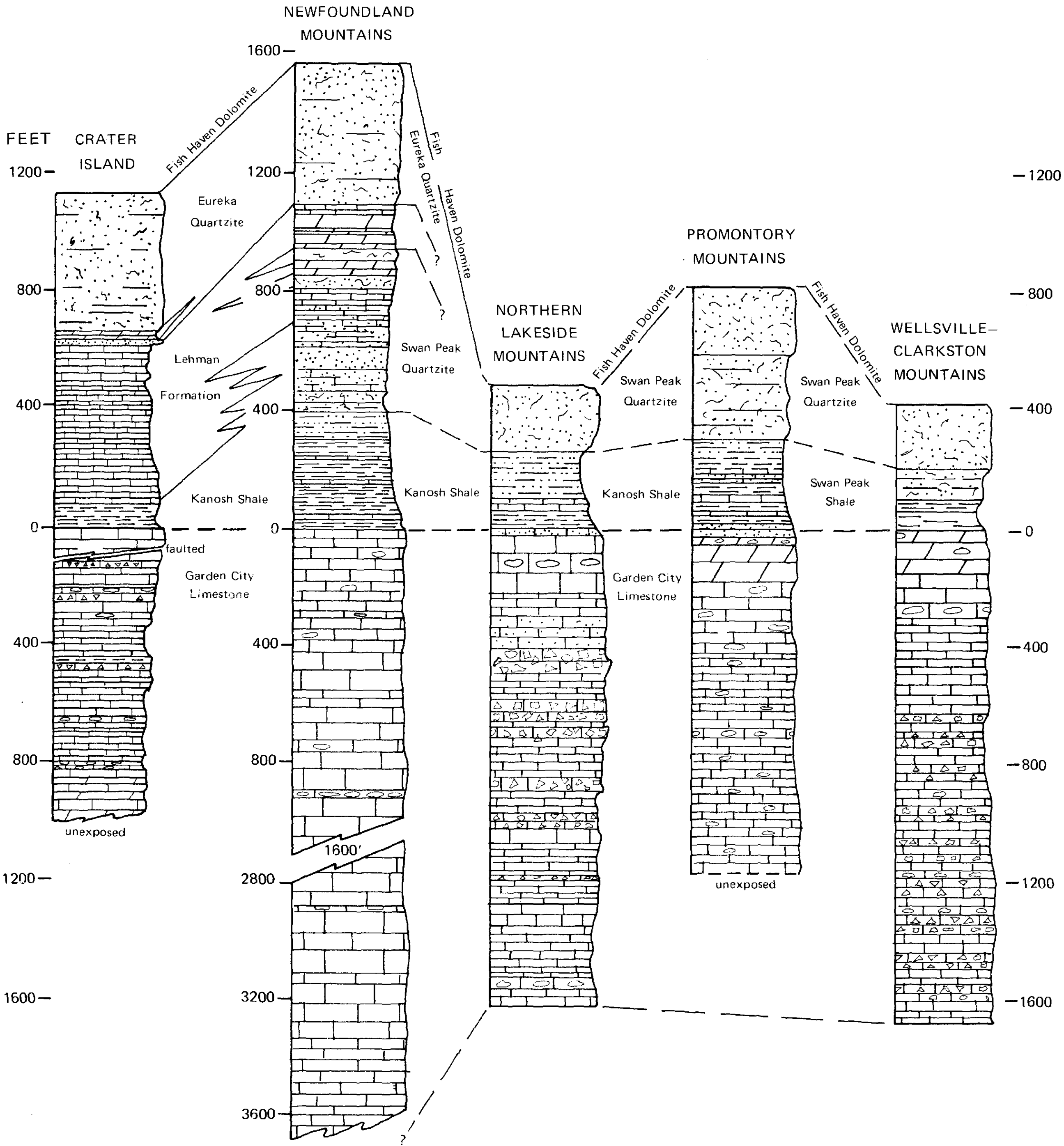


Figure 18. Correlation of Lower and Middle Ordovician units in Box Elder County.

become progressively silty and the top 10 to 15 feet become thin-bedded and contain sand. These beds grade into the siltstones and very silty limestones of the lower member of the Swan Peak Quartzite. The Swan Peak shales are characterized by interbedded silty thin-bedded limestones, thin-bedded to shaly calcareous siltstone, and silty and calcareous fine-grained sandstones that produce a pronounced reddish brown concave slope. The upper Swan Peak is white to yellow buff, fine- to medium-grained, thick-bedded to massive siliceous sandstone or quartzite which weathers yellow tan to brown. The upper part of the Swan Peak generally produces a cliff with the lower part of the Fish Haven Dolomite. The lower 120 feet of the Fish Haven form a precipitous cliff whereas the remainder forms rounded hills and knolls. This lower Fish Haven is dark gray to black, fine- to medium-grained crystalline dolomite, that contains a great deal of chert in blebs and nodules. The chert is gray tan to black and weathers to shades of brown. Sparsely scattered throughout this unit are crinoid stems and *Halysites sp.* The upper Fish Haven Dolomite consists of medium-gray to black, medium-grained dolomite, that is normally thick-bedded. Black or brown chert is found at irregular intervals, commonly as blebs and nodules. The dolomite often shows color mottling and color laminae. The unit is generally unfossiliferous, except for an occasional cup coral.

The thickest Ordovician section in Box Elder County is in the Newfoundland Mountains, exceeding 5,515 feet. The lowermost Garden City Limestone is 3,600 feet thick and is a monotonous sequence of dark gray, silty, fine to medium crystalline limestones. The silt increases in the upper part of the formation, which contains abundant chert. Above the Garden City Formation are typical Kanosh Shale beds, appearing as a dark brown band beneath the quartzite. The unit consists of almost 400 feet of reddish brown, dark gray to black argillite with subordinate gray limestone, with the upper portion being very fossiliferous. The quartzitic sequence is divided into three formations in the Newfoundland Mountains: Swan Peak Quartzite, Crystal Peak Dolomite, and Eureka Quartzite. The Swan Peak Quartzite consists of interbedded dark gray to white quartzite and finely crystalline black limestone or dolomite. The Crystal Peak is a dark gray to black, silty, thin- to thick-bedded, finely crystalline dolomite 140 feet thick. The Eureka Quartzite consists of 490 feet of mostly massively bedded, fine- to medium-grained white orthoquartzite that weathers grayish tan and forms steep cliffs. The Fish Haven is 356 feet thick and is divisible into three members. Massively bedded black finely crystalline dolomite containing black chert nodules and lenses makes up the lower unit. The middle is thick-bedded, black, cherty dolomite less resistant than the unit below with some of the beds weathering to a light gray and others to a brownish black. The uppermost member is like the lower unit.

On Crater Island, where 1000 feet of the Garden City Formation are exposed, the formation is probably incomplete due to faulting. In the Silver Island Mountains to the south, in Tooele County, the formation is 3,130 feet thick. On Crater Island the unit is mostly bluish gray, thin- to thick-bedded, mottled and banded limestone. Some tan-weathering dolomite is found in the lower part of the exposed section and there are thin intraformational limestone conglomerate beds in the upper third. The Garden City Formation weathers into ledges and slopes. Above it, the Kanosh Shale or Lehman Formation is 637 feet thick consisting mostly of thin, light bluish and brown limestone beds that are mottled rusty brown. Near the base is dark brown to black fossiliferous argillite. The overlying Eureka? Quartzite is light grayish white thin-bedded to massive quartzite 542 feet thick. There is a thin sandy quartzite and a dark gray calcareous dolomite at the base. The upper half exhibits light and dark gray banding. The 372-foot Fish Haven is medium gray to black, thin-bedded to massive crystalline dolomite with chert nodules in the lower part. An unconformity is recorded at the top of the unit.

In the northern Pilot Range the Garden City Limestone is not recognized, and most of this interval is probably eliminated by faulting. Some Pogonip Group rocks are exposed as mostly thin-bedded argillaceous limestone, dark blue to black in color, forming a slope 110 to 165 feet thick. Several small knolls that surround the northern part of the range have incomplete sections of Pogonip Group strata. The Eureka Quartzite overlies the Pogonip and is about 150 feet thick and it in turn is overlain by 375 feet of Fish Haven Dolomite. Sand and chert increase toward the top of the Fish Haven.

In the southern Pilot Range O'Neill (1968, p. 32) has measured 4,576 feet of argillaceous limestone, shale, quartzite and calcareous dolomite that are assigned to the Ordovician. He recognizes the Garden City Formation with a basal member of 605 feet of non-resistant shaly, argillaceous, orange-mottled, medium gray limestone, followed by 465 feet of thin- to thick-bedded ledge and slope-forming argillaceous limestone, followed by 1,370 feet or more of cherty, medium to light gray slope-forming limestone. These outcrops are overlain by 215 feet of argillaceous shales and platy mudstones interbedded with platy, silty limestone beds assigned to the Kanosh Shale. Above the Kanosh Shale is the Lehman Formation consisting of as much as 840 feet of flaggy argillaceous dark gray limestone. Above this O'Neill recognized 46 feet of Swan Peak Quartzite, 89 feet of Crystal Peak Formation, 235 feet of Eureka Quartzite and 450+ feet of Fish Haven Dolomite. Most of his measurements were made in the Nevada portion of the range. Ordovician outcrops are present on the east (Utah) side of the central part of the range, but no studies are available that differentiate the thick interval below the Eureka. This thick sequence is therefore assigned to the Pogonip Group. An incomplete section of Eureka Quartzite is recognizable at this location. Complete sections of the Eureka Quartzite and Fish

Haven Dolomite are present at Lion Mountain, a knoll on the east side of the Pilot Range, but the units have as yet not been measured. Fish Haven Dolomite outcrops are present in the Little Pigeon Mountains.

In the southern Grouse Creek Mountains all but 150 feet of the Pogonip? Limestone are missing because of faulting or intrusion by igneous rocks. The Pogonip? consists of thin to medium-bedded sandy limestone and is devoid of fossils. The overlying Eureka? Quartzite is 450 feet thick, but incomplete in its exposure. It is composed of white, glassy quartzite, which in places has streaks of light blue or orange coloration.

In the western Raft River Range and the northern Grouse Creek Mountains, units tentatively correlated with the Pogonip, Eureka, and Fish Haven are metamorphosed. Here the 500-foot Pogonip? is tan-weathering impure marble in the lower two-thirds and a light gray, almost pure marble in the upper part. The Eureka? is white quartzite, but unlike typical exposures has beds 1 to 6 inches thick and is micaceous along bedding planes. The Fish Haven? has several hundred feet of silvery gray and dark gray dolomite at the base, several hundred feet of massive, usually brecciated, cream-colored dolomite in the middle, and one hundred feet of gray laminated dolomite at the top.

In the eastern Raft River Mountains a suite of rocks have been described and labelled Lower? Paleozoics that are probably Ordovician in age. The suite is divisible into three parts, upper, middle and lower. The lower subunit is 3,500 feet thick, of which 40 percent is limestone, 34 percent is dolomite, 12 percent is quartzite, and 1 percent is schist. The unit is thought to correspond with the Pogonip Group. The middle subunit is 197 feet in thickness and is a metaquartzite corresponding to the Eureka Quartzite. The upper Fish Haven equivalent is light gray, finely crystalline dolomite and is 100 feet thick.

Silurian

The Silurian Period is represented by a single formation in Box Elder County, the Laketown Dolomite (figure 17). Its description varies only slightly from mountain range to mountain range and its thickness varies from a low of 350 feet in the southern Grouse Creek Mountains to a maximum of 1440 feet at Wellsville Mountain (Northern Wasatch Range). It is 1,070 feet thick in the Pilot Range, 534 feet on Crater Island, 1,313 feet in the Newfoundland Mountains, 650 feet in the Lakeside Mountains, 760 feet in the Promontory Range and is about 1240 feet in the West Hills. Generally the Laketown Dolomite is a light to dark gray, thick-bedded to massive dolomite that weathers to rounded sugary surfaces and has minor cherty intervals. Locations of Silurian outcrops are shown on figure 19.

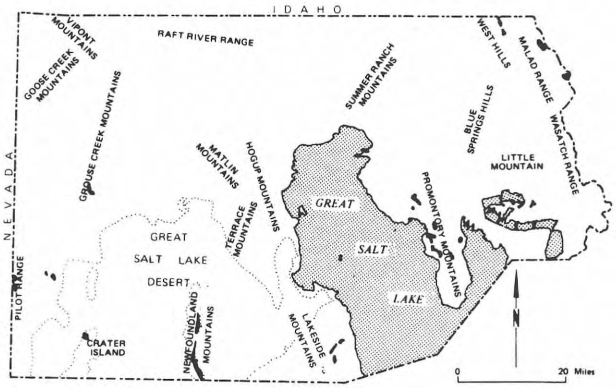


Figure 19. Silurian outcrops of Box Elder County.

In the Pilot Range the Laketown Dolomite can be divided into three subunits on the basis of color; a lower light gray, a middle dark gray, and an upper light to medium gray. On Crater Island the Laketown has a fossiliferous upper contact and abundant chert beds in the lower two-thirds. In the Grouse Creek Mountains lenses of brown quartzite appear irregularly in the unit. In the Newfoundland Mountains the Laketown can be subdivided into seven units mostly on the basis of color: the lowest unit 1 is very light gray dolomitic siltstone and dolomite, unit 2 is medium gray, massive and forms a prominent sheer cliff, unit 3 is dark gray to black, unit 4 is medium gray weathering to light gray, unit 5 is dark gray and cherty and very fine-grained, unit 6 overlies unit 5 disconformably and is similar to it except that it is not as fine-grained, and the uppermost unit 7 is a light gray tan.

In the Lakeside Mountains the color is more uniform, generally a light to medium gray. The lower beds may be streaked with sand and many of the beds contain vugs lined with milky or clear quartz crystals. Pentamerid brachiopods, thick crinoid columnals, and light colored chert are found in selective beds. In the Promontory Range the Laketown is characteristically massive, forming sheer cliffs. It consists of interbedded light and dark gray dolomite units ranging from 53 to 430 feet in thickness. It is divided into five subunits on the basis of color; the lowest, unit 1 is gray to light gray and 133 feet thick, unit 2 is dark gray to black, cherty and 71 feet thick, unit 3 is light to silvery gray and 430 feet thick, unit 4 is gray to dark gray and 71 feet thick, and the uppermost, unit 5 is light to silvery gray and 53 feet thick.

In the West Hills (Samaria Mountain) near Portage, the Laketown is massive, fine to coarsely crystalline with 15 separate units distinguished chiefly on the basis of slight variations in color and topographic expression. In the lower part the units are mostly dark to medium gray and contain much dark chert in nodules and stringers. In the upper half the units are mostly light gray with sugary weathering surfaces. Chert is less common except for the uppermost 100 feet. The Laketown is very thick at Wellsville Mountain and in the northern Wasatch Range, perhaps 1200 to 1600 feet thick. The lower part is alternating light to dark gray, fine to coarsely crystalline, massive to medium-bedded dolomite. The upper part is mostly medium gray and massive dolomite.

As already noted, it is difficult in most areas to separate the Ordovician Fish Haven Dolomite from the Silurian Laketown Dolomite. Many investigators simply combine the two units; others have used subtle color changes, topographic expression, or the top or base of a fossiliferous unit they have found. Figure 20 shows that this interval of rock is very uniform in thickness wherever complete sections are found, ranging from 1440 to 1776 feet. At the same time the thicknesses recorded for the Fish Haven (140 - 1,019 feet) or the Laketown (653 - 1,440 feet) are much more erratic, indicating that the contacts may not have been placed at consistent time lines.

Devonian

Devonian rocks have been identified in most of the mountain ranges of Box Elder County and in the sub-

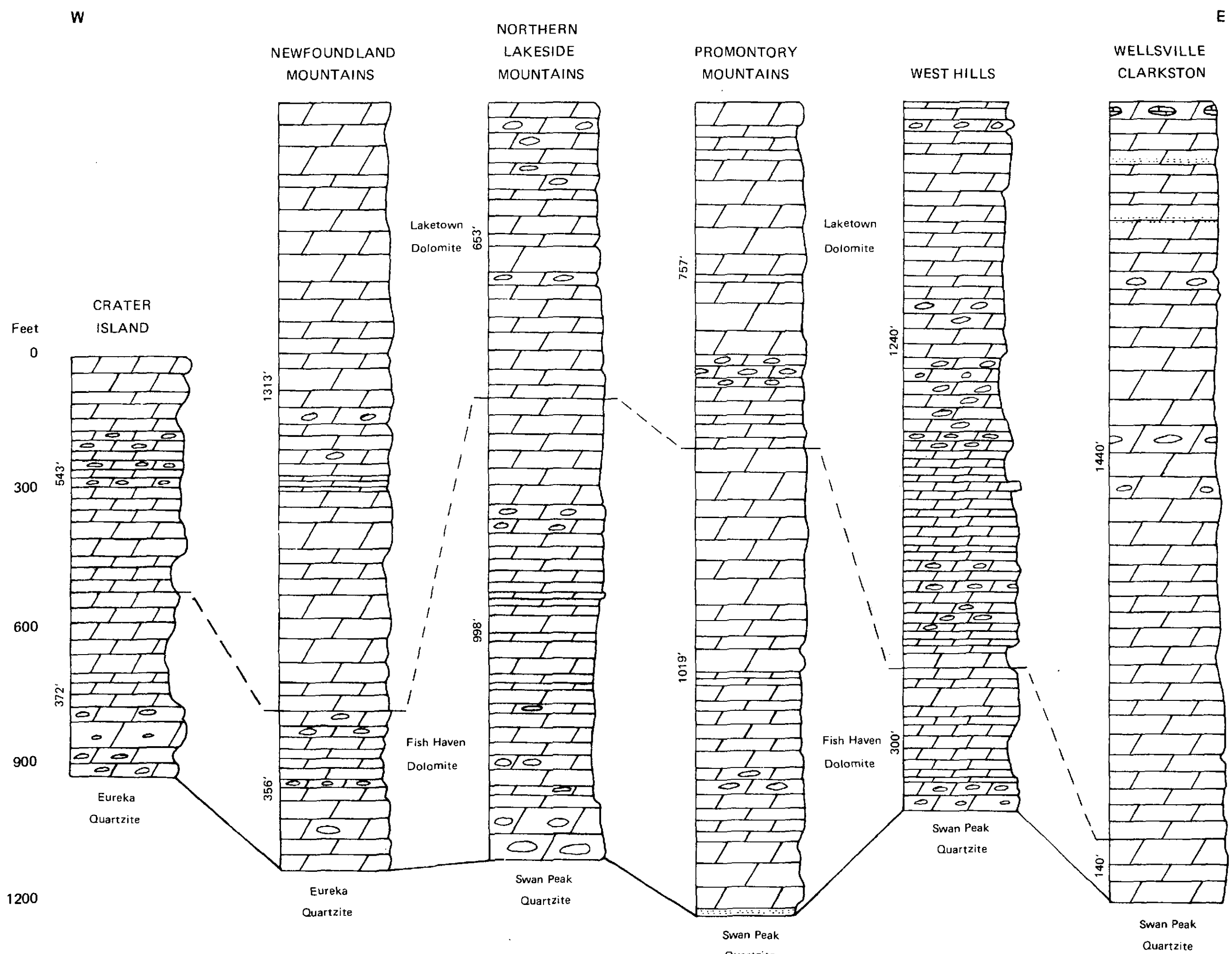


Figure 20. Correlation of Laketown and Fish Haven Dolomites in Box Elder County.

surface of Curlew Valley (figure 21 and 22). Measured sections, in areas where the tops and bottoms of the system are exposed, range from 2,000 to 4,200 feet. Devonian rocks of the Pilot Range are typical of the western Box Elder County region and two units are recognized, the Simonson and Guilmette Formations. The Simonson Formation rests unconformably upon the Silurian Laketown Dolomite and is a monotonous sequence of alternating light and dark gray calcareous dolomite. It produces step-like slopes and is less resistant than the units above and below. The Simonson is thin- to medium-bedded and about 550 feet thick. The overlying Guilmette Formation is divisible into three subunits: an upper shaly limestone, a middle massive quartzite, and a lower massive limestone. The lower limestone is dark gray to blue black, thick-bedded to massive with dolomite stringers near the base. It is sandy and cherty near the top and is 850 to 900 feet thick. The quartzite member, light gray to medium gray rock that weathers to reddish massive cliffs, ranges in thickness from nothing to 270 feet. The upper shaly limestone is dark gray to black, platy limestone, usually mottled or finely laminated by silty and argillaceous stringers along bedding planes. It is medium resistant and between 305 and 345 feet thick. The maximum thickness for the entire Guilmette Formation is about 1,515 feet.

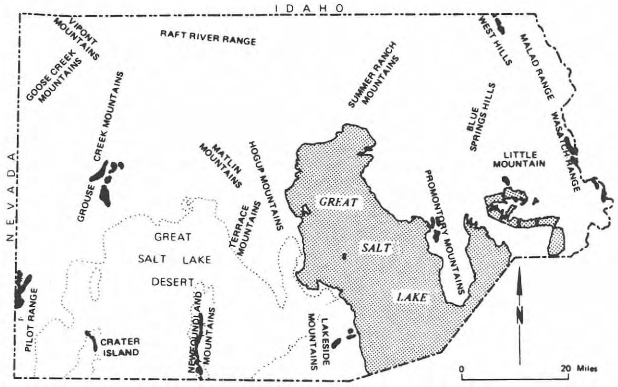


Figure 21. Devonian outcrops of Box Elder County.

The same two units are present at Crater Island, but here the sequence is almost 3,300 feet thick. The Simonson Dolomite is a complex of banded light gray and dark gray dolomite, calcareous dolomite, dolomitic limestone and limestone. It weathers into step-like slopes, is 1,176 feet thick, and is in thin to medium beds. The Guilmette Formation is over 2,100 feet thick and consists of light to dark gray, finely crystalline, thin-bedded to massive limestone. In the middle of the unit are a pair of purplish brown calcareous siltstone units. An unconformity is thought to be present at both the top and bottom of the Devonian.

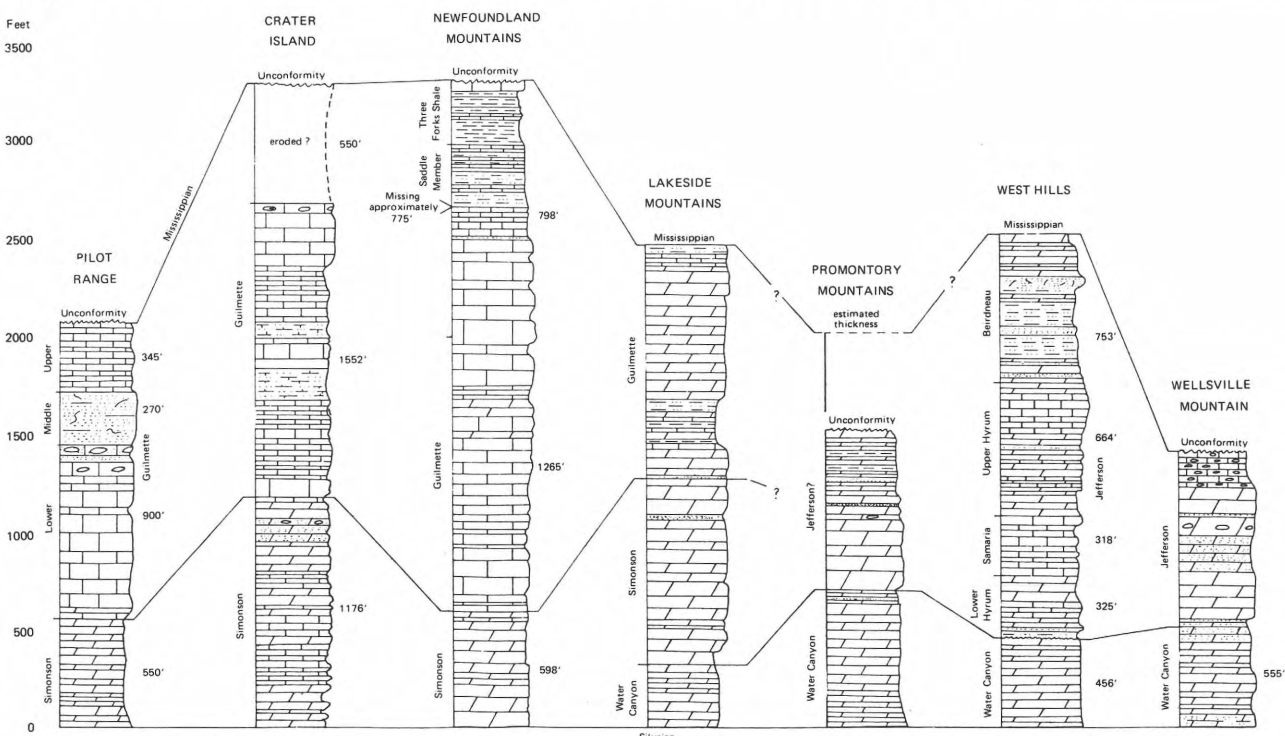


Figure 22. Correlations of Devonian formations across Box Elder County.

In the southern Grouse Creek Mountains the Simonson Dolomite consists of 505 feet of light-colored dolomite and subordinate limestone. The measured lower contact is with the Grouse Creek pluton; the upper contact is faulted. The normal gray-banded characteristic is present where the unit has not been altered and bleached by the nearby monzonite stock. The Guilmette Formation is 95 percent medium-bedded to massive, uniformly blue gray limestone. Thin quartzitic layers are found sparsely interbedded in the very resistant unit. The minimum exposed thickness for the Guilmette is 1,500 feet.

The thickest Devonian section occurs in the Newfoundland Mountains. The Simonson Dolomite is almost 600 feet thick and typical in its light and dark-gray banding. Locally there is a thin, medium gray, dense dolomite (up to 75 feet thick) at the base of the unit. The Guilmette Formation is mostly dark-gray to black, massive limestone with a few intervals of gray thick-bedded dolomite. Near the top of the 3,200-foot unit are some calcareous purple siltstones. The youngest Devonian beds of the Newfoundland Mountains are fossiliferous, gray to black calcareous shales with a few interbeds of black silty limestone. About 330 feet of strata with this description have been designated the Three Forks? Shale.

In the Lakeside Mountains the lowermost Devonian is the Water Canyon Dolomite, about 340 feet thick. It is less resistant to erosion than the Silurian Laketown Dolomite beneath it and the Simonson above. Its fresh color is a mouse gray, but it weathers to a very light gray or white. It is aphanic in texture and the unit may correlate with the lower 75 feet of the Simonson Dolomite in the Newfoundland Mountains. The Simonson is again the typical light and dark gray banded dolomitic unit with laminae varying from tenths of inches to several feet. Beds are one to two feet thick in general, chert is rare, and an occasional medium bed of quartzite may be found. The Simonson Dolomite is 960 feet thick near Lakeside. The uppermost Devonian unit is the Guilmette Formation. There are three subunits based on resistance to erosion; the upper and lower parts being cliff-forming. The lowermost subunit is light to dark gray, thin-bedded to massive dolomite with an 8 to 12-foot layer of resistant crossbedded sandstone or quartzite at the base. The middle subunit is a complex of gray, lavender-weathering limestones and calcareous shales with subordinate dolomite and siltstone. The upper part is mostly medium-to dark-gray dolomite in beds 1 to 3 feet thick. The entire Guilmette Formation is 1,200 feet thick in the northern Lakeside Mountains and no unconformity can be demonstrated at the top of the Devonian. To the west of the Lakeside Mountains the lower Devonian unit is principally dolomite and the upper unit is principally limestone. In eastern sections the Devonian consists of the Water Canyon and Jefferson Formations, both dolomitic with some sandy units near the top. The Lakeside Mountains section is transitional; the basal unit corresponds well to the Water Canyon Dolomite to the east, but is thinner. The dolomitic unit above is a replica of Simonson sections westward. The upper unit exhibits characteristics of both the Guilmette to the west and the Jefferson to the east.

Devonian rocks have not been recognized in the Raft River Range. In 1972 the Bureau of Reclamation drilled a test well 1 mile northwest of the town of Park Valley on the south side of the Raft River Range in section 28 T. 13 N. R. 13 W. From 460 feet to the total depth of 1312 feet a dark gray, hard, dense, somewhat dolomitic and siliceous limestone was encountered. Small calcite seams were present throughout. Although the age is unknown, the rock resembles the Devonian Guilmette Formation.

East of the Raft River Range in Curlew Valley, drilling has intercepted over 1,500 feet of Devonian rock. The wells did not pass into the Silurain, however, and the section is partial. The descriptions mention the presence of silty, calcareous, carbonaceous black shale, dark gray silty and sandy limestone and calcareous dolomite, many beds somewhat metamorphosed.

The Devonian Period of the Promontory Range has two formations, the Water Canyon Dolomite and the Jefferson Formation. Most of the 1,576-foot Devonian is dolomite; there are only minor exceptions. The thickness is variable and thought to be due to pre-Mississippian erosion; in some areas the Jefferson is completely missing. Considerable strata may have been removed during this pre-Mississippian erosional interval, even from the thickest known sections. In some places all of the Jefferson and up to 200 feet of the Water Canyon Dolomite may have been removed. The Water Canyon is 705 feet thick in complete sections. The unit is a slope-former but its outcrop pattern is like a flight of stairs, with beds 2 to 5 feet thick. It is white to light gray and very finely crystalline. A peculiarity is the presence of tiny vugs lined with clear, euhedral quartz crystals. The overlying Jefferson was found to be 871 feet thick at its best location, with perhaps another 500 feet concealed. This would bring the Devonian of the Promontory Range to more than 2000 feet in thickness, but the covered area is suspected of having structural complications. The unit is a ledge and slope-former and entirely dolomite except for a few thin quartzite beds. Most of the dolomite weathers dark to blackish gray, a few beds weather light to medium gray. The Jefferson would seem to correlate with the Simonson Dolomite on the basis of stratigraphic position, but the light and dark gray banding of the latter is not developed.

In the West Mountains near Portage, the Water Canyon and Jefferson Formations make up the Devonian, and are 2,515 feet thick. The Water Canyon is finely crystalline to aphanic dolomite and silty and argillaceous dolomite. The 455-foot unit is dark gray to dark gray-brown on fresh surfaces, but characteristically weathers to a very light gray; the silty or clayey dolomites weather to shades of gray, red brown or pink. Beds are six inches to three feet thick and these produce smooth-surfaced, blocky, step-like ledges in outcrop. The Jefferson Formation is subdivided into a lower Hyrum Dolomite, 1,308 feet thick, and an upper Beirdneau Sandstone, 753 feet thick. The lower 325 feet of the Hyrum are principally dark gray interbedded dolomite and limestone, with a 40-foot basal interval of tan orthoquartzite and silty calcareous sandstone. The next 318 feet are medium blue gray, aphanic to medium-grained, silty, fossiliferous limestone. The remaining Hyrum consists of light to dark gray ledge and slope-forming, interbedded dolomite and limestone that contains significant chert. The Beirdneau is made up of light gray orthoquartzite and sandstone and light to dark gray dolomite. The Jefferson-Mississippian contact is a paraconformity and considerable erosion is thought to have occurred as indicated in the Promontory Range.

At Wellsville Mountain the Devonian is 1,400 feet thick; at Rendezvous Peak, in the northern Wasatch Range, it is 1,300 feet thick. The Water Canyon Dolomite is divisible into 2 subunits: a lower 290 feet of medium-gray, dolomitic sandstone weathering yellow gray, and an upper 265 feet of medium dark gray, medium-bedded dolomite that weathers light gray to white, and contains fish fragments. The Water Canyon is 350 feet thick at Rendezvous Peak and 555 feet thick at Wellsville Mountain. The Jefferson at Wellsville Mountain has only the Hyrum Dolomite present and thins southward from 850 feet near Honeyville to 50 feet at Moss Rock Canyon, one mile south of Calls Fort. Near Rendezvous Peak the thickness is 0 to 950 feet. The Hyrum consists of dark gray dolomite, sandy dolomite, quartzite and limestone. The upper part is cherty and fossiliferous limestone. Some Beirdneau Sandstone may be present in the form of light to olive brown, fine-grained, thin-bedded sandstone, at Rendezvous Peak.

The upper part of the Jefferson Dolomite is also nicely exposed at the southwest corner of Little Mountain. It can be differentiated into a lower black dolomite, a unit of alternating light and dark dolomite, a sandy or quartzitic unit and an upper unit of fine-grained or aphanic, less-resistant, light-weathering dolomite. A partial section of at least 1,000 feet is exposed at Little Mountain.

Mississippian

The Mississippian and the lowermost part of the Pennsylvanian period are represented by the Chainman Formation in the western part of the county. The Mississippian portion of the Chainman is Chester in age; the entire Mississippian interval is missing in the Newfoundland and Raft River Mountains. On Crater Island a thin unit (Joana Limestone) of earliest Mississippian (Kinderhook) age is also present. In the Lakeside Mountains the Mississippian is rather thick (over 6,600 feet) and most of the exposed units complement, rather than duplicate, the Chainman interval and include the Lodgepole, Deseret, Humbug, Great Blue, and perhaps the Manning Canyon Formations. It is this assemblage that is usually found in the mountain ranges in the eastern half of the county (figures 23, 24, 25).

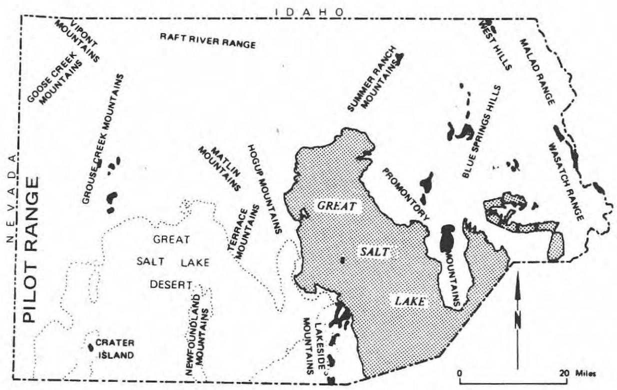


Figure 23. Mississippian outcrops of Box Elder County.

In the Pilot Range the Chainman Formation cannot be differentiated from the overlying Pennsylvanian Diamond Peak Formation. A separation could possibly be made at the north end of the range, but elsewhere the black shale lithology of the Chainman interfingers with the clastics of the Diamond Peak. The Chainman Shale is slope-forming and consists of fissile siltstone. This shale is argillaceous and hard and weathers into angular chips and plates. Interbedded with the shale and sandstone are brown-weathering silty limestones. Shales and limestones are more prevalent in the lower part of the section and disappear towards the top. The Diamond Peak Formation is a series of alternating slopes and ledges of well-indurated brown and tan sandstone and gritstone. About 470 feet of strata are present.

At Crater Island two Mississippian units are separated by an unconformity. The Joana Limestone (Lodgepole Limestone equivalent), 0-35 feet thick, overlies the Devonian Guilmette Formation unconformably and consists of mostly dark gray, crinoidal, coarse-grained limestone that forms slopes and ledges. The Joana was deposited on an erosional surface of the Guilmette. A few miles to the south, in Tooele County, the Joana thickens to 200 feet; in the northern part of Crater Island it thins to discontinuous patches that are confined to depressions on the upper Guilmette surface. The Chainman Shale is 0-307 feet thick and is made up of purple gray and yellow brown fissile siltstone. To the south, in Tooele County, the Chainman thickens to 1200 feet of black shales, brown quartzite, thin conglomerates, sandy and silty limestones and calcareous siltstones. In the northern part of Crater Island the Chainman contains some black shales and thin quartzites.

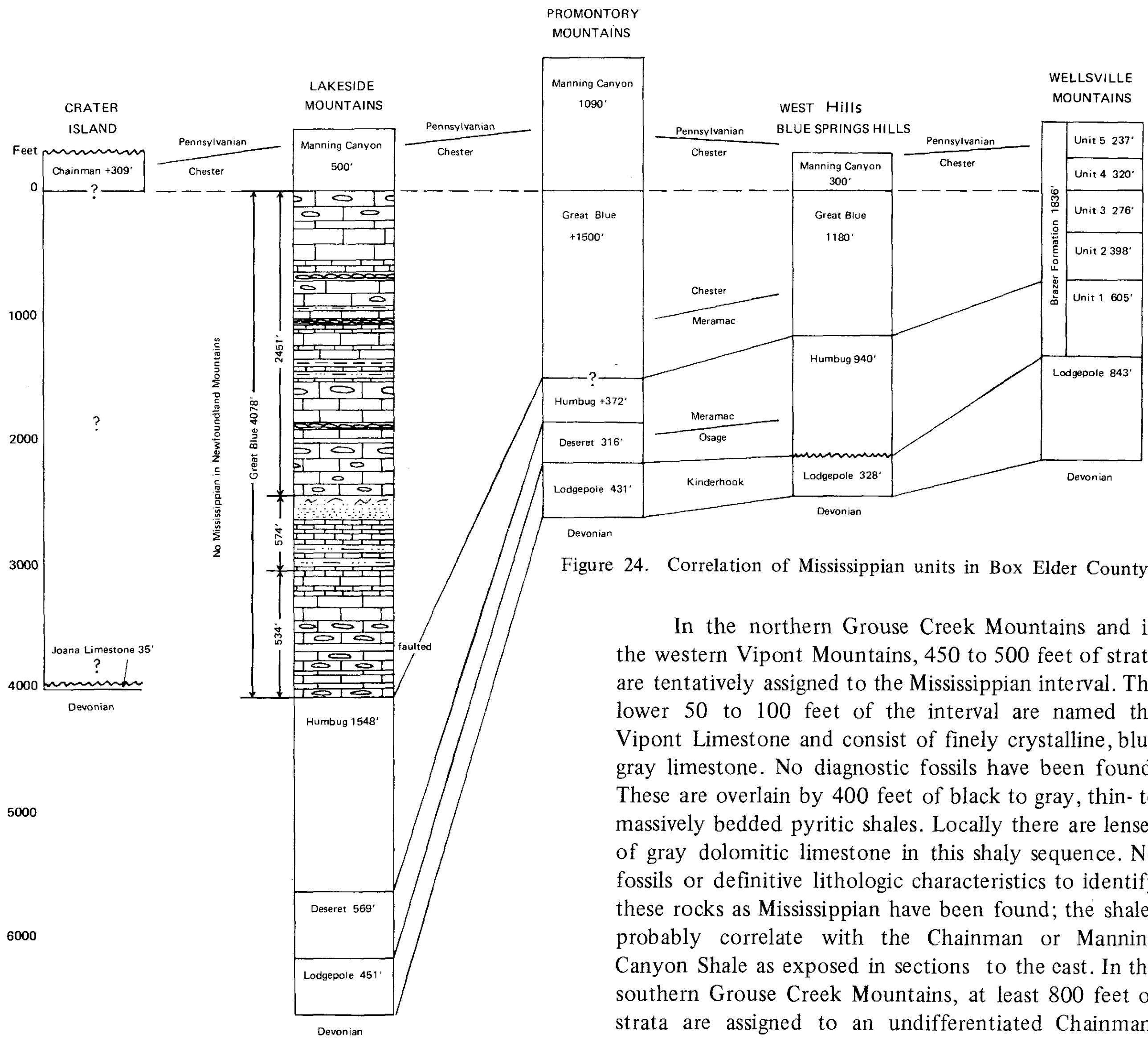


Figure 24. Correlation of Mississippian units in Box Elder County.

In the northern Grouse Creek Mountains and in the western Vipont Mountains, 450 to 500 feet of strata are tentatively assigned to the Mississippian interval. The lower 50 to 100 feet of the interval are named the Vipont Limestone and consist of finely crystalline, blue gray limestone. No diagnostic fossils have been found. These are overlain by 400 feet of black to gray, thin- to massively bedded pyritic shales. Locally there are lenses of gray dolomitic limestone in this shaly sequence. No fossils or definitive lithologic characteristics to identify these rocks as Mississippian have been found; the shales probably correlate with the Chainman or Manning Canyon Shale as exposed in sections to the east. In the southern Grouse Creek Mountains, at least 800 feet of strata are assigned to an undifferentiated Chainman-Diamond Peak interval. Here the Chainman-Diamond

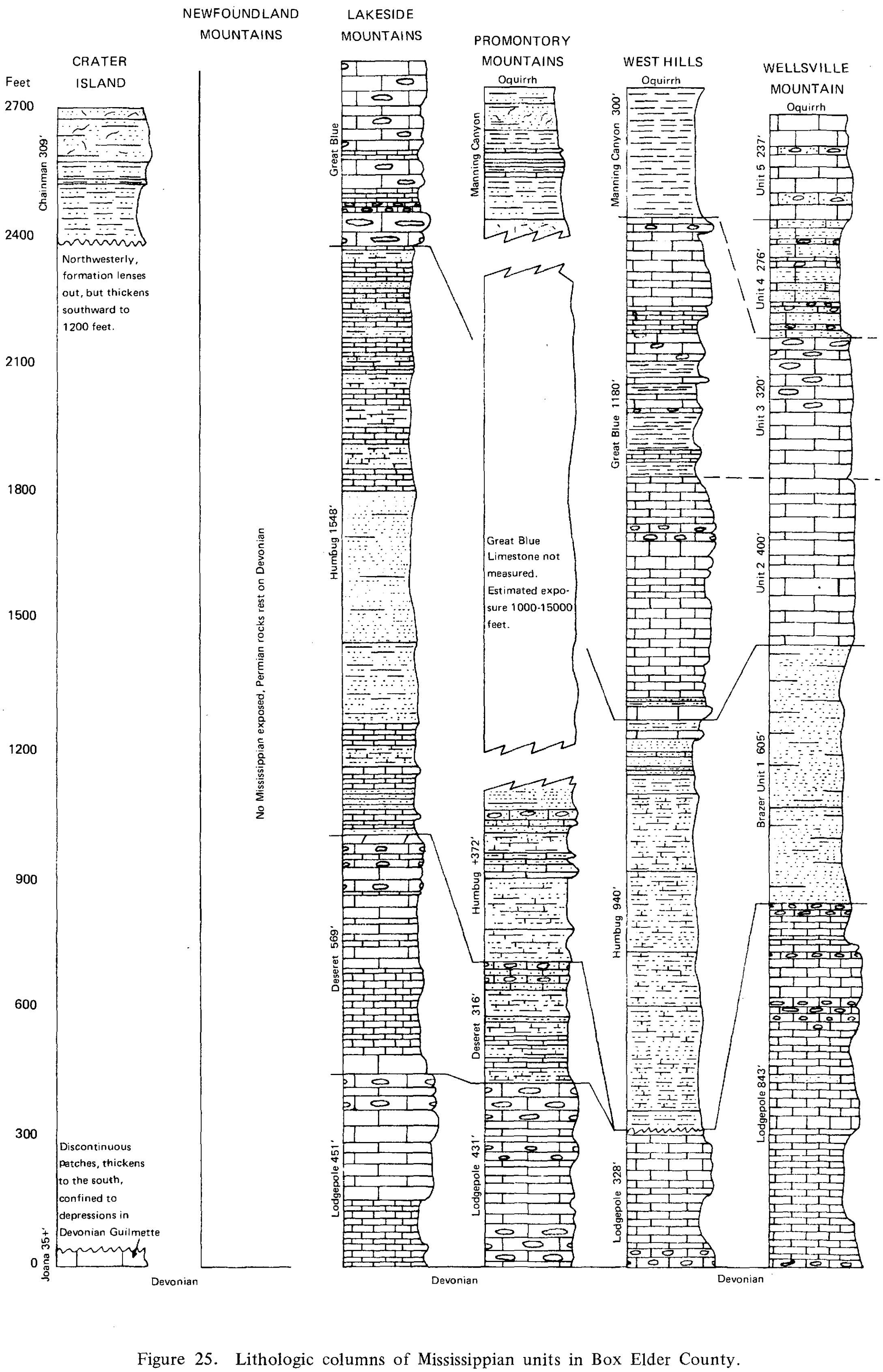


Figure 25. Lithologic columns of Mississippian units in Box Elder County.

Peak is a sequence of sandy limestones, meta-argillites, sandstones, quartzites and pebble conglomerates that rests paraconformably upon the Devonian Guilmette Formation. Representative descriptions of this interval in the central Grouse Creek Mountains are given in table 6.

The erosional unconformities associated with the Mississippian in the western mountains eliminate the interval in the Newfoundland Range, but the thickest exposed section in the county is found in the Lakeside Mountains, only 24 miles farther to the east. In the northern Lakeside Mountains four formations are exposed and a fifth may be present under alluvial cover. The Lodgepole Limestone (Madison) overlies the Devonian Guilmette Formation and is divisible into two subunits; a lower dark gray, non-resistant limestone in 2 to 8 inch beds and an upper cliff-former of dark gray to black, medium-bedded to massive limestone. The lower subunit is 153 feet thick and the resistant beds are 378 feet thick. The Deseret Limestone is about 570 feet thick, medium resistant and mostly a homogeneous dark gray to black, medium- to thick-bedded limestone. The Humbug Formation is about 1,500 feet thick, is non-resistant to erosion, and consists of talus-producing tan gray, fine-grained calcareous sandstone and shaly, platy, and slabby silty limestone. The youngest exposed unit of Mississippian age is the Great Blue Limestone and near Lakeside it is 4,000 feet thick. The Great Blue can be subdivided into three members, the lower and upper of which are resistant and ledge-forming. The lower member is thick-bedded to massive, dark gray limestone that is fossiliferous and cherty. It typically contains horn corals. The middle unit is calcareous sandstone and tan and brown, shaly, silty, light gray bioclastic limestone. Some of these limestone beds are cherty. The upper member (almost 2,500 feet thick) is mostly thick-bedded to massive gray limestone that is silty, sandy, cherty. The Manning Canyon Shale, partly equivalent to the Chainman Shale, may be present in the northern Lakeside Mountains between the fault blocks of the Great Blue Limestone beneath lake deposits and alluvial cover. However, its presence cannot be verified.

No Mississippian rock has positively been identified in the Raft River Range, but drilling in Curlew

Table 6. Representative sections and petrography of the Chainman-Diamond Peak Formation (undifferentiated) in the central Grouse Creek Mountains (after Todd, 1973, p. 27).

	Cycle Spring area (500 feet maximum)	North and South Hills (400 feet)	James Hills
1-5' feet	Black phyllite	Dark-gray crinoidal marble to black, sandy marble (up to 75') interbedded with thick-bedded, light-gray quartzite to pebble and cobble conglomerate (conglomerate beds 6-20 feet). Along strike, quartzite and conglomerate grade into buff-weathering thin quartzite beds in sandy phyllite. Minor black phyllite	Black marble grades to gray marble, yellow to brown-weathering, interbedded with tan pyritic phyllite. This rock (LS) is gradational into Oquirrh gray marble, over about 30 feet
35-45' feet	Interbedded dark-gray sandy limestone, (poorly to non-bedded, with crinoid hash, calcite blebs) and black phyllite. Limestone locally contains patchy dolomite. Along strike, pebbly lenses and beds give way to gray and brown-weathering quartzite, and to pebble and cobble conglomerate (10-30') interbedded with phyllite		Black, pyritic, crinoidal, micaceous marble (1-3 mm beds) interbedded with 30' (or less) pebble and cobble conglomerate
	Blocky, brown-weathering, greenish-black phyllite (locally, chloritoid porphyroblasts)	Massive, flinty black phyllite with pebbly quartzite interbeds; changes laterally to shingly phyllite with brown-weathering, sandy partings containing layers coarse sand to small pebble conglomerate	Black phyllite
	Flinty phyllite with veins of white quartz		
∿450' feet	Blue-gray-weathering, phyllitic quartzite to quartzose phyllite (bedding defined by lensoid trains of sand, fine pebbles; by continuous layers of sand)		
	(All lithologies bear ½ cm pyrite)		

P 11. Massive outcrops of the Great Blue Limestone near Lakeside.

P 12. Horn corals in dark blue limestone of the lower part of the Mississippian Great Blue, northern Lakeside Mountains.

Valley, immediately east of the range, has intercepted such rock. About 2,800 feet of Mississippian strata, consisting of black shales, dark limestones, and yellow and brown quartzites and sandstones, were logged.

In the Promontory Range a little over 2,600 feet of Mississippian rock is exposed, not including a possible 1,000 feet of Manning Canyon Shale. The Lodgepole Limestone is 430 feet thick and is a cliff-former. There usually are four very thick ledges separated by thin covered intervals and the lithology is a uniform black, very finely crystalline limestone. The unit is cherty, especially in the upper part. The chert is present mostly as black nodules, but also in stringers up to six inches in thickness and up to 100 feet in length. A distinctive characteristic of the Lodgepole includes thin dark red hematitic streaks parallel to the bedding. The Deseret Limestone is 316 feet thick and slope-forming, and consists mostly of limestone with subordinate siltstone and calcareous sandstone. The Deseret, in outcrop, is dull gray, silty, sandy, cherty; the black chert often exceeds 50 percent of the rock mass. The sandy units are very fine-grained and weather to a drab brown color which very much resemble the overlying Humbug Formation. The Humbug is poorly exposed and faulted, and only the basal 372 feet are exposed. The unit is similar to the Deseret, but the siltstone and calcareous tan sandstones predominate over limestone. The Great Blue Limestone exposures of the Promontory Range have not been measured because they are incomplete and complexly faulted. The thickness of the unit is estimated to be at least 1,500 feet. It is generally resistant limestone that is dark gray to bluish gray. There are subordinate layers of arenaceous limestone, calcareous sandstone, chert, and black shale. The Great Blue crops out in the North Promontory Mountains, but the section is incomplete, consisting of thick-bedded, finely crystalline, blue gray limestone that forms rough ledges. Almost 1,100 feet of Manning Canyon Shale have been measured in the Promontory Range, but the section is faulted and incomplete. It consists of black, silty shale (80 percent) and pale green to tan, very fine-grained quartzite (20 percent). Manning Canyon outcrops are also present in the Summer Ranch (Hansel Mountains) and North Promontory Mountains. A 696-foot section measured in the Summer Ranch Mountains shows 200 feet of black shale at the base, followed by 95 feet of quartzite or sandstone, 200 feet of shale and siltstone and about 200 feet of quartzite. The measurement represents the uppermost part of the formation; the top is conformable and in contact with the base of the overlying Pennsylvanian Oquirrh Formation.

In the West Hills the Lodgepole Limestone has been measured to be 328 feet thick and is divisible into four subunits based on topographic habit. The lower 50 feet form an escarpment and are blue gray, thin-bedded, very fine-grained limestones with abundant black chert. The second subunit, 134 feet thick, is slope-forming, light blue gray, medium-bedded calcarenite. The next subunit is cliffy, medium gray, fine-grained calcarenite, 116 feet thick. The uppermost subunit is coarse crinoidal, slope-forming limestone. The Deseret Limestone is not recognized and the upper boundary of the Lodgepole is thought to be an unconformity. The Humbug is 940 feet thick and consists predominately of brown-weathering calcareous sandstone and siltstone and sandy gray limestone. The Great Blue Limestone is about 1220 feet thick in the West Mountains and is mostly medium to dark blue-gray limestone that is medium-bedded to massive and ledge-forming. About 530 feet above the base and extending upward 300 feet are softer, covered units, perhaps a shaly limestone member such as the one exposed in the Lakeside Mountains. The upper half of the Great Blue is especially fossiliferous and indicates a Late Mississippian age. The Manning Canyon Shale is usually poorly exposed and only 300 feet thick. Isolated exposures indicate a lithology of black shale, gray green to brown shale, yellow brown sandstone, siltstone, and organic detrital limestone.

At Wellsville Mountain and at Rendezvous Peak in the northern Wasatch Range only two Mississippian units are recognized: a lower 843-foot Lodgepole Limestone and an upper 1,840 foot Brazer Formation. The Lodgepole is divided into three subunits: a lower cliff-former 95 feet thick, a slope-former 534 feet thick, and an upper cliff-former 234 feet thick. The unit consists of thin- to medium-bedded, dark gray, fossiliferous limestone with chert nodules. The Brazer Formation, as measured by Williams (1958), in the Dry Lake area of Cache County a few miles from the Box Elder County line, is 3,670 feet thick and divisible into five members. The lowest member is 900 feet of calcareous brown-weathering sandstone and thought to correlate with the combined Deseret and Humbug Formations. Unit 2 is thick-bedded, dark gray limestone, correlating wih the lower limestone member of the Great Blue Limestone, and is about 400 feet thick. Unit 3 is argillaceous limestone, 470 feet thick, that correlates with the middle shaly limestone member and with at least part of the upper member of the Great Blue Limestone. Unit 4 at the Williams (1958) section is dark cherty limestone and unit 5 is silty limestone and black shale of which at least part correlates with the Manning

Canyon Shale. Beus (1958) and Gelnett (1958) note that they measured a complete section of Brazer Formation at Wellsville Mountain near Deweyville, Utah and found it considerably thinner than the one reported by Williams. The five units of Beus and Gelnett in ascending order are 605, 398, 320, 276, and 237 feet thick and are described as (1) slope-forming calcareous sandstone, (2) medium-bedded, cliff-forming limestone, (3) medium bedded, cherty limestone, (4) slope-forming, thin-bedded sandy limestone inter-bedded with some thin cherty limestone beds and (5) medium-bedded limestone. At Rendezvous Peak, in the southeastern corner of the county, only the lower two members of the Brazer are present and are here 1,250 feet thick.

The Mississippian rocks of eastern Box Elder County exhibit a nearly continuous depositional sequence extending from the end of the Devonian to the beginning of the Pennsylvanian. The Mississippian section at Wellsville Mountain is almost 2, 700 feet thick, but thickens westward into the Great Basin. In the West Hills the section is 2,750 feet thick; in the Promontory Mountains there are 3,670+ feet of Mississippian rocks, and in the northern Lakeside Mountains there are 6,650+ feet. Farther west most of the Mississippian sequence disappears and the only unit with reasonable continuity is the Chainman-Manning Canyon Shale (excepting its disappearance in the Newfoundland and Raft River Mountains).

Pennsylvanian

The uppermost Chainman and Manning Canyon Formations, as discussed in the Mississippian section, are considered to be lowermost Pennsylvanian (Morrow) in age. In north-central Utah the Pennsylvanian section above these units is usually represented by a single formation, the Oquirrh. Along the western margin of Box Elder County formational names have been introduced from Nevada, but the section is very much like the Oquirrh. The Oquirrh Formation is not restricted to the Pennsylvanian, and thick sections of the unit extend into Permian time. Subdivisions of the Oquirrh Formation have been dated in many places by identifying contained fusulines. The Pennsylvanian is better represented in eastern sections; many intervals are lacking to the west. Many of the Oquirrh subdivisions have been involved in regional thrusting and many expected units may never have been deposited over part of the area. The poorest Pennsylvanian representation is in the southwestern part of the county (figures 26 and 27).

In the eastern part of the county, at Wellsville Mountain, Hintze (1973, p. 123) shows 2,350 feet of Pennsylvanian Oquirrh Formation unconformably overlying the Manning Canyon Shale. There is a lower member, 900 feet thick, consisting of thick-bedded gray limestone ledges, dated as Atokan. The remainder is Desmoines (1,100 feet), Missouri (450 feet), and Virgil (900 feet) and consists of thin- to medium-bedded gray sandstone and sandy limestone interbedded with occasional thick beds of gray limestone. Another measured section taken at the northern end of the mountain (Beus, 1958, p. 51) shows only 450 feet of Morrow, Atoka and Desmoines Oquirrh and another 2,050 feet of Virgilian Oquirrh.

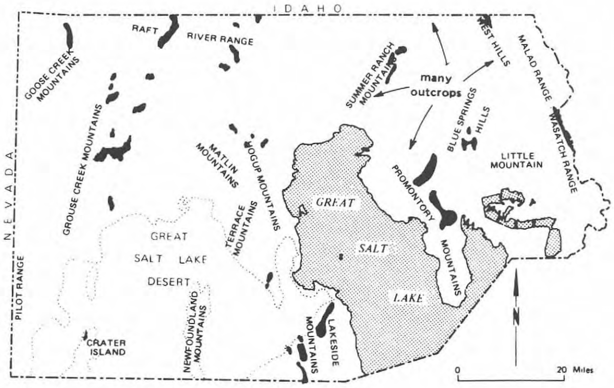


Figure 26. Pennsylvanian outcrops of Box Elder County.

Most of the West Hills area consists of Oquirrh Formation outcrops, but these are mostly Permian in age. A Pennsylvanian section has been measured just across the state line in Idaho, at Samaria Mountain. Here the Pennsylvanian Oquirrh consists of two units; a lower West Canyon Limestone Member 1,305 feet thick and an upper unnamed unit 1,700 feet thick. The West Canyon Member is in conformable contact with the Manning Canyon Formation and fossils indicate a lower Middle Pennsylvanian (Atoka) age. The West Canyon Member consists mostly of 5- to 15-foot ledges of blue gray limestone separated by less resistant silty limestone interbeds. Chert is common. An unconformity separates the member from the upper beds. The upper unit is dated uppermost Pennsylvanian (Virgil) and is thought to thin into Utah. This upper unit is mostly sandy limestone, calcareous sandstone and ortho-quartzite in beds 1 to 3 feet thick.

Oquirrh Formation outcrops dominate the northern portions of the Promontory Range. The mountain range is considerably faulted and a complete thickness has not yet been measured. It is presumed that no overlap occurs in three partial sections where a total of

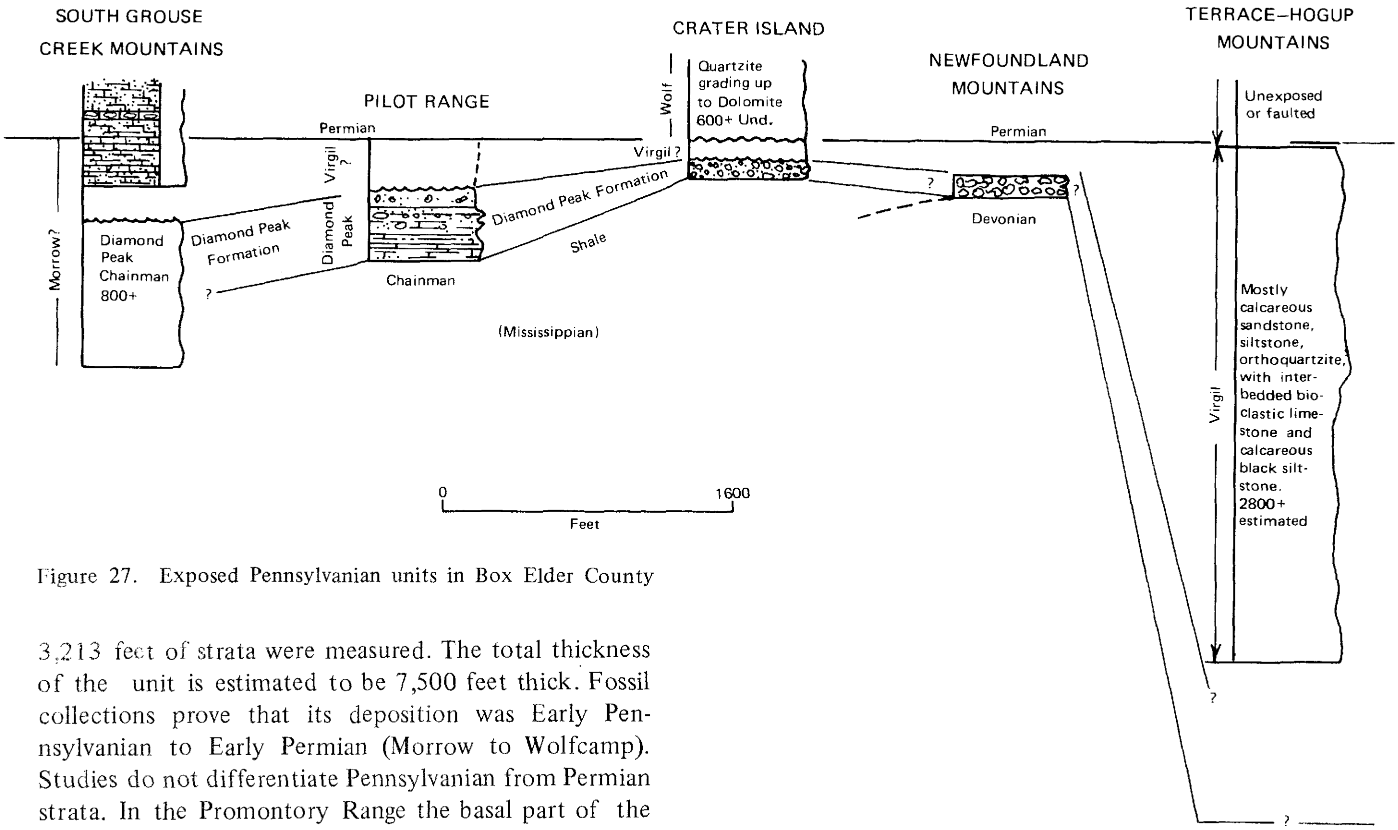


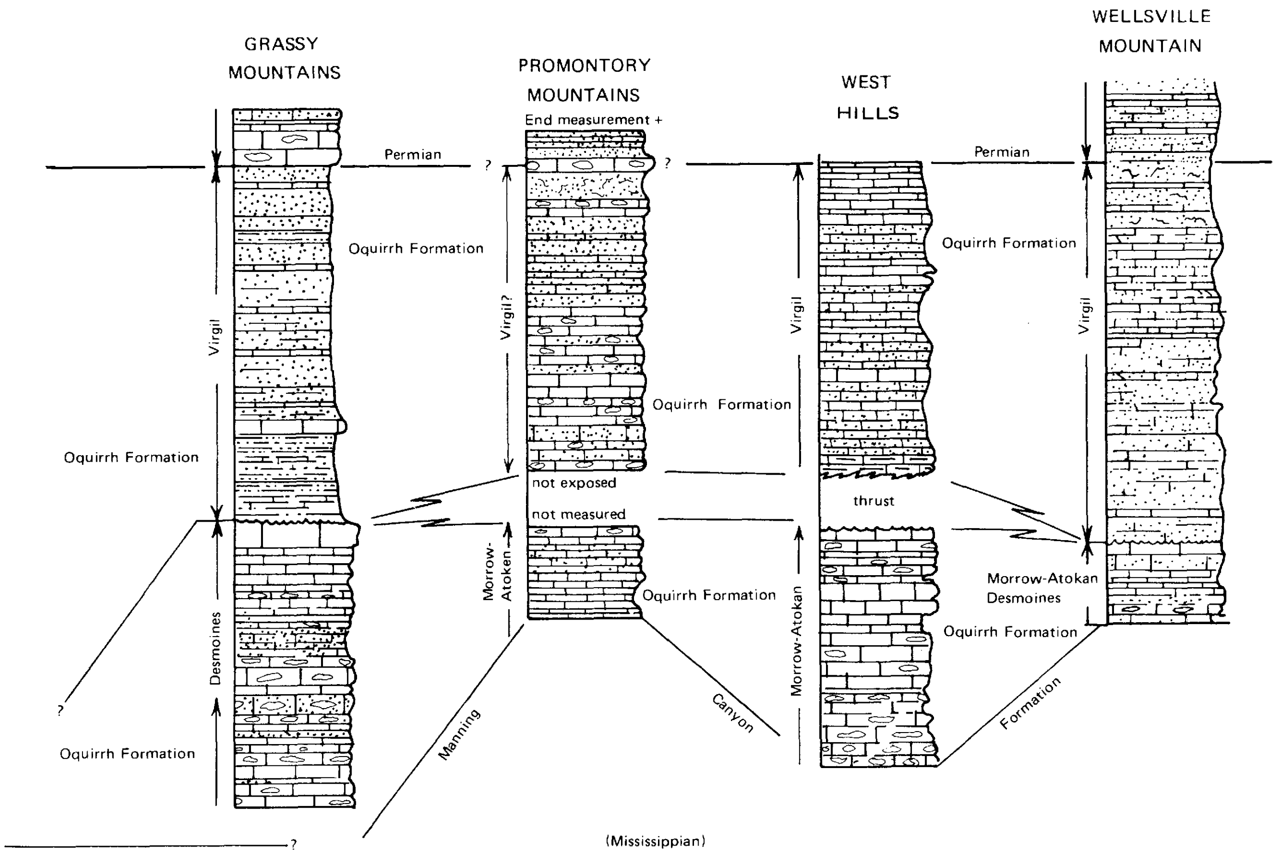
Figure 27. Exposed Pennsylvanian units in Box Elder County

3,213 feet of strata were measured. The total thickness of the unit is estimated to be 7,500 feet thick. Fossil collections prove that its deposition was Early Pennsylvanian to Early Permian (Morrow to Wolfcamp). Studies do not differentiate Pennsylvanian from Permian strata. In the Promontory Range the basal part of the unit is mostly bioclastic gray to light bluish gray limestone. Some of this limestone is silty or fine-grained sandy and interbedded with minor amounts of gray, very fine-grained calcareous sandstone. The limestone beds average 10 to 20 feet in thickness and can be traced for considerable distances. The remainder of the formation is sandier than the lower unit and the principal lithologies are arenaceous limestone and calcareous orthoquartzite. Occasional tan gray, fine-grained, slightly calcareous, thin-bedded sandstones are also present. The same two-fold division is recognized in the North Promontory Mountains and in the Summer Ranch Mountains. In The North Promontory Mountains 3,000 feet of Oquirrh Formation were measured and the total thickness is estimated to be 8,500 feet.

In the eastern part of the Raft River Mountains the Oquirrh present is 1,000 - 2,000 feet thick and of Pennsylvanian age. Most of the identified fossils (fusulines) give the rock an Upper Pennsylvanian age (Virgil) and descriptions show the rocks to be sandy and silty limestones and brownish weathering quartz sandstones and quartzites. Farther west these beds are underlain by 1,200 feet of gray sandy and silty fossiliferous limestones which in turn overlie at least 1,600 feet of gray medium-bedded to thick-bedded limestones. In the extreme western part of the range only 1,000 feet of the unit is exposed and it is divisible into two subunits; an upper brown-weathering gray orthoquartzite and calcareous sandstone and a lower dark gray sandy limestone. The lower unit is thought to be Middle Atokan in age, the upper unit is thought to be Virgilian in age.

The oldest exposed rocks of the Terrace and Hogup Mountains belong to the Oquirrh Formation. Possibly 2,800 feet of Pennsylvanian Oquirrh along with 6,600 feet of Permian Oquirrh are exposed. Fusulines date the Pennsylvanian beds as Virgil, and are described as yellow to orange calcareous sandstone, tan and gray siltstone, and pink and purple orthoquartzite. The lower and oldest portion is platy calcareous siltstone interbedded with calcareous sandstone.

The Oquirrh Formation is best developed in the northern Grassy Mountains where measured sections exceed 12,000 feet in thickness. It has been subdivided into six units, the lower two of which (3,550 feet) are mostly Pennsylvanian in age. Unit 1 is the oldest exposed Pennsylvanian unit in the Grassy Mountains and is a cliff-forming unit of thick-bedded, medium-grained or medium crystalline limestone. Some thin yellow sandstones or thin-bedded limestones are occasionally found

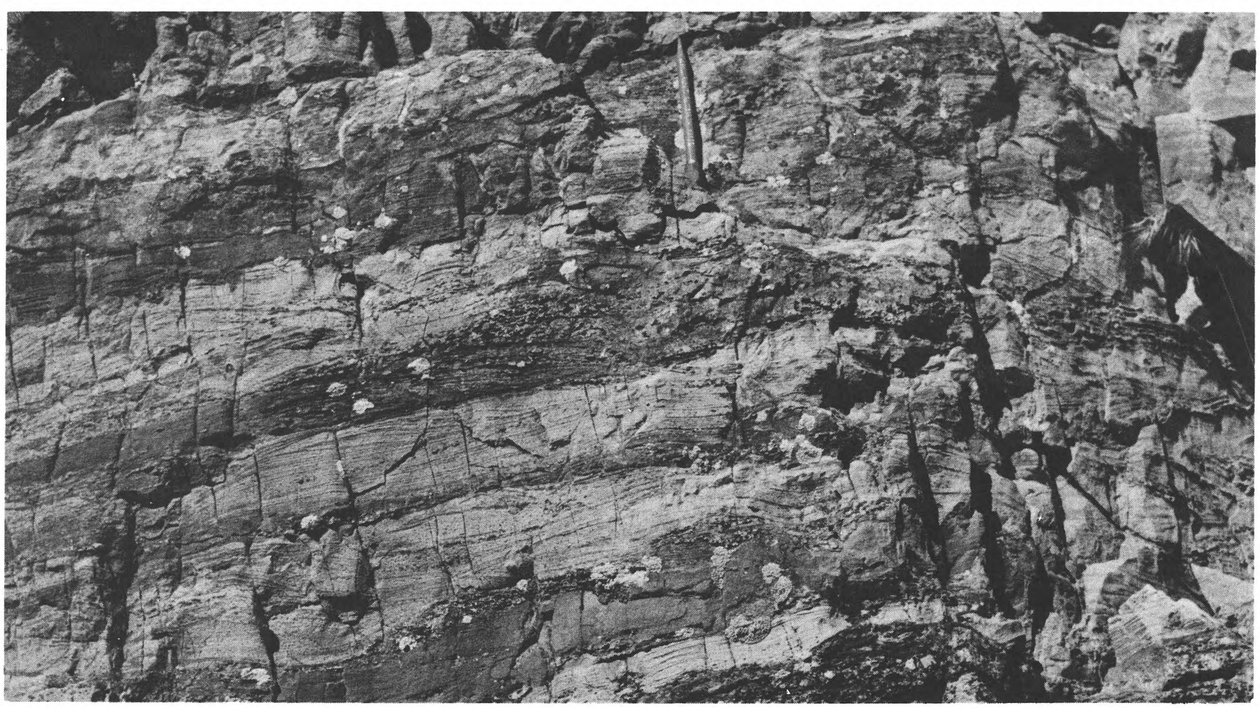


and chert is common. Locally, the unit is fossiliferous and fusulines collected near the top date the unit as Desmoines. The lower reaches of the unit may contain some Atokan rock. The thickness of unit 1 is 1,607 feet and the base is not exposed. The lower 500 feet of unit 2 are very soft, tan to brown red, thin-bedded siltstones and silty limestones. The middle of the unit consists of friable, tan, yellow and buff calcareous fine-grained sandstone, a little over 1,500 feet thick. The upper 270 feet are thick-bedded to massive, sandy and medium-resistant gray limestone beds. Fusulines collected from most of the unit indicate a Virgil age; those collected from the upper 272 feet are Wolfcamp in age (Lower Permian). The upper four units of the Oquirrh Formation are Wolfcamp and Lower Leonard in age.

There are no recognized Mississippian or Pennsylvanian rocks in the Newfoundland Mountains. At Crater Island the Diamond Peak Conglomerate is recognized and Oquirrh-like rocks overlie it; the latter are thought to be mostly Permian in age. The Diamond Peak is 0-90 feet thick and consists of light grayish-brown conglomerate that forms a massive cliff. The subangular pebbles are mostly limestone, chert and quartzite. The unnamed Oquirrh-like unit consists of very fine-grained brownish gray orthoquartzite that grades upward into medium gray dolomite and forms blocky ledges and slopes. This unit is estimated to be 600 feet thick and Permian fusulines were found at the top of the unit. Fusulines of Virgil age were reportedly found in the lower portion but this has not been verified.

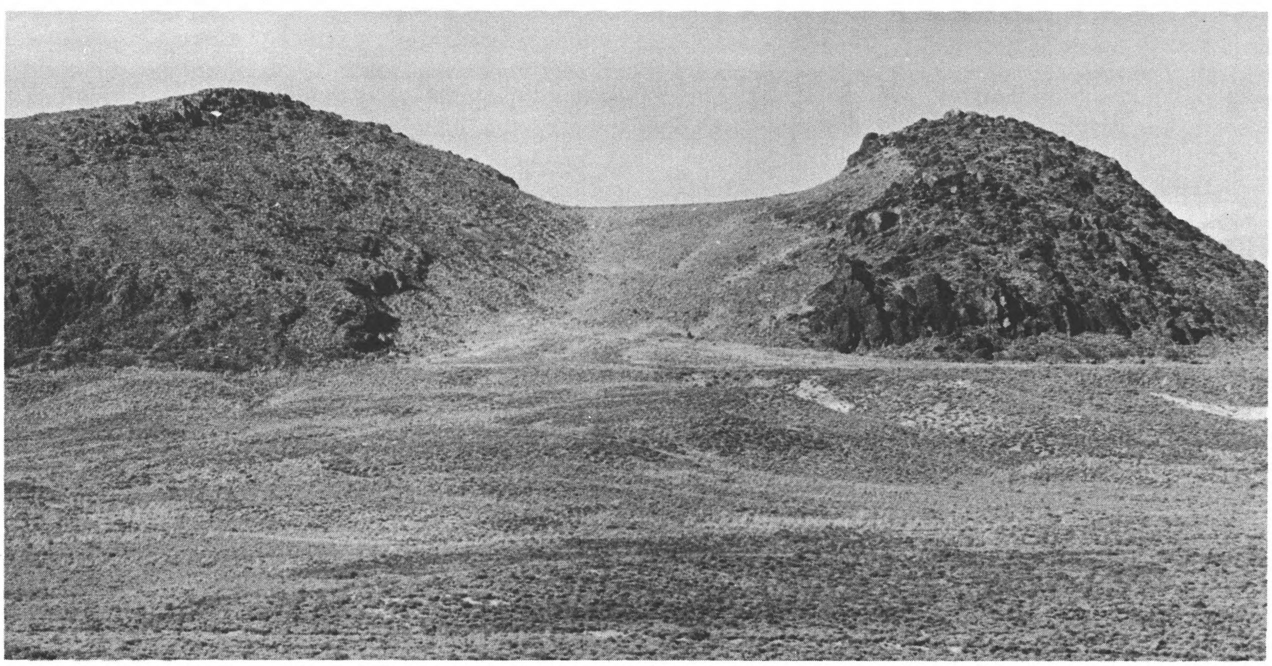
In the northern Pilot Range, along the west boundary of the county, the Pennsylvanian, with the exception of the uppermost part of the Chainman Shale, is a plane of unconformity. In the southern Pilot Range the Diamond Peak Quartzite aggregates 425 feet of pebble conglomerate and interbedded medium gray, coarse-grained quartzite and the Ely-Oquirrh undifferentiated formation, 1,040+ feet thick, represents the Pennsylvanian. The Ely-Oquirrh can be divided into a lower dark gray to black limestone 505 feet thick and an upper argillaceous cherty limestone more than 535 feet thick. The unit is correlated to the Leppy Range in Nevada where microfossil studies indicate an age extending from latest Morrow to early Desmoines. Another 400 feet of rock to which no date has been assigned, are present in the southern Pilot Range, but these might include some Virgilian rocks. Certainly part is expected to be Permian in age.

P 13. Typical outcrop of siliceous limestone in the Permian Pequop Formation of the Hogup Mountains.



P 14. Grandeur Member of the Park City Formation. The unit is mostly dolomite with some chert and fine streaks of sand. Photographed in the Terrace Mountains.

P 15. Sandy, cherty beds near the top of the Oquirrh Formation in the Terrace Mountains.



P 16. Faulted Permian Rex Chert near the Utah-Nevada line.

Permian

Permian rocks are widespread and thick in Box Elder County and are represented in almost every mountain range (figure 28). The strata have been studied more fully in the Terrace and northern Grassy Mountains, but good exposures are also found in the West Hills, North Promontory, Promontory, Summer Ranch, Matlin, and Goose Creek Mountains. Excepting igneous Late Tertiary and unconsolidated units, these may be the youngest strata in the mountain ranges; Triassic rocks are known to be present in only two or three of the ranges. Permian System strata are difficult to correlate because of facies changes, and "chosen" names used in the studies of individual mountain ranges often vary for the same interval of rock. It is evident that general lithologic similarities are present, however, and are correlatable from mountain range to mountain range. Considerable work remains to develop a workable nomenclature and correlation. Hintze (1973, p. 49) shows that Permian rocks in Box Elder County were deposited in or adjacent to three depositional basins: the Ely Basin to the southwest, the Sublett Basin in the central-north, and the Oquirrh Basin to the southeast. For convenience names suggested by field investigators will be retained and correlations will be made to the proper Series subdivision, i. e., Wolfcamp, Leonard, or Guadalupe. Ochoan rocks are not recognized in the county. Correlations will also be made to names of units suggested by Hintze.

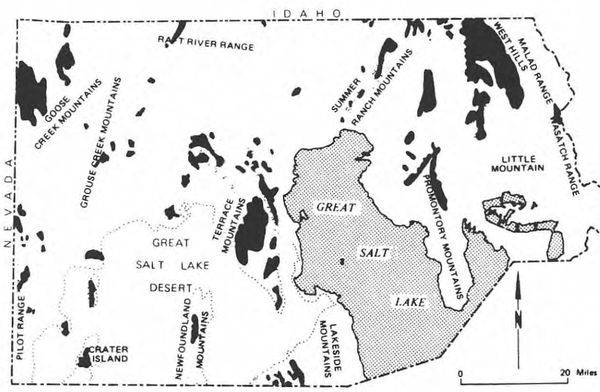


Figure 28. Perr

Strata of Wolfcamp age are exposed in most mountain ranges of the county. The interval is missing in a few of the western ranges (figures 29 and 30). In most mountain ranges the Wolfcamp strata consist mainly of calcareous sandstone, orthoquartzite, and thin-bedded silty or sandy platy limestones. Occasionally thick- or medium-bedded limestone units are to be found that are crinoidal, fossiliferous and fetid. At Wellsville Mountain the Oquirrh Formation extends into the Permian and there may be 3,000 to 4,000 feet of Wolfcamp strata present. The rock consists of thin-bedded to medium-bedded sandstones that weather brown to tan with occasional thick, medium to dark gray bioclastic limestone beds. About 160 feet of limestone beds found at the top of the section have been assigned to the Kirkman Limestone by Hintze which is considered Upper Wolfcamp in age. Tertiary or Quaternary deposits overlie the Permian in a few places on Wellsville Mountain; otherwise the sequence is the youngest uneroded rock of the mountain.

Most of the West Hills area has been assumed to expose the Permian Oquirrh Formation, but unconfirmed reports indicate units as young as Guadalupe are present. A minimum of 1,600 feet of strata have been measured; the sequence is expected to be much thicker. The principal lithologies are limestone, orthoquartzite, and sandy limestone. Cherty limestone and silty and sandy limestone in thin to thick beds make up 80 percent of the measured rock. Many of the beds consist of fossil fragments composed of shell remains, fusulines, and crinoid columnals. The sand and orthoquartzite beds are fine- to medium-grained and the orthoquartzite weathers brown and into angular blocks and plates that locally form conspicuous talus slopes. The uppermost beds are described as interbedded silty, siliceous limestones and black chert reminiscent of Upper Wolfcamp, Leonard, and even Guadalupe beds in the other mountain ranges. At an isolated outcrop, a short distance into Idaho, fossils were found that were of Guadalupe age. This sequence makes up the youngest consolidated material in the West Hills. In the Blue Springs Hills, south of West Hills, the eastern half of the range exposes a thick fine-grained yellow sandstone similar to that described by Stifel (1964) in the Terrace Mountains as the Diamond Creek Sandstone (Leonard). At present it is undetermined whether the rock is Leonard in age or whether it is a similar lithology of Wolfcamp age (Oquirrh Formation).

Oquirrh Formation of Permian age has been mapped as the principal outcropping unit in the North Promontory and Summer Ranch Mountains and in the northern part of the Promontory Range. The thickness of Permian beds is unknown but expected to exceed many thousands of feet; the lithology consists mostly of sandy limestone and calcareous orthoquartzite in thin to thick beds. These sandy beds are conducive to the formation of tan to brown talus that is conspicuous on many hillsides. The youngest identified fossils show the rocks to be Lower Permian (Wolfcamp) in age.

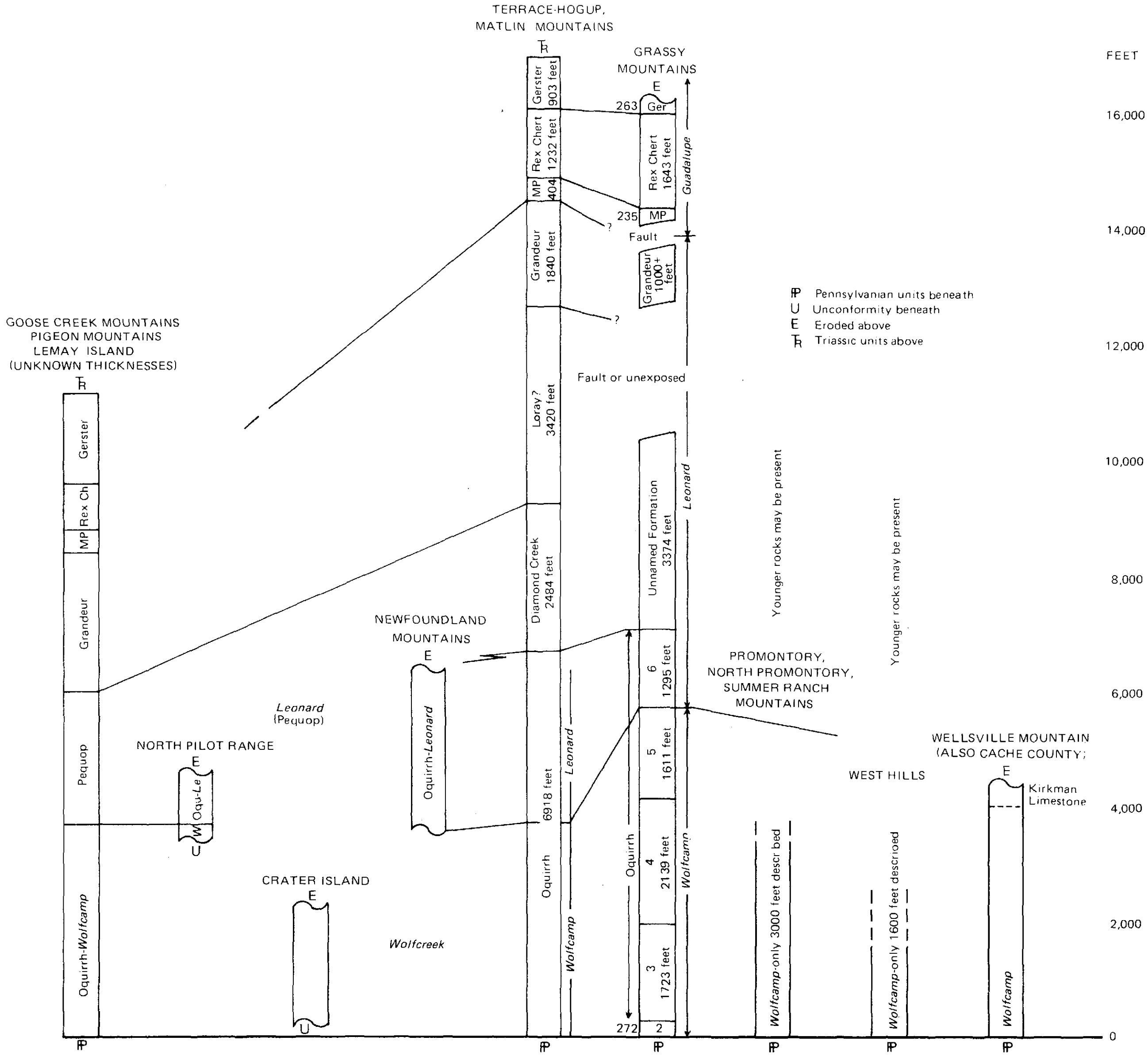


Figure 29. Correlation of Permian units, Box Elder County.

Permian strata in the northern Grassy Mountains of Box Elder County and adjacent Tooele County have been measured and exceed 13,500 feet in thickness. The lower formation is the Oquirrh and five of its six members contain Permian fossils. The members are designated numerically in ascending order. Unit 1 is Pennsylvanian in age, as is all but the upper 272 feet of Unit 2. The upper part of Unit 2 and Units 3 to 5 are Lower Permian (Wolfcamp) and Unit 6 is lower Middle Permian (Leonard). Hintze, (1973, p. 50 and 122) prefers to use Pequop Formation rather than extending the Oquirrh Formation into Leonard age rocks.

The upper 272 feet of Unit 2 contains Wolfcamp fusulines and is thick-bedded to massive, sandy, medium resistant, gray limestone. Clean and sandy limestone layers alternate to produce a banded outcrop. The limestones grade into resistant sandstone and orthoquartzite beds at the top of the unit. Unit 3 is 1700 feet thick and marked by the presence of much dark-brown talus. The unit consists mostly of thick-bedded to massive, tan and yellow gray sandstone and orthoquartzite occasionally interrupted by a medium to thick dark crinoidal limestone bed containing fusulines. Unit 4 is about 2100 feet thick and resembles Unit 3. Ortho-

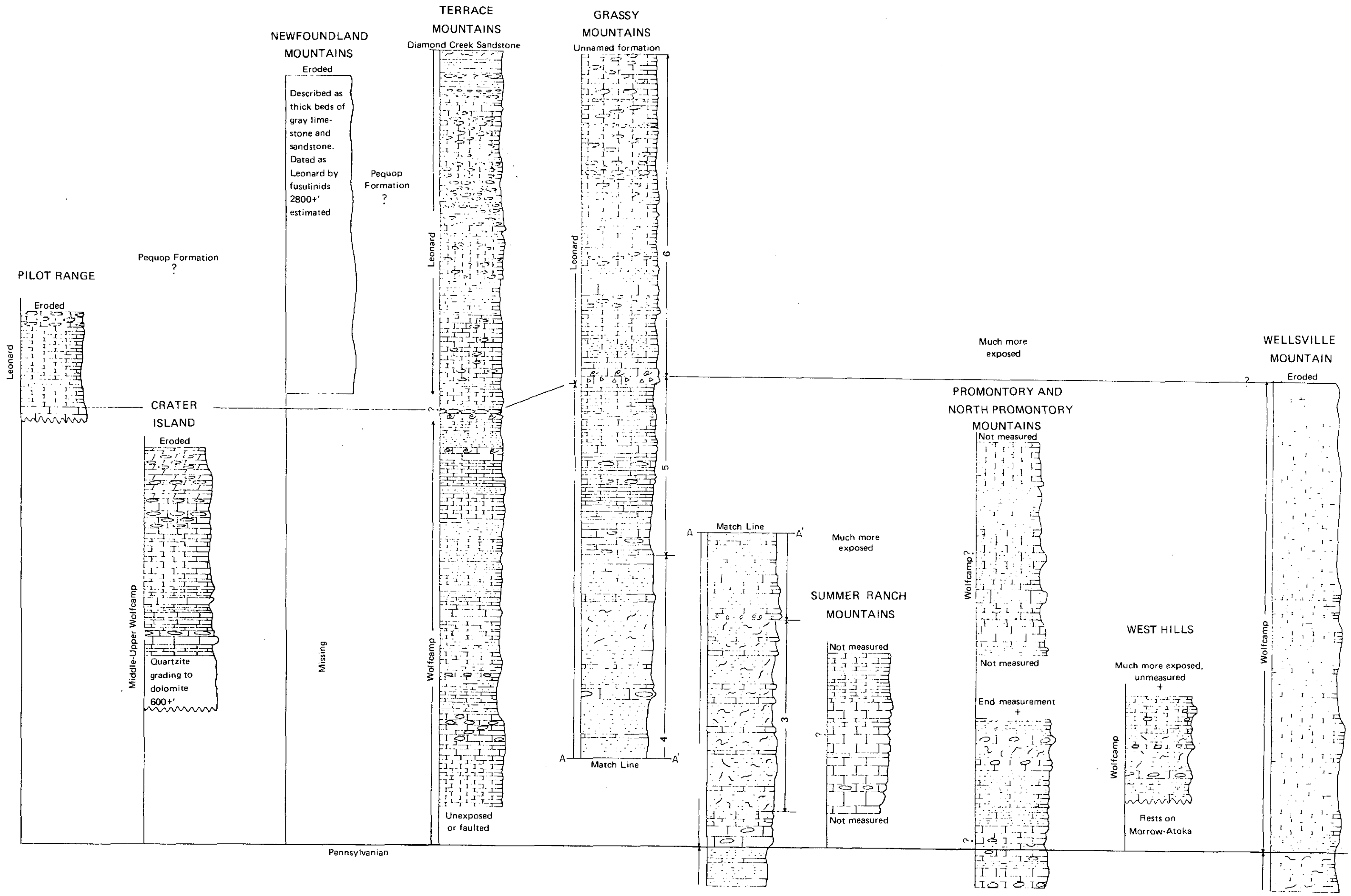


Figure 30. Correlation of the Permian section of Oquirrh Formation in Box Elder County.

quartzite is less abundant and the crinoidal limestones are a bit more abundant. The lower contact is placed at the base of a persistent pebble conglomerate 30 to 100 feet thick. Several limestone beds of the unit yield indentifiable fusulines. Unit 5 is about 1600 feet thick and consists of interbedded blocky, dark gray limestone, fine-grained and thin-bedded lavender-weathering limestone, siliceous limestone, and a few sandstone or siltstone layers. Unit 4 grades into Unit 5 over a broad less resistant interval, the middle of which provides the contact. Unit 6 (or the Pequop Formation) is almost 1300 feet thick in Box Elder County and has a conspicuous siliceous limestone lithology. The limestone is dark gray, but weathers to a bright yellow or brown; it is fine-grained with 2 to 4 inch beds, and chert is abundant. There are a few shaly or thin-bedded, light lavender-weathering silty limestones similar to those found in Unit 5. Fusulines date Unit 5 as Upper Wolfcamp and Unit 6 as Lower Leonard. The lower contact of Unit 6 is placed at the base of a persistent gastropod shell bed or reef. This reef is conglomeratic in part and can be traced from one end of the Grassy Mountains to the other in a north-south direction and varies in thickness from 20 to 100 feet. The principal fossils in the reef include *Euphemitopsis* cf. *E. subpapilosa* and *Plagioglypta canna*.

Above the Oquirrh Formation or Pequop Formation is an unnamed unit 3,000 feet or more in thickness. The lower 500 feet are dominantly bedded chert with subordinate limestone; the upper part is a poorly exposed complex of limestone, sandstone, dolomite and chert. *Plagioglypta canna* is the only identified fossil found in the formation to date and entire beds of this fossil are found in its upper parts. The Unnamed Formation is considered to be Leonard in age by its stratigraphic position, and correlation is made to the Diamond Creek? Sandstone and Loray? Formation as exposed in the Terrace Mountains to the north, even though there are significant lithologic differences.

The youngest recognizable unit of the Grassy Mountains of Box Elder County has been called the Grandeur Member of the Park City Formation. Perhaps 1,000 feet of strata are poorly exposed and consist of interbedded light gray weathering limestone, dolomitic limestone, and dolomite. Chert is common as nodules and blebs and is occasionally bedded. In the Tooele County portion of the Grassy Mountains exposures of Meade Peak? Limestone, Rex Chert, and Gerster Formations are to be found. The Meade Peak? Limestone consists of light gray to black, medium- to coarse-grained oolitic phosphatic limestone, in beds 15 to 24 inches thick. Much interbedded chert and some dolomitic limestone is present. The Rex Chert consists of interbedded chert, limestone and dolomite. The limestones and dolomites are similar to those in the Grandeur. The chert is found as beds, nodules, blebs and stringers and is tan, light blue and brown. The Gerster Formation consists of fossiliferous light gray-weathering limestone with much chert in beds and nodules (figure 31).

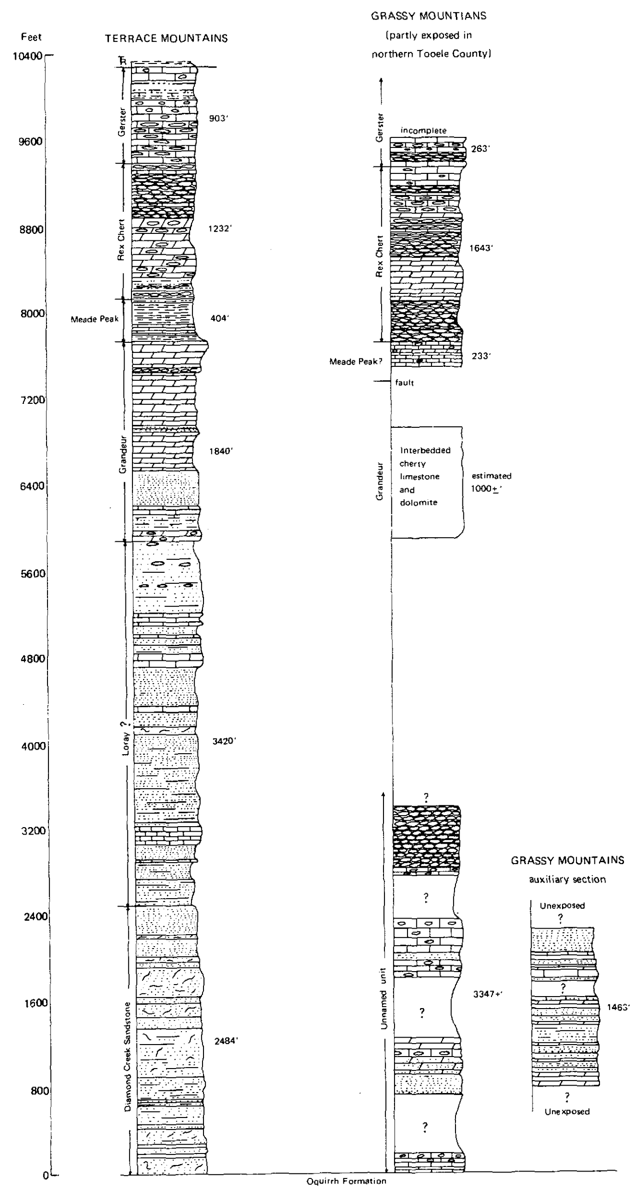


Figure 31. Correlation of post Oquirrh units between the Terrace and Grassy Mountains.

The thickest and most complete Permian section in Box Elder County is in the Terrace Mountains where nearly 17,000 feet have been measured and described. Exposures of the Permian Oquirrh Formation are incomplete, but 6,700 feet have been measured and determined to be of Wolfcamp and Leonard age. This compares well with the complete 7,000-foot Oquirrh Formation section in the Grassy Mountains. The Oquirrh Formation exhibits ledge and bench topography and is made up of calcareous siltstone, arenaceous bioclastic limestone, fine-grained crystalline limestone, calcareous sandstone and orthoquartzite. Toward the top, silty siliceous limestone with chert becomes common as it does in the Grassy Mountains. This upper sequence may be correlated with the Pequop Formation of the Ely Basin; it is not known how much of the section is Leonard in age, but a *Euphemitopsis-Plagioglypta* unit was found more than 3,000 feet below the top containing Middle Wolfcamp fusulines. Such a unit in the Grassy Mountains is dated as Lower Leonard, but the presence of several *Euphemitopsis*-bearing beds in the Terrace Mountains indicates that this fauna was prolific from Wolfcamp to Leonard time. It is estimated on the basis of the similar siliceous limestone lithology at the top of the formation that about 1600-2000 feet of strata in the Terrace Mountains may be assigned to Unit 6 or the Pequop Formation.

In the Terrace Mountains the Diamond Creek? Sandstone overlies the Pequop Formation and is 2,484 feet thick. Almost all of this interval is sandstone or orthoquartzite; a few medium gray, medium-bedded limestone beds are found in the lower 1850 feet. Fossils are few and shed no light on the exact age of the units. Although there are many sandstone beds in the Unnamed Formation equivalent in the Grassy Mountains, there are far more limestone and chert beds.

The Loray? Formation overlies the Diamond Creek? Sandstone and is 3,420 feet thick. It is composed of alternating yellow to gray fine-grained calcareous sandstone and silty or cherty limestone and dolomite. The sandstones are less well-indurated than those of the Diamond Creek? Sandstone and no diagnostic fossils have been identified in the unit. The Loray? Formation was probably deposited in latest Leonard or earliest Guadalupe time.

Above the Loray? Formation, the Grandeur Member of the Park City Formation is about 1,840 feet thick in the Terrace Mountains, and consists mostly of dolomite, silty and cherty limestone, and calcareous sandstone.

The Meade Peak Phosphatic Shale Member of the Phosphoria Formation lies above the Grandeur and consists of 400 feet of mudstone, silty and cherty dolomite or limestone and shale. Many of its beds are thin-bedded, platy or shaly. The unit is usually poorly exposed and forms a distinct swale between its more resistant neighbors. The Rex Chert Member of the Phosphoria Formation is 1230 feet thick and forms very prominent cliffs. It is a unit of bedded chert, cherty siltstone and mudstone with some interruptions by cherty limestone and dolomite which may be tongues of the Grandeur Member extending from the south and west. Tongues of the overlying Gerster Formation may be present in the upper part of the Rex Chert unit as well.

The uppermost Permian unit in the Terrace Mountains is the Gerster Formation, which is a little over 900 feet thick. It consists mainly of crystalline, bioclastic, silty, argillaceous and cherty limestone. Many of the beds are fossiliferous and contain a fauna peculiar to the unit in western Utah exemplified by *Punctospirifer pulchra (Spiriferina pulchra)*, an easily recognized brachiopod.

Many isolated knolls and hills expose bedrock of Permian age in western Box Elder County. A very prominent group of knolls to the west of the Terrace Mountains are known as the Matlin Mountains. Most of these outcrops are labelled as Oquirrh Formation on older geologic maps, but many contain outcrops of younger Permian and Triassic rocks. Cursory field investigation of the Matlin Mountains indicate the presence of beds correlating with Units 3 to 6 in the Grassy Mountains, and with the corresponding units as exposed in the Terrace Mountains. A gastropod reef with *Euphemitopsis* cf. E. *subpapilosa* and *Plagioglypta canna* was also found.

In the Newfoundland Mountains, 2910 feet of consolidated Permian sediments unconformably overlie Devonian rocks. The basal conglomerate is 70 to 140 feet thick, and most of the cobbles and pebbles are of dolomite with subordinate limestone. The remaining strata have been named the "interbedded series" or have been correlated with the Pequop Formation, Unnamed Formation, and Grandeur Member. The beds are alternatingly fine to coarsely crystalline, light to dark gray limestone, and medium- to coarse-grained gray sandstone that weathers yellow, tan, or brown. In some parts of the mountain range the carbonates are dolomitic. Fusulines found in the unit date is as lower Middle Permian (Leonard) in age.

About 1,000 feet of interbedded limestones and sandstones present in the southern Grouse Creek Mountains are correlated with the Oquirrh Formation, and part is known to be Wolfcampian in age. In the central and northern Grouse Creek Mountains and extending into the Raft River Range are many scattered outcrops of Pennsylvanian and Permian Oquirrh Formation. These, however, exhibit a degree of metamorphism that obliterates some of the relationships. A description of the entire Oquirrh Group as found in the central Grouse Creek Mountains is given in table 7. Todd (1973) has identified a black chert unit which may correlate with the Rex Chert and the Gerster Formation on the west side of the Grouse Creek Mountains.

A. R. Young (1962), provided an unpublished map of the Goose Creek Mountains for use in preparing the Northwest quarter of the geologic map of Utah (W. L. Stokes, 1963), which shows large outcroppings of Permian rocks. Identified units include the Oquirrh Formation of Wolfcamp age, Pequop Formation, Grandeur Member of the Park City Formation, and the Meade Peak and Rex Chert Members of the Phosphoria Formation. Thicknesses are unavailable. The Triassic is present and immediately overlies the Rex Chert.

A little over 1800 feet of Permian rock has been measured on Crater Island and called Permian undifferentiated. The lower two-thirds of the unit consists of light to dark gray and bluish gray crinoidal limestone that is thin-bedded to massive and contains dark chert beds and lenses in the lower part. A few thin beds of brown-weathering resistant quartzite or conglomerate interrrupt the ledge-forming sequence. The upper third consists of brown-weathering, gray aphanitic dolomite forming slight ledges and steep slopes. The contact between the upper and lower members is gradational. Fusulines date the Permian undifferentiated unit as Middle to Upper Wolfcamp.

The interval in the Pilot Range is subdivided into an undifferentiated Upper-Pennsylvanian-Wolfcamp unit, the Pequop Formation, and a "post-Leonard" unnamed unit. The Pennsylvanian-Wolfcamp unit unconformably overlies the mostly Mississippian Chainman Shale and is about 130 feet thick. The major rock type is medium- to coarse-grained limestone that might be correlated with the Ferguson Mountain Formation of the Ely Basin. The Pequop Formation is 840-875 feet thick and has a basal unit, 310 feet thick, of silty limestone. Above this are 50 feet of limy siltstone followed by thin-bedded platy limestones, 490 feet thick. The uppermost "post-Leonard" unit is 125 feet thick and consists of ridge-forming siliceous, cherty limestone and dolomite with argillaceous partings, Lithologically it resembles Unit 6 of the Grassy Mountain Oquirrh Formation.

Table 7. Generalized stratigraphic section and petrography of Oquirrh Group in the Central Grouse Creek Mountains (Todd, 1973)

	STRATIGRAPHIC SECTION
Upper part	Tan-weathering gray quartzite, interbedded with minor dark gray, impure, lumpy marble (beds about 1 foot) and thin, shingly gray marble (1/2-3/4 inch shingles) with brown-weathering, sandy partings. Quartzite is fine to medium grained, well sorted and rounded, moderately well bedded (1-1½ feet); locally massive. Well-developed fracture cleavage. Base of dominantly clastic upper part is often meta-siltstone, tan, pyritiferous phyllite which grades to quartzite; it may be calcareous.
	Transition from middle to upper part marked by break in slope.
Middle part	Light, medium gray to dark gray marble (small crinoid plates) with 2 cm to 2 inch, lensoid, brown weathering quartzite interbeds; quartzite beds locally up to two or more feet; local white to light gray dolomite, and schistose (argillaceous) layers. Thin, platy marble with sandy or phyllitic partings whose number and thickness increase, on average, up-section.
Lower part	Gray marble with increasing sandy interbeds. White to light gray, massive marble (may not be present). Black crinoidal marble interlayered with, and grading to, clean gray marble with crinoid hash; marble tends to become silty and sandy above.

PETROGRAPHY

Strongly metamorphosed marble: Alternating layers 1) white calcite, 1 mm grains, with minor quartz, feldspar and 2) calcite with more quartz, feldspar, muscovite and dark organic material. No fossil material recognizable. Strong metamorphic fabric showing penetrative slip, strained calcite, strongly shaped grains.

Slightly recrystallized marble: Relict bedding in impure marble defined by 1-2 cm carbonaceous vs. less carbonaceous layers. Foliate texture. Minor, recrystallized, bioclastic grains (algal(?), echinoid, mollusc (?)); intraclasts or pellets; coarse calcite mosaic. Minor quartz, K-feldspar (silt), white mica, partially replaced by calcite. Matrix: clear calcite (shaped grains) plus minor quartz. Chert replacive to echinoid fragments. Matrix more abundant than bioclastic grains.

Quartzite: Well-sorted, well-rounded quartz grains 1/8-1/2 mm. Abundant fine-grained calcite cement. Minor K-feldspar and plagioclase, very sparse white mica. Calcite has partly replaced plagioclase. Strong quartz grain shape frabic. Matrix calcite appears to have recrystallized. Accessories: pyrite, zircon, sphene, chlorite.

Thick undescribed sections of Permian rock exist in many of the knolls in western Box Elder County. Lemay Island exposes the Grandeur Member of the Park City Formation, Rex Chert, and Gerster Formation; Lion Mountain has Rex Chert thrusted over Devonian, Silurian and Ordovician units on its east side; the Little Pigeon Mountains have exposures of Wolfcamp and Leonard fusulinid-bearing sandstones and platy limestones and Grandeur Member of the Park City Formation; Pigeon Mountain and Terrace Mountain (not Terrace Mountains) expose the Rex Chert and Gerster Formation; the small knolls north and south of Lucin are mostly Grandeur Member and Rex Chert.

Mesozoic

The Mesozoic Era is very poorly represented by sedimentary rocks in Box Elder County; two formations are recognized in the Triassic and none are recognized in the Jurassic and Cretaceous.

Triassic rocks are exposed on the west flanks of the Terrace and Grouse Creek Mountains; some additional outcrops have been reported in the Goose Creek Mountains and in the Matlin Mountains (figure 32).

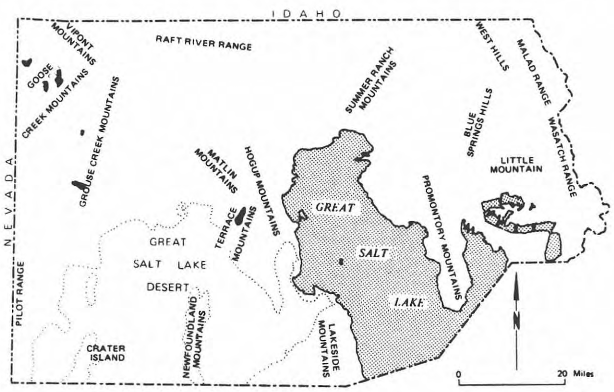


Figure 32. Triassic outcrops of Box Elder County.

The two represented formations are the Dinwoody and the Thaynes and both are of marine origin. The older Dinwoody Formation is exposed only in the Terrace Mountains, where it is 1,670 feet thick and complete. Here the formation is divided into an upper "Claraia" zone and a lower "Lingula" zone. The lower 260-300foot "Lingula" zone consists of interbedded maroon, green to olive gray shale and crystalline and bioclastic maroon, brown, and gray limestone. The shales weather into small chips or flakes. The limestones are thin- to medium-bedded, blocky weathering, and constitute about 75 percent of the zone. In the lower one-third of the "Claraia" zone, silty limestone and shale are common lithologic constituents. The upper two-thirds consists of thin-bedded to laminar, olive yellow to tan calcarenite. In the Terrace Mountains the upper part of the Thaynes Formation is eroded away and the lower contact is conformable with the Dinwoody Formation. Only 330 feet remain and thin-bedded silty limestones make up 80 percent of the unit, with dark-brown to gray bioclastic limestones making up the remainder (figure 33).

The only Triassic unit recognized in the Grouse Creek Mountains is the Thaynes Formation; it is also the youngest formation in the mountain range excluding the semi-consolidated and patchy Tertiary and Quaternary deposits. The Thaynes is exposed on the west slope of the mountains; below Rocky Pass Canyon it consists of brown sandy to shaly limestone, clean limestone, and sandstone. The ratio of these three lithologies is 15:4:1. The presence of chert is more pronounced in westernmost exposures and occurs in beds averaging three inches in thickness. An estimated 1,200 feet of rock are exposed, but upper and lower contacts are obscured by faulting or younger overburden.

Triassic rocks assigned to the Thaynes Formation have been recognized by A. R. Young (thesis in progress, 1978) in the Goose Creek Mountains, and in the Matlin Mountains by V. C. Todd (Red Dome and Runswick Wash quadrangles, U. S. Geological Survey mapping in progress, 1978). In the Matlin Mountains the rock is described as fine-grained silty-sandy, dark gray limestone with minor dolomite and chert containing fresh or brackish water fossils and pink-weathering, silty-sandy dolomite and chert with cross-laminated sandy limestone to limy sandstone, with minor dark gray to black limestones containing Triassic brachiopods. The writer also noted olive-green shales and dark-gray to black, thin-bedded to medium-bedded limestone of Triassic age in the Terrace Mountain (not Terrace Mountains) area.

Tertiary

Tertiary strata, which in some areas have been found to exceed 3,000 feet in thickness, are exposed in the foothills surrounding many of the mountain ranges. These rocks extend under the Quaternary deposits in the valleys between the mountain ranges. The beds are heterogeneous and are deposits of fluvial, lacustrine, and volcanic environments. The beds have been studied in detail in only a few localities and can as yet not be correlated from area to area. Most are believed to be Late Tertiary in age, perhaps Miocene and Pliocene. The

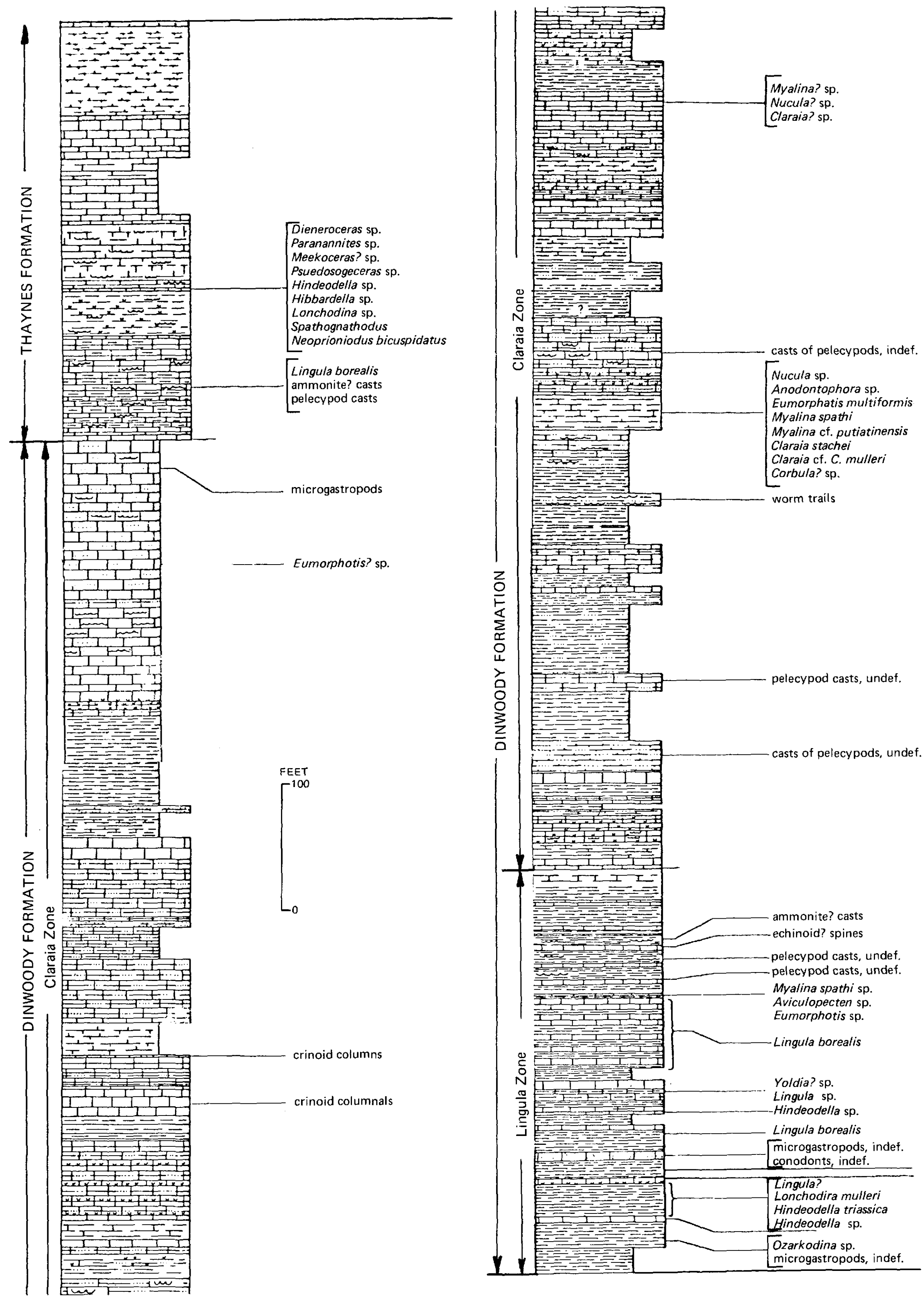


Figure 33. Triassic Lithology in the Terrace Mountains (after Stifel, 1964).

more complete work to date has been done in the northwest corner of the county in the Goose Creek Basin and in the northeast corner of the county and adjacent Cache Valley.

In Goose Creek Basin the Tertiary consists of two formations, but one of these (Payette Formation) may not extend into the Utah portion of the basin. If it does, the beds will be entirely subsurface (figure 34). The exposed unit is the Salt Lake Formation or group and this is the only unit that has been recognized in other parts of the county. In the Goose Creek Basin the Salt Lake Formation consists of two parts; a lower unit, at least 1,550 feet thick, consisting mostly of volcanic ash interbedded with shale, sandstone and conglomerate, with welded tuff beds appearing near the top, and an upper unit, 700 feet thick, of interbedded white and grayish orange volcanic ash with lentils of conglomerate and a thick bed of welded tuff at the bottom. Some of the shales of the lower unit are carbonaceous and lignitic. Similar beds are present in the Grouse Creek Basin. Drilling in this basin shows the Salt Lake Formation to consist of clay, shale, volcanic ash interbedded with lenses of gravel and rhyolite, dacite, and quartz latite flows. Some of the lava has the appearance of basalt, but close examination of the rock reveals the differences.

Adjacent to the Pilot Range the Salt Lake Formation is 2,500 to 3,000 feet thick and is dominated by platy siliceous limestone and mudstone, tan and yellow gray sandstone, cream colored limestone and brownish pebble conglomerate. Some tuffaceous beds and minor carbonaceous shales are also present. In the southern Grouse Creek area the Salt Lake Formation is divisible into three units; a lower mudstone-vitrophyre with a few conglomeratic beds, a rhyolite flow rock, 150 to 200 feet thick, and an upper lithic tuff-vitrophyre member. The lower and upper units have not been measured: the lower beds are mostly white and light gray in color and the upper units are red, white, black and occasionally yellow and green in color.

Salt Lake Formation beds also crop out around the Raft River Range, but have not been studied in detail or measured. The beds may be several hundreds of feet thick and are presumed to be a typical assemblage of tuffs, tuffaceous sandstones, shales and conglomerates. In a well just north of Park Valley about 365 feet of these beds were penetrated before older rocks were encountered. In another well, at Muddy Creek, east of the Grouse Creek Mountains, 400 feet of Salt Lake Formation was encountered (figure 34). The depth to the underlying older rocks can be expected to be extremely variable. The formation has also been recognized around the Terrace and Hogup Mountains. Here it includes deposits of bentonitic clay, vitric tuff, and freshwater limestone or marl along with some conglomeratic beds. The maximum measurable thickness is 190 feet.

In her preliminary mapping in the Matlin Mountains, V. C. Todd (in progress, 1978) describes the sequence as interbedded fanglomerate, conglomerate, sandstone, and tuffaceous fine-grained fresh water lake deposits; chiefly fanglomerate in the lower part and lake deposits in the upper part. This writer's experience indicates that the Salt Lake Group is an interbedded unit of fanglomerate, conglomerate, tuffaceous gritstone, sandstone, siltstone and claystone. In local areas these are further interbedded with volcanic flows. The fluvial deposits (fanglomerates and conglomerates) generally dominate in the sequence, but the lacustrine units are important locally. Many fanglomerates of the Salt Lake Group have been modified by pedimentation and are covered by a thin veneer of younger gravels. The sections vary greatly; in places the lacustrine sediments dominate in the lower parts and fanglomerates dominate in the upper parts; in other areas the reverse is true.

The Salt Lake Formation has not been recognized around the Lakeside, Newfoundland, and Promontory Mountains, nor in the West Hills. In wells drilled in Curlew Valley, the valley fill is identified as Quaternary and Tertiary, 3,880 feet thick. The sediment is described as light tan and gray tuff, inter-bedded with tuffaceous limestone and beds of conglomerate and tuffaceous sandstone. In places lava flows up to 15 feet thick are encountered at depths of a little over 150 feet. A few beds of calcareous pink and yellow siltstone and shale are also encountered. In a well near Rozel Point, west of the Promontory Mountains, at least 2,000 feet of the Salt Lake Formation are encountered. The top of the Tertiary is estimated to be about 200 feet beneath the surface. The entire section consists of volcanic ash and/or lacustrine shale, sandstone, siltstone, mudstone, and marlstone. Recent drilling in the Salt Lake Graben indicates as much as 10,000 feet of Salt Lake Formation.

In Cache Valley, to the east of Wellsville Mountain in Cache County, the Salt Lake Group is reportedly locally over 12,000 feet thick. At Wellsville Mountain over 2,000 feet of Salt Lake Group strata are exposed. Two units are recognized; a lower Collinston Conglomerate, 1500 feet thick, and an upper Cache Valley Forma-

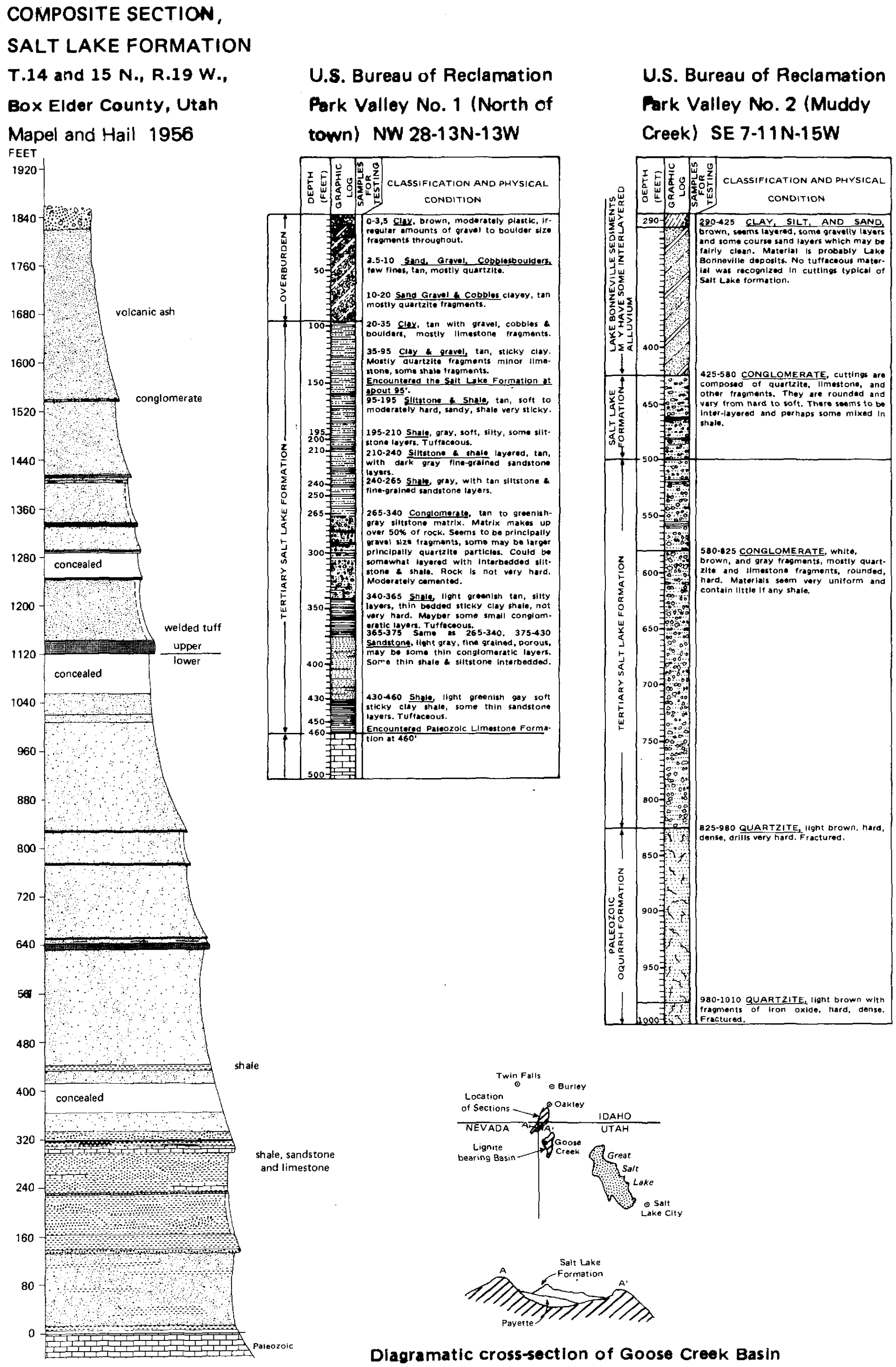
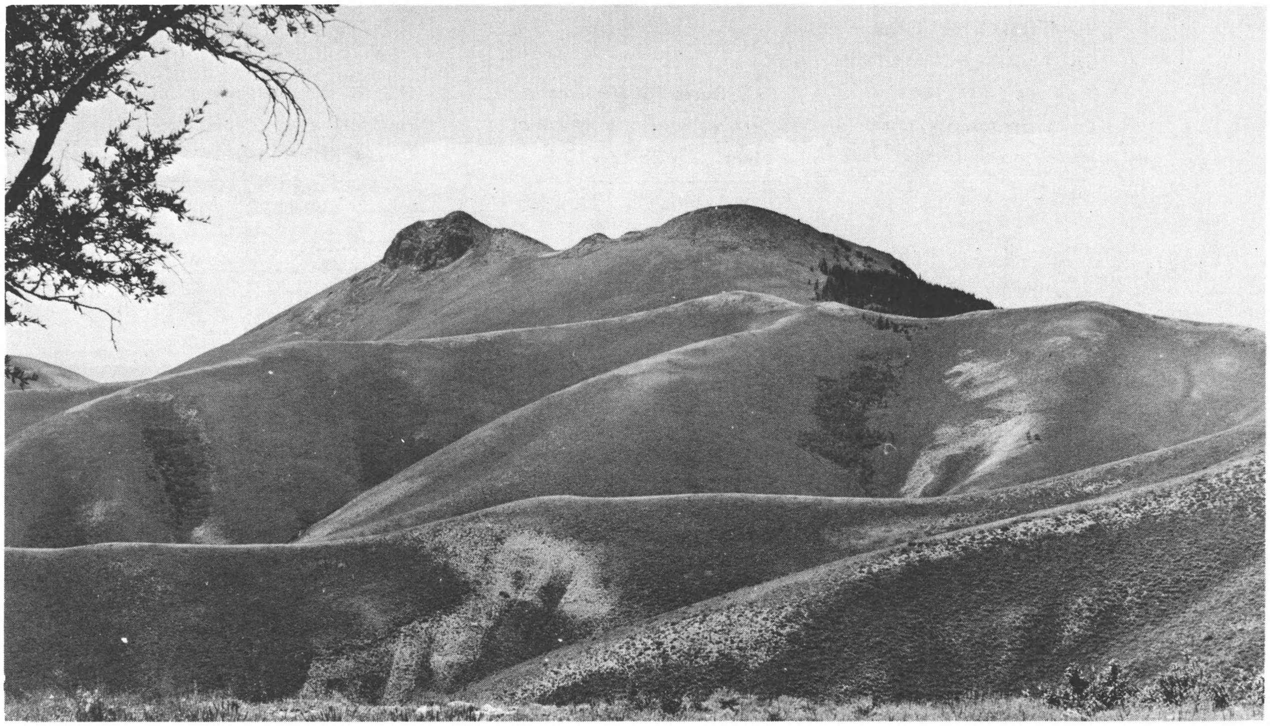
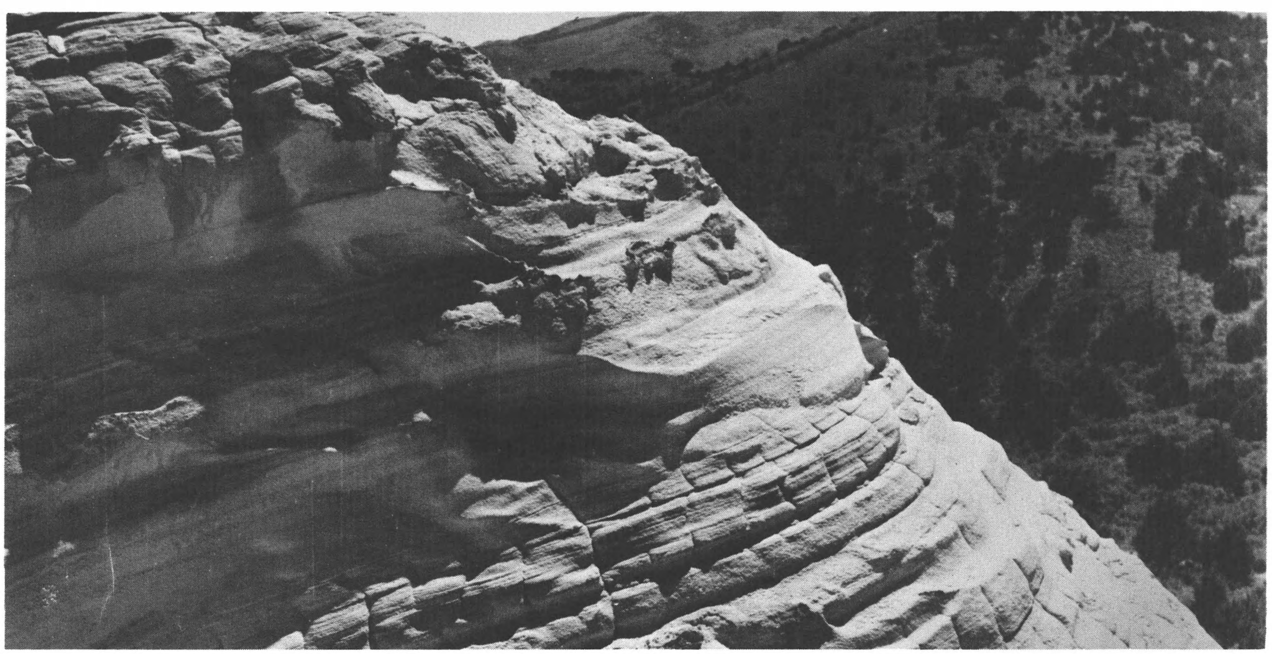


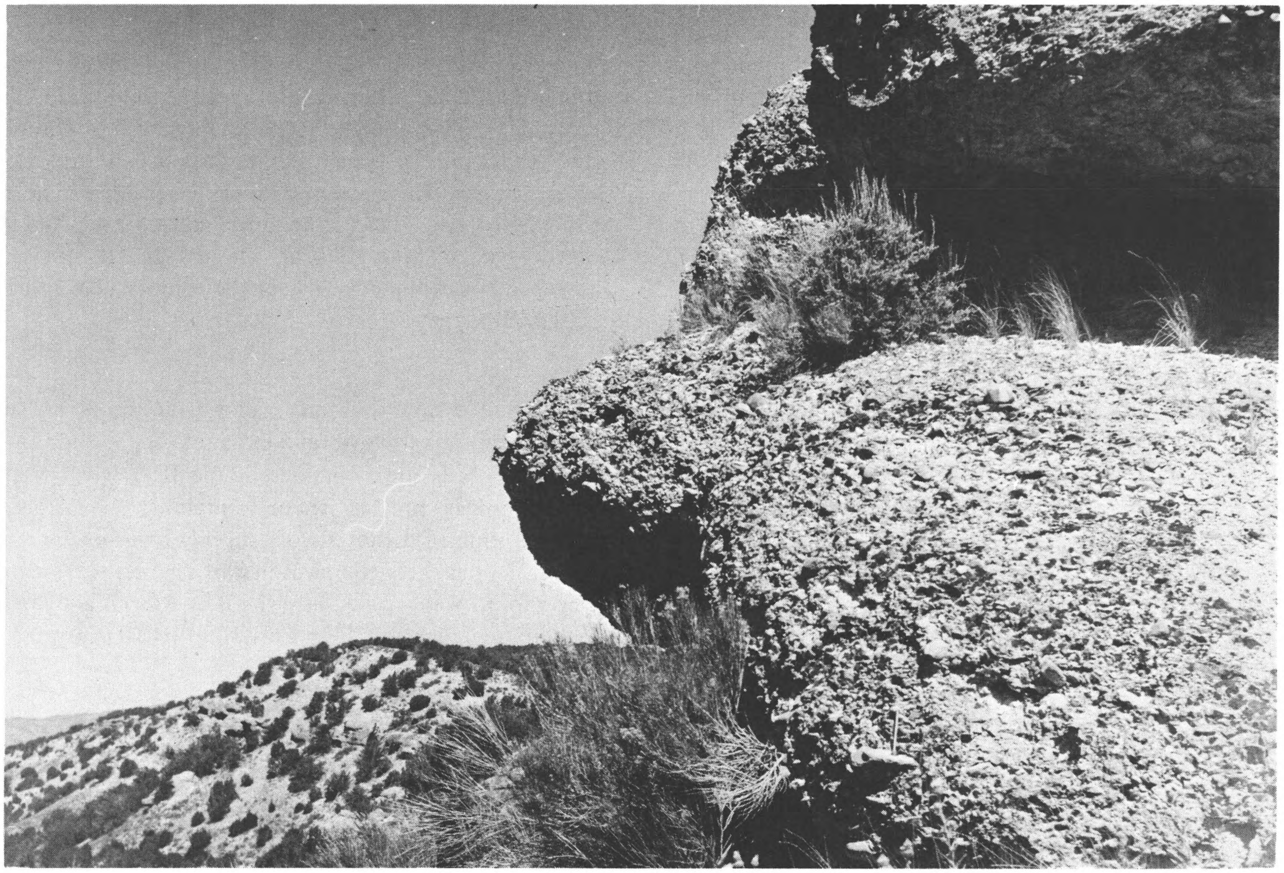
Figure 34. Sections of Salt Lake Formation in western Box Elder County.



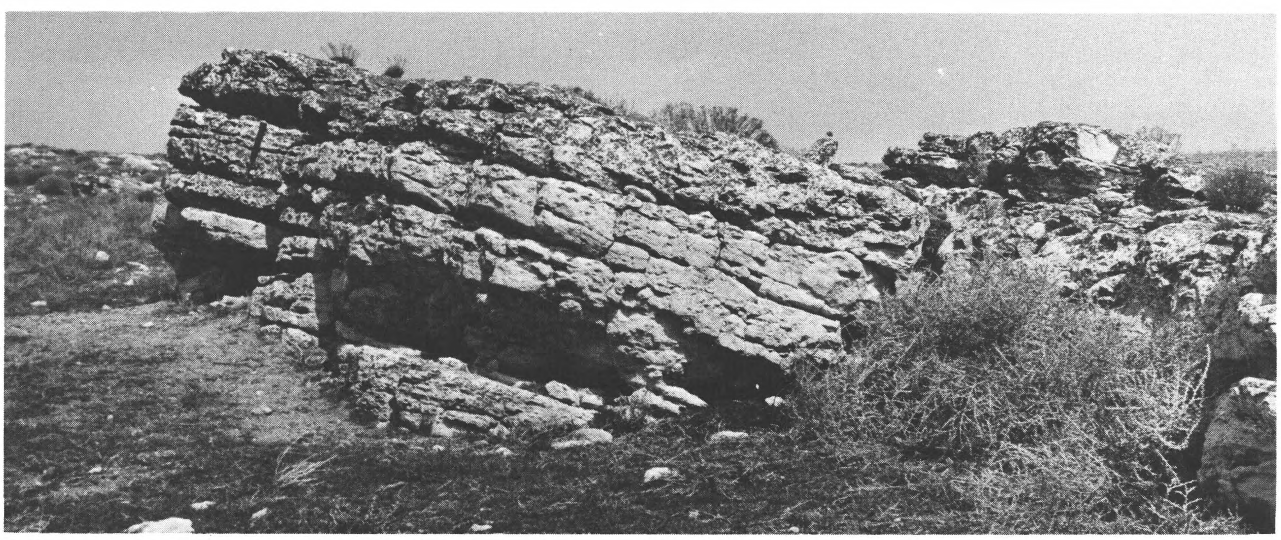
P 17. Twin Peaks in the Goose Creek Mountains. The upper outcrops are Tertiary rhyolite and the smooth slopes below are outcrops of the Permian Pequop Formation.



P 18. Outcrops of tuffaceous sediments of the Salt Lake Group in the Grouse Creek Mountains.



P 19. Conglomerate outcrops of the Salt Lake Group dipping easterly on the west flank of the Grouse Creek Mountains.



P 20. Eastward dipping limestone beds of the Tertiary Salt Lake Group in the Rozel Point area. Note hammer for scale.

tion with about 630 feet of exposed strata. The Collinston Conglomerate consists of subrounded pebbles and cobbles of dark gray limestone, medium brown sandstone, and light tan quartzite cemented by white to pale orange calcite. The Cache Valley Formation consists of light gray tuffs, tuffaceous sandstone and limestone, and conglomerates of light and dark gray limestone.

An additional older Tertiary unit, the Wasatch Formation, is present in scattered patches in the northern Wasatch Range and Wellsville Mountain. The Wasatch Formation consists of a conglomerate made of calcareous sandstone and limestone believed to be Eocene in age. The maximum thickness of the unit is estimated to be about 500 feet.

Quaternary

Quaternary rocks are most widespread in Box Elder County and cover 70 percent of the surface. The bulk of these deposits was laid down in a lacustrine environment, but significant volume is of fluvial origin. Smaller volumes of gravity, glacial, and eolian deposits are found in the area as well.

Much of Box Elder County was inundated by Lake Bonneville during the Pleistocene. This huge lake left numerous terraces, bars and spits along the margins of the hills and mountains and on the extremely flat surface of the Great Salt Lake Desert. The Terrace Mountains were so named because of the outstanding development of terraces along their flanks.

The deposits formed by the lake are here divided into four groupings of greatly varying significance: the lake clays, muds and silts; the sand and gravel deposits; diatomaceous marl, and ice-rafted deposits.

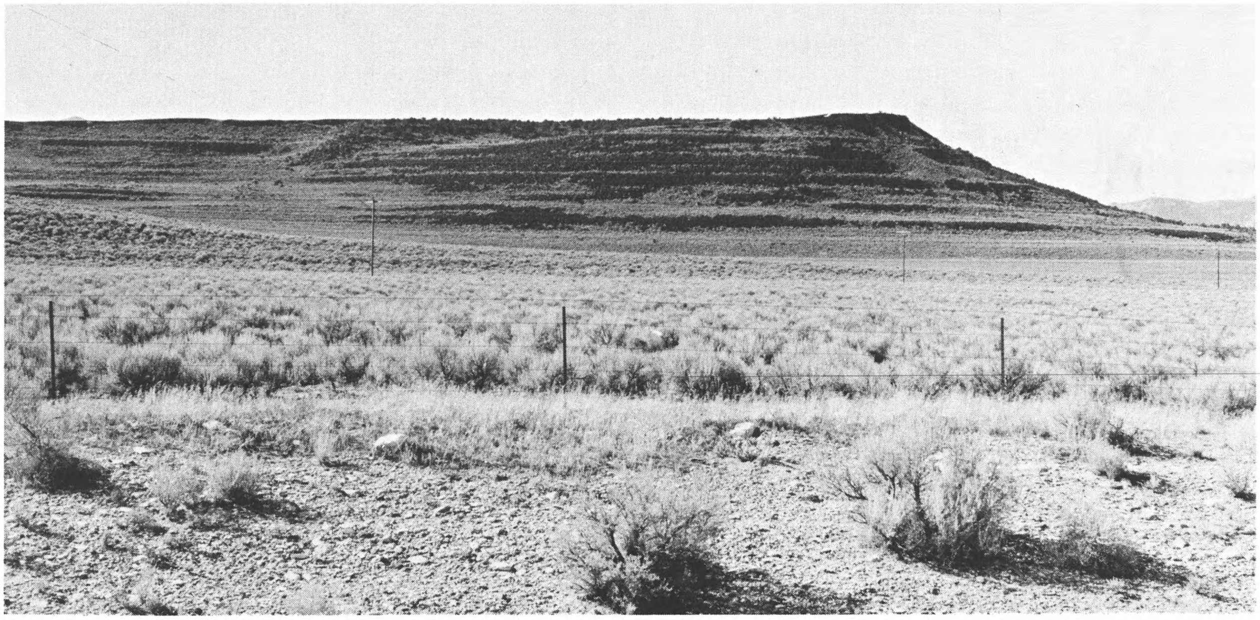
Mud flat areas. Of greatest volume are the lake clays, muds and silts exposed over most of the mud flat areas (some under a thin veneer of post-Bonneville basinal deposits) and in the intermontane valleys. On the mud flat this material is water-saturated at or near the surface and is sticky and tenacious. In the summer the upper surface may dry out to form a crust over which a vehicle may pass, but driving across this crust is a dangerous practice. The drying out process is irregular and the thickness and resulting strength of the crust cannot be predicted. If the vehicle breaks through into the mud it can become so hopelessly mired that abandonment is the only solution. Shallow drilling and digging show that the mud is the dominant material; however, some oolitic lenses may be encountered. The briny saturating water contains from 10,000 to 250,000 ppm of dissolved solids which may indicate that there are interbedded evaporite beds at depth such as have been discovered under Great Salt Lake. In the upper layer of mud, large crystals of gypsum develop; these are undoubtedly the source of the gypsite dunes that accumulate along the margins of the area. Drilling has shown that the thickness of this mud is irregular, and up to 1,200 feet have been penetrated so far. The associated brines are pumped for commercial use in the vicinity of Wendover in Tooele County.

In the intermontane valleys the clays are not usually saturated with brine and are more varied; sandy and silty beds are common. In the Bear River Valley some springs provide water containing in excess of 38,000 ppm of dissolved solids; generally, however, the water contains less chemical matter and supports desert vegetation. Wells drilled into the Bear River Valley often encounter brackish water with 1000 to 10,000 ppm of dissolved solids.

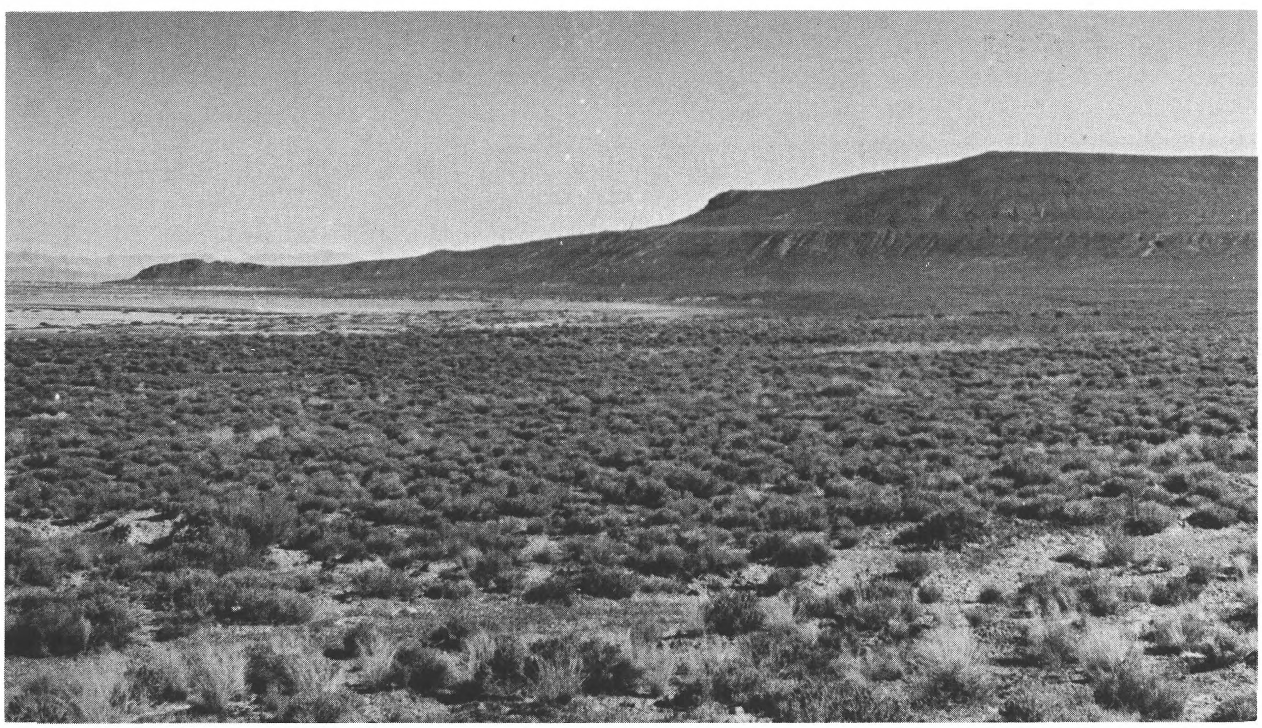
Gravel deposits. Of great volume, and often found in great thicknesses, are the varied gravel deposits of Lake Bonneville. The bars, spits, deltas, and lake terraces are huge deposits of sand and gravel that have been and are being used as prime road-building material. The greatest thicknesses are adjacent to mountain ranges containing Precambrian Z and Upper Paleozoic rocks, which were readily reduced to gravel by Lake Bonneville. The thicker accumulations of talus and scree are also found in areas where such rocks are exposed. The lake bed deposits consist of well-rounded to subangular boulders, cobbles, and pebbles in contrast to the angular nature of the shore deposits. In many cases this coarse material is mixed with a sandy loamy matrix which increases in volume at lower elevations or as the distance increases from the mountain masses.

Diatomaceous Marl. In former protected coves of Lake Bonneville are found stratified deposits of diatomaceous marl. The color is pale-yellow to white, and beds to 25 feet in thickness are known. Much is impure and diluted with pebble and sand streaks. The white outcrops usually stand out against the gray dust, silts, clay or mud deposits of Lake Bonneville.

Ice-rafted deposits. Most of the rare ice-rafted deposits are large boulders of rock from adjoining ranges lodged against a high lake terrace. In a few places immense blocks of bedrock are lodged against a prominent shoreline.



P 21. Shorelines of ancient Lake Bonneville have left their marks on the Knolls of Box Elder County. These horizontal "lines" are known as levels.



P 22. The "snout" of Crocodile Mountain in the Hogup Mountains. In many areas, including this one, large amounts of gravel accumulated along the levels of Lake Bonneville.

Post Bonneville deposits. Post-Bonneville basinal deposits, for the most part, consist of a thin veneer of fine clastics or chemical matter. This material may include dust from the wind, the suspended fines of playa lakes (or precipitated chemical matter), or the alkali efflorescences and salt crusts deposited as the ground water rises to the surface by capillary action. Occasionally the water table rises and emerges above the surface for a time and the brine is allowed to evaporate in the desert sun. The latter action is more significant in the western part of the Great Salt Lake Desert. The volume of such sediments is small and the prevailing winds do much to dissipate their accumulation.

Occasionally a desert storm is so severe that a flood will debouche onto the mud flat. On such occasions very coarse material, including boulders, may be deposited on the flat. If the mud is slippery, a surface of little friction may develop between boulder and mud; boulders have been known to be blown by the wind for several hundreds of feet.

The post-Bonneville deposits have little if any economic value. In exception are the salt crusts such as the Bonneville Salt Flats to the south of the area in Tooele County, where the surface is used as a high-speed runway for racing automobiles; most land speed records have been set there. A smaller salt crust is known in western Box Elder County between Crater Island and the Pilot Range, but its value as a race track is negated by its better developed neighbor, although the crust itself may contain valuable sodium and potash salts.

Around the base of the steep slopes or cliffs of the mountain ranges and bedrock knolls are talus, scree, rock rivers, and other gravity deposits. Land-slides are included in this division. Generally individual deposits are thin and their volume small when compared with those of fluvial, colluvial or lacustrine origin. Such gravel and riprap might be exploited for local use where quantities are sufficient. The quartzitic or sandstone bedrock units, such as Precambrian Z and Pennsylvanian and Permian Oquirrh outcrops, produce the largest amounts of such rubble during their erosion.

Glacial deposits are limited in extent and volume. They have been reported in the Raft River Range and in the Grouse Creek Mountains. In the Raft River Range glaciation is in evidence above 8,000 feet and cirques have been noted at the heads of Sawmill, Rosevere Fork, and Lake Fork Canyons. Other canyons show evidence of glaciation as well. The deposits consist of morainal matter: unsorted boulders, gravel, and sand.

A complex of alluvium and colluvium is irregularly present over much of the area and is best developed in the sloping land between mountain and mud flat. These deposits include unconsolidated gravel, sand, and silt in the channels and floodplains of streams and the gravelly, stony, sandy, and silty soils associated with intervening alluvial fans, river terraces, valley fill and colluvial deposits.

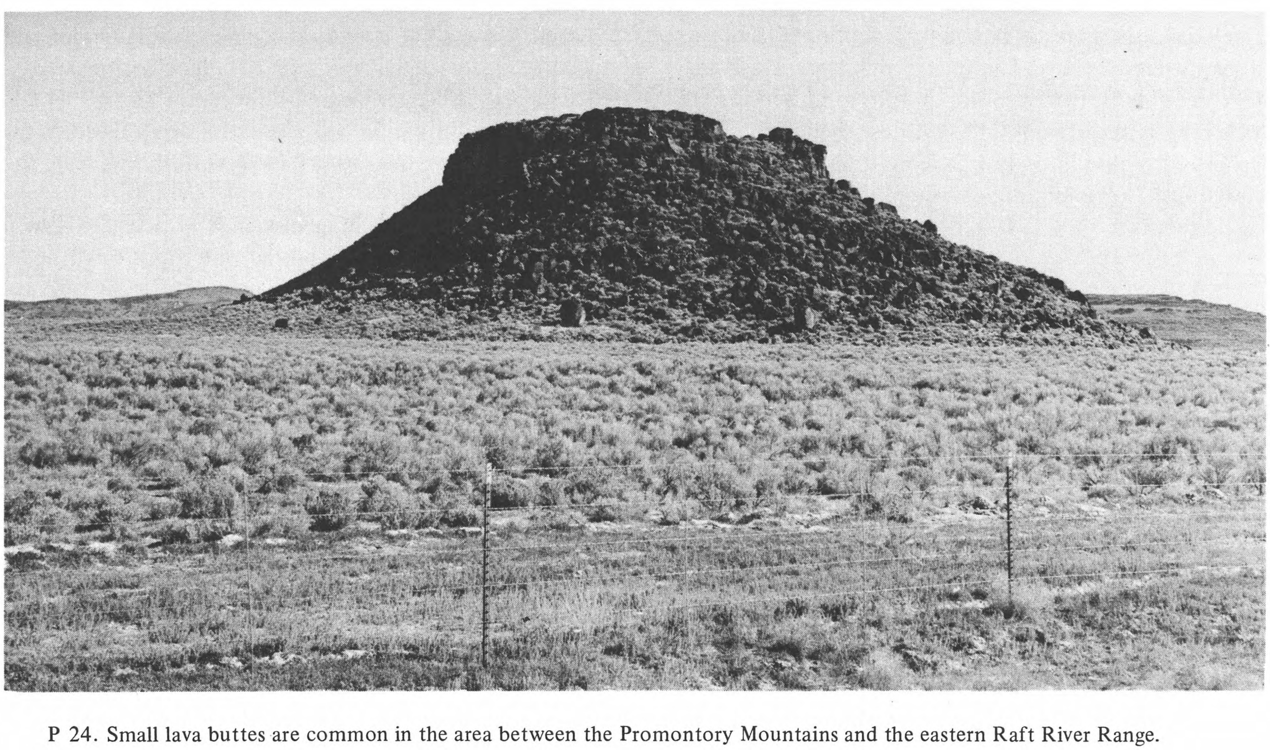
A few dunes consisting of quartz sand, oolite, and gypsite are found at scattered locations throughout western Box Elder County. Dunes congregate parallel to the lower mountain ranges especially along their west sides, along the edge of the mud flat. Lesser amounts are located on the east side or just to the lee of mountain passes near the crests of the ranges. Still other dunes are found resting adjacent to the berms of the more recent Great Salt Lake shorelines. The composition of dunes on the west side of the ranges is generally calcareous gypsite; those on the lee of mountain passes and the few on the east sides are generally of quartzitic sand, and those marginal to the Great Salt Lake are oolitic.

Igneous Rocks

Both intrusive and extrusive varieties of igneous rock are exposed in the Box Elder County area. Intrusives are known in the Pilot Range, on Crater Island, in the Grouse Creek Mountains, at the north end of the Newfoundland Mountains, in the Raft River Range, and in the Wasatch Range. Significant exposures of extrusives are found at the north end of the Pilot Range, in the Goose Creek Mountains, Hogup Mountains, Wildcat Hills, Summer Ranch Mountains and in the North Promontory Mountains (figures 35 and 36).

In the north part of the Pilot Range, on the east side of the divide, is a stock of monzonitic composition exposed in an area covering about 10 square miles. The rock is relatively softer than the sediments it has intruded and is known as the Patterson Pass Stock. The overall color of the rock is gray-white to light gray and the exposed surfaces are granular and friable. Associated with the stock are several diabase dikes. These rocks are black to dark green and weather a deep brown. A small monzonite porphyry stock intrudes Silurian and Devonian strata north of Tecoma Hill on the west side of the range. Like the Patterson Pass material it is easily weathered and eroded. It often appears pink due to the large orthoclase crystals contained in it. Radiometric age dates of these stocks are unavailable. They were intruded after the deposition of the Paleozoic sedimentary units and before the deposition of the Salt Lake Formation.

P 23. Quaternary sand deposits are plentiful around the margins of the mud flat areas and vary in composition. The above accumulation consists of calcareous oolite, other dunes are of gypsite. Sandy areas (silica) are abundant at the edges of the more important drainages.



P 24. Small lava buttes are common in the area between the Promontory Mountains and the eastern Raft River Range.

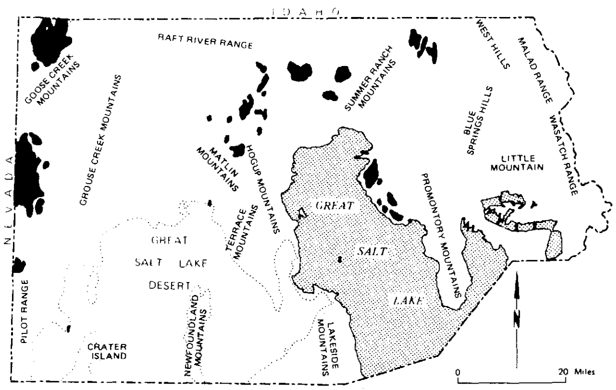


Figure 35. Extrusive outcrops of Box Elder County.

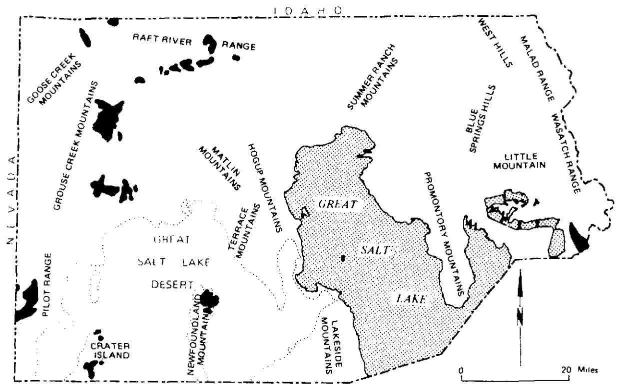


Figure 36. Intrusive outcrops of Box Elder County.

Extrusives in the Pilot Range are mostly found at the very north end. A large oval-shaped brown-colored mass of rhyolite can easily be seen by the traveler along Utah Highway 30. The rhyolite is a porphyry with phenocrysts of glassy quartz and earthy white spots (weathered sanidine). At the base is a glassy vitrophyre, partly banded with black, red, and yellow glass. Adjacent to the rhyolitic mass is a basalt flow and dike. The flow forms a south-sloping flat-topped butte. The walls show vesicular, scoriaceous basalt, with columnar jointing.

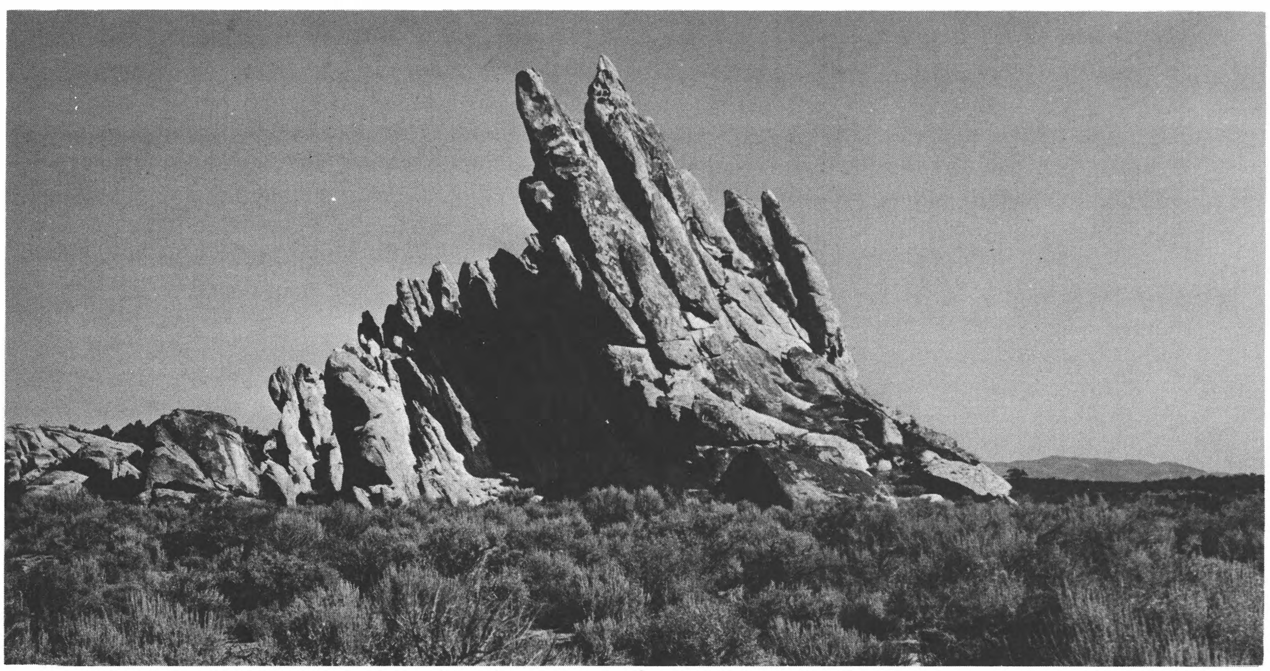
North of the Pilot Range, in the Goose Creek Mountains, are large areas of rhyolite-dacite-quartz latite flows. The appearance of the rock is similar to the rhyolite at the north end of the Pilot Range. The Goose Creek extrusives are thicker, better developed, and show more differentiation. The major rock type is a massive dark reddish brown rhyolite porphyry. Beneath this rock type is the vitrophyric unit described for the Pilot Range. This rhyolitic flow extends to the west side of the Grouse Creek Mountains, where the outcrops are not very extensive.

A Tertiary granitic pluton, the Immigrant Pass intrusion, is exposed at the southern end of the Grouse Creek Mountains in an area of a little over 10 square miles. Baker (1959, p. 43) indicates 93 percent of the rock outcrops are quartz monzonite and the remainder quartz diorite (table 8). Compton and others (1977, p. 1248) indicate that the rock is mainly biotite granodiorite verging on adamellite (quartz monzonite). Aplite and pegmatite dikes are locally abundant and widespread. Areas of diorite, syenodiorite, and other mafic rocks are abundant to the south-west. The overall color of the rock is light gray. It weathers into rounded outcrops with granular surfaces. Lamprophyre dikes have been noted intruding sediments around the periphery of the intrusion. These are mostly dark green or medium brown in color. A Rb-Sr isochron age of 38.2±2.0 million years has been determined for the stock (Compton and others, p. 1246). The pluton intrudes rocks of Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian and perhaps Precambrian rock.

Two smaller adamellite Tertiary stocks crop out on the west side of the Central Grouse Creek Mountains, each with an outcrop area of 2 to 3 square miles. The stocks (table 8) are presumed to be cupolas of a larger body of adamellite at depth. They are intruded into a Precambrian adamellite gneiss and are known as the stocks of Red Butte Canyon. They are associated with abundant discordant dikes of alaskite and aplite. The stocks show a hypidiomorphic, equigranular rock consisting of equal volumes of oligoclase, quartz, and potassium feldspar along with 5 percent biotite. The Red Butte Canyon stocks are age-dated at 24.9±0.6 million years (Compton and others, 1977, p. 1246).

The Precambrian gneiss into which the Tertiary stocks have intruded covers an outcrop area of at least 20 square miles. Originally an intrusion of the outer belt of the Wyoming Province (2.5 billion years), it is now a stratiform complex of several rock types. About 3/4 is adamellite gneiss which grades upward from coarse and medium grained gneiss to fine-grained gneiss. About 15 percent of the rock is of granodioritic or tonalitic composition, 5 percent is quartzo-feldspathic and pegmatoid rock and 5 percent is amphibolite and metasedimentary schists. Many smaller exposures of Precambrian adamellite are found scattered in the northern Grouse Creek Mountains; more are found in the Vipont Mountains than in the Dove Creek Mountains. In the southern part of the Dove Creek Mountains, in the vicinity of Road Canyon, are outcrops of metamor-

P 25. North end of the Pilot Range near the Utah-Nevada border. Rhyolite Butte is to the left and a basalt capped butte is to the right. The rhyolite flow capping Rhyolite Butte overlies tuffaceous beds of the Salt Lake Group. The mountain to the south of the basalt-capped butte exposes Devonian Guilmette Formation and Permian Pequop Formation.



P 26. The Devils Playground consists of an assortment of granitic rock outcrops weathered into grotesque shapes and forms. The Devils Playground is in the southern Grouse Creek Mountains.

phosed granite porphyry in an area aggregating a little more than 160 acres.

Another Tertiary intrusion is found in the Vipont Mountains (northwest arm of the Grouse Creek Mountains) and consists of adamellite and granodiorite. Inconclusive results were derived in an attempt to age-date the rock, which is intruded into Cambrian and Ordovician units. The exposed area covers 3 to 4 square miles.

Precambrian intrusions are also present in the Raft River Mountains. The rock is all metamorphosed, but in the eastern part of the range it looks like a regular igneous rock. Adamellite is again the most important rock type and is exposed in many of the deep canyons. It probably underlies the entire range. The whole rock isochron age of the rock is about 2.2 billion years (Compton, 1975 , p. 4). In the northeast part of the range, near the mouth of Clear Creek Canyon, is a large area (about 9 square miles) in which metamorphosed trondhjemite and mafic igneous rocks are exposed. The former consists almost entirely of white sodic plagioclase and quartz and pegmatite containing K-feldspar. The latter are principally hornblende schist and amphibolite. This rock appears nearly black in outcrop.

Remnants of dacite-quartz latite flow rock occur along the north side of the Raft River range, 1½ to 3 miles east of Standrod. The rock is dark yellowish brown and pale brown, weathering to moderate or dusky brown. Small phenocrysts make up 25 percent of the rock volume and include oligoclase, orthoclase, quartz and clinopyroxene grains. Similar rock in the Albion Range has been dated 8.5 to 9 m.y. old by Armstrong (1970).

In the hills southeast of the Raft River Mountains are numerous small buttes exposing basalt flows. These are scarred by the terraces of Lake Bonneville and it is thought that the original flow covered a much larger area. Indications are that it extended far out into Curlew Valley. Most was eroded prior to the presence of Lake Bonneville. The basalt is a dark gray to brownish black rock that in many places exhibits columnar jointing. Petrographic work shows the basalt has intergranular texture with 58 percent labradorite, 30 percent augite, 10 percent olivine and 2 percent magnetite.

Several exposures of plutonic rock which total approximately 5 square miles are found on Crater Island. Most is quartz monzonite (adamellite), monzonite, or granodiorite; the rock types are gradational. In places

Table 8. Modal compositions of some intrusives in western Box Elder County

1. Immigrant Pass stock (southern Grouse Creek Mountains)[1]

	Quartz monzonite?	Aplite	Red Quartz monzonite
Quartz	34.0%	46.0%	31.0%
K feldspar	39.0%	34.0%	26.0%
Plagioclase	20.0%	18.0%	34.0%
Biotite	7.0%	2.0%	8.0%
Accessories			

2. Central Grouse Creek Mountains[2]

	Quartz diorite	Precambrian Adamellite Gneiss	Tertiary Adamellite
Quartz	19.0%	26.5%	28.0%
K feldspar	1.0%	27.5%	28.0%
Plagioclase	65.0%	39.5%	38.5%
Biotite	8.0%	4.0%	5.5%
Accessories	7.0%	2.5%	tr.

3. Newfoundland stock[3]

	Quartz monzonite
Quartz	15.0%
K feldspar	32.0%
Plagioclase	31.0%
Hornblende and biotite	19.0%
Accessories	3.0%

[1] Baker, 1959
[2] Todd, 1973
[3] Paddock, 1956

the rock grades into syenite and becomes locally rich in biotite, hornblende, and augite. In addition to the pluton (or plutons) are several andesite, rhyodacite, lamprophyre, and aplite dikes that, except for the aplite, exhibit a greenish or brownish color. The fresh intrusive rock itself has an overall medium gray color with a touch of brown. Preliminary age dating by the U. S. Geological Survey indicate the rock to have intruded in Jurassic time. A small body of latite porphyry is found on the southeast side of Lemay Island, which lies 4 miles northwest of Crater Island. The light lavender to pink flow rock has two sizes of feldspar phenocrysts.

The stock at the north end of the Newfoundland Mountains covers an area of five or six square miles. The main body of rock is adamellite (quartz monzonite) with a porphyritic texture, but local areas within the intrusion deviate gradationally in composition from granite to granodiorite. In a few places there is a complete lack of quartz and the rock is classified a monzonite. In hand specimen quartz, pink phenocrysts of perthite and earthy yellowish-white plagioclase phenocrysts are identifiable along with hornblende and flakes of biotite. As on Crater Island, there are several dikes and a few sills intruded into the sediments and the igneous rock alike. These are described as dark, medium-grained to aphanitic, and basic to intermediate in composition. One of these dikes is traceable along a length of 6,000 feet.

In the Hogup Mountains, southeast of the Raft River Range, and in scattered knolls around Curlew Valley are outcrops of extrusive igneous rocks. Most of these outcrops are basalt flows, some with and some without olivine. Most of the basalt is black or dark brown, fine-grained with identifiable phenocrysts of labradorite or augite. Some of the rock is columnar jointed, vesicular or amygdaloidal. A few of the exposures are andesitic, rhyolitic, and dacitic in composition and occur as flows or pyroclastics.

One grouping of hills in Curlew Valley, known as the Wildcat Hills, has outcrops of basalt, andesite, rhyolite, perlite, and welded tuff. The basalt is vesicular, ranges in color from red-brown to dark gray or black, and usually exhibits columnar jointing. Some of the vesicles are filled with calcite. The only megascopically visible phenocrysts are plagioclase. Petrographically the rock is 55 percent labradorite, 15 percent glass, 10 percent magnetite, 5 percent augite, and less than 1 percent olivine. The vesicle space makes up the remainder. Outcrops of andesite to 189 feet thick in the Wildcat Hills found are medium gray with occasional red-brown bands and andesine phenocrysts. Petrographically there are two types of andesite, one with 60 percent and another with 90 percent glass. The remaining rock is plagioclase, augite, and magnetite. Rhyolite to 293 feet in thickness, gray pink to light gray on weathered surfaces, is flow-banded. Visible phenocrysts are of quartz and there are common spherulites, amygdules, and lithophysae. The amygdules range from 1 to 4 inches in diameter and the lithophysae from 1 to 8 inches. Microscopic examination shows tridymite, sanidine, oligoclase, and minor hematite in a glassy matrix. Perlite crops out as flows and dikes and varies in color from gray olive to gray blue green to dark gray. Flow banding is accentuated by parallel layers of semi-rounded obsidian pellets with diameters ranging from 0.1 to 0.4 inches. Spherulites, amygdules, and lithophysae are also present. Lithophysae have been found with diameters of nearly a foot. The rock is 98 percent glass and 2 percent K-feldspar phenocrysts. There is a 45-foot thick welded tuff at one location that is light gray on weathered surfaces. This rock is 99 percent glass; perlitic fractures and embryonic spherulites are common.

Igneous rocks in the Summer Ranch (Hansel) Mountains and North Promontory Mountains are mostly basalt flows. The rock is dark gray to black and vesicular. The groundmass is principally labradorite and glass. A small amount of olivine is usually present. At Rozel Point, along Great Salt Lake and west of the Promontory Range, are other basalt flows. with total thicknesses to 250 feet. The Rozel Point basalt is described as dark gray to brown, somewhat crystalline, and vesicular. Identifiable minerals include olivine, augite, and labradorite.

Metamorphosed Precambrian extrusives have been described in both the Promontory Range and in the Wasatch Range near Willard. In the Promontory Range each of the "oldest, intermediate, and younger" Precambrian sequences contains relatively minor amounts of metamorphosed mafic extrusives. Most of these occurrences have a porphyritic texture and are dark green or dark brown in color. Hornblende or augite phenocrysts have been altered to albite, chlorite and calcite, as has much of the groundmass. These flows generally have a "chilled" zone at the base and are found to 25 feet in thickness.

Some of the Precambrian Z units of the Wasatch Range also have metamorphosed volcanics as minor constituents. The formation of Perry Canyon has minor pillow lava near its base. The Kelley Canyon Formation contains brown-weathering chloritic and carbonatic lamprophyre dikes. The Browns Hole Formation is locally underlain by red to black scoriaceous to amygdaloidal volcanic breccias. The Farmington Canyon Complex consists of gneissic medium- to coarse-grained adamellite (quartz monzonite), with quartz plagioclase and alkali feldspars in nearly equal amounts. This rock also contains minor biotite and hornblende.

Metamorphic Rocks

Both regional and igneous metamorphism have affected rocks in Box Elder County. Rocks altered by regional processes are displayed in the Raft River, Grouse Creek, Pilot, southern Promontory, and northern Wasatch Ranges. The regional metamorphism is due to several tectonic disturbances including several episodes of folding, faulting, and thrust-faulting.

Work in the Raft River-Grouse Creek area, where the metamorphism is well displayed, indicates the metamorphic grade increases downward and westward through the allochthonous sheets and into the autochthon. Compton and others (1977, p. 1237) indicate that the first metamorphic deformation ended about 38 million years ago and a second period was still under way 25 million years ago. They suggest that the deformations were caused by gravity acting on a broadly heated dome. The metamorphism decreases downward into the basement adamellite. Table 9 shows some of the metamorphic minerals that have formed in the formations exposed in the Grouse Creek and Raft River Mountains. Mineral lineations and foliations have aligned themselves parallel to the horizontal in most cases. Metamorphism affected the Precambrian adamellite by producing a gneissose rock with weak lineations and foliations. Metamorphic effects deformed and recrystallized quartz and aggregated biotite flakes and sphene. Plagioclase is often altered to albite, white mica, and epidote. In places the adamellite is more strongly metamorphosed and the gneissic features are increasingly emphasized; locally the rock grades to an augen-gneiss.

In the Pilot Range, Precambrian Z units show low-grade regional metamorphism which locally extends upward and affects Cambrian and Ordovician units. The Precambrian rocks were originally deposited as sandstone, shale, siltstone, thin extrusives, and limestone and are now converted to quartzite, argillite, slate, phyllite, metasiltstone, metavolcanics and marble. Metamorphic minerals most often noted include colorless mica (muscovite and sericite), K-feldspar, quartz, chlorite, tremolite, epidote, and biotite. Schistosity is usually developed in the pelitic rocks and is defined by sericite, chlorite and elongate silt-sized quartz grains.

In the southern Promontory Range the regional metamorphism is low-grade. The effects are confined to the Precambrian and Lower Cambrian rocks; in volcanics the pyroxene and amphibole phenocrysts are replaced by calcite and by lesser amounts of albite and chlorite; pelitic strata are altered to phyllite; sandstones to quartzite, and limestone beds to marble.

The Precambrian Z rocks exposed in the Willard area of the northern Wasatch Mountains are little metamorphosed, perhaps less than those in the southern Promontory Mountains. Locally they show small-scale crenulations and folds at angles at variance to the bedding. The metaquartzite and schist of Facer Creek (Precambrian X) has undergone a somewhat greater degree of metamorphism to produce phyllites, schists, slates, and metaquartzite with muscovite, quartz, chlorite and apple-green fuchsite as metamorphic minerals. The Precambrian X Farmington Canyon Complex in this area is principally a gneissic quartz monzonite.

Table 9. Mineral assemblages in highest grade parts of rock units in Grouse Creek and Raft River mountains

Rock unit	Original rock	Metamorphic minerals
Oquirrh Formation	Silty limestone	Calcite, dolomite, quartz, colorless mica, relict detrital feldspars
Diamond Peak Formation	Shale	Colorless mica, quartz, biotite, chloritoid, graphite
Fish Haven(?) Dolomite	Dolomite	Dolomite, quartz, colorless mica, tremolite, relict K-feldspar
Eureka(?) Quartzite	Sandstone	Quartz, colorless mica
Pogonip Group	Sandy, clayey limestone	Calcite, dolomite, zoisite, calcic plagioclase, colorless mica, biotite, quartz
Schist Mahogany Peaks	Mafic shale	Colorless mica, staurolite, garnet, biotite, quartz
Quartzite of Clarks Basin	Feldspathic sandstone	Quartz, colorless mica, kyanite, chloritoid (locally biotite and garnet)
Schist of Stevens Spring	Shale	Colorless mica, quartz, biotite, garnet, oligoclase, graphite
	Basalt	Green hornblende, plagioclase
	Granite porphyry	Quartz, K-feldspar, oligoclase, colorless mica, biotite
Schist of Upper Narrows	Shale	Biotite, colorless mica, quartz, K-feldspar, oligoclase
Elba Quartzite	Feldspathic sandstone	Quartz, colorless mica, biotite, K-feldspar, plagioclase
Older Precambrian units	Adamellite	Oligoclase, orthoclase, quartz, biotite
	Gabbro	Green hornblende, intermediate plagioclase, garnet, quartz
	Shale	Biotite, quartz, oligoclase, garnet (altered metasomatically during late metamorphism to assemblages with kyanite, staurolite, andalusite, sillimanite)

Note: Minerals listed in order of decreasing abundance.

(after Compton and others, 1977, p. 1241

Igneous metamorphism can be demonstrated at the margins of most of the intrusive bodies of the county. Most changes are slight and are confined to contact zones. In a few places, however, and in favorable adjacent beds, the effects can be demonstrated to extend several thousand feet from the contacts. The most common alterations of this type are bleaching and marbleization of carbonate rock. At least one decorative crushed stone quarry has been opened because of this type of alteration. Contact phenomena include epidotization, tremolitization, garnetization, and the development of tungsten-bearing skarn. Igneous metamorphism is easily demonstrable in the northern Pilot Range, Crater Island, southern Grouse Creek Mountains, and the northern Newfoundland Mountains.

General Structure

Box Elder County may be regarded as a typical Basin and Range region. Mostly north-south elongated mountain ranges are scattered irregularly over the county, separated by wide valleys or plains. These valleys or basins are filled with unconsolidated Quaternary sediments and with consolidated, partly consolidated or unconsolidated Tertiary sediments. The Quaternary units are generally horizontally bedded. At the margins, where the edge of the basin fill meets the hard-rock units of the mountains, the unconsolidated units dip gently away from the mountains in the position in which they were originally deposited. The sediments in the basin of the Great Salt Lake Desert are lacustrine in origin and lie extremely flat. Gilbert (1890), working on the history of Lake Bonneville, postulated that there should be isostatic rebound in the area once covered by the lake. Work by Crittenden (1961 and 1963) and Eardley (1962) has confirmed this. The isostatic adjustment is greatest in the Grassy-Lakeside Mountains area and least along the margins of the Ancient lake. In the county, the elevation of the highest of the Lake Bonneville shorelines, called the Bonneville level, ranges from 5,130 to 5, 380 feet, a difference of 250 feet. The linear distance between the high and the low point is about 85 miles so that the tilting would amount to an insignificant 0.03 degrees (figure 37).

Tertiary Structures

Little is known of the attitudes and structure of Tertiary strata buried beneath the Quaternary unconsolidated rocks in the valleys and basins. In several areas, where Tertiary rock is exposed, the beds are faulted and moderately tilted. In the Goose Creek basin the late Tertiary Salt Lake Formation is tilted an average of 3 degrees in a general easterly direction, and locally dips have been measured that exceed 30 degrees. The strata are cut by normal faults that are traceable for several miles with displacements ranging from a few feet to as much as 900 feet. These rocks are similarly tilted and faulted in the Grouse Creek basin, but less is known about them. A larger outcrop of Salt Lake Formation at the northeast end of the Pilot Range is steeply tilted (40 to 87 degrees) to the east and illustrates that the deformation on this Late Tertiary unit has been significant.

Around the Grouse Creek, Raft River and Matlin Mountains the Salt Lake Formation outcrops generally have gentle to moderate dips, but locally reach 30 degrees. Exposures of the Salt Lake Formation around the Terrace Mountains are very small; the largest outcrop is a little less than a square mile in area, but the dip is about 25 degrees. At Rozel Point the dips in the Late Tertiary unit range from 10 to 17 degrees northeast.

Larger outcrops of the Salt Lake Group are exposed at the south end of the Malad Range (Clarkston Mountain) and at the north end of Wellsville Mountain. Here the rocks have a general easterly dip which increases eastward from a few degrees to as much as 30 degrees. Several faults with varied trends cut the formation locally. Not enough data are available at the present time to determine the broad or regional structural features of the Tertiary rocks. Certainly they were distorted by Basin and Range faulting and it may be safe to say that the buried Tertiary strata between the exposed mountainous masses are present in many broken blocks and are tilted at varying degrees.

Pre - Tertiary Structures

The Precambrian, Paleozoic, and Mesozoic age units exposed in the mountain ranges and inselberge scattered across the county are mostly consolidated. These strata were not greatly disturbed by tectonic activities until Mesozoic and Cenozoic times. However, several disconformities are recognized between formations, and basining occurred beginning in Mississippian time. Most of the units are marine in origin; the seas retreated from the area for the last time at the close of the Triassic period. Since that time these rocks have been involved in several mountain building events and were subject to erosion until the area once again became a basin (?) of deposition in Late Tertiary time. Basining may have been simultaneous with the beginning of Basin and Range faulting, which is responsible for the mountain and basin pattern; earlier orogenies are mostly responsible for the interior structures of the individual mountain ranges. The Basin and Range orogeny is characterized by tensional deformation, principally producing north-south trending normal faults; earlier events characterized by compressional deformation produced intrusions, metamorphism, high-angle and low-angle thrust faults and folds. Prior to Basin and Range faulting and the subsequent filling of the basins by more recent continental sedimentation, the complexly folded and faulted consolidated rocks were continuously exposed across the county. The strike of these rocks was roughly north-south, except in the area of the Raft River Range. The complexity of structure continues beneath the valley fill so that attempts at structural correlation would be meaningless. This is emphasized by drilling information obtained in Curlew Valley; here thick folded Devonian rocks were encountered adjacent to the Raft River Range where no rocks of this age are thought to be present.

Structure of Mountain Ranges

Cross-sections of the structure of the various mountain ranges are given in plate 3.

The Pilot Range trends north by northeast with its southern part in Nevada and northern part in Box Elder County, Utah. The entire length is about 30 miles and the average width about 4 miles. The major faults, mostly of Basin and Range origin, are north-south. The interior structure is marked by igneous intrusion, complex faults and thrust faults, and the rocks are steeply folded. The strike of the beds is generally parallel to the long direction of the range. At the north end of the range the strike of the beds is north-south, and the dip is generally to the east. A few fold axes are present, trending both north-south and east-west, which locally alter the strike direction. The dips are moderate to steep. The Patterson Pass pluton, which dominates the east side of the range, locally affected the dominant north-south strike. In the central part of the range both Precambrian and Ordovician units dip moderately to steeply to the east with the strike being subparallel to the north by northeast trend of the range. The Ordovician Pogonip Formation, exposed on the east side, is thought to be thrust over the Precambrian units. Both Precambrian and Ordovician units are cut by numerous

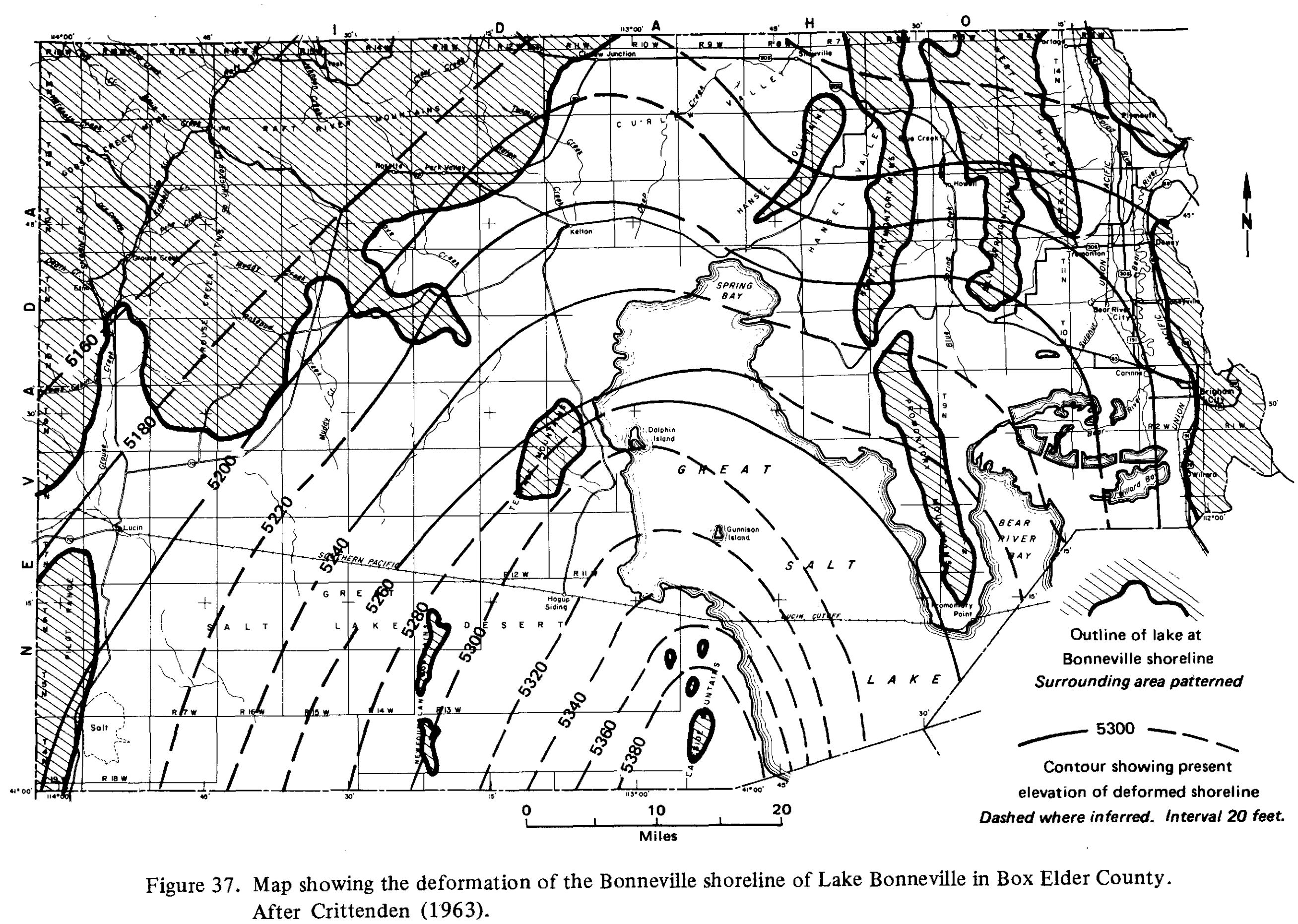


Figure 37. Map showing the deformation of the Bonneville shoreline of Lake Bonneville in Box Elder County. After Crittenden (1963).

parallel and transverse high angle faults. A similar structural situation persists into the southern part of the range, but Cambrian units appear under the Ordovician rocks in the upper plate of the thrust. Scattered small granodiorite bodies have intruded both lower and upper plate rocks. A few northeast trending fold axes alter the general eastward dip. The small mountainous masses and knolls to the east of the Pilot Range (Pigeon Mountain, Little Pigeon Mountains, Lion Mountain, Lemay Island and the Lucin Hills) are similar in their structural features; all have a general northerly strike, all exhibit easterly dips, and all are affected by a mosaic of high angle faults. Inasmuch as Permian rocks seem to overlie Devonian rocks directly, another thrust sheet is suggested above the Devonian.

Farther north the Rhyolite Mountains extend for 18 miles along the Nevada border and are separated from the Pilot Range by Tecoma Valley and Thousand Springs Wash. The northern limit of the Rhyolite Mountains is placed along White Rock Creek-Warm Creek. Except for some knolls and hills of mostly Permian rock at the southern end, most of the range exposes volcanic rocks and Tertiary sediments and tuffs. The Goose Creek Mountains trend northeasterly from the Nevada border north of White Rock Creek-Warm Creek to the Vipont Mountains, a distance of about 15 miles, and expose Permian, Triassic and Tertiary units. The older formations have been subjected to folding, thrusting, and faulting. The major trend of both faults and strata is north-south with moderate to steep dips to the east. The Tertiary sediments and tuffs are interlayered with rhyolite flows in some areas and are cut by north-trending normal faults and tilted.

The Grouse Creek Mountains (figure 38) are perhaps the most complex structurally. They trend north-south, but have been affected by folding, regional thrusting, dynamic metamorphism, intrusion, and faulting. The total length of the range is about 36 miles. The range bifurcates 22 miles north of its southern terminus into two thin ranges divided by a structural feature known as Junction Valley. The northwest arm is known as the Vipont Mountains and the northeast arm is known as the Dove Creek Mountains.

The Grouse Creek Mountains expose three allochthonous sheets that lie one above the other on an autochthon of Precambrian rocks. These basement rocks, consisting primarily of gneissic adamellite (and the Older Schist), are domed up. The lower allochthonous sheet contains Precambrian Z (?), Cambrian (?), and Ordovician units; the middle sheet contains Silurian to Lower Permian units, and the upper sheet contains Upper Permian and Triassic strata. The movement along these flat-lying thrust faults was west to east. All of the units are drastically reduced in thickness over the Precambrian dome. Parts of the section may have been sliced out by thrusting and part may have been removed by uplift and erosion. Silurian and Devonian rocks are entirely missing in the area of greatest doming and not found anywhere as slivers between the thrust sheets. Metamorphism and thrust faulting are believed to have occurred simultaneously, and it is thought that the movement along the two lower faults occurred at the same time. The uppermost sheet rocks exhibit no metamorphic changes whatsoever. Folding both preceded and was simultaneous with the thrust-faulting; strong recumbent folding may have initiated the low-angle faulting. Later the Grouse Creek Mountains strata were raised and tilted westward along a series of Basin and Range, north-northeast trending normal faults with a maximum of 5,000 feet of displacement. At least one of the thrust sheets is evident in the Matlin Mountains to the east.

The Raft River Range, about 25 miles long and with a maximum width of 10 miles, is an east-west trending doubly plunging anticline with an exposed core of Precambrian adamellite-intruded schists and quartzites. The arching and high angle faulting are thought to have occurred during Pliocene time since Miocene (Salt Lake Group) strata are deformed. Prior to that time the Raft River Range area experienced the same tectonic events that affected the Grouse Creek Mountains; folding, metamorphism, thrust faulting, and thinned or missing consolidated units. Remnants of the lower two allochthonous sheets remain and surround the core, dipping away from the anticlinal axis or with the plunge. Most of the thrust fault and metamorphic deformation is thought to have occurred during Miocene time.

Crater Island is about 8 or 9 miles in length and 4 to 5 miles wide. The major Basin and Range fault (s) is not demonstrable, but the abrupt rise of the mountain on the east side suggests its presence. The strike of the beds and of the major faults is roughly north-south with beds dipping gently to moderately westward. Local variations in strike and dip exist near the igneous bodies located near the south and north ends of the range. The dip of the exposed strata is generally to the west, and averages 11 degrees. The intrusions have been dated as Jurassic (W. J. Moore, 1975, personal communication), and intrude Ordovician and Upper Permian rocks. Thrust faulting has not been recognized, but rapid thinning and discontinuous units occur between Devonian and Missis-

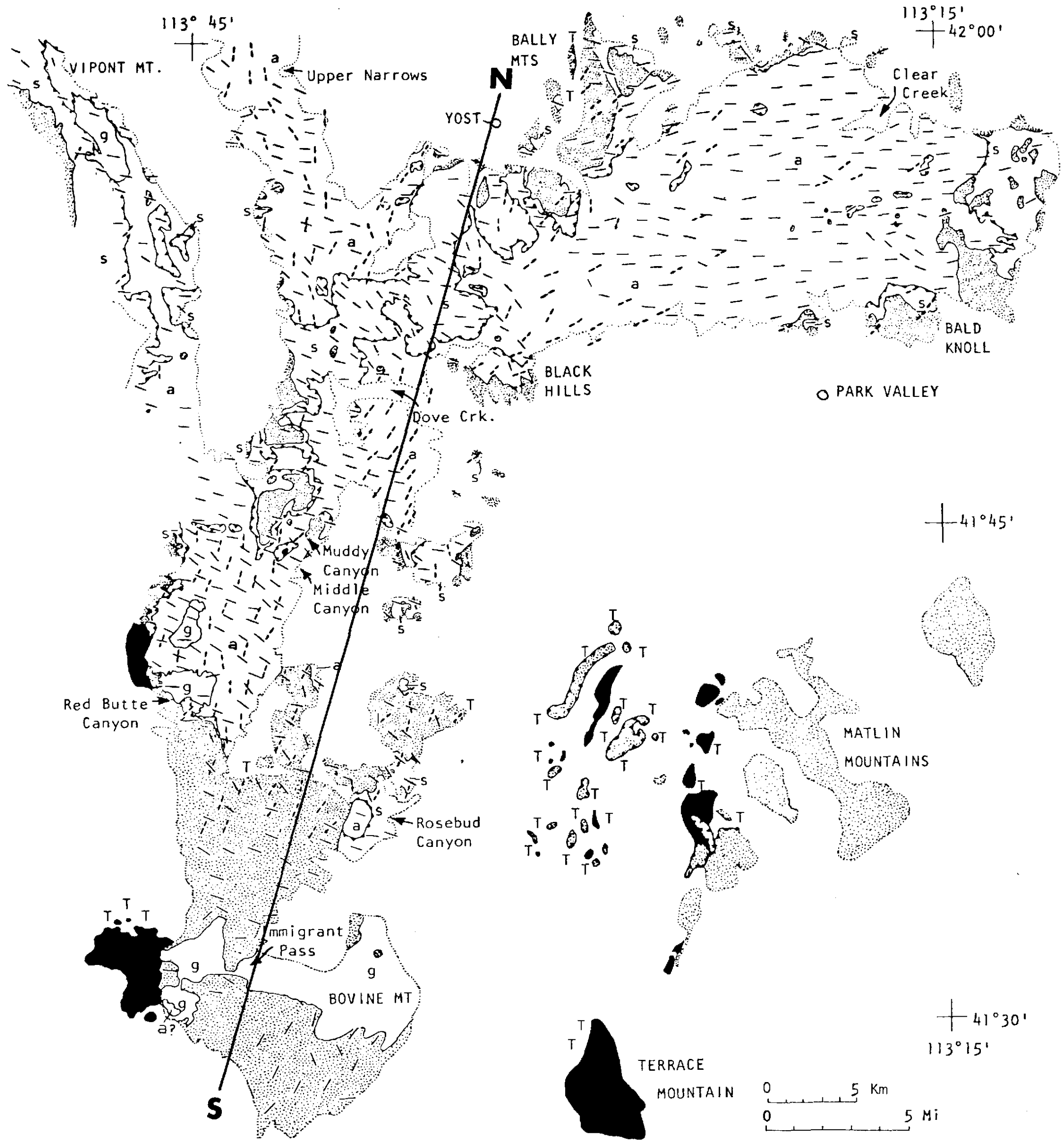
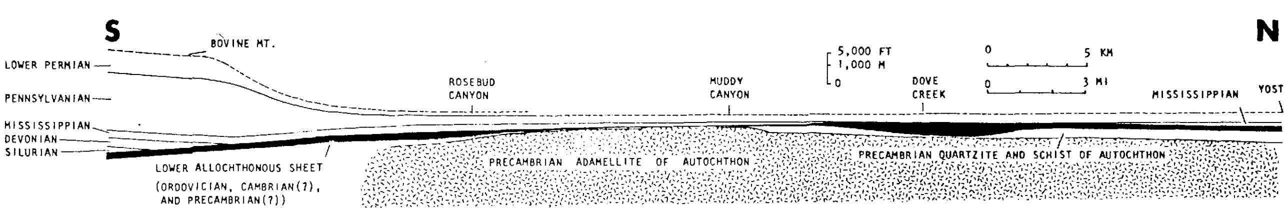


Figure 38. Structure map of Grouse Creek Mountains (north-south outcrop), Raft River Mountains (east-west outcrop), and vicinity. High-angle faults have been omitted. Black = upper allochthonous sheet; dots = middle sheet (and subsidiary sheets derived from it), s = lower sheet; a = autochthon; g = Tertiary granitic bodies. Dotted boundaries = depositional contacts with Cenzoic rocks; T = allochthonous sheets on Tertiary beds. Heavy dashes show axial trends of first metamorphic folds and lineations; thin unbroken lines show trends of second metamorphic folds and lineations.



Partly reconstructed north-south vertical section from west end of Raft River Mountains to south end of Grouse Creek Mountains, at natural scale, showing stratigraphic composition of middle allochthonous sheet. Lower sheet and units in autochthon are shown virtually as they are now, but units in middle sheet south of Rosebud Canyon have been reconstructed from greatly folded and faulted fragments. (Compton & Todd, 1978).

sippian rocks and between the Lower and Upper Permian strata. These positions match thrust faults recognized in the Grouse Creek Mountains.

The Newfoundland Mountains are about 18 miles long and average about three miles in width. The strike of the beds and major faults is generally north-south with dips moderately to steeply westward. There are many secondary east-west faults as well. These high angle faults are found with displacements ranging from a few feet to several hundred feet. It is assumed that there is a north-south trending Basin and Range fault on each side of the Newfoundland Mountains, the one with the larger displacement positioned on the east. Folding, other than tilting, is only locally evident and unimportant in this mountain range. There is no evidence that thrust faulting has occurred, but Mississippian and Pennsylvanian rocks are missing and Leonardian rocks (Lower Permian) unconformably? overlie Devonian strata. The Newfoundland quartz monzonite stock, intruded into Lower Paleozoic strata in the north end of the range, has not yet been dated. The stock has locally influenced the structure and metamorphosed adjacent rock.

The Grassy Mountains are about 24 miles long, about 8 miles lie within Box Elder County. The northern edges of the Grassy Mountains (figure 39) have rocks trending northwest and dipping southwesterly, but there are some anticlines and synclines parallel to the strike that reverse the dips locally. The dips, normally moderate in this part of the Grassy Mountains, in places are steep to overturned. The northern part of the range is separated into several ridges and knolls of more resistant rock. To the south it becomes evident that the rocks have been folded by compressional forces; high angle thrust faults that are subparallel to strike repeat or cut out strata and rocks are bent into paralleling anticlines and synclines. The strata are in places overturned. All of these structures end against the Lakeside Mountains to the east. One interpretation suggests that the Grassy Mountains represent imbricate fault slices of a low angle or horizontal fault at depth which ends at the North Lakeside fault (figure 39). Pennsylvanian and Permian rocks are exposed in the Grassy Mountains.

The Lakeside Mountains are an arcuate mountain mass, 30 miles in length, on the west shore of Great Salt Lake and east of the Grassy Mountains. The northern half is in Box Elder County; where the width ranges from 3 to 5 miles. South of the county line the range trends northwesterly and north of the line it trends northeasterly. The principal Basin and Range fault, the Lakeside fault, is on the west side of the range. The Box Elder County part of the range is divisible into two parts; a southern Sally Mountain block and a northern set of parallel ridges. Sally Mountain exposes Cambrian to Mississippian units that dip northwesterly 5 to 45 degrees. Transverse faults cut the strata at irregular intervals. The northern set of ridges represents repetitions of parts of the thick Great Blue Limestone and each ridge has its own west-side fault. A synclinal axis (Lakeside syncline) crosses the ridges diagonally 5 miles south of the Southern Pacific Railroad tracks and strikes east by northeast. Dips on both flanks are moderate (to 40 degrees). At the northern end of the range, Strongknob Mountain is a small knoll, north of the railroad tracks, exposing a faulted mass of Ordovician to Mississippian rock. In it are two sets of irregularly spaced faults; one trending about N. 10°E., the other trending N. 80°W. The major structural features of the Lakeside Mountains are influenced by a structural high centered in the south arm of the Great Salt Lake. Even the Basin and Range faults tend to parallel the margins of this dome.

The Terrace and Hogup Mountains are located north of the Grassy Mountains on the west shore of the north arm of Great Salt Lake. The north-south Terrace Mountains range consists of a central mass about 16 miles long and 10 miles wide and numerous knolls extending north and south. The strike of the exposed strata and principal structural features is north-south except in the north (Hogup Mountains) where the strike bends to the northeast. The exposed consolidated units, Pennsylvanian to Triassic in age, in most parts of the central mass dip moderately to the west (to 70°, most 20 to 30°). Near the west margin is the West Terrace synclinal axis, west of which the rocks dip easterly to 35 degrees. The younger Triassic rocks are exposed in this syncline. Closely spaced, smaller-amplitude anticlines and synclines found in local areas alter the general picture. The major north-south faults are more closely spaced to the west, adjacent to the West Terrace syncline. There are a few transverse faults, a few of which bend and become north-south trending features.

The eastern Matlin Mountains, west of the Terrace and Hogup Mountains, expose several knolls of Permian rock. The strike of the strata and accompanying major faults is roughly N. 45° W. and the dip is at all angles to the southwest.

The structure of the Promontory Range is characterized by abundant faulting; only locally has folding been intense or can thrust-faulting be demonstrated.

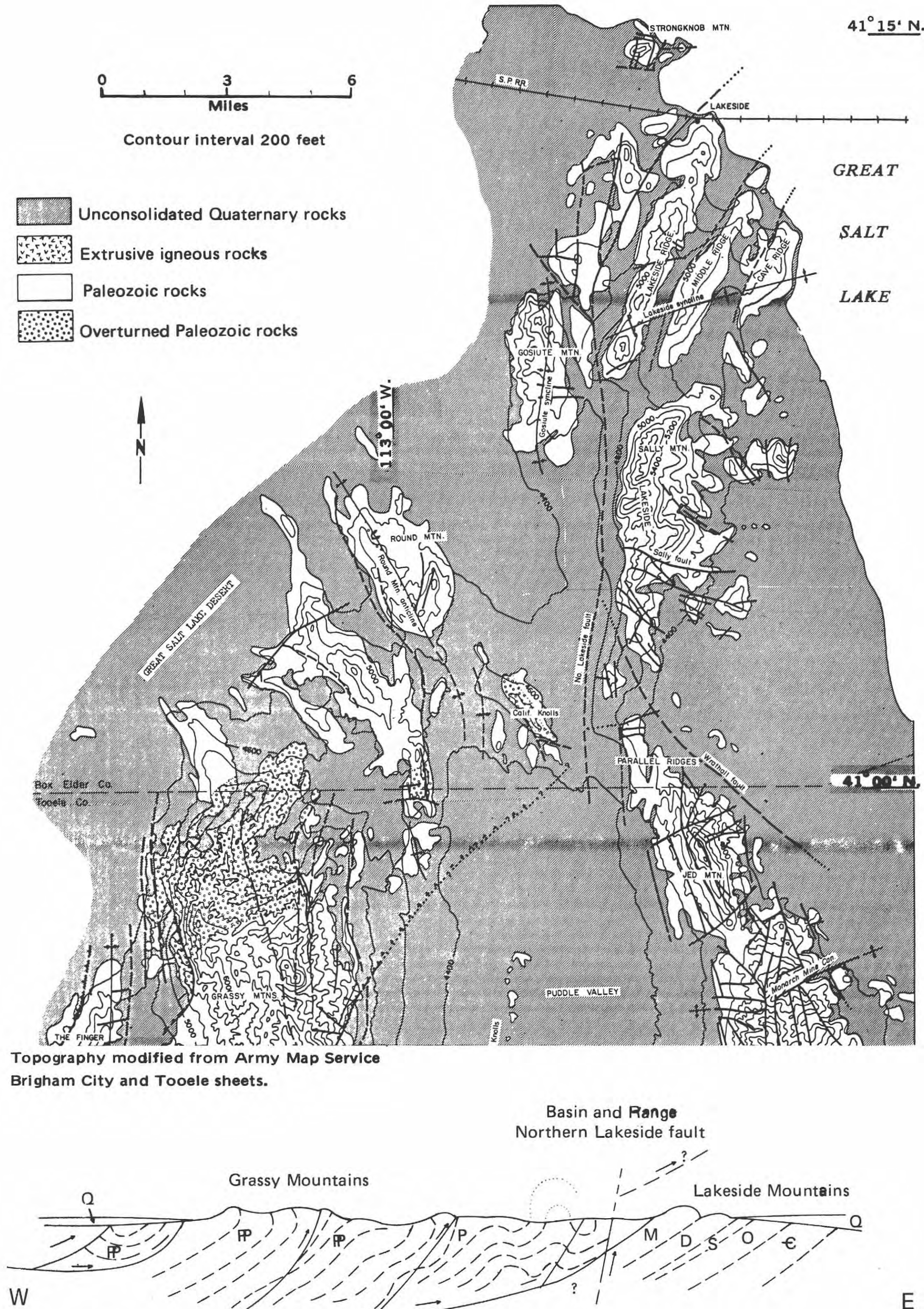


Figure 39. Interpreted structure across the Grassy Mountains at the Tooele-Box Elder line considering the possibility of a low-angle type thrust fault at depth.

Major faults are grouped into north-south and into east-west systems. The thirty-mile long, 4 to 5 mile wide range may be divided into a north structural block and a south structural block. In the southern block the principal faults trend east by northeast across the range and north-south Basin and Range faults are known from geophysical work on each side of the range. The smaller blocks between the faults are tilted to the northeast, exposing Precambrian to Mississippian rocks; the older units are exposed to the south and west. Dips are moderate to steep; in the northern structural block, north and east trending faults are more widely spaced. Pennsylvanian and Permian rocks are exposed. The small blocks between the faults are characterized by north-south folding in which the limbs dip gently. The structural regimen of the north block of the Promontory Range continues northward into the Summer Ranch (Hansel Mountains) and North Promontory Mountains.

The Summer Ranch Mountains, located south of Snowville, expose Manning Canyon (Mississippian) and Oquirrh Formation (Pennsylvanian) rocks, and are bounded on both sides by north-by-northeast trending Basin and Range faults. The warped beds generally dip to the east to an arcuate synclinal axis situated along the east margin of the range. Dips are mostly moderate and range to 45 degrees. The main mountain mass is to the north and is about 7 miles long and 3 to 4 miles wide. Several knolls and ridges extend to the southwest for an additional 10 miles.

The North Promontory Mountains trend north 25 miles from Promontory to the Idaho line. There is a major Basin and Range fault along the west side of the southern 15 miles, along which Pennsylvanian and Permian Oquirrh Formation rocks are exposed in a 2-to 3-mile wide band. A few transverse faults cut the range; Tertiary Salt Lake Formation strata are preserved along the downdropped sides. The Oquirrh Formation dips moderately to the east and the Salt Lake Formation dips gently to moderately toward the faults. To the north the range widens to 6 miles and the flanks are covered by Tertiary basalt flows.

The West Hills (north) and Blue Springs Hills (south) are contiguous mountain masses separated by Interstate Highway 80N. Both are dominated by Pennsylvanian and Permian exposures, but Ordovician to Mississippian rocks are exposed in the northeast part of the West Hills and Manning Canyon Formation outcrops are found along the west side of the Blue Springs Hills. Little Mountain is a large outlier knoll located south of the Blue Springs Hills and it exposes Devonian to Permian strata. Together the three mountain masses are about 25 miles long in Utah (they continue to the north in Idaho as Samaria Mountain) and are 4 to 12 miles in width. The Pennsylvanian and Permian rocks are deformed into many tight paralleling folds having north-south or north-northwest trends. The fold axes are difficult to trace and are limited in length. A principal Basin and Range fault is thought to be present on the east side of the West Hills as the rocks dip moderately to the west in the eastern parts of the range. One important interior fault, the North Canyon fault, extends northwesterly across the range from a few miles south of Portage into Idaho. It is a high angle fault with the downdropped block to the southwest and a displacement of 3,500 feet. The Ordovician to Mississippian rocks to the northeast strike northerly and dip moderately to the west. Other faults found in the West Hills are minor and have north-south or east-west trends. Less is known about the interior structure of the Blue Springs Hills, but some significant transverse faults have been mapped. A thrust fault is believed to break through within the mountain mass. The principal faults at Little Mountain are north-south and the Middle Paleozoic units dip toward the northeast.

The northern Wasatch Range, along with Wellsville and Clarkston Mountain, forms the east boundary of the county. The range is bound on the west side by a principal north-south Basin and Range fault, a part of the Wasatch fault system. The rocks of the mountains are tilted in homoclinal fashion and dip moderately to steeply eastward or northeastward. Irregularly spaced transverse faults cut the range, especially across Wellsville Mountain. Clarkston Mountain is that part of the Malad Range of Idaho that extends into Utah. The mountain is 7 miles long and 3 miles wide and the west slope is in Box Elder County. Upper Cambrian, Ordovician and Silurian rocks are exposed which dip moderately to the east and strike north-northwest. Numerous north-northwest trending faults that dip westward cut the mountain. Both reverse and normal faults are indicated. A 6-mile sag in the topography occurs between Clarkston Mountain and Wellsville Mountain where the Bear River flows from Cache to Box Elder County. A hilly divide joins the mountains and exposes Tertiary Salt Lake Group outcrops. Windows of Middle and Upper Paleozoic rocks protrude irregularly through the Tertiary strata. A larger exposure of the Laketown Dolomite (Silurian) in the canyon of the Bear River (Narrows Hill) strikes north and dips 30 to 35 degrees to the west, opposite to that in Clarkston Mountain and in Wellsville Mountain. Wellsville Mountain extends southward from the topographic sag to the canyon of Box

After U.S.G.S., index to topographic maps of Utah, November 1977.

5 0 5 10 15 MILES

(OM): ORTHOPHOTOMAP (TOPOGRAPHIC). MULTICOLOR, SHOWING PHOTOGRAPHIC IMAGERY WITH TOPOGRAPHIC MAP DETAIL.

(OM/T): A STANDARD TOPOGRAPHIC MAP AND AN ORTHOPHOTOMAP ARE BOTH AVAILABLE.

(68 PR): MAP PHOTOREVISED 1968 (REVISION NOT FIELD-CHECKED)

(S) FOLLOWING QUADRANGLE NAME INDICATES MAP IS ALSO AVAILABLE IN A SHADED RELIEF EDITION

ADVANCE SHEETS AVAILABLE IN BLACK AND WHITE EDITION ONLY

Figure 40. Status of U. S. Geological Survey topographic mapping in Box Elder County, December, 1976. Unmarked quadrangles are in preliminary form and as yet unpublished. Small quadrangles (7½ minute) are published at 1:24,000. Large quadrangles (15 minute) are published at 1:62,500.

Elder Creek (U. S. Highway 89 between Brigham City and Mantua). The trend of the mountain is north-northwest; the strata strike a little more northwesterly, exposing the older units to the south. Precambrian to Permian outcrops are found in a complete section dipping 30 to 50 degrees to the east. The strike and trends indicated in Wellsville Mountain continue southward, exposing older and older rocks. An important thrust fault (Willard thrust) strikes and dips nearly parallel with the beds. The overlying allochthonous sheet contains Precambrian Z units with Lower Paleozoic units appearing in order to the northeast. In the autochthon, Cambrian units of a different facies than those exposed in the allochthon unconformably overlie the Precambrian X Farmington Canyon Complex gneissic quartz monzonite. Again numberous paralleling faults with moderate westward dips are common along with high angle transverse faults.

STATUS OF TOPOGRAPHIC AND GEOLOGIC MAPPING IN BOX ELDER COUNTY, 1977

Topographic mapping by the U. S. Geological Survey will be completed when projects now in progress are finished. Box Elder County can be subdivided into 134 7½ minute quadrangles. There are 6 published 15-minute quadrangles in use in the northwestern part of the county (figure 40). Four are dated 1959, the other two are dated 1961. All but 8 of the 7½ minute quadrangles were published after 1964. The 8 are all located in the more populated southeast corner and the oldest 6 of these were completed in 1955. All of these were photo revised in 1969. Twenty-two maps remain to be published; these will all be produced as 7½ minute quadrangles and are all located in the south central part of the county in the Great Salt Lake Desert (figure 40).

The State Geologic Map covers the entire county at a scale of 1:250,000. Larger scale geologic mapping has primarily been done as part of university dissertations or for university field mapping course work. Perhaps 15 percent of the county geology mapped at scales greater than 1:250,000 has been published as U. S. Geological Survey maps. Most of the geologic mapping covers mountain range areas; valley and basin areas have generally been neglected. An updated county geologic map is provided as plates 1 and 2; the available mapping of figure 41 has been incorporated, and the remaining areas were cursorily mapped or modified from the State Geologic Map. Map references corresponding to the numbers of figure 41 follow:

MAP REFERENCES:

1. Adams, O. C., 1962, Geology of the Summer Ranch and North Promontory Mountains, Utah: Utah State University M. S. thesis.
2. Anderson, W. L., 1957, Geology of the northern Silver Island Mountains, Box Elder and Tooele Counties, Utah: University of Utah M. S. thesis.
3. Baker, W. H., 1959, Geologic setting and origin of the Grouse Creek pluton, Box Elder County, Utah: University of Utah Ph. D. dissertation.
4. Beus, S. S., 1958, Geology of the northern part of Wellsville Mountain, northern Wasatch Range, Utah: Utah State University M. S. thesis.
5. Beus, S. S., 1963, Geology of the central Blue Spring Hills, Utah-Idaho: University of California - Los Angeles Ph. D. dissertation.
6. Blue, D. M., 1960, Geology and ore deposits of the Lucin mining district, Box Elder County, Utah and Elko County, Nevada: University of Utah M. S. thesis.
7. Compton, R. R., 1972, Geologic map of the Yost quadrangle, Box Elder County, Utah and Cassia County, Idaho: U. S. Geological Survey Miscellaneous Geologic Investigations Map I-672.
8. Compton, R. R., 1975, Geologic map of the Park Valley quadrangle, Box Elder County, Utah, and Cassia County, Idaho: U. S. Geological Survey Miscellaneous Investigations Series, Map I-873.
9. Doelling, H. H., 1964, Geology of the northern Lakeside Mountains and the Grassy Mountains and vicinity, Tooele and Box Elder Counties, Utah: University of Utah Ph. D. dissertation.
10. Ezell, R. L., 1953, Geology of the Rendezvous Peak area, Cache and Box Elder Counties, Utah: Utah State University M. S. thesis.
11. Felix, Clarence, 1956, Geology of the eastern part of the Raft River Range, Utah: Utah Geological Society Guide Book 11, p. 76-97.
12. Gelnett, R. H., 1958, Geology of the southern part of Wellsville Mountain, Wasatch Range, Utah: Utah State University M. S. thesis.
13. Hanson, A. M., 1949, Geology of the southern Malad Range and vicinity in northern Utah: University of Wisconsin Ph. D. dissertation.
14. Howes, R. C., 1972, Geology of the Wildcat Hills, Utah: Utah State University M. S. thesis.
15. Mapel, W. J. and W. J. Hail Jr., 1959, Tertiary geology of the Goose Creek district, Cassia County, Idaho, Box Elder County, Utah, and Elko County, Nevada: U. S. Geological Survey Bulletin 1055H, p. 217-254.

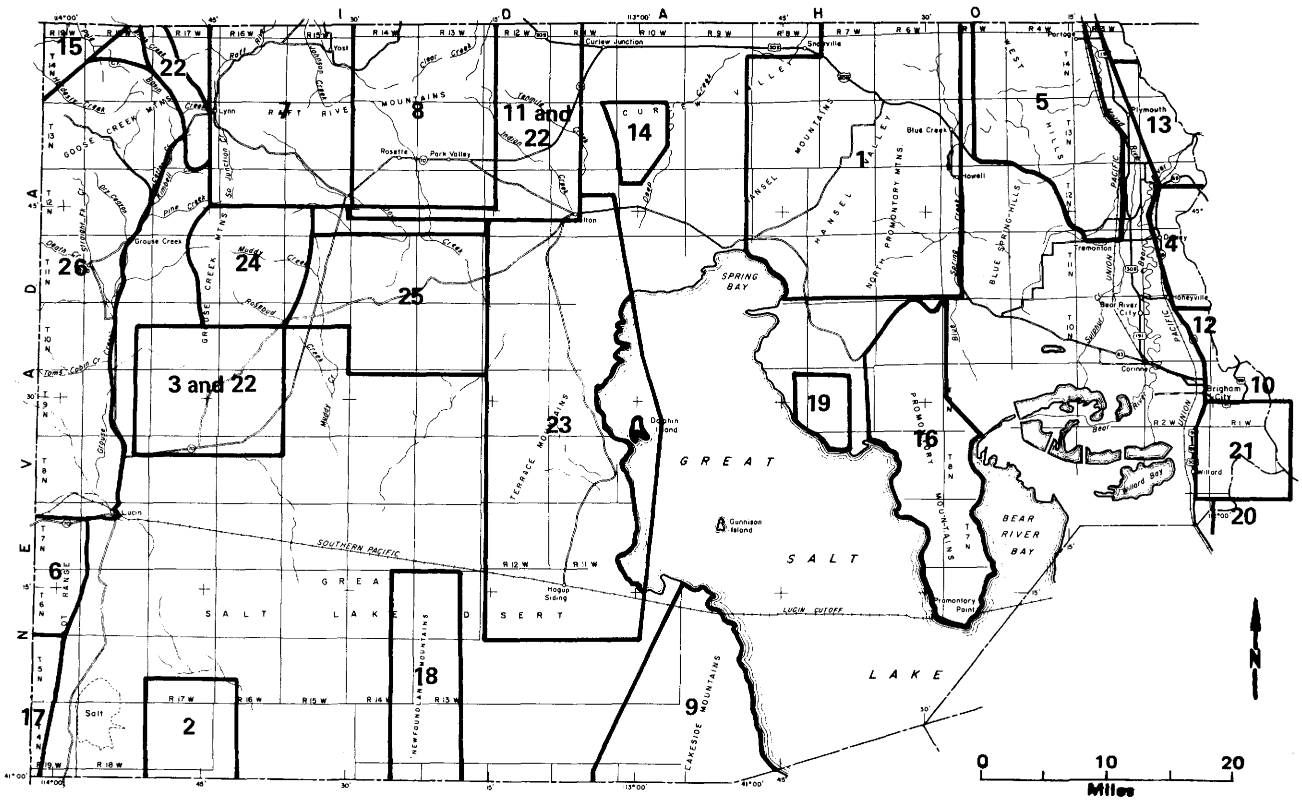


Figure 41. Index to geologic mapping in Box Elder County at scales greater than 1:250,000. Numbers correspond to map references in text.

16. Olson, R. H., 1960, Geology of the Promontory Range, Box Elder County, Utah: University of Utah Ph. D. dissertation.

17. Miller, D. M., 1979, U. S. Geological Survey, unpublished mapping.

18. Paddock, R. E., 1956, Geology of the Newfoundland Mountains, Box Elder County, Utah: University of Utah M. S. thesis.

19. Slentz, L. W. and A. J. Eardley, 1956, Geology of Rozel Hills: Utah Geological Society Guide Book 11, p. 32-40.

20. Sorensen, M. L. and M. D. Crittenden, Jr., 1972, Preliminary geologic map of part of the Wasatch Range near North Ogden, Utah: U. S. Geological Survey Miscellaneous Field Studies, Map MF-428.

21. Sorensen, M. L. and M. D. Crittenden, Jr., 1976, Preliminary geologic map of the Mantua quadrangle and part of the Willard quadrangle, Box Elder, Weber, and Cache Counties, Utah: U. S. Geological Survey Miscellaneous Field Studies, Map MF - 720.

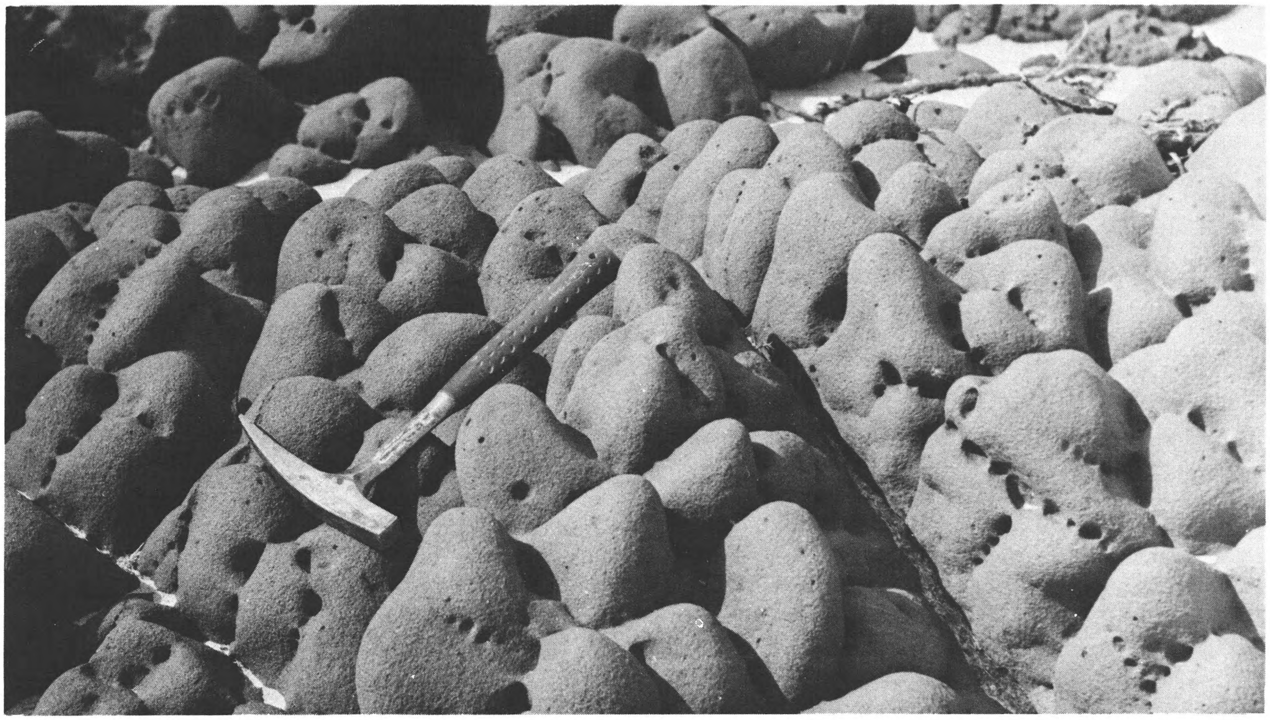
22. Stanford field classes (R. R. Compton), various years through 1976.

23. Stifel, P. B., 1964, Geology of the Terrace and Hogup Mountains, Box Elder County, Utah: University of Utah Ph. D. dissertation.

24. Todd, V. R., 1973, Structure and petrology of metamorphosed rocks in central Grouse Creek Mountains, Box Elder, County, Utah: Stanford University Ph. D. dissertation.

25. Todd, V. R., in progress 1978, Preliminary geologic maps of parts of the Russian Knoll, Runswick Wash, Warm Springs Hills, Prohibition Spring, Red Dome and Matlin quadrangles: U. S. Geological Survey.

26. Young, A. R., thesis in progress, 1978, Geology of the Goose Creek Mountains, Box Elder County, Utah: University of Utah.



P 27. Peculiar weathering habit of basalt along the shores of Great Salt Lake, Rozel Point area.

P 28. West side of North Promontory Mountains. Most mountain ranges are bounded on one or both sides by a north-south trending fault. A steep escarpment usually indicates the presence of such a fault.

Geology and Mineral Resources of Box Elder County, Utah

by Hellmut H. Doelling

with

Jock A. Campbell

J. Wallace Gwynn

Lee I. Perry

Part 2

Economic Geology

MINERAL RESOURCES

Construction materials, principally stone and sand and gravel, have provided almost 75 percent of the cumulative mineral value produced in Box Elder County through 1974. Their production remains important to the county's mineral output. Salts harvested from Great Salt Lake have provided 17.9 percent of the cumulative mineral value and their value percentage should continue to increase in the future. Metals production, which provided the principal values in many of the earlier years, amounts to only 6.9 percent of the cumulative mineral value. Although prospecting is active and some development work occasionally done, only tungsten has been produced since 1963.

The cumulative value of mineral production through 1974 as recorded by the U. S. Bureau of Mines Mineral Yearbooks amounts to 68.5 million dollars; supplemental publications and literature elevate the sum to at least 131.6 million dollars. In this study, mineral values are credited to the county in which the raw material was extracted. Recent pumping of brines from the north arm of Great Salt Lake, in Box Elder County, is credited by the U. S. Bureau of Mines to Weber County, where the processing plant is located. Similarly, Box Elder County is credited with lime production although the limestone is quarried in Cache County.

Figure 1 graphically illustrates the relative importance of the commodities produced in Box Elder County in percent and in millions of dollars. Table 1 lists the value of mineral production as recorded by the U. S. Bureau of Mines Mineral Yearbooks for the years 1951 to 1974. Almost half the cumulative mineral value was derived between 1956 and 1959 when the Southern Pacific Railroad causeway was constructed. This immense project used 43,750,000 cubic yards of rock fill, most of which came from the quarries on the Promontory peninsula. The maintenance of the railroad causeway continues to consume large quantities of construction materials annually.

The mines, quarries, pits and evaporation ponds in Box Elder County have produced riprap, railroad ballast, crushed stone, sand and gravel, road fill, decorative dimension stone, field stone, marble, soil conditioners, diatomaceous earth, animal food agglomerants, limestone, guano, bentonite, calcareous mud (for cement production), sheet mica, variscite, gypsum crystals, opalite, clay, salt, graphite (?), lignite, petroleum, uranium (?), iron for flux and paint pigments, gold, silver, copper, lead, zinc, molybdenum, tungsten, antimony, and bismuth. In addition its potential resources include titanium, rare earths, kyanite, barite, dolomite, silica, oolite flux, gypsite and salines.

METALS

The records for base and precious metals in Box Elder County are complete except for years when reported production was combined with that of other counties by the U. S. Bureau of Mines Mineral Yearbooks, and for the pre-1900 years. Other available literature has filled this gap considerably and was used in preparing table 2, but a breakdown of annual production prior to 1911 is impossible. No annual production records exist for tungsten and for the other base metals.

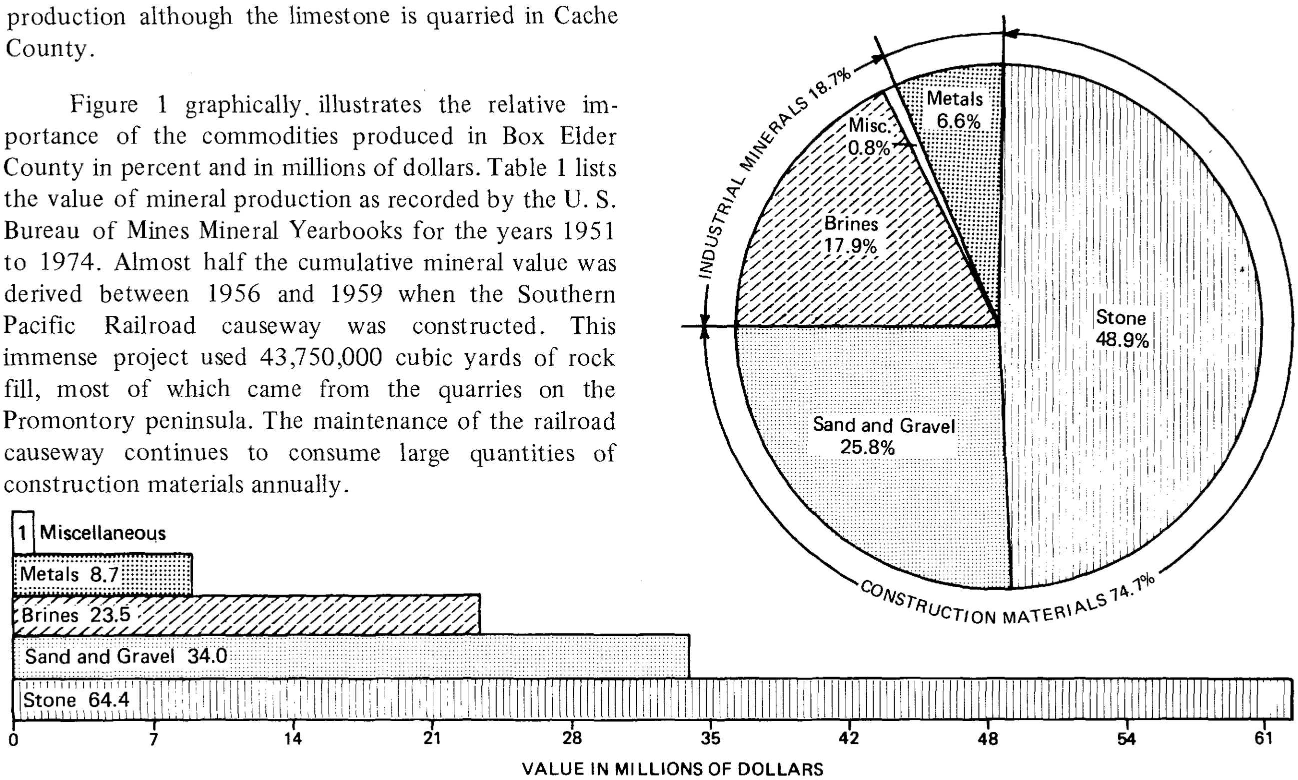


Figure 1. Values of the principal mineral commodities mined in Box Elder County through 1974

Table 1. Value of mineral production, Box Elder County, 1951-1974

Year	Commodity	Amount
1951	Stone, sand and gravel, lead, zinc, silver	$ 186,432
1952	Stone, sand and gravel, lead, zinc, silver	110,855
1953	Sand, and gravel, iron ore, stone, copper, tungsten, silver, gold	393,315
1954	Sand and gravel, tungsten	265,238
1955	Sand and gravel, stone, tungsten, copper, lead, silver, zinc, gold	180,725
1956	Sand and gravel, stone, tungsten, lead, zinc, silver, copper	775,421
1957	Sand and gravel, stone, salt, gem stones, copper	16,300,907
1958	Stone, sand and gravel, salt, gem stones, lead, zinc, mica, silver	21,055,170
1959	Stone, sand and gravel, salt, gem stones	2,352,060
1960	Sand and gravel, salt, gem stones	607,470
1961	Sand and gravel, lime, salt, zinc, lead, gem stones, silver, stone, gold	1,208,018
1962	Sand and gravel, stone, lime, salt, gem stones, silver, lead	1,124,742
1963	Sand and gravel, stone, lime, salt, lead, silver, gem stones, zinc, gold, copper	1,137,122
1964	Stone, sand and gravel, lime, salt, clay, petroleum	1,938,430
1965	Sand and gravel, lime, salt, stone	W
1966	Sand and gravel, stone, lime, salt, petroleum	1,243,578
1967	Sand and gravel, lime, salt, stone, petroleum	1,175,133
1968	Sand and gravel, lime, salt, stone	1,421,000
1969	Stone, sand and gravel, salt, lime, tungsten	2,910,000
1970	Sand and gravel, stone, lime	W
1971	Stone, sand and gravel, lime, salt	W
1972	Stone, sand and gravel, lime, salt	1,782,000
1973	Stone, lime, sand and gravel, salt	1,840,000
1974	Stone, lime, sand and gravel, salt, tungsten	1,975,000
	Total value listed	$59,982,616

NOTE 1. 1956-1959 were the years in which the Southern Pacific Railroad causeway across Great Salt Lake was constructed.

NOTE 2. Recent pumping of brines from the north arm of Great Salt Lake, in Box Elder County, is credited by the U. S. Bureau of Mines to Weber County, where the processing plant is located. Similarly, Box Elder County is credited with lime production although the limestone is quarried in Cache County.

The total recorded value of the produced precious and base metals has amounted to $8.6 million; at today's prices (1977) this metal would be valued at $37.4 million. Production of all metals except for tungsten ceased in 1963.

Box Elder County has four important metal mining districts, each leading in the production of one or two of the precious and base metals. Lucin, located along the Nevada border, is the most important district, having produced 99.5 percent of the copper and 74.6 percent of the lead from the county. The total value of its production is about $3.75 million. The Ashbrook district, located in the northwest corner of the county, has garnered most of its $3.35 million production by mining 92.4 percent of the county's silver. The Promontory district, near the southern end of the Promontory Range, has generated $0.9 million, mostly for zinc (90.3 percent) with significant amounts of lead (23 percent). Park Valley district, in the southwest part of the Raft River Range, produced $0.47 million in gold (72 percent). Other mining districts include Crater Island, Rosebud, Yost, Clear Creek, Newfoundland, Box Elder, Willard and Sierra Madre. Their locations and principal commodities are shown on figure 2.

Lucin Mining District

Valuable metal ore was first discovered at the north end of the Pilot Range in 1868 and in 1872 the Lucin district was named after a Central Pacific Railroad station immediately to the northeast of the Pilot Range. Mineral deposits have since been located from Patterson Pass to the north end of the range, but the major productive area has been around Regulator Canyon, located 6 to 7 miles south of the Southern Pacific Railroad tracks at the Nevada-Utah line. The district is almost entirely in Box Elder County, Utah, but a few mines open in adjacent Elko County, Nevada. The nearest towns of consequence are Montello, Nevada, 12 miles west, and Wendover, Utah, 36 miles south (figure 3).

Table 2. Production of gold, silver, copper, lead, and zinc from Box Elder County 1870-1963

Years	Gold Ounces	Silver Ounces	Copper Pounds	Lead Pounds	Zinc Pounds	Principal districts	Value
1870-1910	20,444.59	247,583	11,945,500	3,737,802	- - -	Lu, PV, Ash.	$2,647,505
1911	300.41	2,291	289,769	70,385	- - -	Lu, PV.	46,812
1912	133.71	3,372	845,253	85,734	- - -	Lu, PV.	148,163
1913	253.78	1,205	622,206	15,832	- - -	Lu, PV.	103,113
1914	19.83	3,259	205,473	21,827	- - -	Lu, PV.	30,391
1915	- - -	47	328,630	38,458	2,482,578	Lu, Pr.	367,182
1916	54.57	6,020	981,830	1,218,319	2,668,401	Lu, Pr, PV, NF.	688,248
1917	188.32	20,464	1,361,341	839,283	609,037	Lu, Pr, PV, Ash.	526,701
1918	116.10	21,009	885,407	375,645	455,673	Lu, Pr, PV, Ash.	310,242
1919	47.02	10,087	210,606	256,729	35,666	Lu, Pr, PV, Ash, NF.	67,653
1920	1,024.97	525,853	43,468	18,130	24,140	Lu, Ash.	605,771
1921	1,331.62	716,809	1,938	7,306	- - -	Lu, Ash.	744,915
1922	2,976.03	1,043,671	28,735	310,310	411,476	Lu, Ash.	1,144,091
1923	1,967.99	776,326	30,579	181,941	- - -	Lu, Ash, Ro	694,500
1924	15.57	542	67	13,165	- - -	Lu, Ash, PV	1,747
1925	57.71	12,374	8,312	27,075	- - -	Lu, Ash, Pr.	13,317
1926	62.52	6,683	16,550	13,317	- - -	Lu, Ash.	8,844
1927	0.68	52	11,320	19,292	- - -	Lu, Ash, Pr, NF.	2,741
1928	- - -	67	85	31,385	- - -	Pr, NF, CC.	1,871
1929	- - -	88	20,205	8,238	- - -	Lu, NF, SM.	4,122
1930	15.00	179	24,008	5,960	- - -	Lu, PV.	3,798
1931	13.01	16	- - -	- - -	- - -	Lu, PV.	273
1932	275.11	124	3,697	4,265	- - -	Lu, PV, RR, CC.	6,083
1933	68.64	143	137	8,547	- - -	Lu, PV.	1,794
1934	81.89	14,765	1,263	15,513	- - -	Lu, PV, Ash, CI, Wi.	13,082
1935	313.40	64,946	422	4,200	- - -	Lu, PV. Ash.	57,852
1936	229.60	71,082	2,663	2,391	- - -	Ash, PV.	63,444
1937	142.00	42,958	380	6,017	- - -	Ash, PV.	38,599
1938	33.00	3,182	102	15,913	- - -	Lu, PV, Ash, GC.	3,954
1939	31.00	8,667	298	511	- - -	Ash, CI, PV.	7,023
1940	73.00	25,266	2,000	25,000	15,000	Lu, Ash, CI.	22,943
1941	60.00	10,762	900	2,000	- - -	Ash.	9,973
1942	3.00	45	1,000	17,300	16,000	Pr. CI.	2,905
1943	6.00	450	3,000	109,800	119,000	Lu, Pr, CI.	22,007
1944	12.00	855	25,000	90,200	107,500	Lu, Pr, CI.	23,874
1945	11.00	225	28,000	89,500	155,000	Lu, Pr. CI.	29,847
1946	29.00	229	26,500	68,000	90,000	Lu, Pr, CI, PV.	23,885
1947	39.00	390	42,700	18,500	29,800	Lu, Pr, CI, SM.	16,955
1948	3.00	843	89,700	42,500	- - -	Lu, CI.	27,940
1949	1.00	264	100	12,500	- - -	Lu	2,269
1950	- - -	32	23,100	- - -	- - -	Lu	4,834
1951	- - -	52	35,700	- - -	- - -	Lu	8,686
1952	- - -	22	- - -	18,000	14,000	Pr.	5,242
1953	1.00	76	26,000	- - -	- - -	Lu.	7,564
1954			no production				
1955	2.00	466	20,000	6,000	2,000	Lu, Ash.	9,092
1956	- - -	72	100	600	500	Lu.	270
1957	- - -	- - -	1,800	- - -	- - -	Lu.	542
1958	7.00	1,164	- - -	2,000	410	?	1,515
1959-1960			no production				
1961	1.00	515	- - -	22,000	46,000	Lu, CC.	8,033
1962	- - -	21	- - -	90	- - -	CC.	32
1963	2.00	699	100	21,600	1,800	Lu.	3,413
		no production after 1963					
Totals:	30,453.07	3,646,312	18,195,944	7,911,580	7,283,981		$8,581,980

*District Initials:

Lu.	Lucin	Pr.	Promontory	NF.	Newfoundland	CI.	Crater Island
PV.	Park Valley	RR.	Raft River	Ro.	Rosebud	Wi.	Willard
Ash.	Ashbrook	GC	Grouse Creek	CC.	Clear Creek	SM	Sierra Madre

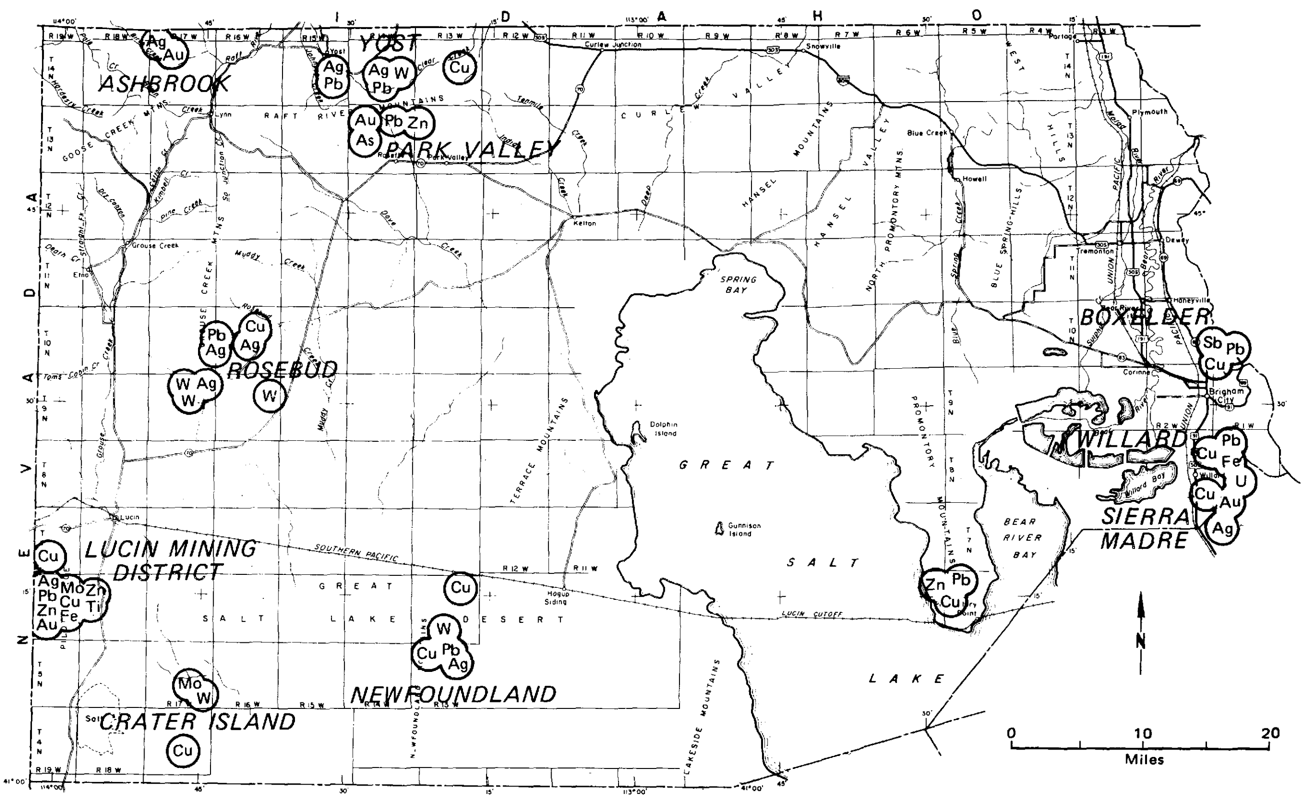


Figure 2. Metals mineralization localities

The principal metals of the Lucin district are copper, lead, silver, zinc and iron. A small amount of gold and perhaps molybdenum has also been produced. Production records are incomplete, but data collected from U. S. Bureau of Mines and U. S. Geological Survey publications indicate that a minimum of $3.75 million worth of metal was recovered. The actual figure is probably between 3.8 and 4.5 million dollars. Mining activity was strong in the district until 1920; it has been intermittent from then until the final shipments of ore were made in the early 1960's. Since 1920 bursts of activity occurred especially during World War II. Recorded production of copper has been 18.2 million pounds, lead 5.9 million pounds, zinc 0.6 million pounds, silver 260,000 fine ounces, gold 670 fine ounces and at least 10,000 tons of low-grade iron ore.

The ore deposits appear to be replacements and fracture fillings in limestone and dolomite of Ordovician, Silurian, and Devonian age. The replacements are usually located along faults and pipes formed by the intersections of faults and fractures. A large body of monzonite crops out east of the deposits and a smaller body crops out one-half mile north of Regulator Canyon on the west side of the Pilot Range. These igneous bodies may have been responsible for the mineralization, but only non-commercial metal occcurrences have been found adjacent to the contacts. Mineralogically the deposits are of two types, those dominating in copper minerals and those dominating in lead, silver, and zinc.

The principal copper mineralization is at Copper Mountain which stands at the head of Regulator Canyon on the crest of the Pilot Range. The ore bodies are in the Devonian Guilmette Formation and follow a pair of north-south trending faults. The richer bodies appear to have been pockets of native copper, cuprite, chalcopyrite surrounded by chrysocolla, complex copper clay minerals, copper pitch, malachite and azurite. The ore bodies are enveloped in a thick gossan of goethite, limonite, and hematite. Minute quantities of lead, silver, and zinc minerals were noted in the ore. The copper mineralization appears confined to the upper one-third of Copper Mountain; tunnels driven to intersect the ore bodies below the upper workings discovered little copper but intersected occasional lead-silver-zinc bodies.

Lead-silver-zinc ore bodies dominate in most of the remainder of the district. The principal lead-silver-zinc production has come from Tecoma Hill, an east-

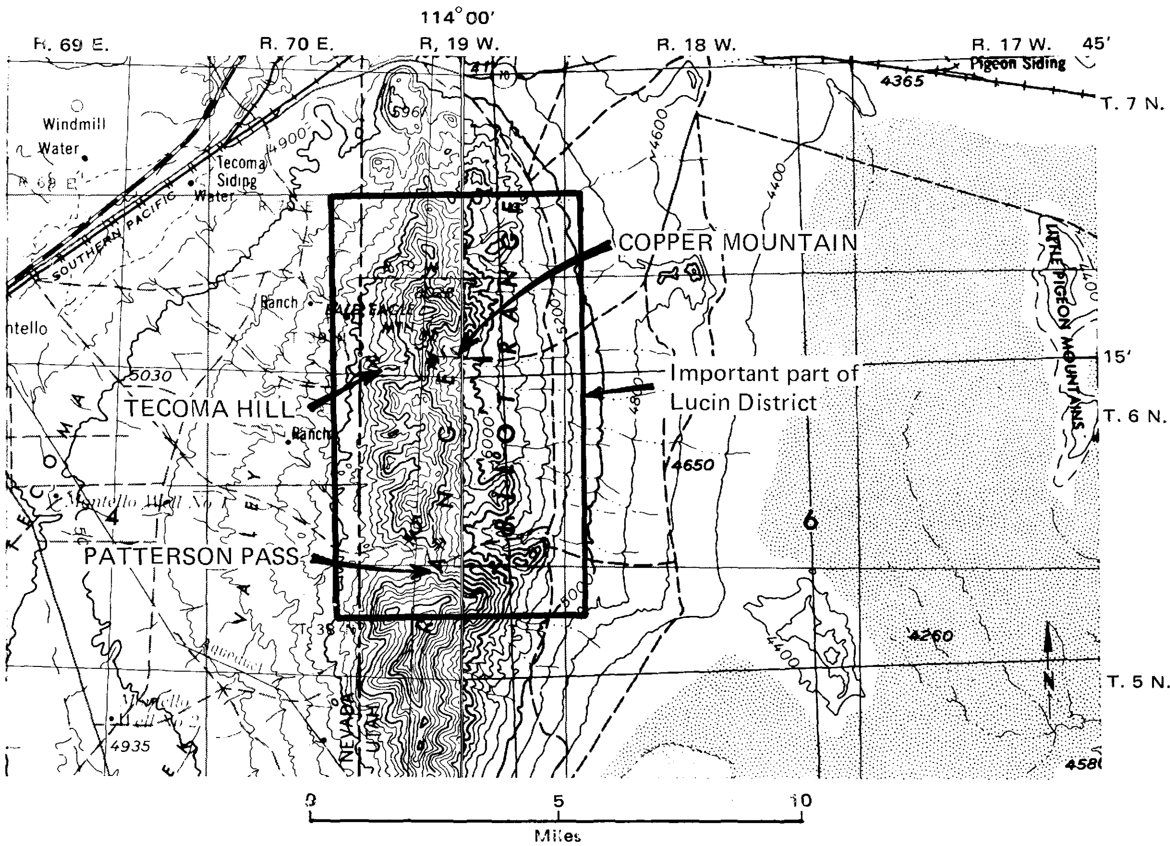


Figure 3. Location map of Lucin mining district

west-trending ridge immediately north of Regulator Canyon. The principal deposits are in the Ordovician Fish Haven Dolomite, but significant ore has also been found in the Silurian Laketown Dolomite and in the Devonian Guilmette Formation. Minerals include smithsonite, hemimorphite, cerussite, plumbojarosite, goethite, limonite, hematite; and in lesser quantities, limonitic anglesite, wulfenite, barite, pyrite, galena, sphalerite, and native silver.

The Tecoma Hill and Copper Mountain workings have provided at least 90 percent of the district's production. These are located on a badly faulted horst with boundary faults that trend west by northwest and cut across the range at right angles. In 1972 a drilling program placed two holes along the strike of the Copper Mountain faults to the south of the principal ore bodies hoping to locate extensions of the ore bodies. One hole was placed in the northwest corner of 22-6N-19W and another in NWNESW of 22-6N-19W. The first hole was drilled to a depth of 905 feet and the second to a depth of 1,072 feet. The wells were spudded in Pennsylvanian rocks which were suspected of unconformably overlying the ore-bearing Devonian Guilmette Formation, but the drilling passed directly through the Pennsylvanian into unmineralized monzonite and the program was abandoned.

Available records indicate that extremely rich copper, lead, and zinc ore was sent to smelters in the early days. Silver ore containing as much as 140 ounces per ton was shipped in carload lots. By 1920 nearly 90 percent of the total metal produced to date had been shipped. All of the known high-grade ore has been mined, but considerable tonnages of low-grade copper and lead-silver-zinc still remain in the old workings. The amount of this reserve is unknown, but on part of Copper Mountain over 80,000 tons of low-grade copper ore have been blocked out. The copper content of this block averages 1-4 percent and consists of oxide copper minerals that require complex beneficiation.

The ore bodies generally were roughly tabular and followed a favorable bed of limestone, or a fault. The ore zone rarely exceeded a width of 4 to 6 feet and a length of 50 feet. In the best mines (Tecoma Hill and

Copper Mountain) the lengths extended to several hundred feet and thicknesses were found to a few tens of feet. Presently there are no active mines or prospects in the district but many claims are being maintained and development work continues on an intermittent basis in most of the better mines and prospects. Cursory examinations were made of many of the workings and the available literature was studied to produce the following inventory.

Parkdale Claims

The Parkdale claims are located on a ridge south of Patterson Pass in the center of 3-5N-19W. The workings consist of three pits along a 10-foot wide quartz vein in Cambrian or Precambrian mica schist. Mineralization consists of chrysocolla in the quartz. The trend of the vein is north-northwest in rocks described as olive green to black slate and phyllite that locally grade to mica schist. It is doubtful that there has been any production (figure 4).

North Side of Patterson Pass Canyon Mines, and Prospects (Lead-silver-zinc)

The mines and pits on the north side of the canyon can be divided into two groups: upper workings above the 7,000-foot level and lower workings on the south-facing wall of the canyon. All are located in 33-6N-19W, but the upper workings are in the N ½ NWNE of the section. A plan of the workings is given on figure 5. Essentially there is a master mine trending northeasterly along an ore zone that follows a bedding plane. In addition to the main adit there are two other openings, an incline and a shaft; the incline follows the mineralized bedding plane.

The host rock is dark crystalline limestone in the Devonian Guilmette Formation. The mine follows the most intensive of several horizons that have mineral shows. Mineralization consists of masses of limonite in which pockets or tabular bodies of oxide lead and zinc minerals, cerussite, anglesite and hemimorphite can be identified. No sulfides were noted, but small quantities may have been present in the now mined-out ore bodies. It is assumed that silver was locally abundant, as it was in the better known mines of the district. The mineralization weakens at the deeper end of the mine along the main level, but it is evident that there has been a modest production. Additional ore may possibly be found down-dip from the main area of mineralization.

A pit with limonite mineralization is present between the upper and lower workings along the dugway road that joins the two and is located near the crest of a divide that separates Patterson Pass Canyon from a westward draining gulch to the north.

The lower workings consist of a master mine and other scattered developments and are found in the SWNE of Section 33 with the exception of a short adit in the SENE of Section 33. In this area the Guilmette Formation strikes east of north and dips southeasterly 30 to 45 degrees. The master mine consists of 1800 feet of drifting of which only 600 feet appear to be mineralized. One area of mineralization is located 500 feet from the portal and is 200 feet long. Another is at the far end of the mine where goethite and cerussite have been identified. Calcite, cerussite and galena were noted on the dump. A small amount of ore was probably produced from this mine (figure 6).

Most of the minor diggings of the lower group are located 500 feet west of the master mine. There are at least three shallow pits and two short adits. Again a bedding plane is limonitized; the limestone host is black to medium-gray and brecciated in part. No metalliferous oxides were noted on the dumps but the gossan showed boxworks and numerous cavities. Little if any ore came from the workings. An additional adit is located 600 feet east of the master mine. The opening is caved; the dump indicates the adit was cut in tan to brown quartzite, moderately stained with limonite. This is the middle massive quartzite member of the Guilmette Formation (figure 7).

Mouth of Patterson Pass Canyon Mines and Prospects (Lead-silver-zinc)

A spur of the mountain made up of Silurian Laketown Dolomite extends westward on the north side of Patterson Pass Canyon. The foundations of auxiliary buildings for some of the mines and remnants of ore piles are noted at about the state-line along the road. It is assumed that this was a loading point for ore from all mines in the canyon and specifically for those on the north side of the projecting spur (figure 7). There are several shallow pits in gossanized limestone on this spur; the main workings consist of a caved adit with a glory hole above it. The dumps are of modest size, indicating that some ore was realized.

Hogans Alley Mines (Lead-silver-zinc)

The principal workings in Hogans Alley Canyon

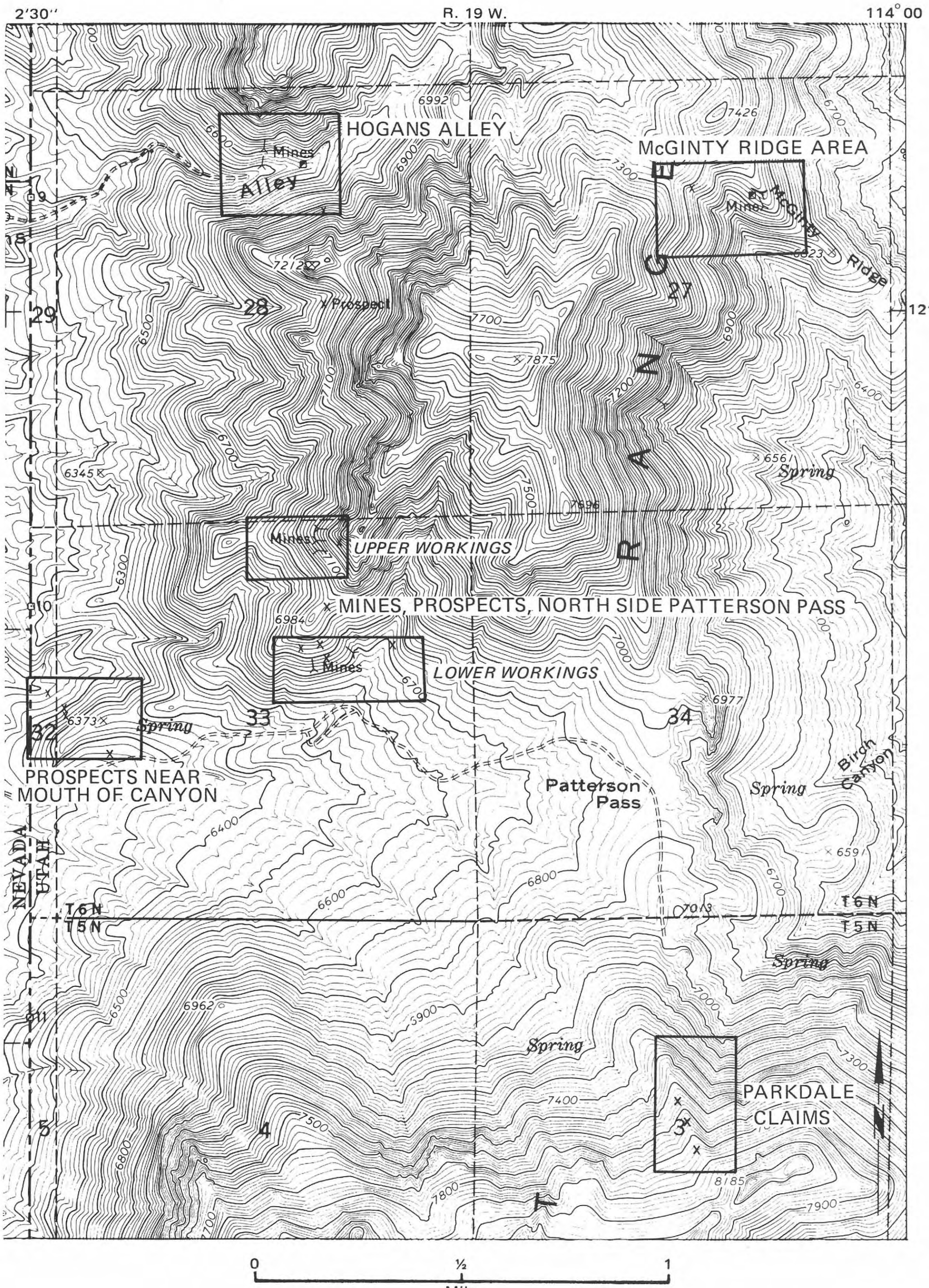
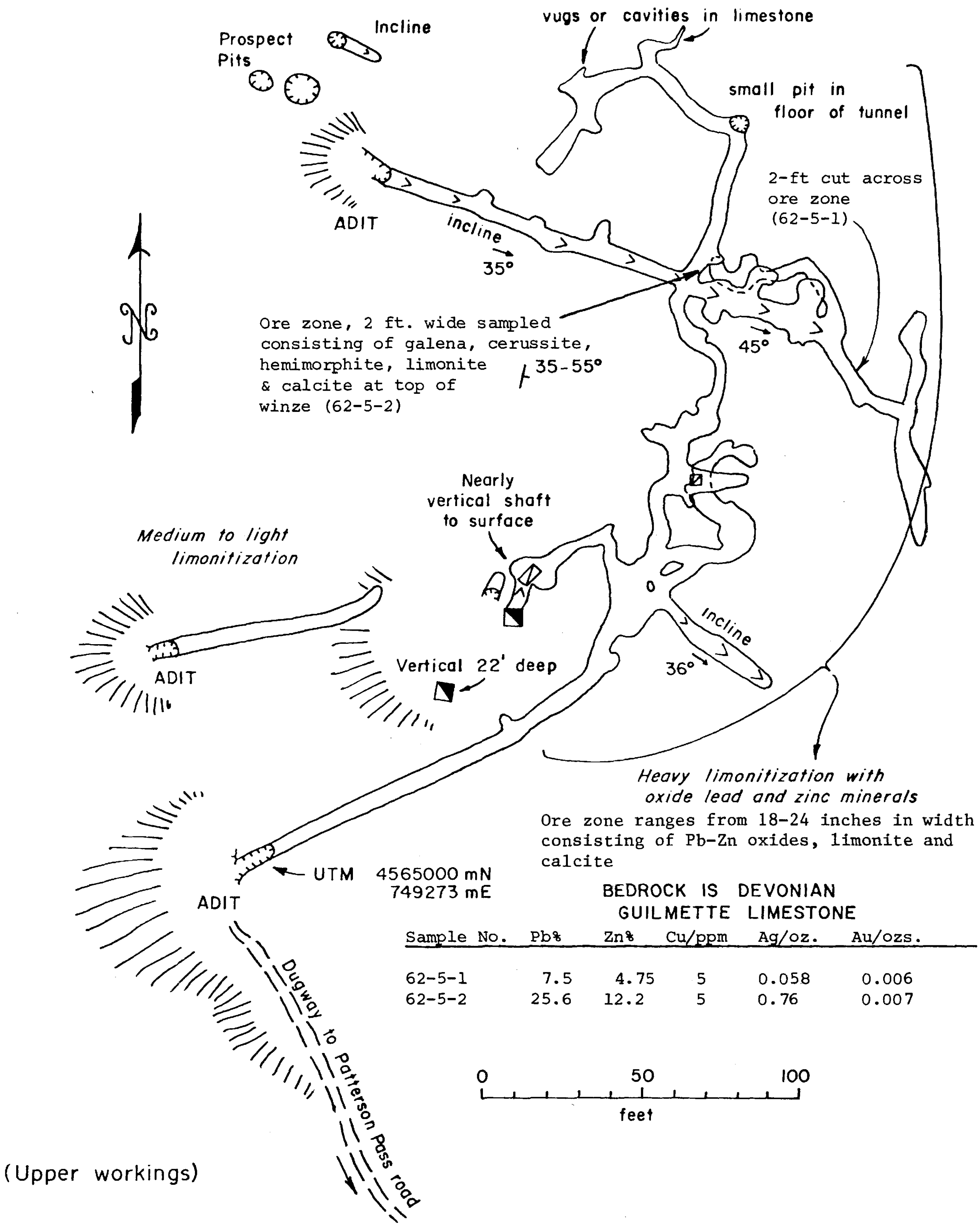
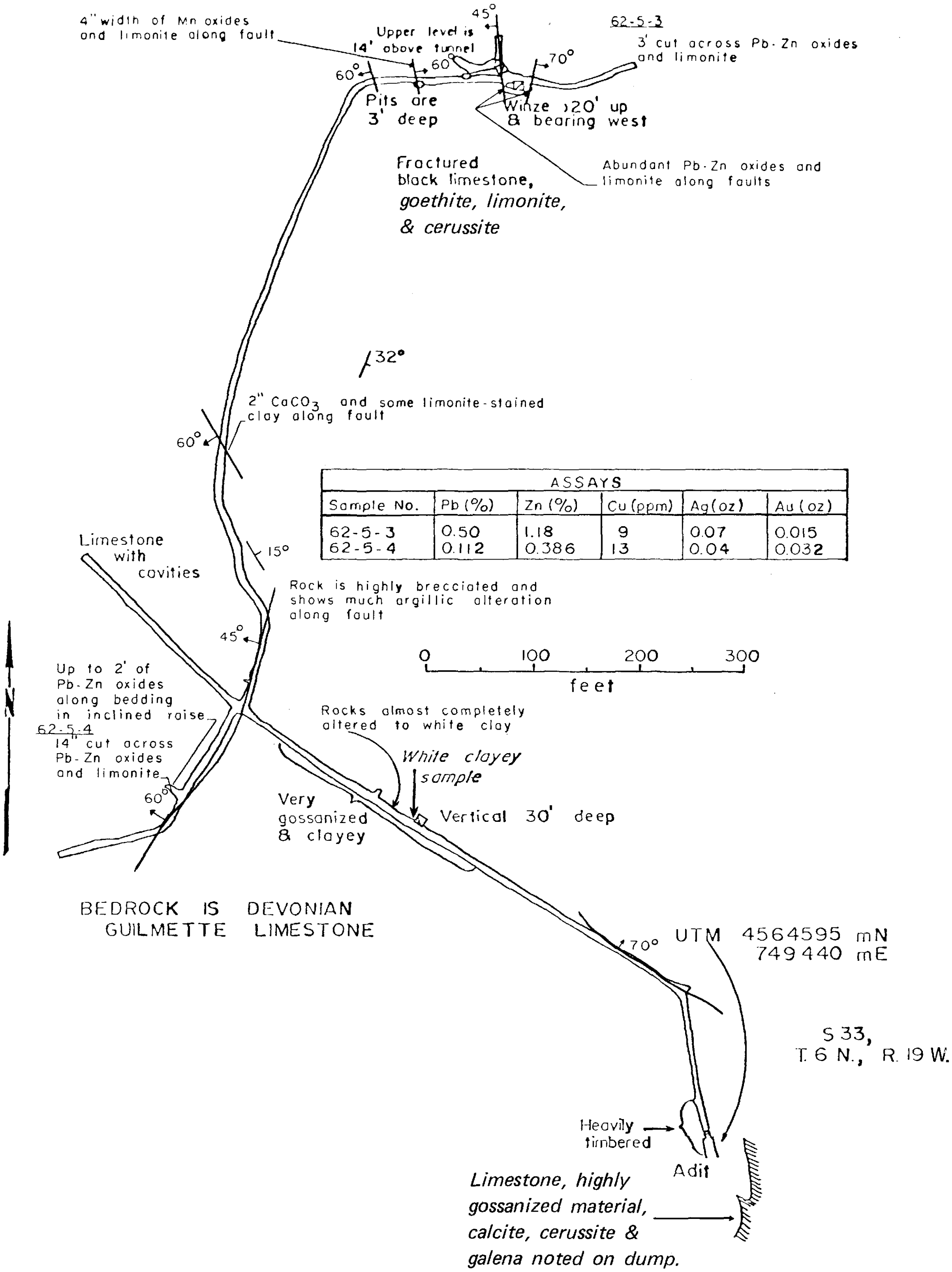


Figure 4. Mines and prospects in the vicinity of Patterson Pass, Lucin mining district.



Sample No.	Pb%	Zn%	Cu/ppm	Ag/oz.	Au/ozs.
62-5-1	7.5	4.75	5	0.058	0.006
62-5-2	25.6	12.2	5	0.76	0.007

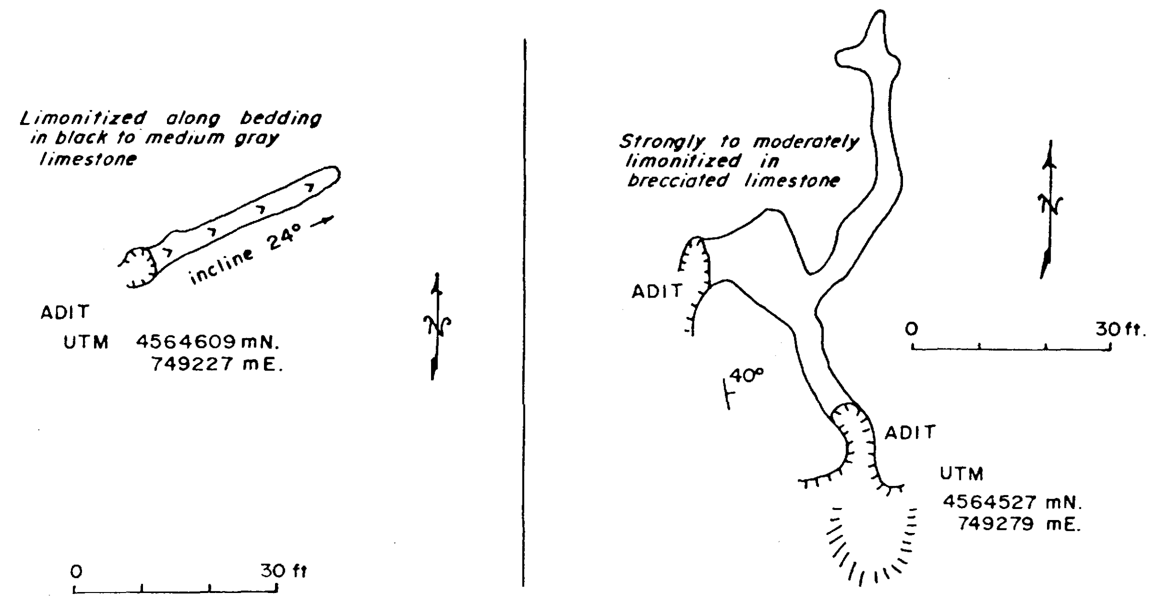
Figure 5. Mines and prospects north side Patterson Pass.



ASSAYS

Sample No.	Pb (%)	Zn (%)	Cu (ppm)	Ag (oz)	Au (oz)
62-5-3	0.50	1.18	9	0.07	0.015
62-5-4	0.112	0.386	13	0.04	0.032

Figure 6. Mines and prospects north side Patterson Pass (lower workings).



Small workings, 500 to 600 feet west of main mine, north side of Patterson Pass Canyon.

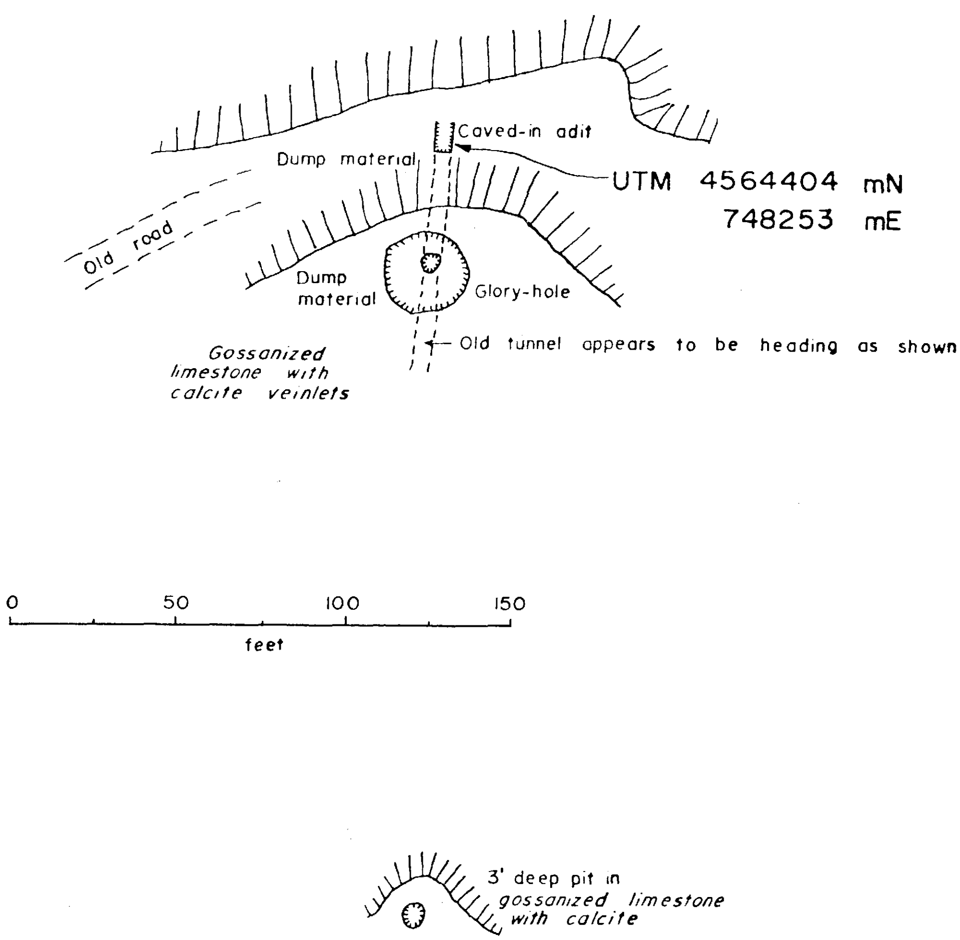


Figure 7. Mines and prospects near mouth of Patterson Pass canyon.

consist of two adits and a shaft. The upper working ("Wheelbarrow Tunnel") on the north wall of the canyon is the most heavily mineralized; remnant oxide minerals of lead and zinc remain on the wall along its approximately 175-foot length. A sample gouged from the wall of the mine yielded a trace of gold, 0.9 ounces silver per ton, 9.2 percent lead and 7.5 percent zinc, and no copper. The lower adit was dug to intersect the mineralized bed which seemingly projects downward along the bedding, but at the calculated position the bed was not mineralized. The developmental adit is "active" (1974) and work continues intermittently in search of the vein. According to the owner, analyses of core drilled from the deeper parts of the workings showed good percentages of lead-silver-zinc. The drill intersected stringers of mineralized rock. Mineralization follows the bedding plane in the upper "Wheelbarrow Tunnel" workings, and cuts vertically across fracture zones. The strike of the beds in the "Wheelbarrow Tunnel" roughly follows the adit and the dip is about 50 degrees easterly. Five hundred feet to the east in the canyon bottom is a 30-foot shaft in very rusty limestone. Several small pits are located on the north side of the canyon, several thousand feet to the east. Above the 30-foot shaft on the south side of the canyon is a 3 x 5-foot pit 3 feet deep cut in limonitized, light gray limestone. High on the west-facing slope of the mountain (elevation 7,100 feet), south of the canyon and shaft, is a small adit 10-20 feet long in limonite-stained limestone. It trends southeasterly and is partly caved (figure 8).

McGinty Ridge Prospects (Copper)

McGinty Ridge is in 27-6N-19W on the east side of the Pilot Range not far from the crest. The geology is mapped as Diamond Peak Conglomerate in fault contact with the Guilmette Formation. Not far removed are monzonite and igneous dike outcrops. There are three workings; an incline, a short adit and a collapsed adit. All are located along an east-west line paralleling the fault. The workings are small and the best mineral show is at the incline; chrysocolla, brochantite, copper pitch, manganese stains, limonite, hematite, and bornite-chalcopyrite stains are observable on the dump (figures 9 and 10).

South of McGinty Ridge on the east-facing slope of the mountain in the Guilmette Formation and in the south half of the section are at least two minor lead-silver-zinc prospects in gossanized limestone. One is a 3-foot and the other a 10-foot adit. No production is thought to have come from any of them.

Cook Canyon Prospects (Lead-Silver-Zinc)

There is an incline between Hogans Alley and Cook Canyon in SW21-6N-19W (UTM 4567143 mN, 748810 mE) which measures 5 x 5 x 12 feet and dips 45 degrees to the east. The dump shows rusty limestone and calcite. A small prospect pit (2 x 2 x 2 feet) is about 15 feet to the north and 2 small pits each about 3 x 3 x 3 feet are 50 feet to the south. A small incline about 4 feet wide and 18 feet deep, trending southeast at 30 degrees, is found on the south side of Cook Canyon. The dump shows rusty limestone (UTM 4567500 mN, 748607 mE). A small pit measuring 4 x 6 x 6 feet is located 100 feet farther north.

The main working in Cook Canyon is 150 feet north of the stream bed (figure 9). It consists of a cut and an adit 50 feet long with two shafts. The first shaft, near the portal, is about 25 feet deep. The second, in the adit, is more than 100 feet deep. Large masses of calcite are observable in the mine; mineralization is mainly limonite and hematite. All of the Cook Canyon workings are cut in the Guilmette Formation, presumably for lead, silver and zinc. A small amount of ore may have been produced from the shafts.

Box Canyon Prospects (Lead-Silver-Zinc)

These prospects are located north of Box Canyon proper in the next paralleling gulch (figures 9 and 10). The mineralization is similar to that found in Cook Canyon and Hogans Alley. Slightly to the north, but between these two workings, are three rusty pits, the largest of which is 6 x 6 x 4 feet deep.

Mineral Mountain Mines and Prospects (Lead-Silver-Zinc)

Several mines and prospects in the Mineral Mountain area are located on the north-facing slope of Regulator Canyon (figures 11 to 14). The mines are cut in the Silurian Laketown Dolomite and all have similar mineralization. Rusty zones follow bedding planes and fracture zones and are more pronounced at the intersections of two of such features. Natural cave openings and vugs are favorable areas for mineralization. No sulfide minerals were seen at any of the mines, but sparse hemimorphite, cerussite, anglesite and smithsonite were identifiable in heavily limonitized zones.

Prospects and mines Nos. 1 to 4 (figure 12) are high on the hill. Mine No. 1 is the most interesting, bearing heavy limonitization, and may have produced a

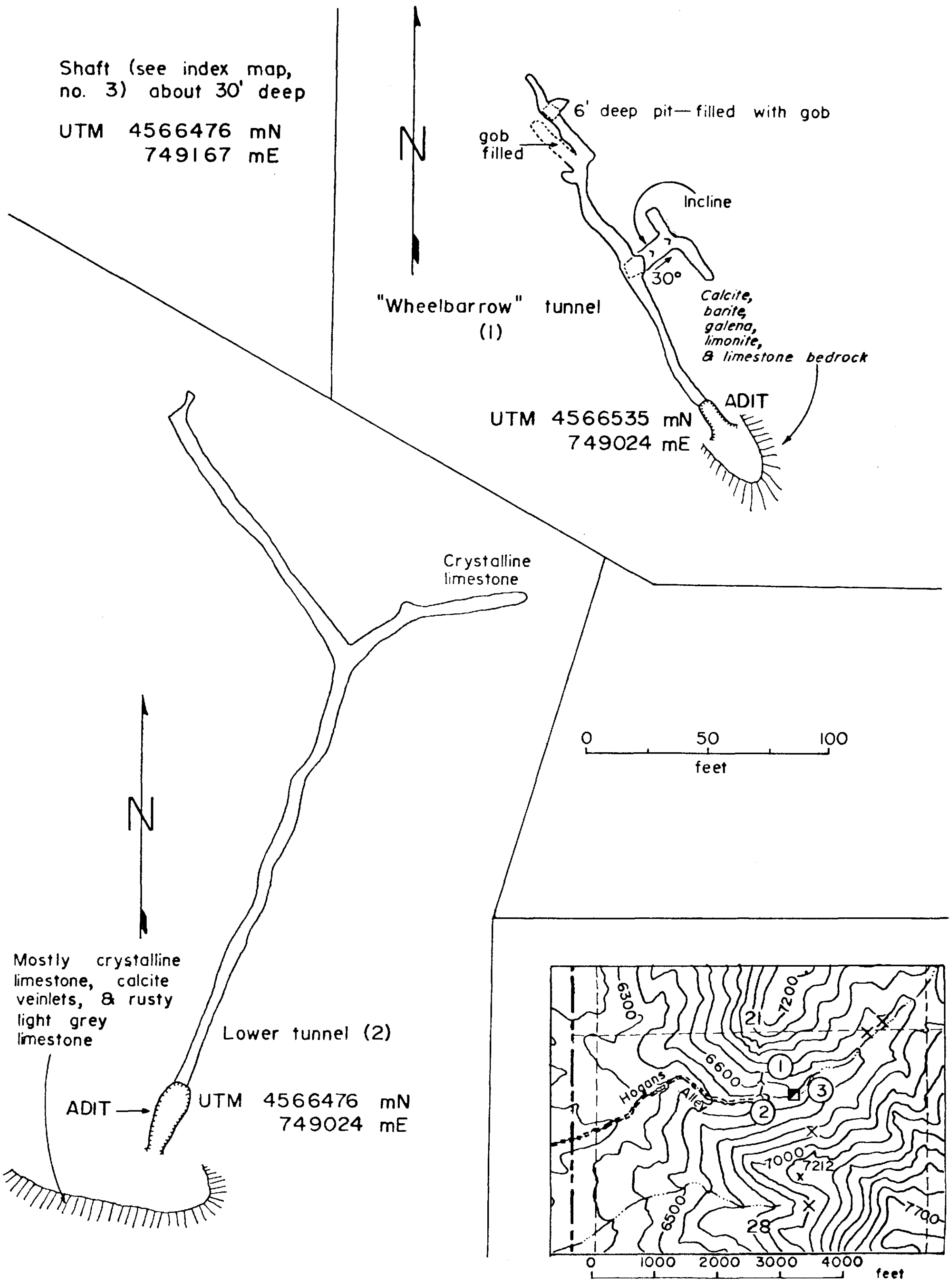


Figure 8. Hogans Alley mines, S. 28, T. 6 N., R. 19 W. Lucin mining district

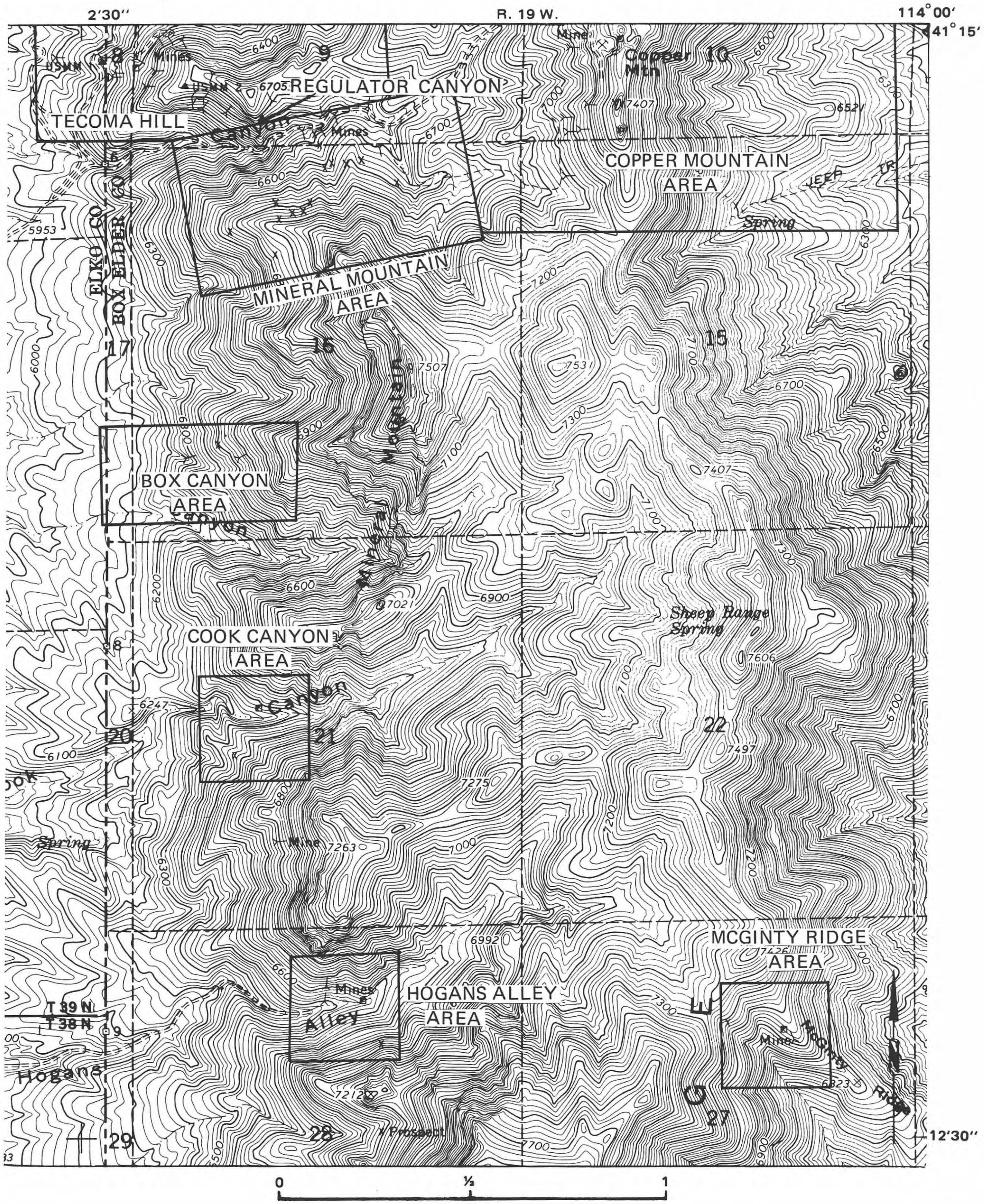


Figure 9. Location of mines and prospects between Patterson Pass and Regulator Canyon, Lucin mining district.

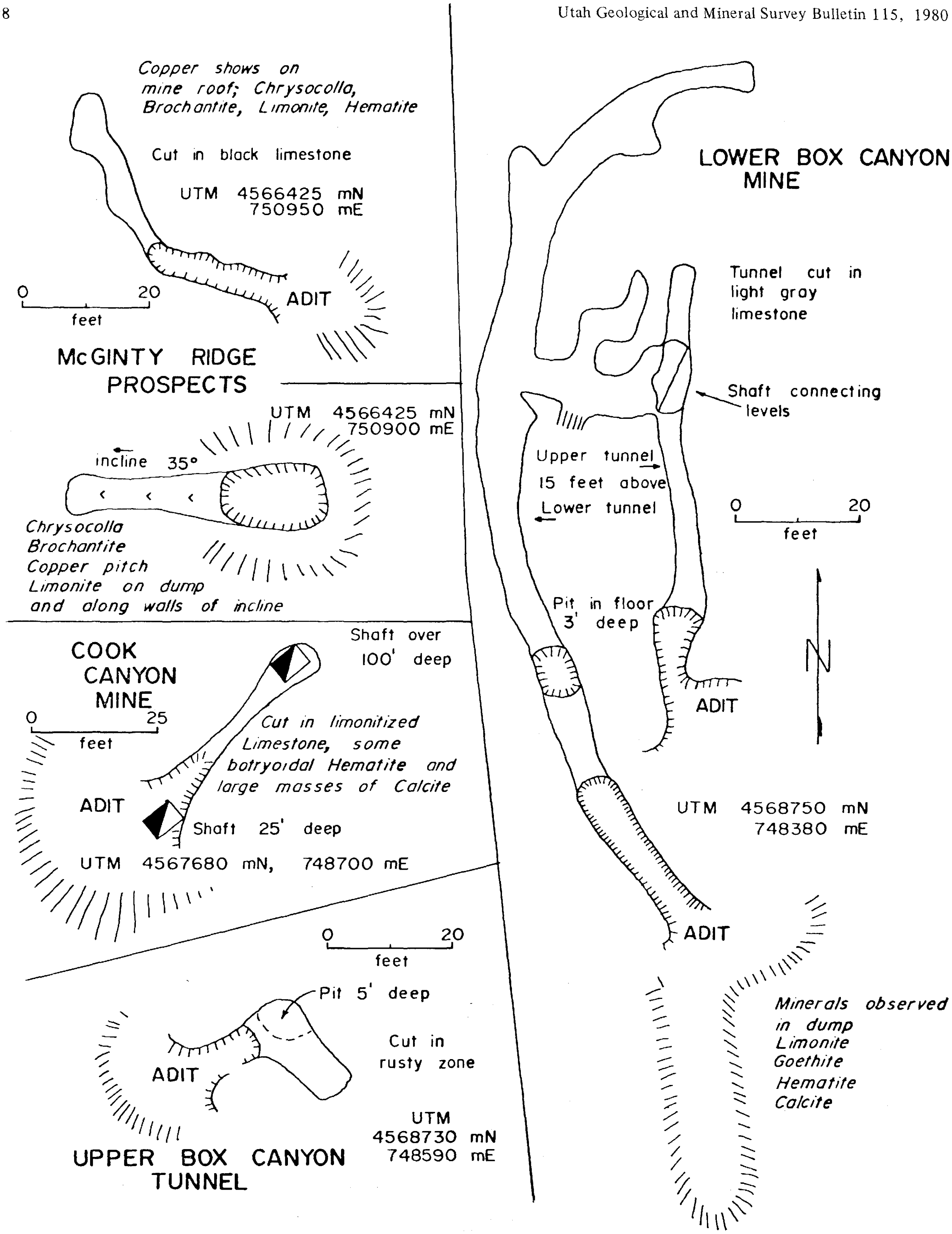


Figure 10. Various mines and prospects located in Box and Cook Canyons and along McGinty Ridge, Lucin mining district.

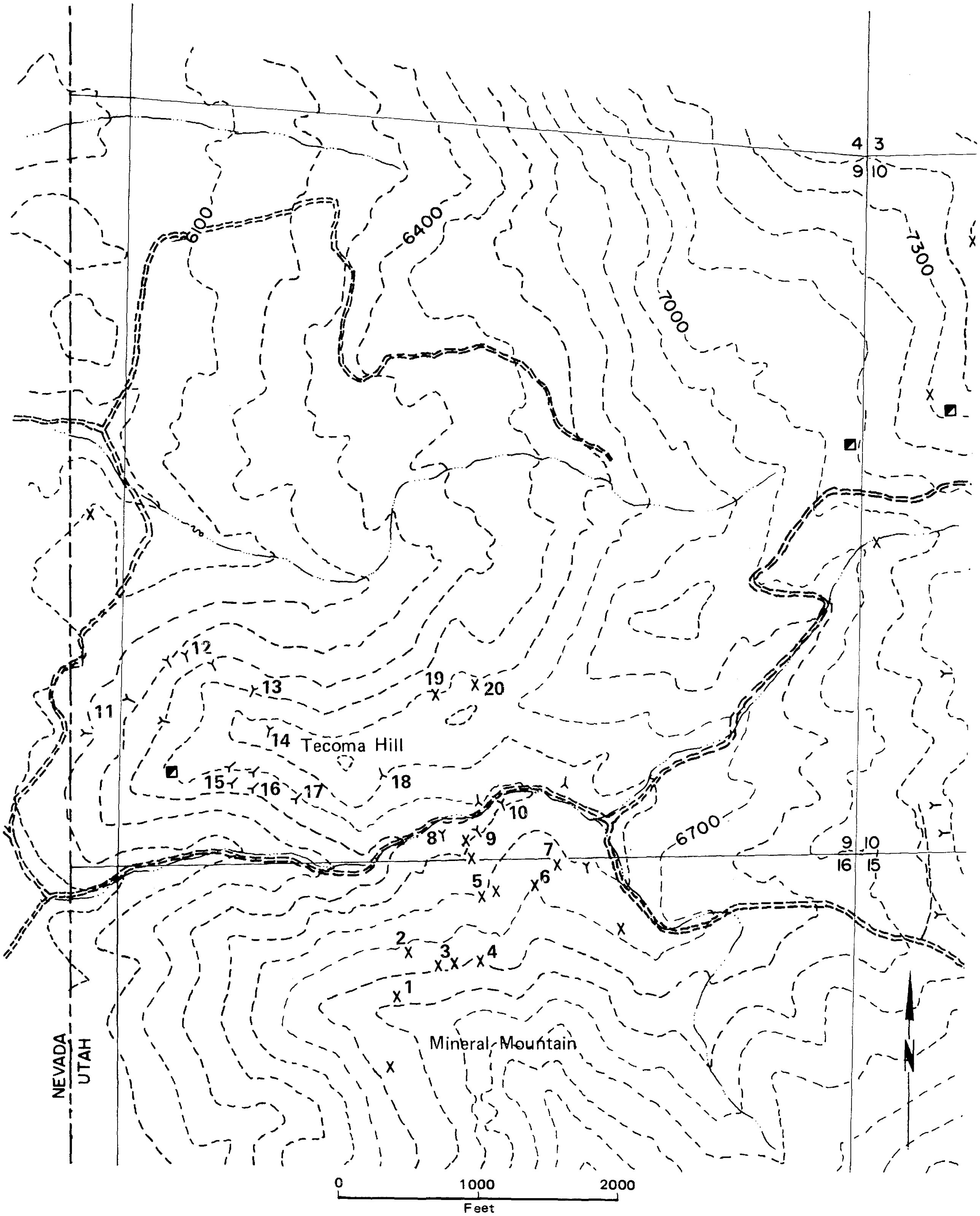


Figure 11. Regulator Canyon area, Lucin mining district.

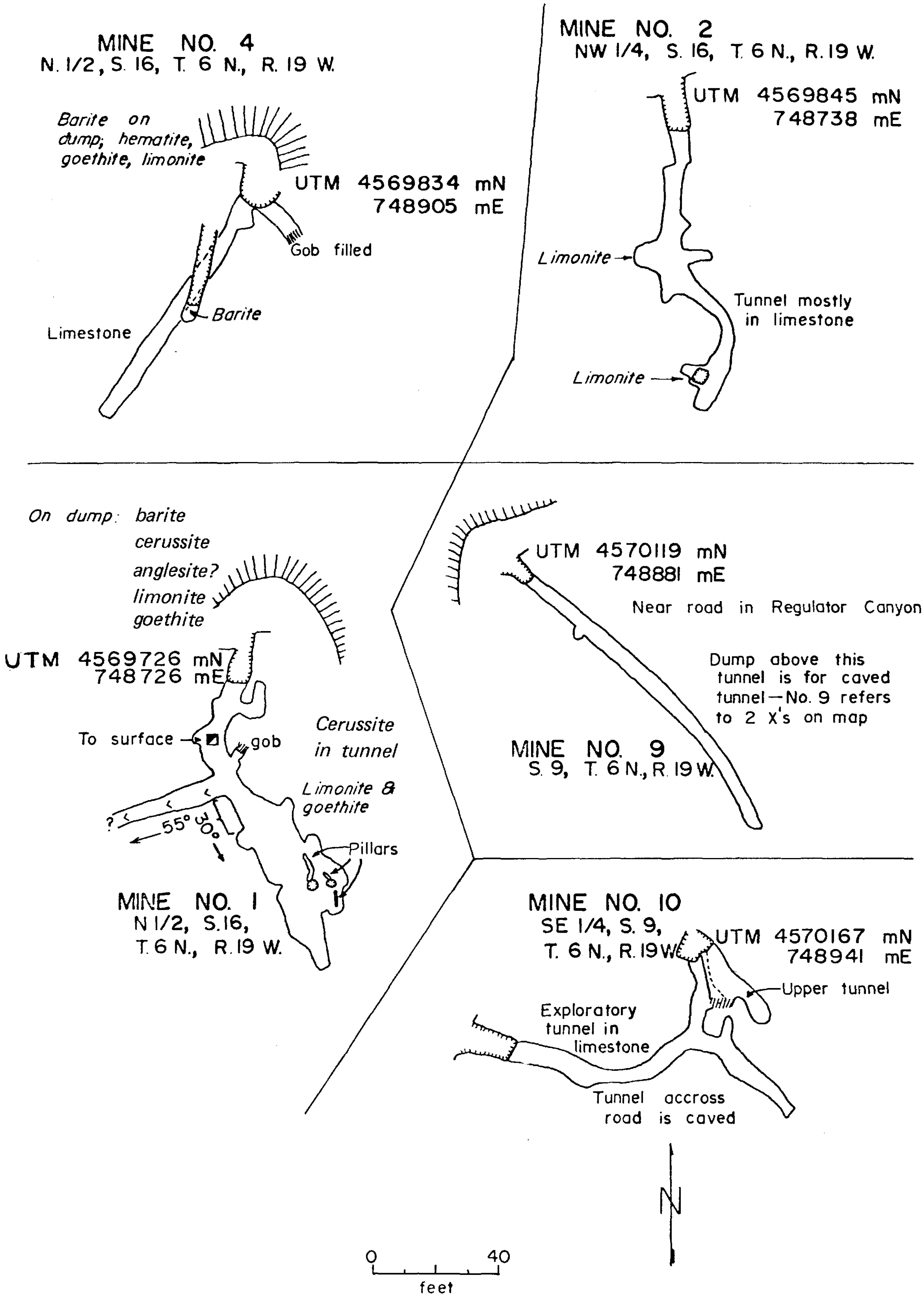


Figure 12. Mineral Mountain mines, Lucin mining district.

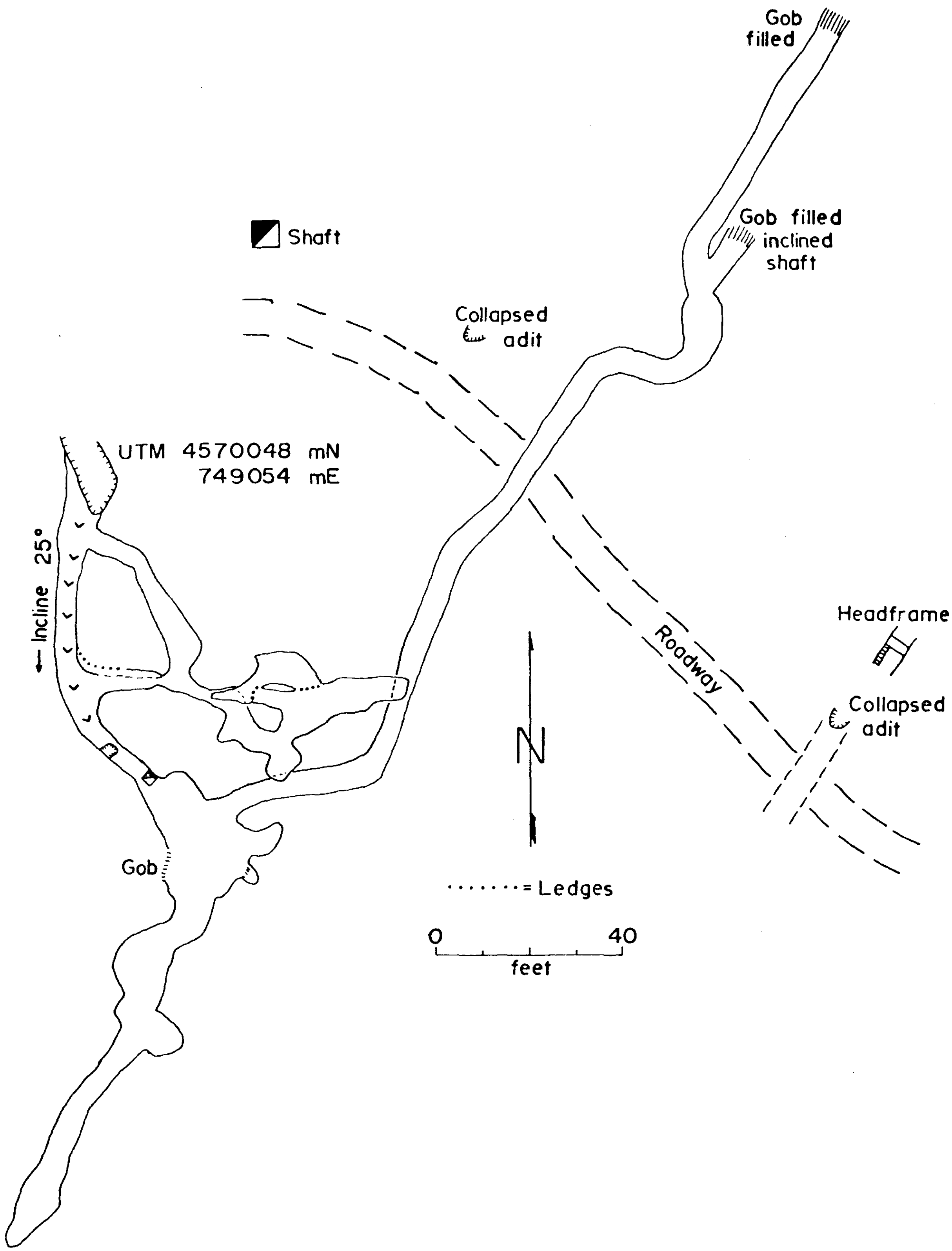


Figure 13. Mineral Mountain mine no. 7. S. 16, T. 6 N., R. 19 W, Lucin Mining district.

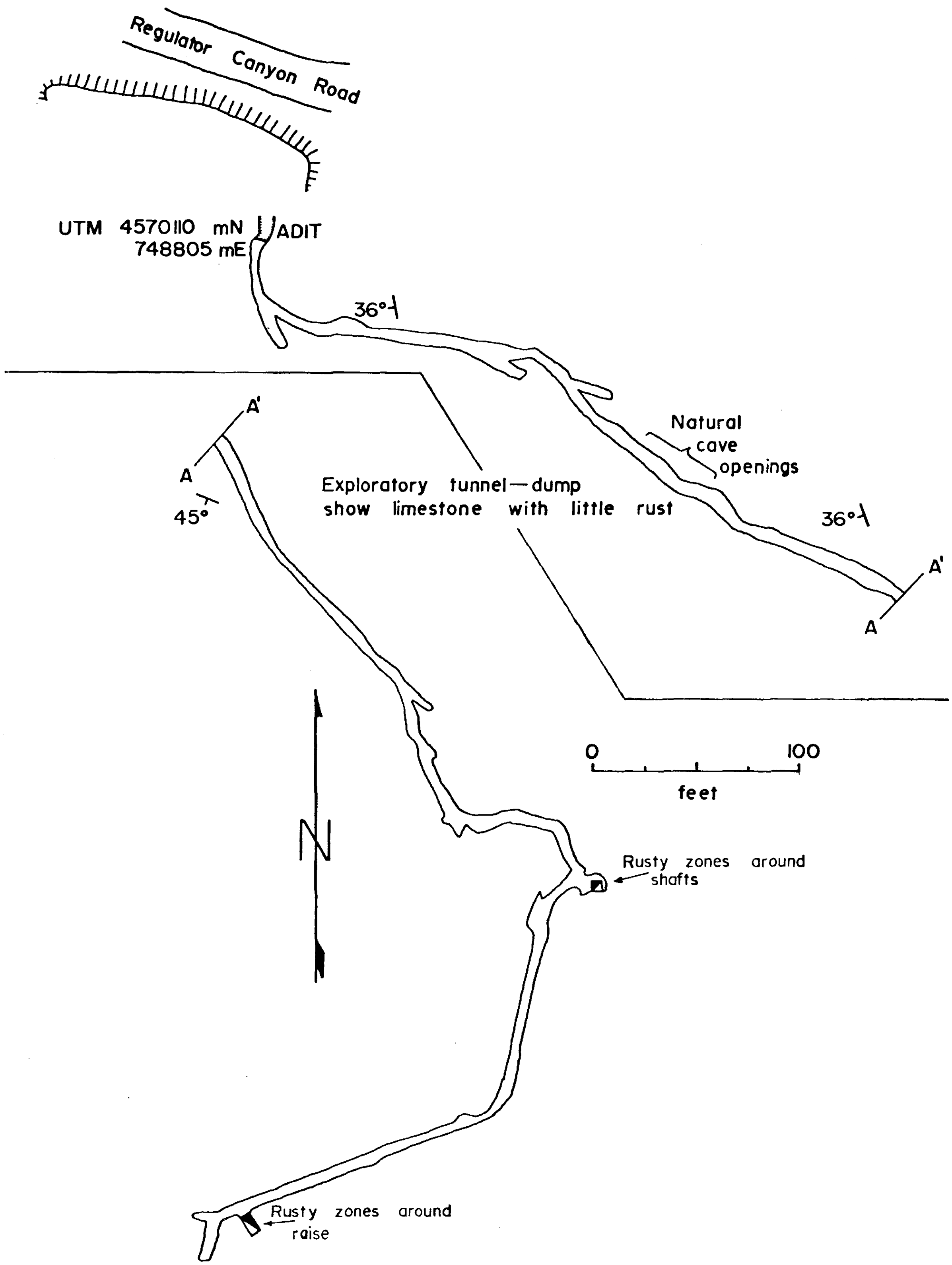


Figure 14. Mineral Mountain mines and prospects S. 9, T. 6 N., R. 19 W, Mine no. 8, Lucin Mining district.

little ore. Mine No. 2 is found a little below No. 1 in elevation and its gray dump indicates an exploratory tunnel. Two small stringers of light limonite mineralization were intersected, but no ore was discovered. No 3, not illustrated, is a 6-foot deep pit with an adjoining 6-foot adit cut in a rusty zone about 30 feet northwest of No. 4. The No. 4 workings consist of a lower adit, an upper cut and the start of another adit. The limonite mineralization is moderate; no ore minerals are noticeable, but some of the carbonate country rock has been irregularly replaced by barite. Workings Nos. 5 to 7 are down the hill and a little farther up the canyon. Several collapsed adits and at least two short open adits (unmapped) 6 feet and 40 feet long respectively make up No. 5. Collapsed mine buildings are on the dumps. The short adits appear to be exploratory and show little mineralization. Mine No. 6 is a shaft, 68 feet deep, cut in carbonate rock. The mineralization appears light to moderate and is concentrated along a narrow vein. Mine No. 7, accessible through an incline from the surface along a rusty fissure, shows strong limonitization near the fissure. A shaft, several collapsed adits, and another incline, the latter with headframe still standing, are adjacent to this mine. The dumps are large and show heavy limonite mineralization; it is assumed that some ore was produced. Mines Nos. 8, 9, and 10 are near road level and appear to be exploratory. Mine No. 8 has intercepted some rusty shoots; shafts have been dug at these locations (figure 14). A few workings extend to the north side of the road in Regulator Canyon just below the junction in SE Section 9.

Tecoma Hill Mines and Prospects (Lead-Silver-Zinc-Iron-Copper-Molybdenum)

Several important mines have been opened at Tecoma Hill, notably the Tecoma and Black Warrior (figure 11) which together have produced about 90 percent of the Tecoma Hill ore. The more important mines are at the west end of the hill in the north-striking, east-dipping Fish Haven Dolomite. The northwest corner of the hill is intruded by monzonite porphyry, but there is little alteration at the igneous-sedimentary contact and little ore has accumulated there. The minerals reported include:

anglesite	chalcopyrite
cerussite	native gold
wulfenite	halloysite
smithsonite	sericite
hemimorphite	plumbojarosite
malachite	calcite
limonite	native silver
goethite	alunite
hematite	kaolinite
galena	chrysocolla
pyrite	jarosite
sphalerite	azurite

Some of the mines reportedly yielded fine specimens of galena, pyrite, and sphalerite, but these minerals were not abundant. Sulfates, carbonates, molybdates and oxides produced most of the metal values. The wulfenite crystals are significant and rather large in some of the mines. The amount of gold produced has been small.

For the most part ore fissures trend easterly and northeasterly. The ore bodies consist of fissure fillings and replacements in favorable beds, and occur as irregular shoots and bunches.

The Tecoma Hill workings have been partly mapped and are located by number on figure 11. The Tecoma mine (No. 11, figures 15 and 16) had the greatest production. Its workings are partly open (Henry Tunnel). Large quantities of limonite still remain in the mine along with the remnants of former lead-silver-zinc ore bodies. The better lead-silver ore bodies were contained in a northeast trending fault zone which becomes barren east of the property. The fault planes and relationship to ore are well exposed in the mine. The Black Warrior mine (No. 12) workings are inaccessible and the dumps have been disturbed by subsequent open cutting.

Mine No. 13 (figure 17) is an adit cut into the hill on its north side into weathered and altered monzonite. No important mineralization is observable in the mine. Mine No. 14 is a large collapsed adit near the crest of the hill dug southwesterly into a fissure in limestone. The collapse created a large pit, about 75 x 100 feet, and the fissure is exposed in its high-wall. Abundant copper carbonates and iron oxides constitute the principal mineralization. Some cuprite may also be present. Mine No. 15 (figure 18) consists of a group of workings including two adits and some shallow shafts. Each adit contains about 125 feet of drifting cut in rusty fissures filled with limonite, jarosite and calcite. Some chrysocolla and malachite is observable. Mine No. 16 (figure 17) is an adit with two branches totaling 130 feet. A short adit is present above mine No. 16 cut in a rusty fissure. A sample collected in an ore remnant in a face of a stope in a distant part of mine No. 17 (figure 19) assayed 0.04 ounces gold per ton, 7.8 ounces silver per ton, 38.5 percent lead, a trace of zinc and 0.037 percent copper. A sample collected from a 4-foot channel in mine No. 18 chipped across the fissure in which visible

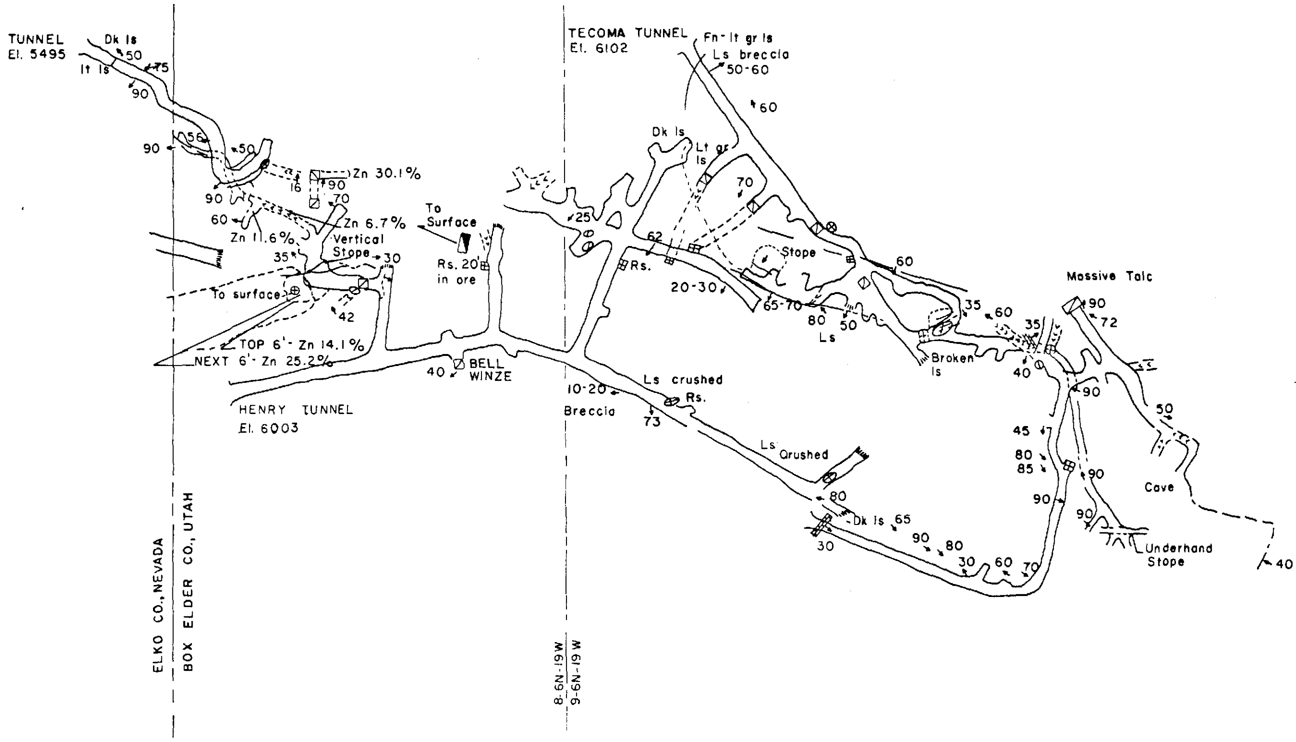


Figure 15. Tecoma Hill no. 11, underground workings, Lucin mining district.

wulfenite crystals could be seen yielded 0.085 ounces gold per ton, 8.5 ounces silver per ton, 9.7 percent lead, 1.1 percent zinc, 0.126 percent copper and 3.81 percent molybdenum. Mine groups Nos. 19 and 20 are prospects cut in slightly mineralized fissures. A little azurite and malachite are present.

Copper Mountain Mines and Prospects (Copper-Iron-Lead-Silver-Zinc)

The Copper Mountain area straddles the crest of the northern Pilot Range above the head of Regulator Canyon, mostly in 10-6N-19W, but also extending into the northwest corner of Section 15, the east edge of Section 9, and the southeast corner of Section 3 (figure 20). The geology has been summarized by Blue (1960, p. 85-88):

> The Copper Mountain fault zone plays a most important role in ore deposition. . . . . .the north-south fracturing in the Copper Mountain area is the most significant in terms of ore control. The zone is about 1000 feet wide and over one-half mile long and consists of normal fault planes that dip steeply both to the east and west. Faults are branching in nature and the intersections and junctions of the minor fractures show in pockets or cavities that were more favorable to ore deposition than were surrounding areas. . .
>
> Ore in the Copper Mountain area is confined to the favorable carbonate beds of the lower massive limestone member of the Devonian Guilmette Formation. For the most part, ore follows bedding surfaces in the limestone and its lower portions, contains redeposited, leached material from the upper part of the deposit. . . . . .Dolomite beds in the Copper Mountain area are not mineralized. Characteristic of the ore bodies is the lack of alteration other than the disintegration between the ore and the Guilmette Formation. . .

Less than a half-mile to the east and paralleling the ore bodies is the Patterson Pass monzonitic stock. Diabase dikes are known in the mineralized area, and Blue continues:

> Relationship of copper and iron ores to the Patterson Pass stock is uncertain. Because the stock is the only igneous body of any size or consequence in the area it is assumed that the ore and igneous material are genetically related. . . . . .In addition to the monzonite stock a diabase dike intrudes in the Copper Mountain area and truncates the eastern-most ore body. . . . . .The dike is accompanied by little or no change (either to the ore body or country rock) other than crushing and minor brecciation (the dike is believed to be post-ore).

Again, as at Tecoma Hill, alteration of the carbonate sediments by the igneous intrusion is minor. The

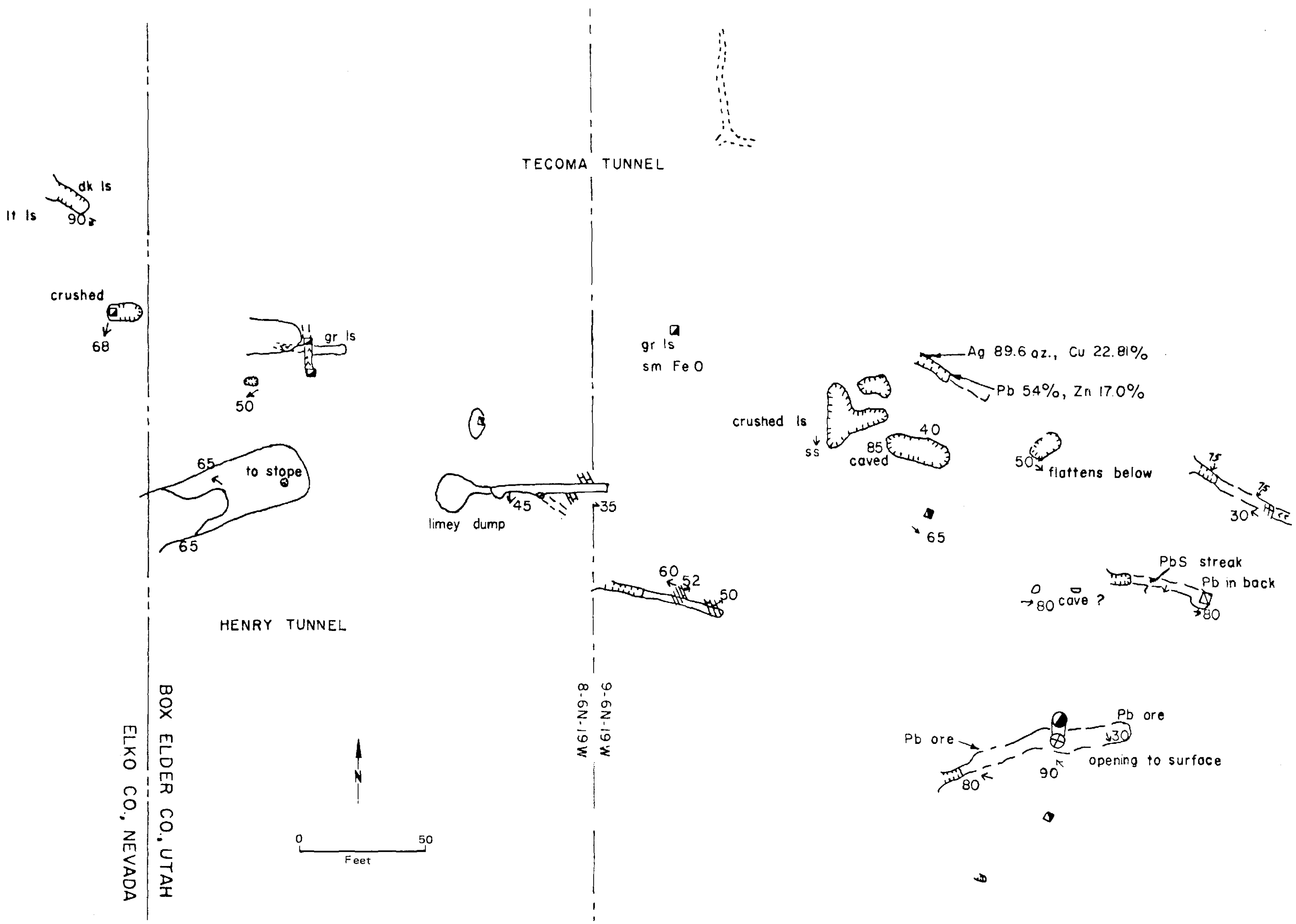


Figure 16. Tecoma Hill, surface workings, Lucin mining district.

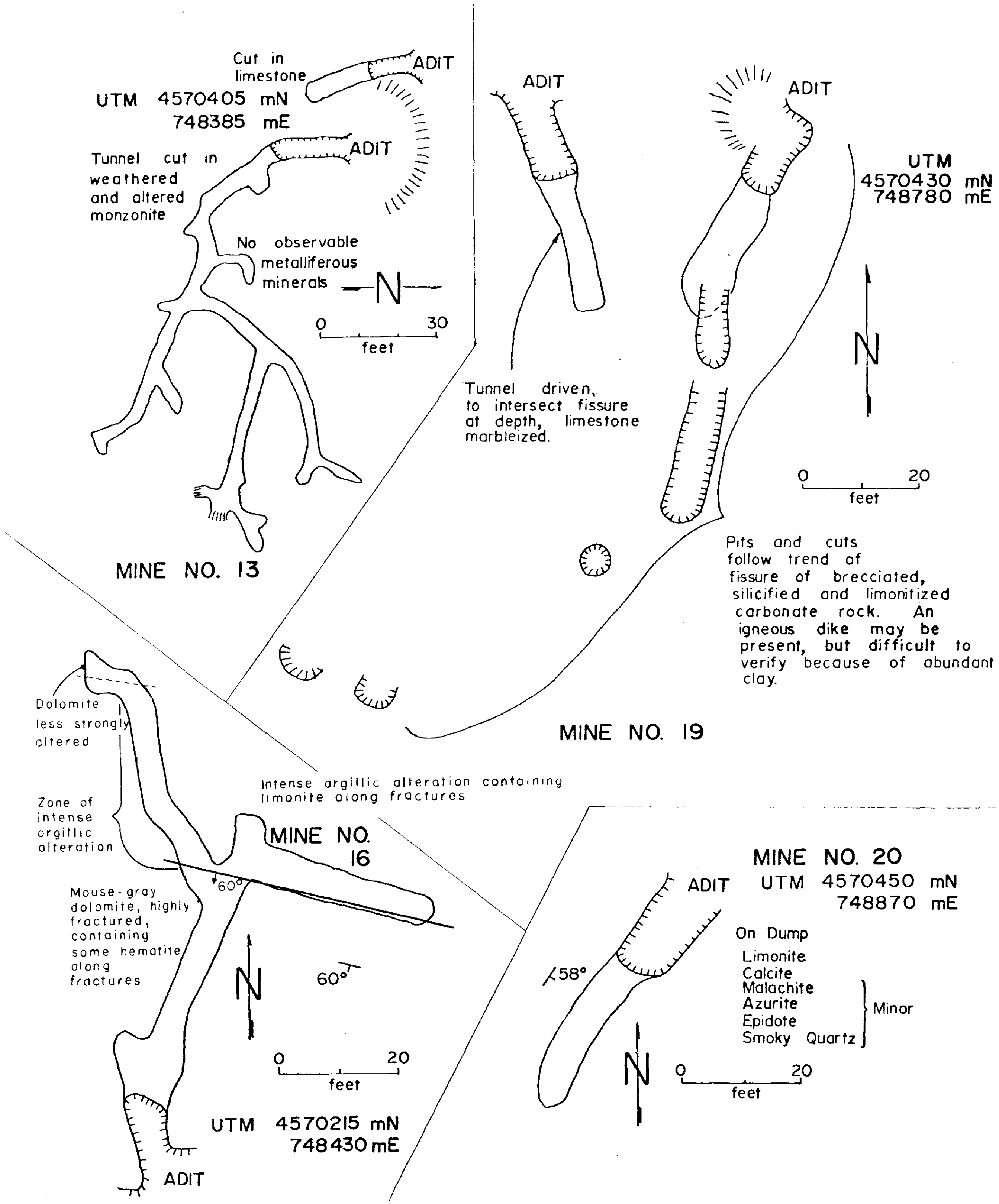


Figure 17. Tecoma Hill prospects, Lucin mining district.

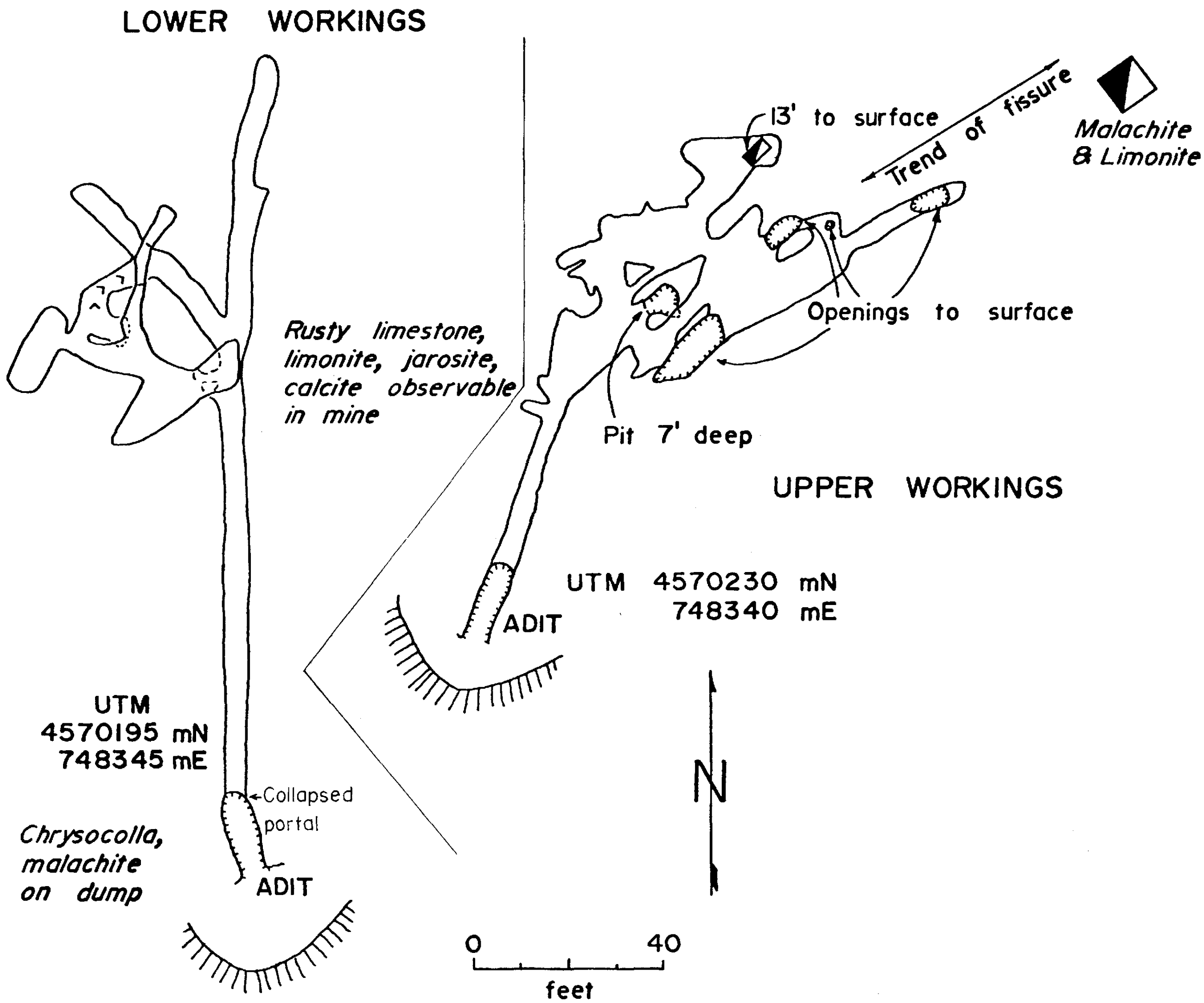


Figure 18. Tecoma Hill mine no. 15., Lucin mining district

mineralization in the Copper Mountain area is of two types. Near the crest of the range, copper and iron are prevalent. On the flanks and at lower elevations of the mountain lead, zinc, silver and iron are important. The discovered ore minerals include:

Copper and Iron Area

Limonite	Native Copper
Goethite	Cuprite
Jarosite	Chrysocolla
Hematite	Copper clays
Azurite	Copper pitch
Malachite	Native silver*
Cerussite*	Galena*
Anglesite*	

Lead-Silver-Zinc-Iron Area

Limonite	Smithsonite
Goethite	Native silver
Plumbojarosite	Copper clays
Hematite	Galena*
Cerussite	Sphalerite*
Anglesite	

*Present in minor quantities

Mines, shafts, inclines, pits and other diggings in Copper Mountain are so numerous that only a portion of them have been mapped. Mines number 21 to 44 are located on figure 20. Copper and iron have been produced from the Copper Mountain mine (s) (No. 21) by both open-pit and underground methods. Most of the

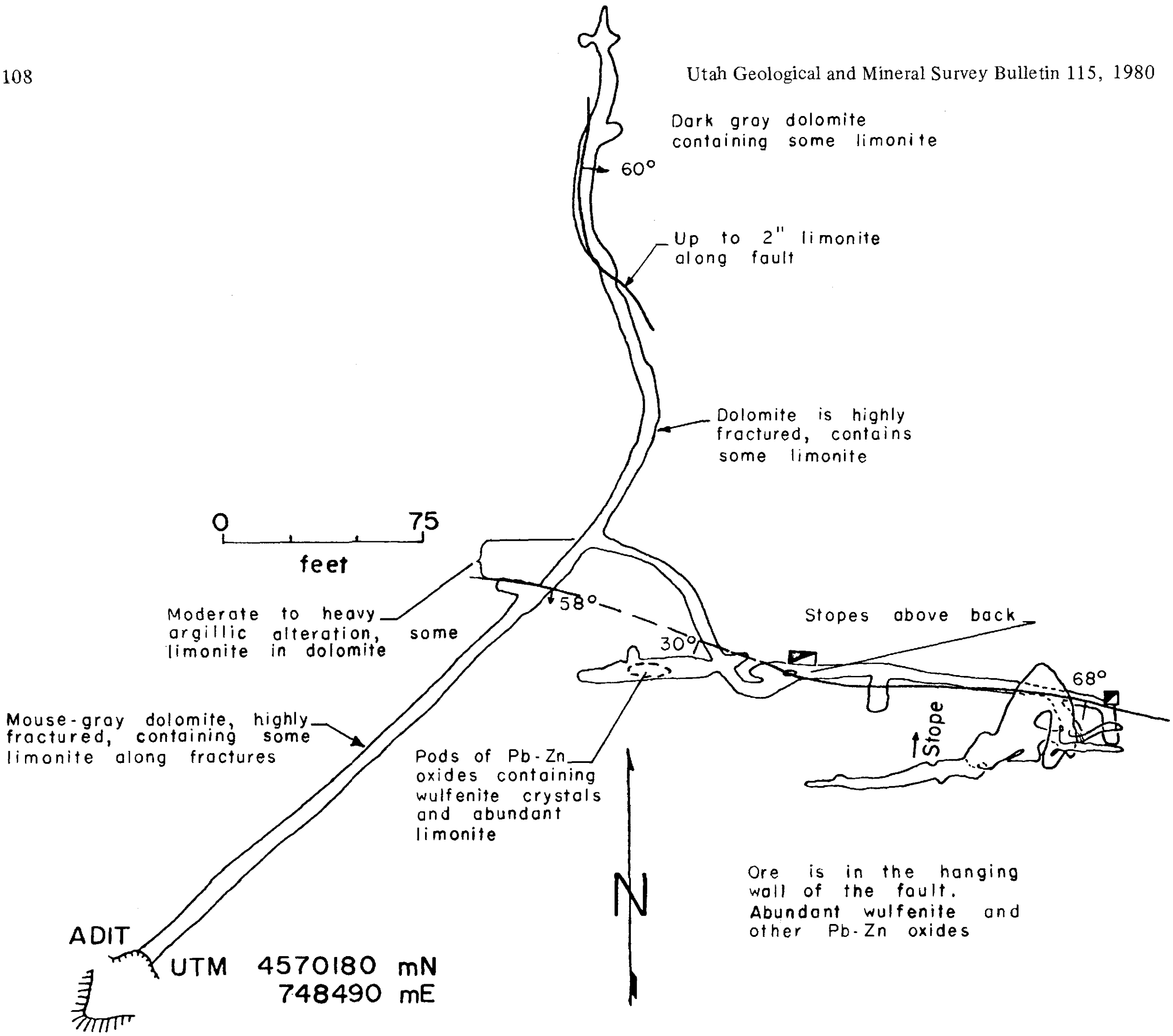


Figure 19. Tecoma Hill mine no. 17, Lucin mining district.

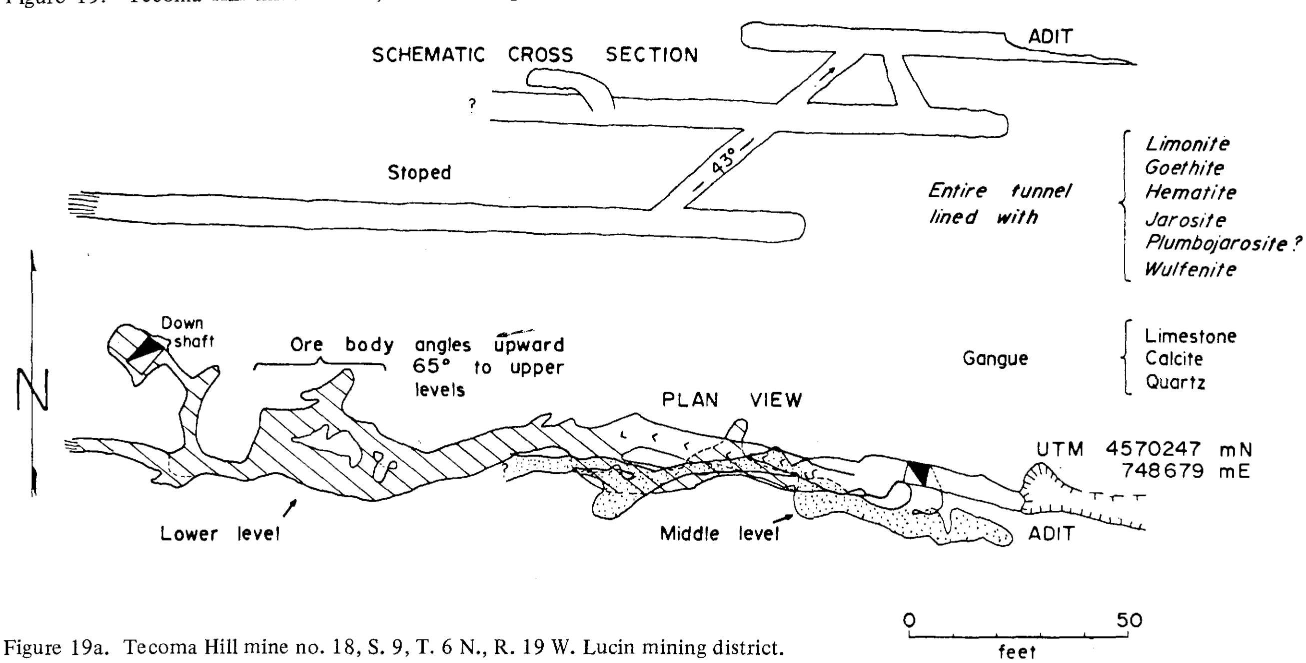


Figure 19a. Tecoma Hill mine no. 18, S. 9, T. 6 N., R. 19 W. Lucin mining district.

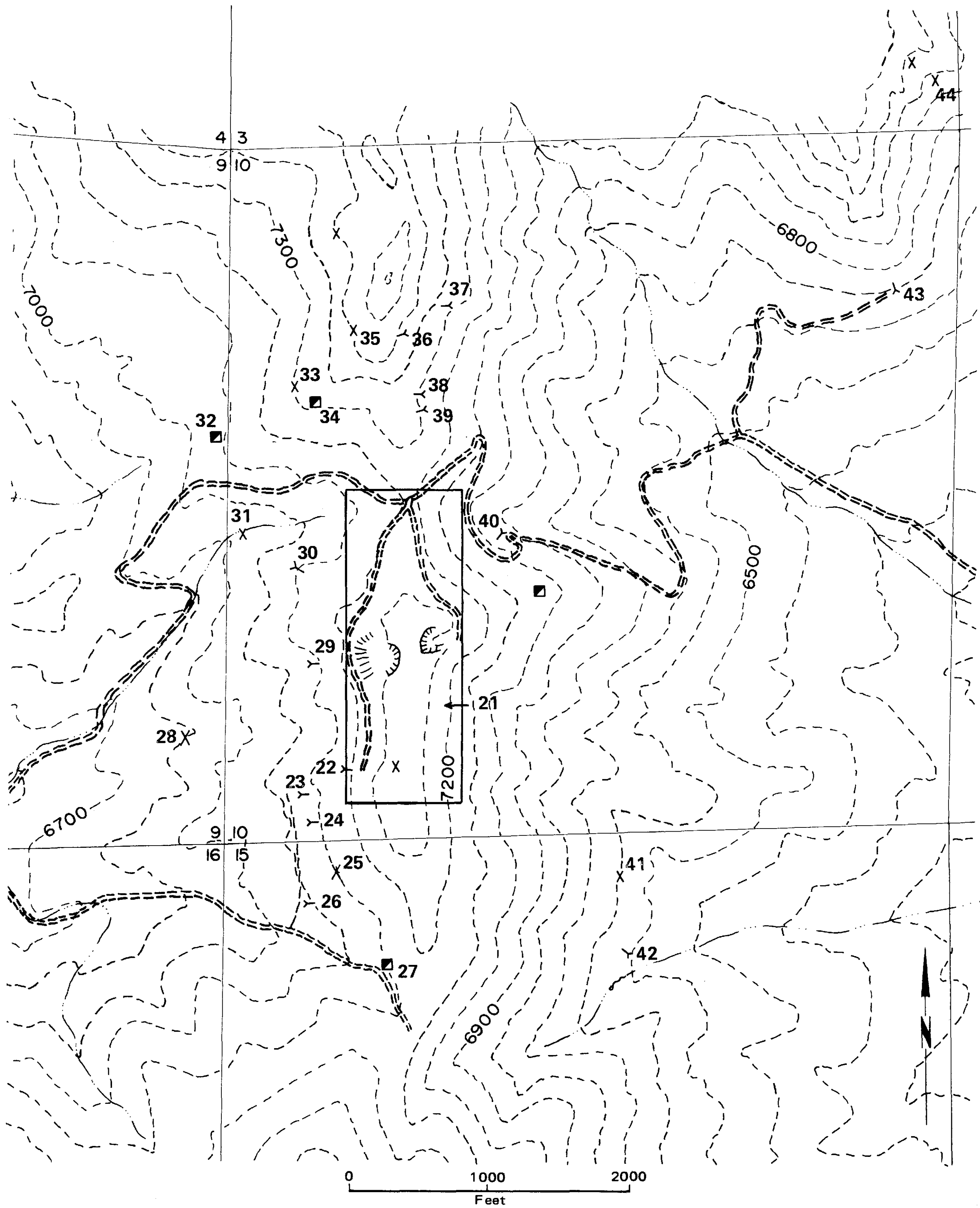


Figure 20. Copper Mountain mines and prospects, Lucin mining district.

upper portion of the mountain is gossanized, consisting of soft, reddish-brown iron masses mixed with a soapy milk white to reddish brown clayey material. The clayey material contains up to 27 percent alumina. According to Blue (1960, p. 84-85):

> Three ore bodies are exposed at the summit of Copper Mountain within a distance of more than 2000 feet, but no connection between them has been observed. The main producing bodies, separated by a relatively barren zone, are the central and eastern; the central one being the largest and most important copper producer. It extends along strike for 150 feet at the surface and 300 feet down the western slope from the top. The central and eastern ore bodies are continuous faces of copper and iron mineralization for 250 and 220 feet respectively. The eastern-most ore body, with a greater concentration of the iron mineralization, has been truncated abruptly on the east side by a vertical diabase dike. Little ore has been recovered east of the dike.
>
> The western ore body is the smallest of the three; it contains similar mineralization but is noticeably affected by either north or east trending faulting.

An assay of a sample of the low-grade ore that remains, collected in 1957, yielded the following (analyzed by Techmanix and Combined Metals Reduction Co.):

Copper	3.0 percent
MgO	2.6 percent
CO_2	3.8 percent
Zinc	0.1 percent
Silver	0.2 ounces
Calcium oxide	3.4 percent
Silica	29.7 percent
Sulfur	trace
Lead	none
WO_3	0.02 percent
Iron	11.4 percent
Alumina	21.9 percent
ignition loss	16.1 percent
Gold	trace

An analysis of ore taken from the west side open pit by composite channelling showed an average copper content of 2.4 percent. Blue (1960, p. 91) reports a proven ore reserve of 80,000 tons, an indicated reserve of 130,000 tons, and an inferred reserve of 3,000,000 tons of copper ore at a grade of 2.5 percent. At present mining and beneficiation costs render the project uneconomical.

The Green Carbonate mine (No. 22, figure 21) is southwest of the main surface workings. There is an ore zone 6 inches to 2 feet thick of bluish copper-bearing clay and chrysocolla remaining in the mine. A sampling of the ore zone across its thickest observable place assayed 2.343 percent copper. Mines Nos. 23 to 28 (figure 22) are mostly smaller workings in gossanized fissures and were more important for lead-silver than for copper. Mine No. 23 is a collapsed adit and inclined shaft that were not mapped. Mines Nos. 25 and 27 are vertical shafts of unknown depths.

Mine No. 29 (figure 23) is the Vesuvius tunnel, consisting of about 1500 feet of workings, mostly exploratory; only thin, widely spaced fissures containing lead and zinc mineralization were intersected. The purpose may have been to tie in with the Walker tunnel that extends from the east side of the mountain range, and to intersect the Copper Mountain ore bodies at depth. Mine No. 30 (figure 24) is cut in very rusty rock with a clay zone in its deeper parts. Mine No. 31, a long and straight exploratory tunnel cut in limestone, intercepted only a few calcite veinlets and limonite partings. A 42-foot shaft at about the middle of the tunnel probes the thickest limonitic parting. Prospects Nos. 32 to 35 (figure 25) are all small in extent and follow easterly or northeasterly trending limonitic fissures. Small amounts of lead-silver ore were removed from some of them. In an inclined shaft (No. 32) a small amount of clayey black material in the center of the fissure (across ½ inch) was collected and analyzed and showed 0.015 ounces gold, 31 ounces silver, 39.3 percent lead, 1.5 percent zinc and 0.226 percent copper. Mine No. 34 is a vertical shaft of unknown depth.

Mines Nos. 36-39 (figure 26) are small to intermediate in size and are also on east- or northeast-trending limonitic fissures. Two, designed to intersect such fissures, are cut in unaltered country rock. The others probably produced small amounts of ore. A three-foot channel cut in the ore zone of Mine No. 36 showed 7.6 percent lead, 4.0 percent zinc, and 9.6 ounces of silver per ton. Mine No. 40 (figure 27), the Walker tunnel, intersected two fissure systems that produced lead-silver-zinc ore. An analysis of oxide minerals taken across a 2-inch ore remnant yielded 0.05 ounces gold, 14.7 ounces silver, 15.4 percent lead, 22.4 percent zinc and 0.144 percent copper. The sample was collected 200 feet from the portal in a stope at the north end of the mine cut along an east-west fissure. Other assays are shown on figure 27.

Southeast of Copper Mountain is a prospect (Mine No. 41) cut in limestone following a thin rusty parting and the caved portal of a substantial working as attested by the large dump (Mine No. 42). The larger working is a tunnel cut toward Copper Mountain from the Patterson

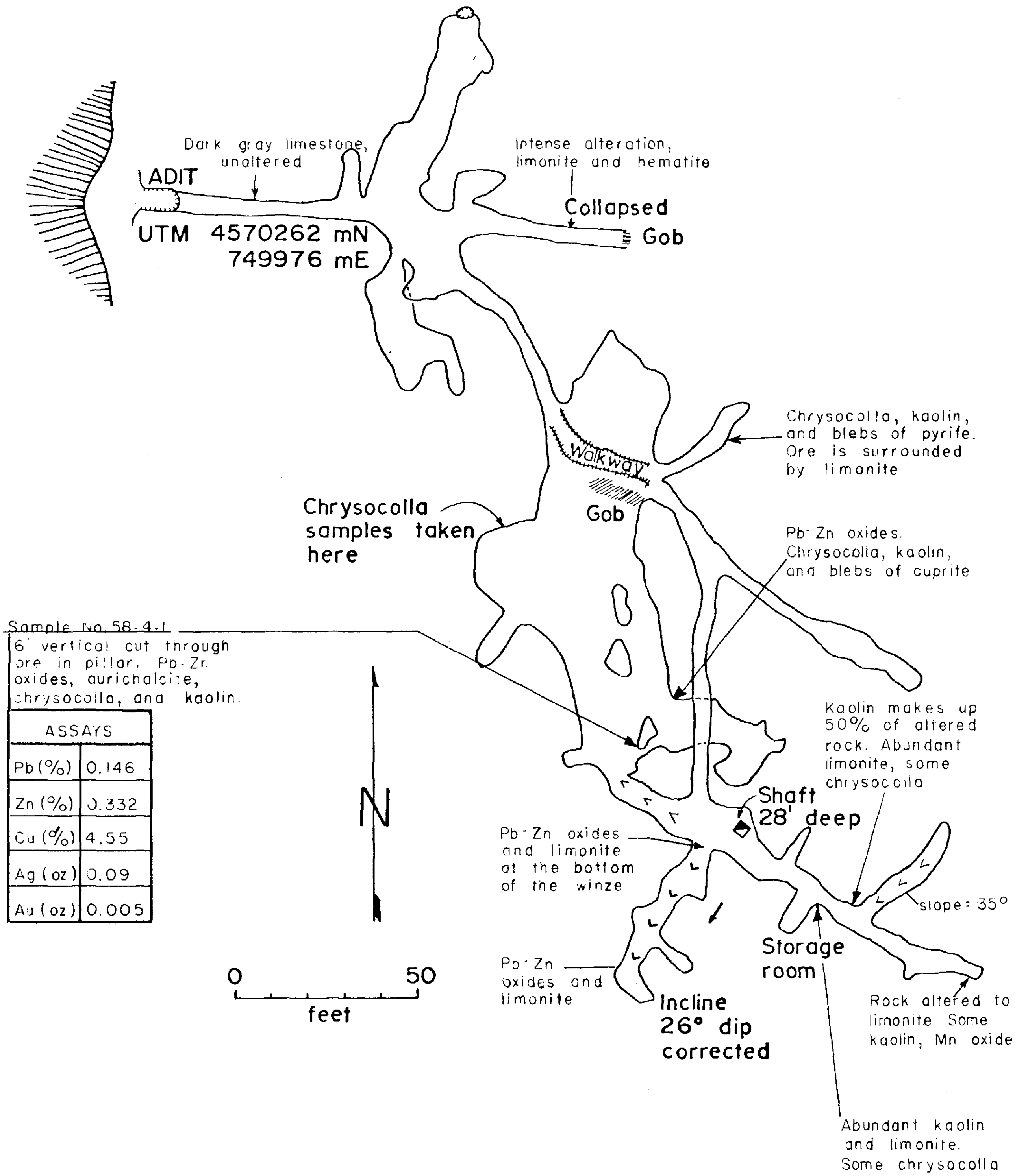


Figure 21. Copper Mountain mines and prospects: mine no. 22. (Green Carbonate mine) Lucin mining district.

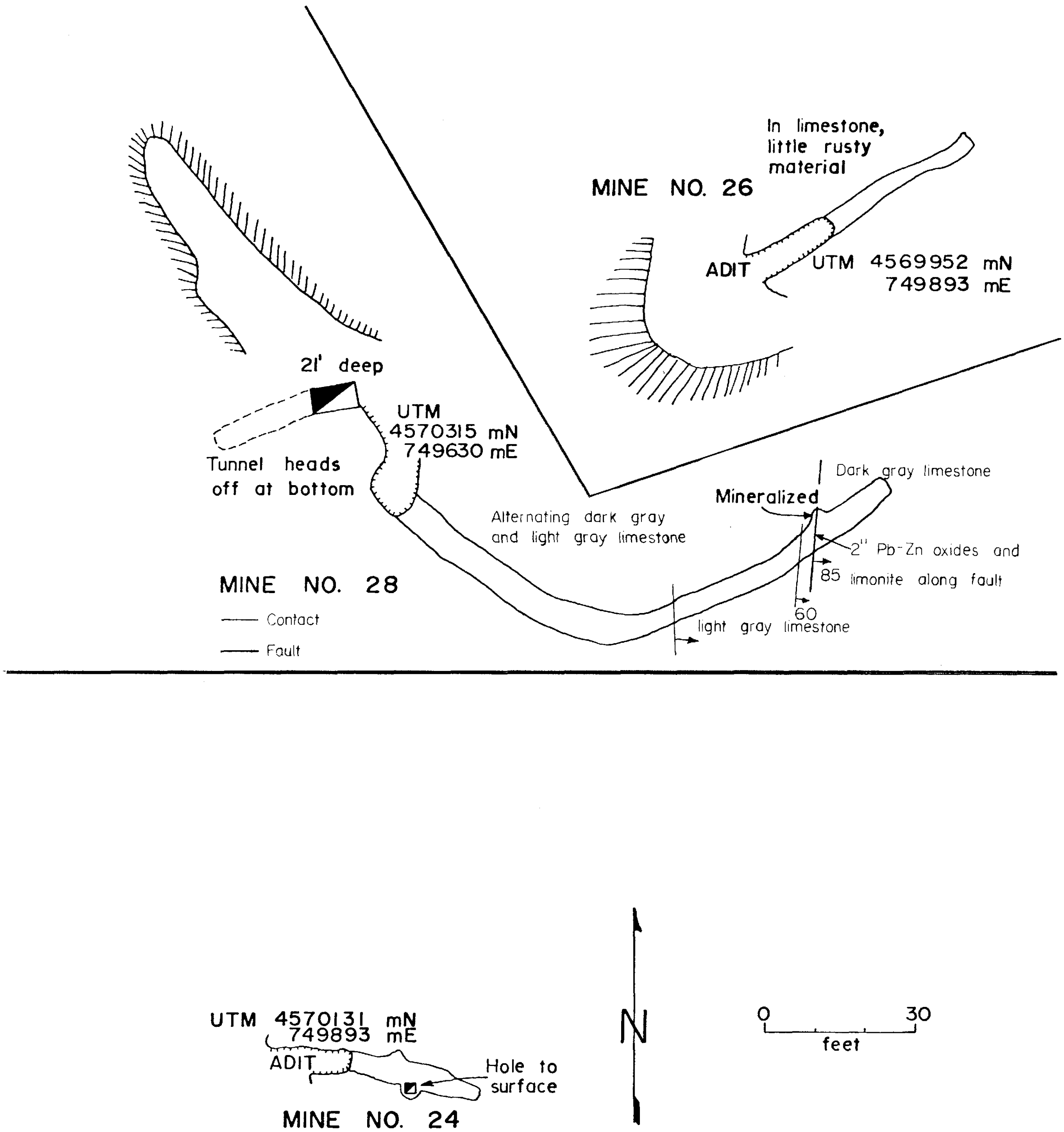


Figure 22. Copper Mountain mines and prospects, Lucin mining district.

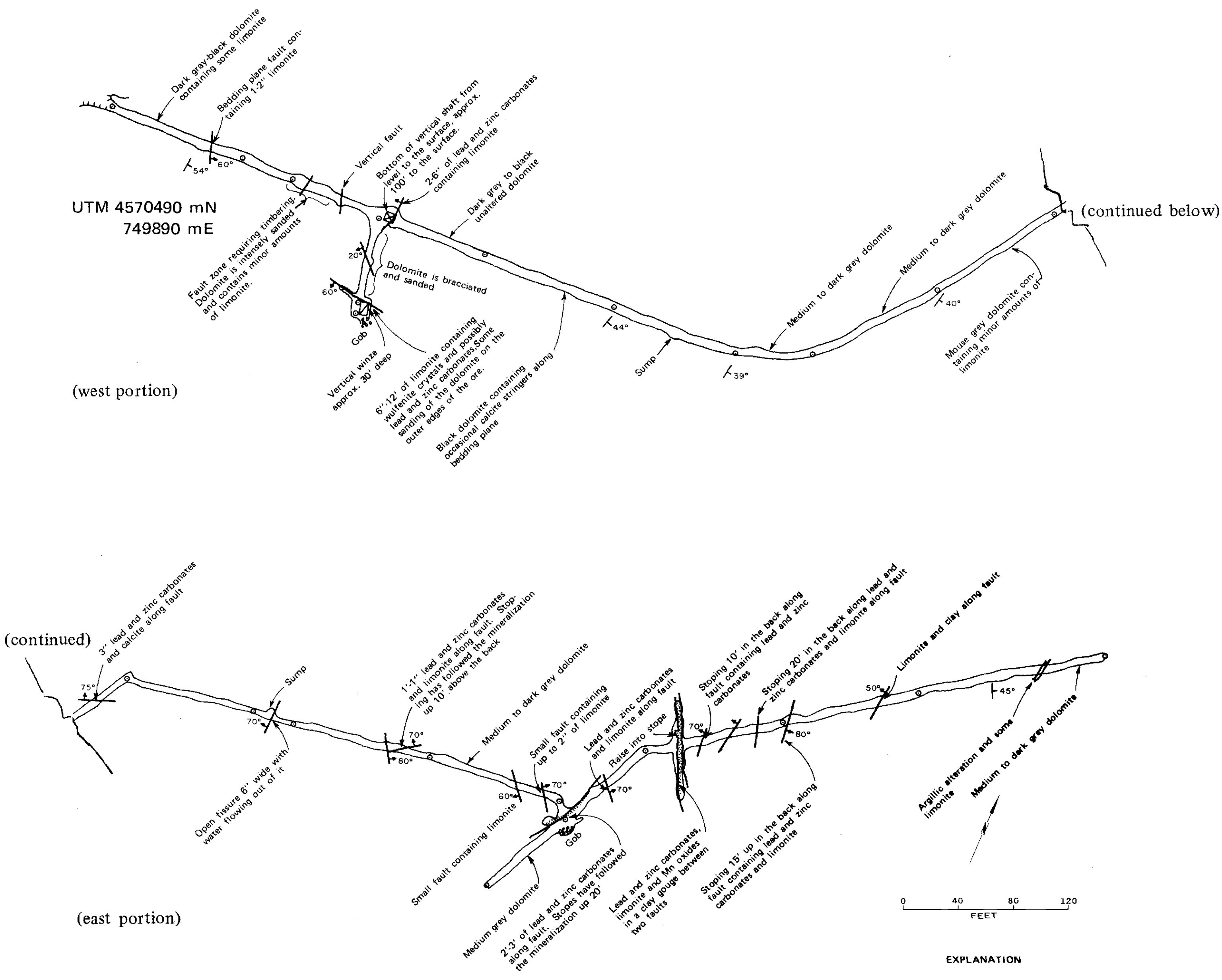


Figure 23. Mine 29, Vesuvius tunnel, Lucin mining district

Pass Monzonite. The dump consists mostly of unaltered monzonite and limestone, indicating an exploratory effort.

Northeast of Copper Mountain are a few smaller mines (Nos. 43 and 44) that have yielded a little ore (figure 28). These intersect clayey igneous dikes and northeasterly trending limonitic fissures. In Mine No. 43 pyrite was noted in brecciated limestone. In Mine No. 44 a thick mineralized zone is cut at right angles by the workings; a very clayey zone (a highly altered dike) is first intersected and the limonitic zone beyond it is pocketed with a light blue smithsonite and a little copper clay. An analysis of the blue material yielded a trace of gold, 0.1 ounce silver, 0.5 percent lead, 15.5 percent zinc and 0.352 percent copper.

East Canyon Area Prospects (Copper)

The East Canyon area is relatively unimportant

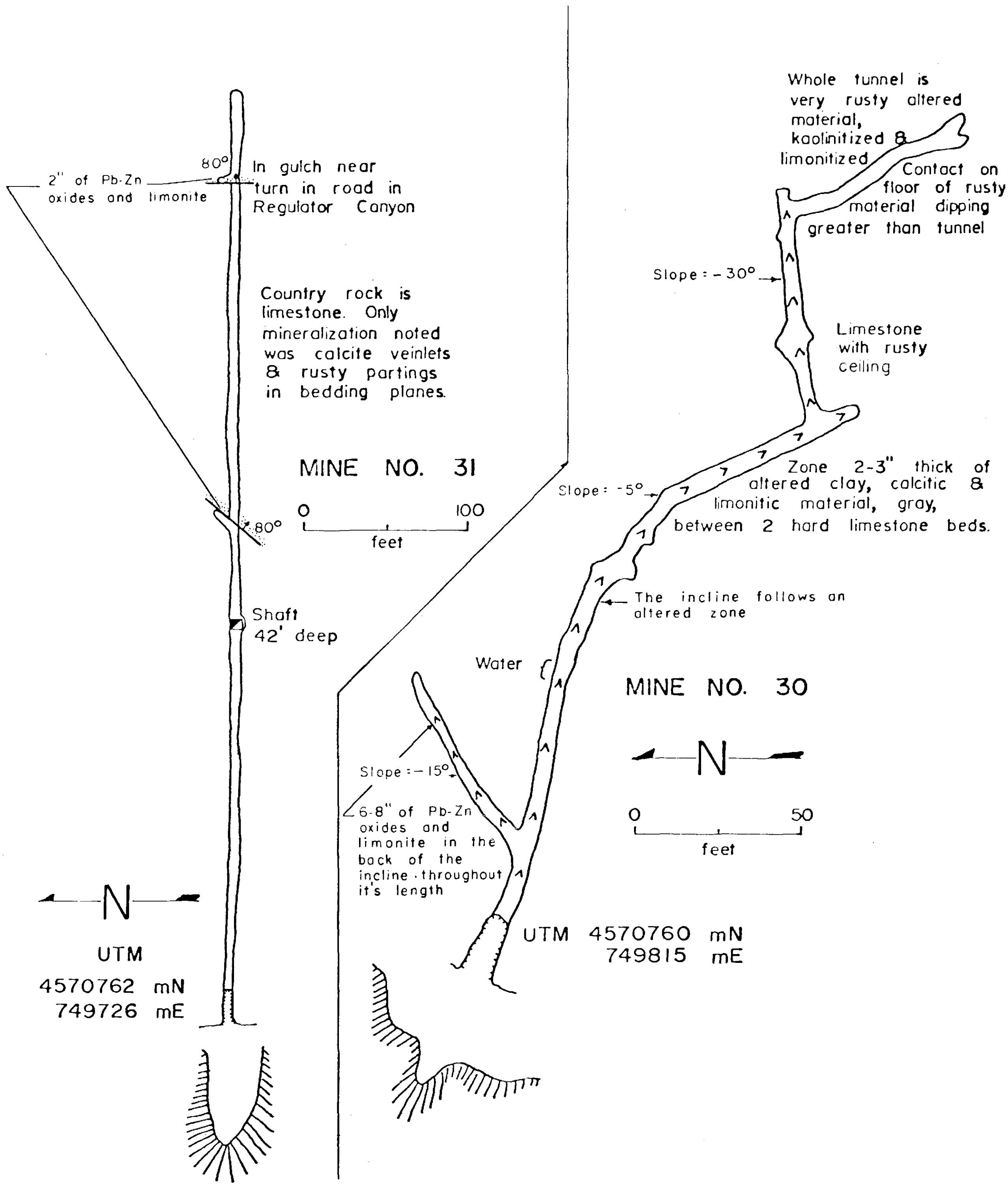


Figure 24. Copper Mountain mines and prospects, Lucin mining district.

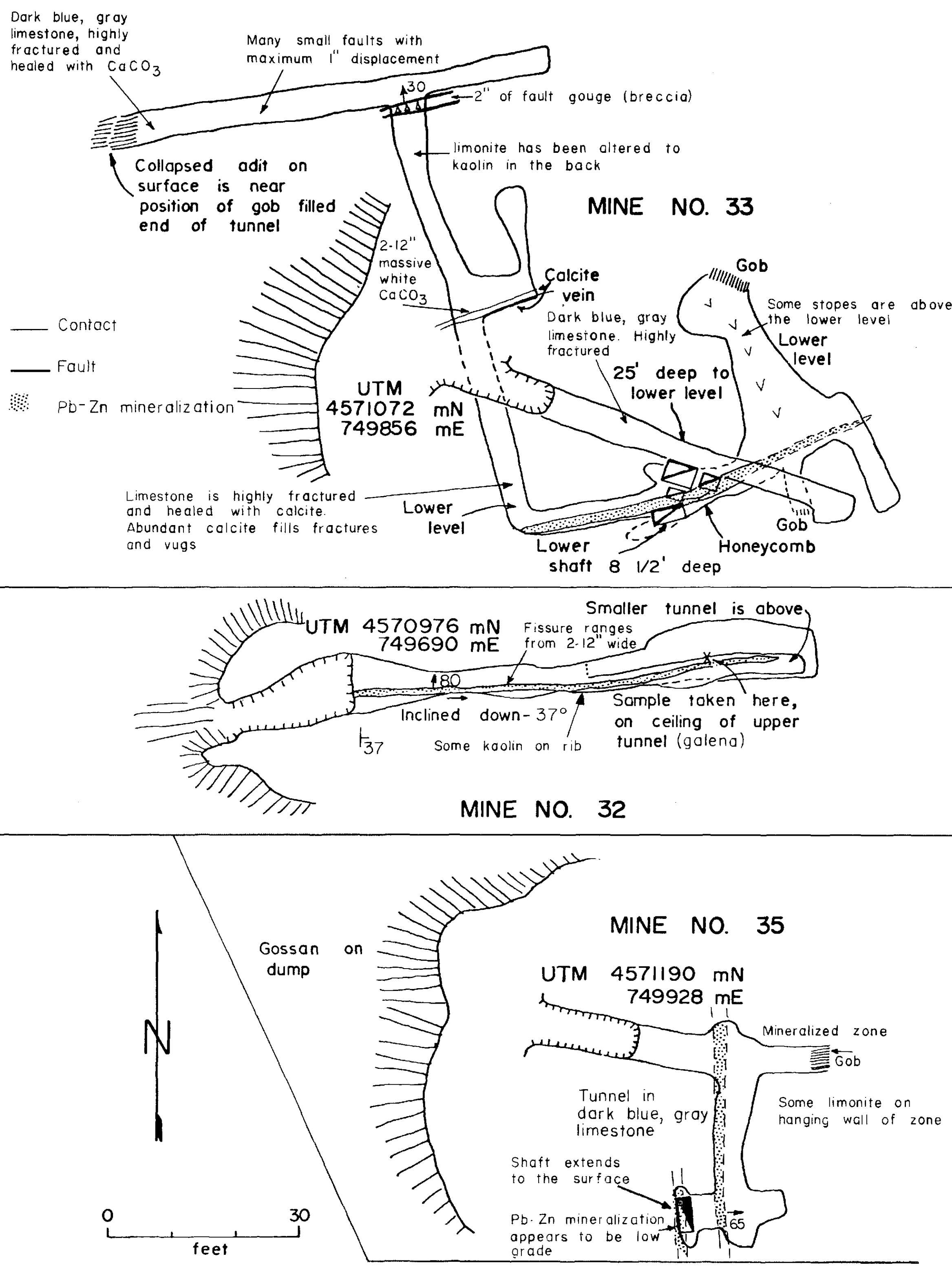


Figure 25. Copper Mountain mines and prospects, Lucin mining district.

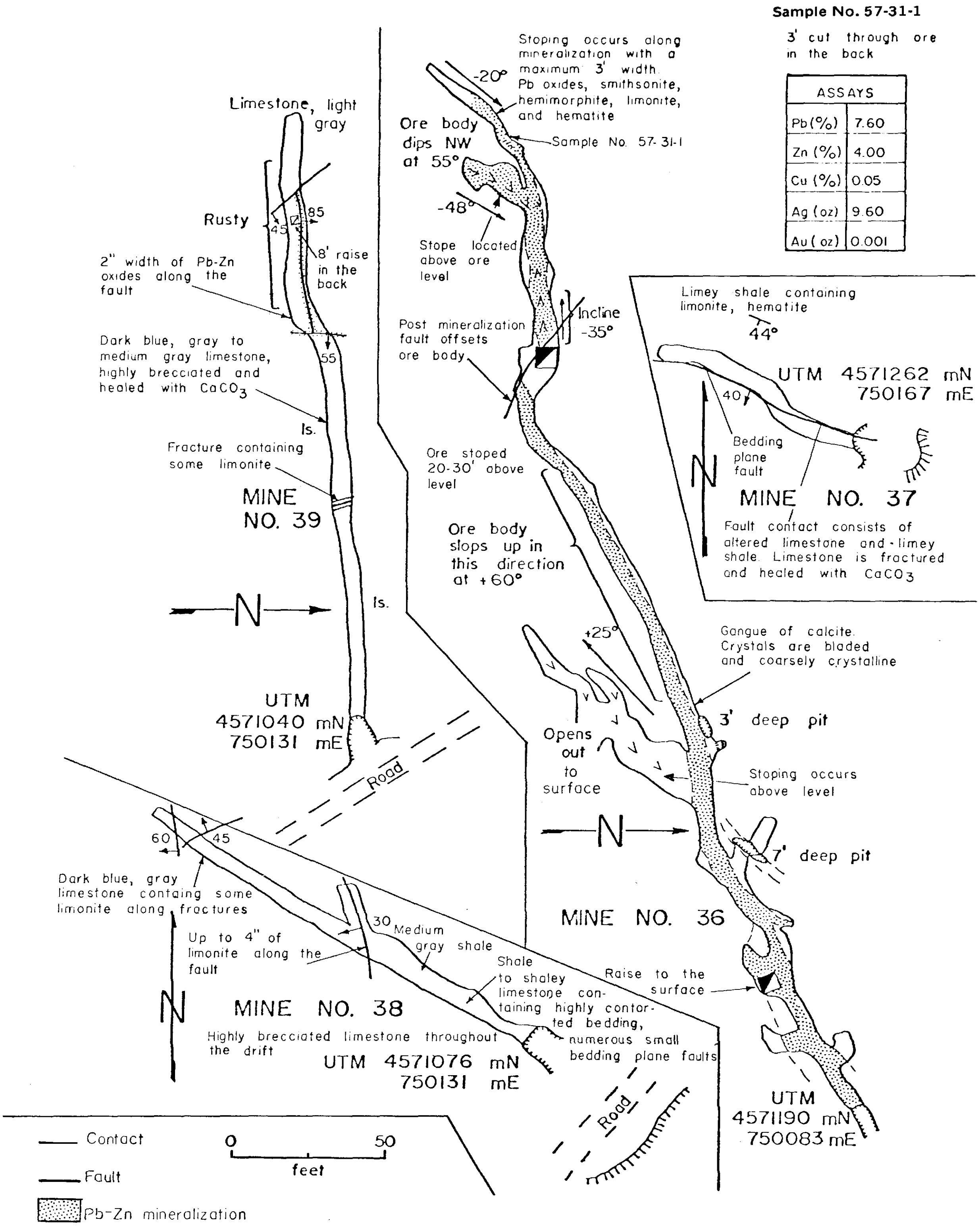
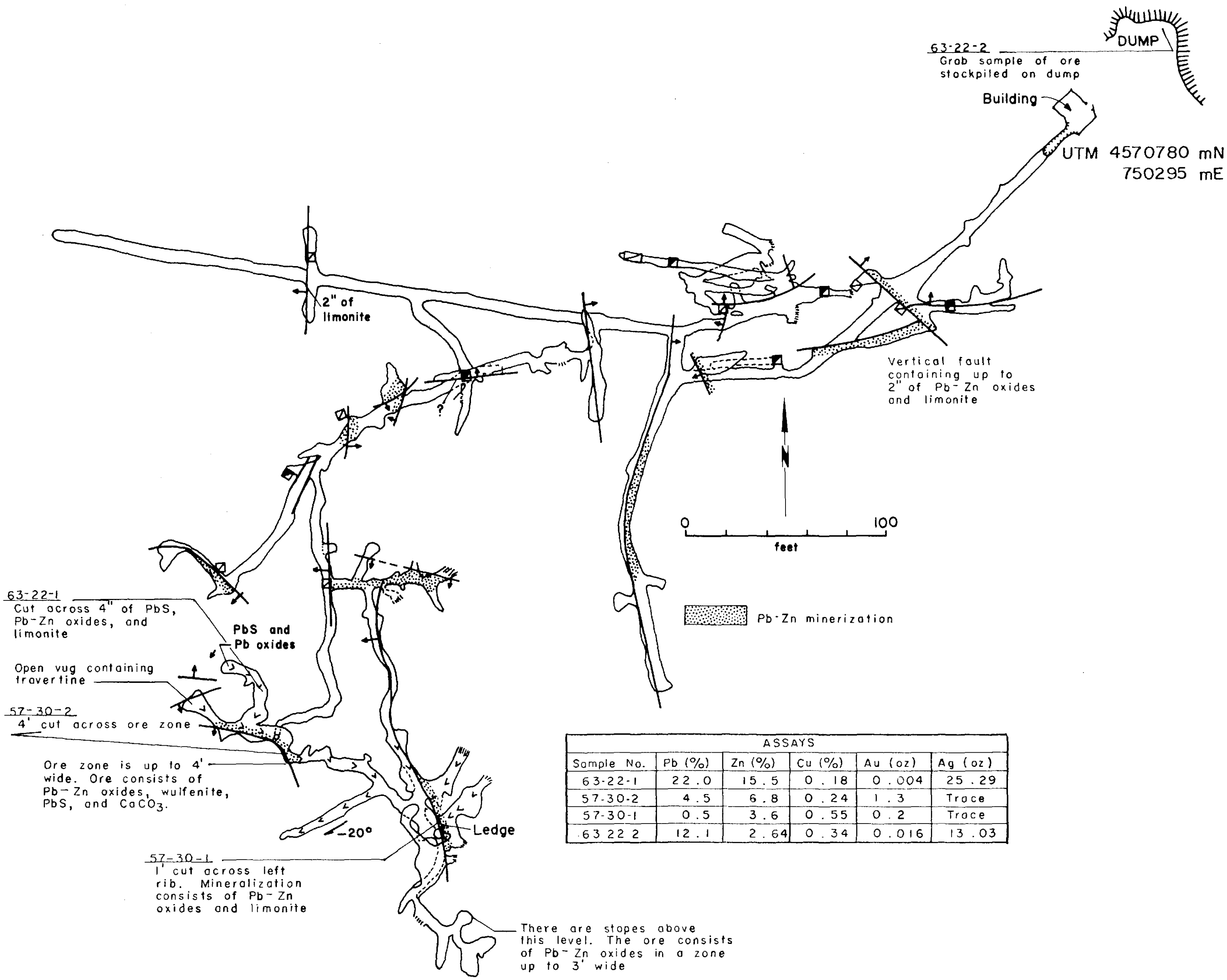


Figure 26. Copper Mountain mines and prospects, Lucin mining district.



ASSAYS					
Sample No.	Pb (%)	Zn (%)	Cu (%)	Au (oz)	Ag (oz)
63-22-1	22.0	15.5	0.18	0.004	25.29
57-30-2	4.5	6.8	0.24	1.3	Trace
57-30-1	0.5	3.6	0.55	0.2	Trace
63 22 2	12.1	2.64	0.34	0.016	13.03

Figure 27. Copper Mountain mines and prospects, mine no. 40, (Walker tunnel).

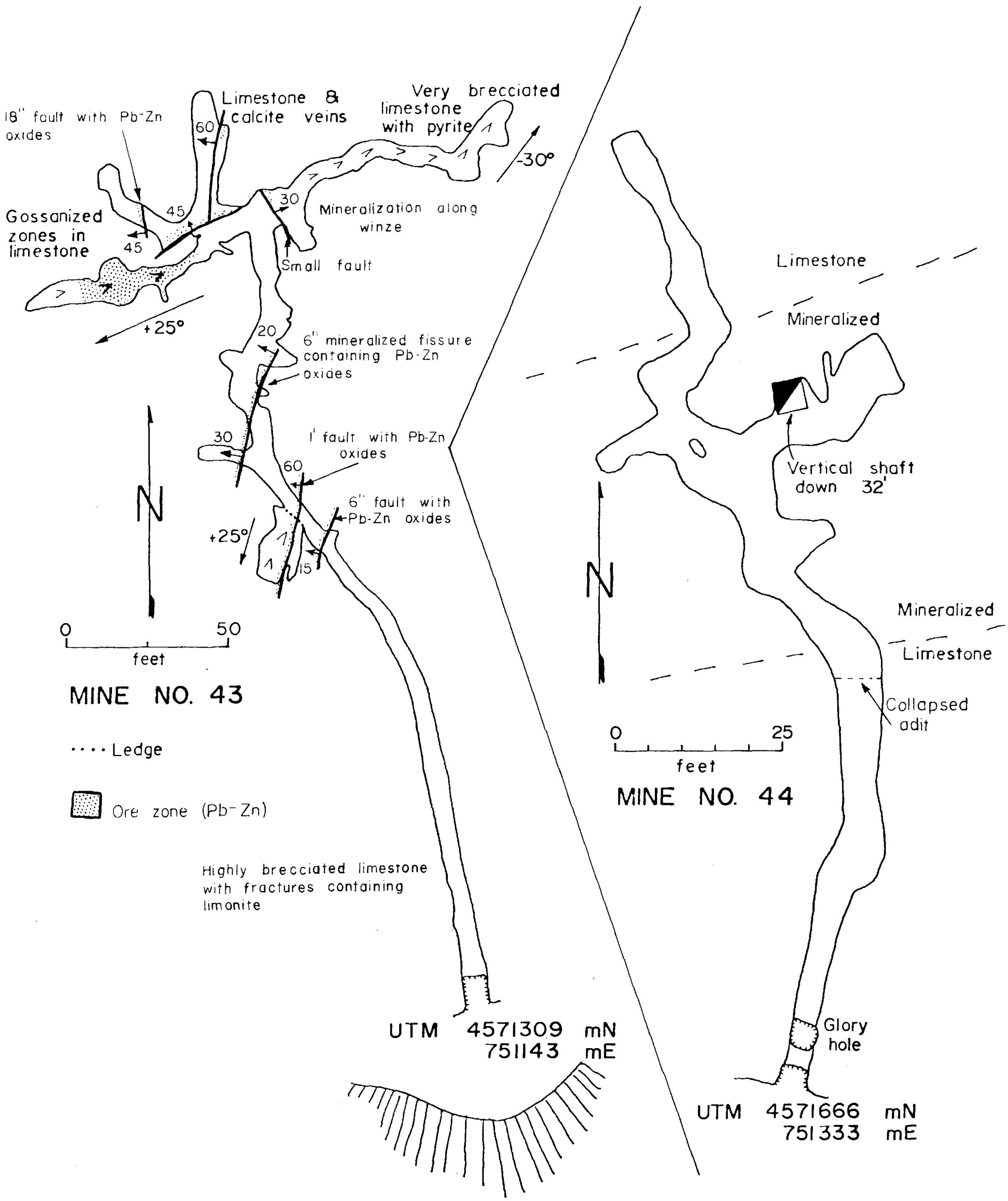


Figure 28. Copper Mountain mines and prospects, Lucin mining district.

and very little ore, if any, has been produced. Those prospects (Nos. 45-47 on figures 29 and 30), just north of the Black Warrior mine along Nevada State line explore contact mineralization between monzonite porphyry and Laketown or Simonson Dolomites. The carbonate rock is bleached and marbleized and an epidote-garnet skarn is found along the contact. There is only an occasional hint of metals mineralization in the form of malachite stains. Farther north in sections 4 and 5-6N-19W, prospects occur in badly faulted lower Paleozoic carbonate rocks along northwest-trending fissures that parallel a fault separating the Simonson from the Laketown Dolomite. The carbonates are bleached and in places tremolitized. The fissures contain quartz, limonite, and copper staining. The workings include a 15-foot adit, an 18-foot inclined shaft, a pit 8 x 8 x 8 feet and 5 small pits all on one fissure near the top of a hill. The UTM location for the center of these workings (No. 48) is 4572340 mN and 748120 mE; they have not been mapped.

Mine No. 49 is cut in unaltered carbonate rock and shows no mineralization (figure 31). The group at No. 50 (figure 31) consists of three workings on three northeast-trending fissures in light gray carbonate country rock. The fissures contain siliceous limonitic and hematitic material abundantly stained with malachite and azurite and the country rock is bleached in their proximity. 50-a is a short incline following a thin, weakly mineralized zone trending N. 30 degrees E. Mine No. 51 (figure 31) is very old and the dump is overgrown with vegetation. It is cut in weakly limonitized carbonate rock and a little barite, limonite, and siderite are present on the dump near the portal. Lead-silver may have been the objective of the prospectors that opened this mine.

Crystal Cave Area Mines and Prospects (Lead-Silver-Zinc)

All of the prospects of this area (figures 32,33,34) are in 33-7N-19W in the Guilmette Formation, and each is located on a limonitized fissure trending east or northeast. At Mine No. 56 (figure 33) cerussite and pyrite are present; this incline is cut along the best known mineralization in the area. Mine No 57 (figure 34), about 540 feet long, was dug to intersect the vein of No. 56. A fissure with slight to medium limonitic mineralization was intersected half-way. Crystal Cave was discovered at the end of the tunnel and prevented further development. Large masses of translucent calcite are found in the mine.

Other Prospects around the Lucin District (unmapped)

A prospect located in SWNE 36-7N-19W, UTM 4574575 mN, 251190 mE, consists of a shaft 12 feet deep in gossanized limy sandstone. The length and width are 3 x 6 feet and the entire shaft is walled with boards to prevent caving. The rock is crisscrossed with calcite veinlets and between the crisscrossing is a porous limonitic sandstone with noticeable boxwork cavities. Limonite is the only observable mineral and the mineralization appears local.

A small mine is found in SE 14-7N-19W, UTM 4578250 mN, 250110 mE, near the north end of the Pilot Range. The adit trends roughly 36 feet southward and is accompanied by two neighboring prospect pits. Mineralization is primarily limonite. A layer of brecciated limonitic material (Eisenhut) covers a hard limestone of the Guilmette Formation.

A small pit found on the west side of Gartney Mountain, SW 1-7N-19W, UTM 4581845 mN, 251075 mE, is three feet deep. It has been dug in limonitized limestones; a short distance east of the prospect are two or three north-south trending white quartz veins. The maximum length of these veins is about 50 feet with a maximum width of three feet.

Tecoma or Jackson Mining District (Silver, Zinc)

To the north of the Lucin mining district across Utah Highway 30 is an area known as the Tecoma or Jackson mining district (unmapped). It is mostly in Nevada, but a few prospects extend into Utah. The geology and mineralization are much like that in the Lucin district. The country rock is Devonian limestone over-lain by a quartzite (Guilmette Formation?) and the ore occurs as irregular replacements along northwest-striking fissures. The ore is cellular cerussite, limonite and smithsonite that is rich in silver. Nearer to the Utah border the prospects and mines have notably been rich in zinc. One of the more important mines was the Queen of the West located ¼ mile west of the Utah line; it shipped ore than ran 18 percent zinc and 80 ounces of silver per ton. The prospects in Utah appear to have had little production and have little potential. Three prospects were visited. The first is a vertical shaft 8 feet deep and 4 feet square cut in a contact between very cherty limestone and gritty olive-green conglomeratic rock. The mineralization consists of limonite and a 2 to 3-inch band of white powdery material. The shaft is in SE

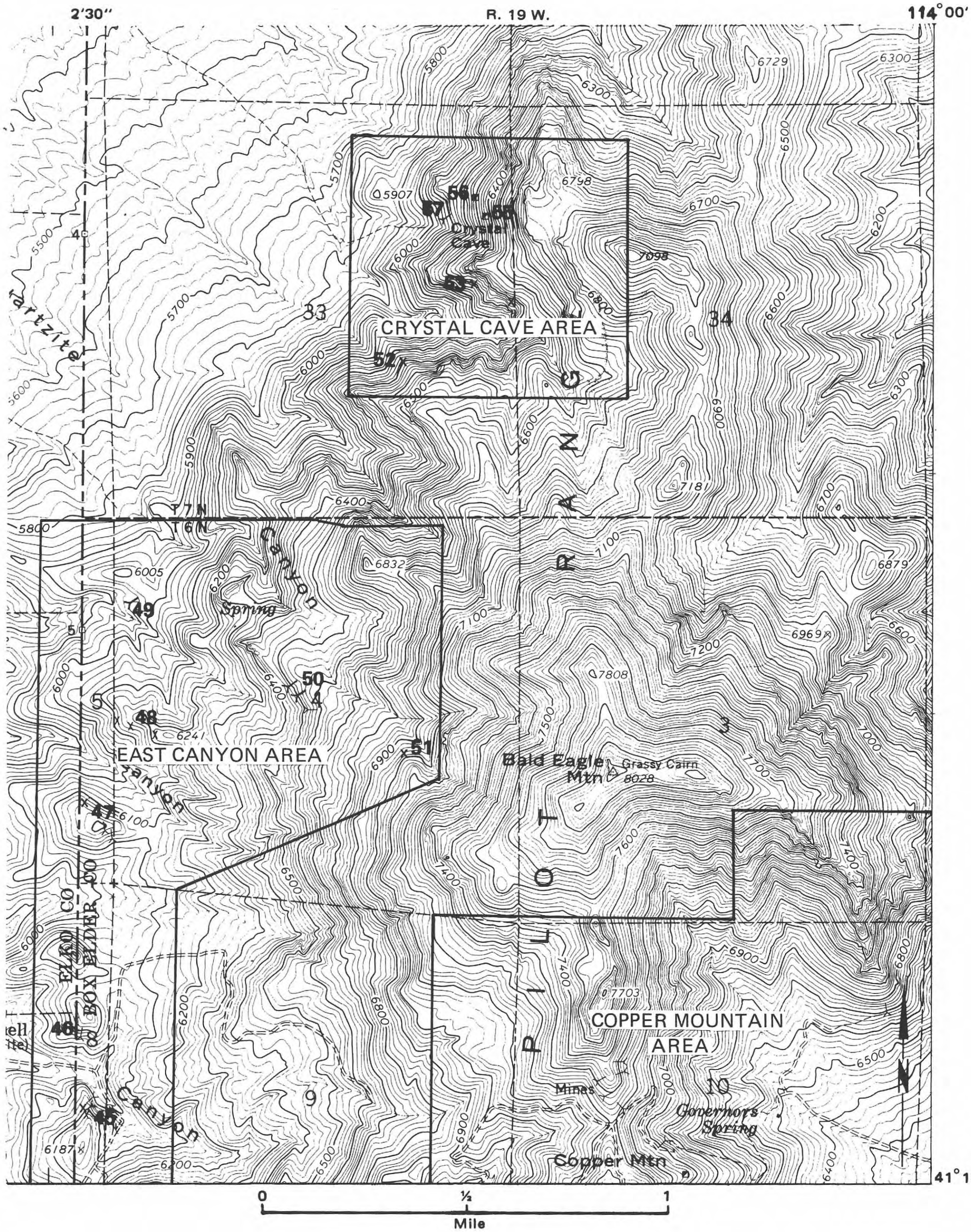


Figure 29. Mines and prospects in the East Canyon and Crystal Cave areas, Lucin mining district.

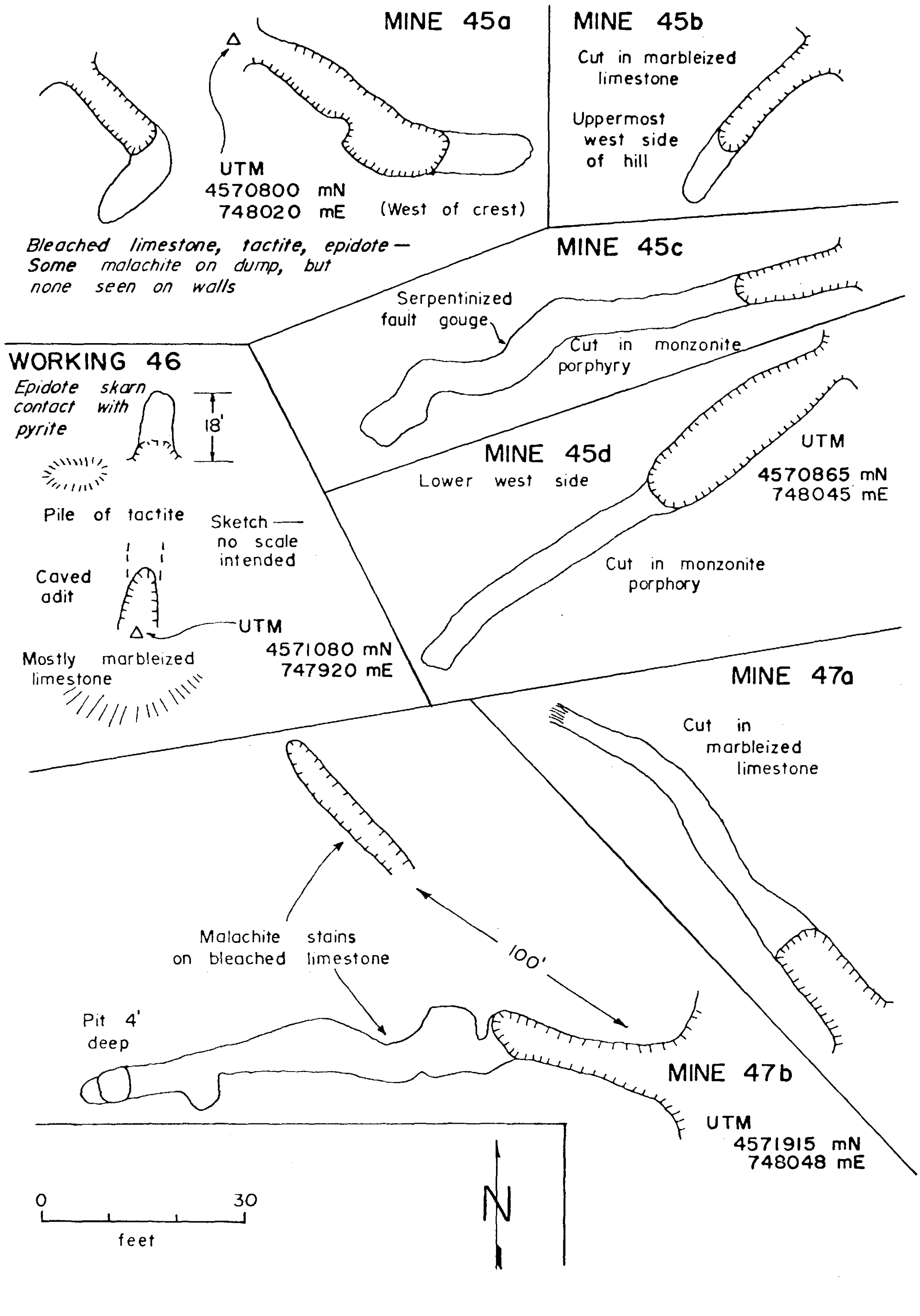


Figure 30. East Canyon area mines, Lucin Mining district.

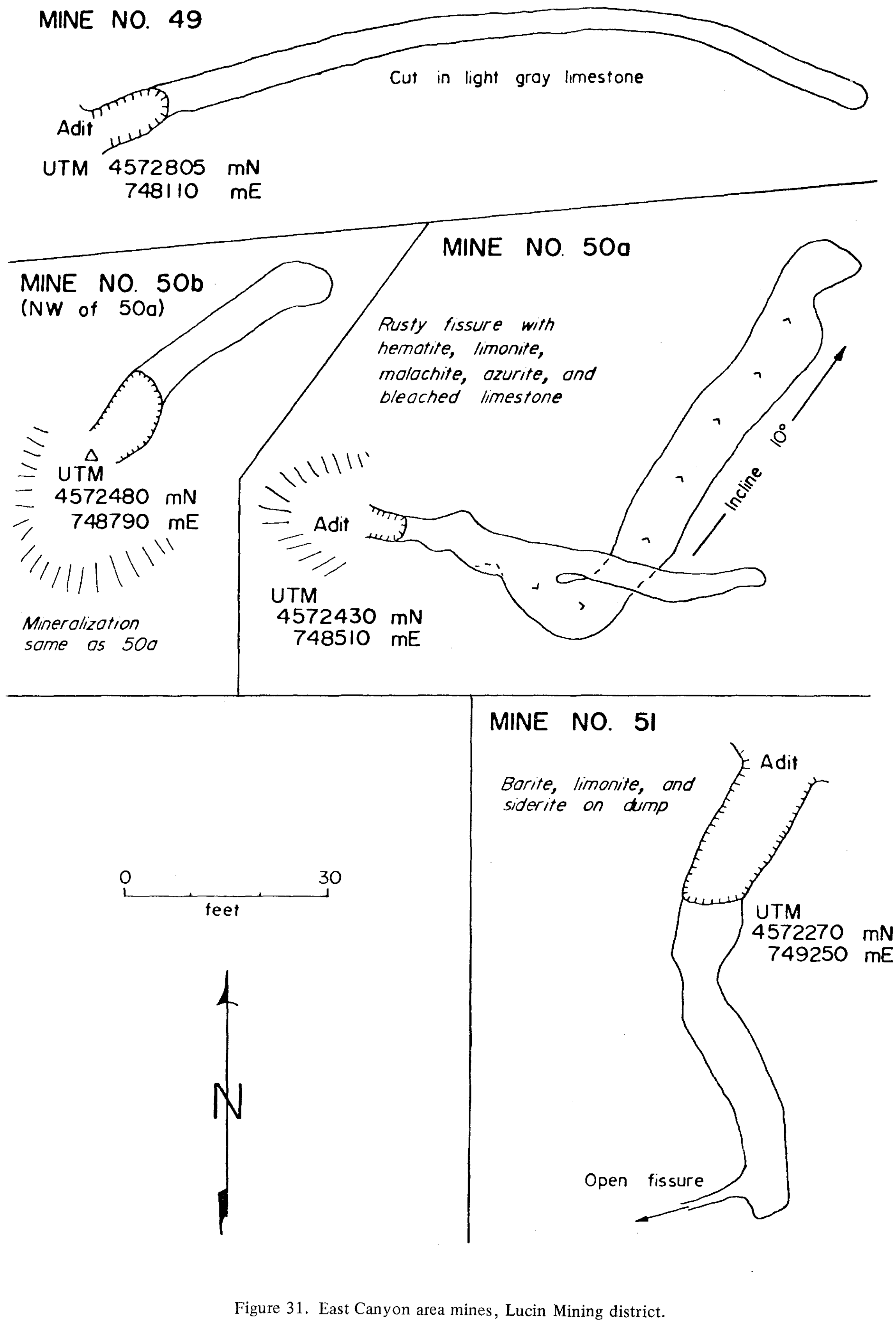


Figure 31. East Canyon area mines, Lucin Mining district.

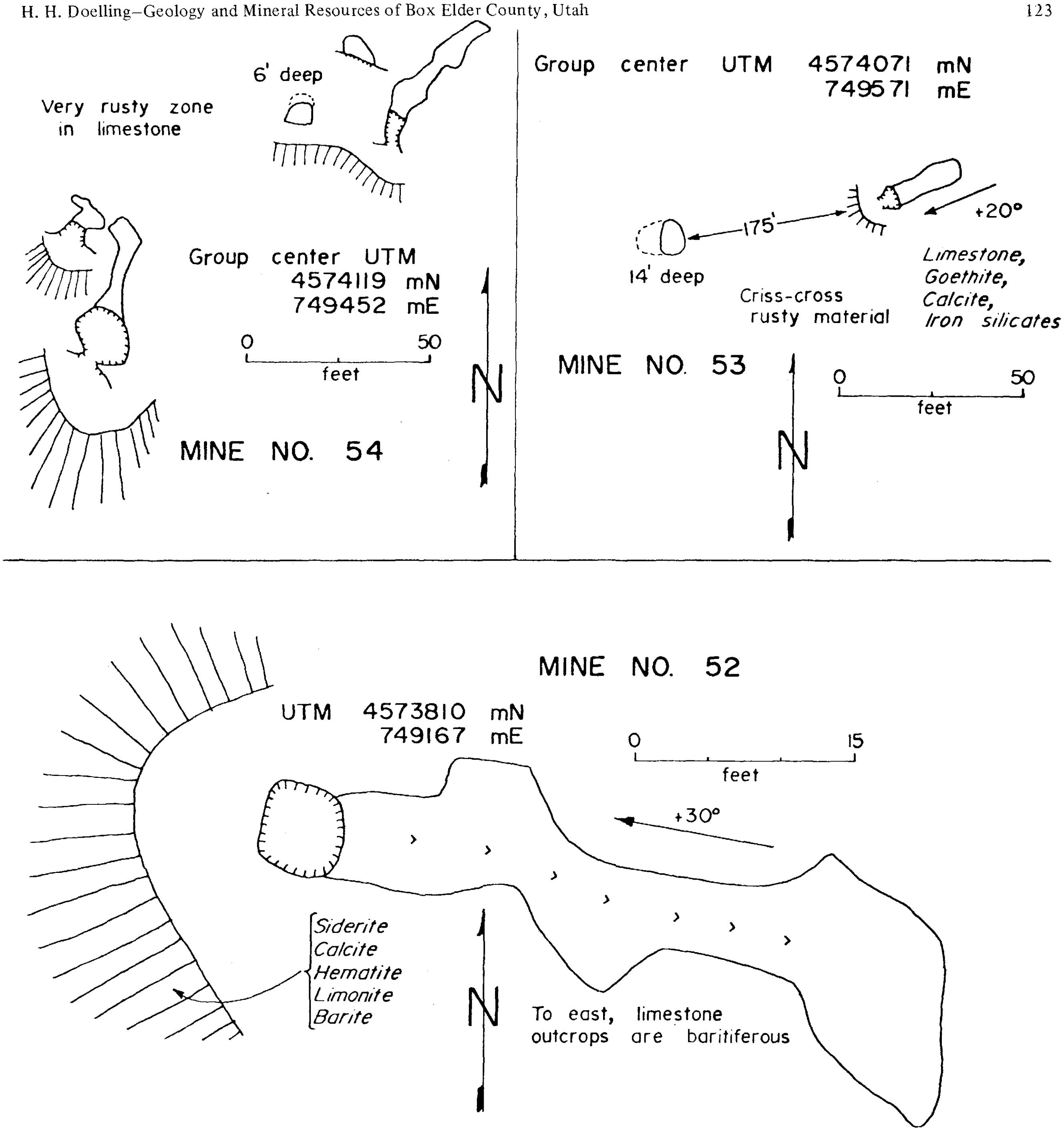


Figure 32. Crystal Cave area mines and prospects, Lucin Mining district.

9-8N-19W, UTM 4589555 mN, 748830 mE. The second is a shaft 4 feet square and 36 feet deep in SW 27-9N-19W, UTM 4594615 mN, 749170 mE. Dump material is limonitic and hematitic limestone. The third prospect consists of a series of cuts, pits, and short adits in NE 34-9N-19W, UTM 4593860 mN, 749645 mE. The country rock is limestone, weakly mineralized with traces of copper.

Black Sands Area

(Titanium)

South of Lucin station on the Southern Pacific Railroad, and principally on the east side of the Pilot Range, are alluvial black sands, the weathering product of the Patterson Pass Monzonite. Located areas are

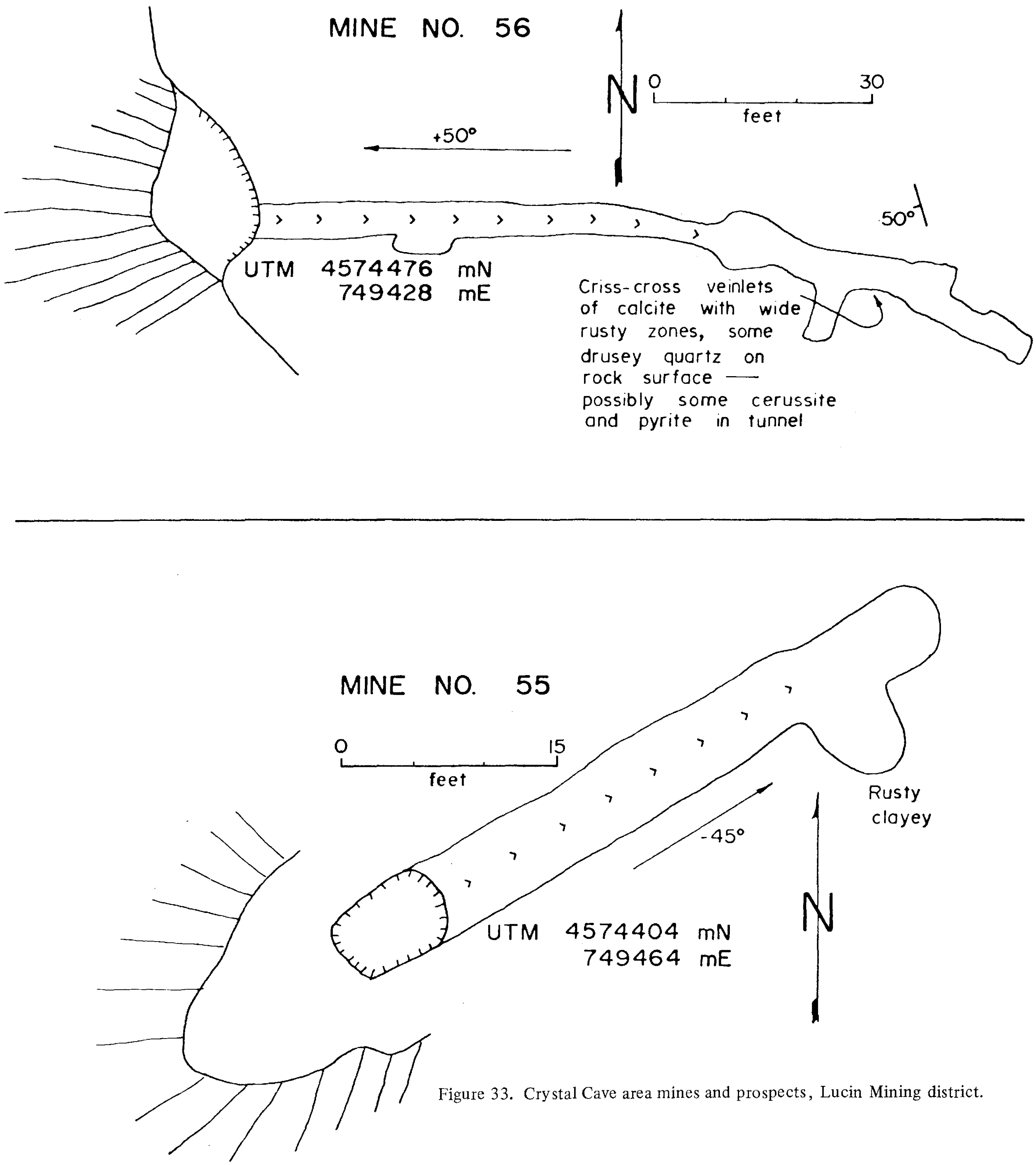


Figure 33. Crystal Cave area mines and prospects, Lucin Mining district.

shown on figure 35 and include sections 22 and 36-7N-19W, 31 and 32-7N-18W; 1, 2 and 12-6N-19W, and 6-6N-18W. No work has been done to determine the thickness and thus the quantity of such sands. Each quarter-section of this area has been sampled yielding the results shown in table 3.

Another sample analyzed by Rogers Research & Analysis Co., Bountiful, Utah 84087, yielded 12.48 percent iron and 2.382 percent titanium. A Mr. Hunter of the U. S. Bureau of Mines' experiment station at Albany, Oregon, has managed to obtain a 70 percent titanium slag from these black sands. If the average

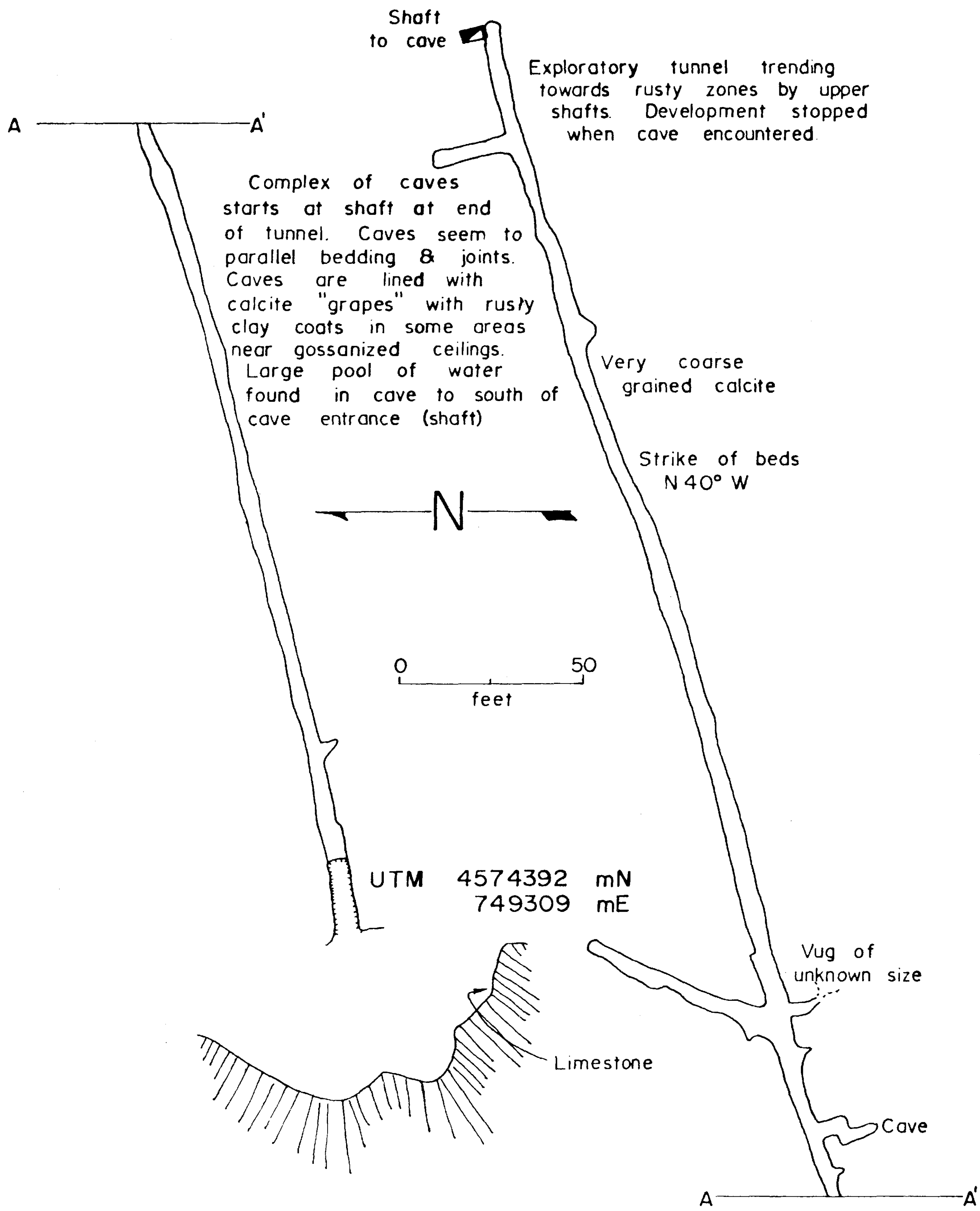


Figure 34. Crystal Cave area mines and prospects (mine no. 57), Lucin Mining district.

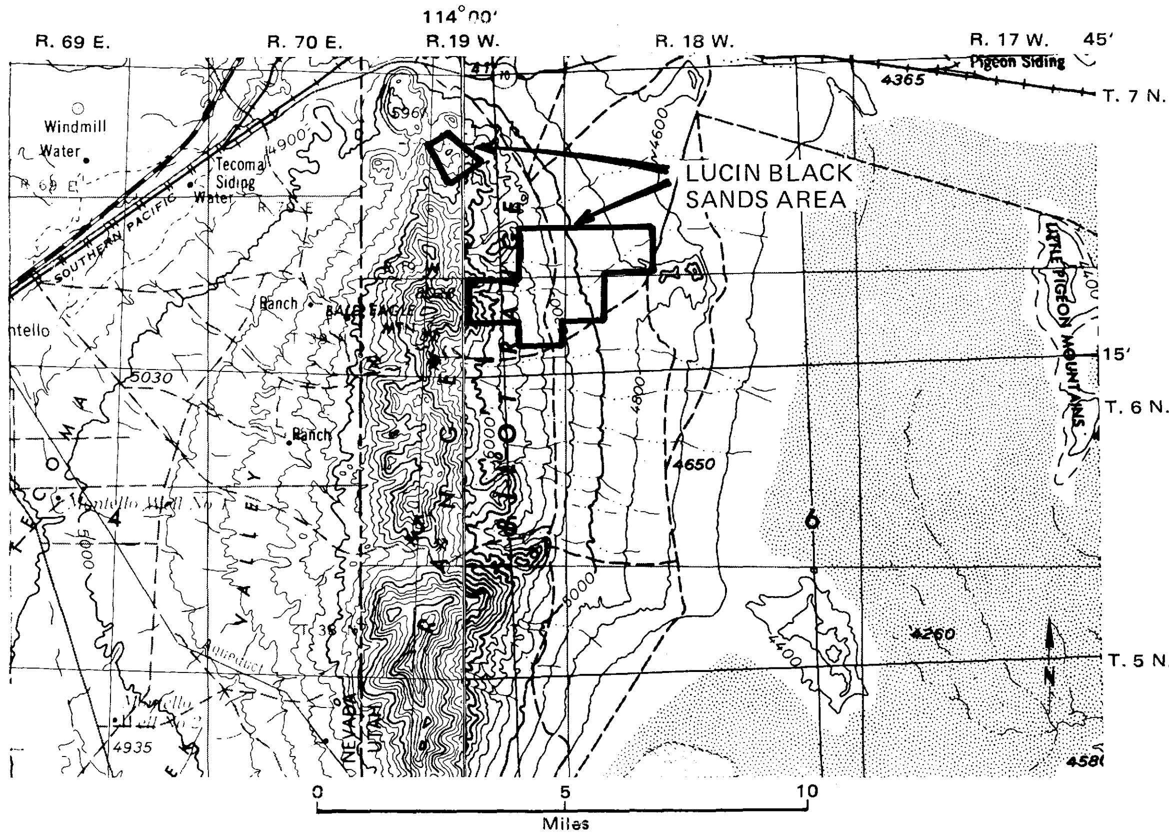


Figure 35. Titanium-bearing area.

ilmenite content is 110 pounds per cubic yard, a square mile would yield about 165,000 tons of ilmenite to a depth of one yard.

Crater Island Mining District

The Crater Island mining district (figure 36) is located in the southwest part of Box Elder County at the northern end of the Silver Island Mountains about 12 miles southeast of the Lucin mining district. It is about 25 miles northeast of Wendover, Utah, the nearest town and paved road. Crater Island is a mountainous mass approximately six miles long north-south and 4 miles wide east-west. It is separated from the major part of the range by a narrow neck or bar of gravel called the Donner-Reed Pass. Otherwise this mountain would be a true island surrounded by the mud-flat "sea" of the Great Salt Lake Desert.

Claiming of the mineral occurrences commenced about 1873 but no production was reported until 1908. In earlier years the district was regarded as an area of the larger Silver Island mining district (mostly in Tooele County), but the term Crater Island district began to be used after 1901. It is impossible to separate the value of the Box Elder County portion of the district as records were generally combined. The Silver Island district was important for silver, lead, copper, and a small amount of gold.

Butler (1920) reports that from 1908 to 1913 the Silver Island mining district produced metals valued at $90,219, but Anderson (1960, p. 159) thinks that almost all production was from the Carrie Mack mine in Tooele County. Bureau of Mines' Mineral Yearbooks show that the Crater Island mining district was active between 1934 and 1948, when 94 ounces of gold, 1,194 ounces of silver, 23,666 pounds of copper and 91 pounds of lead were produced and valued at $7,854. Recently, tungsten deposits were discovered on Crater Island; there was no production through 1974, but development work was being carried out.

Geologically, Crater Island is a mass of Paleozoic rock, badly broken by north-south trending faults and intruded by granitic rock (quartz monzonite and granodiorite) (figure 37). The largest outcrop of igneous rock, the Crater Island stock, is at the south end of the

Table 3. Black sands analyses in pounds per cubic yard

Location	Total black sand	Ilmenite	Magnetite	Zircon
Section 22 NW¼	359	140	218	Unknown
NE¼	397	129	254	13.5
SE¼	383	78	294	10.8
Section 1 SW¼	267	165	202	Unknown
NE¼	216	135	61	20
Section 2 SW¼	232	129	103	Unknown
Section 36 SE¼	251	143	108	Unknown
Section 31 SW¼	305	162	143	Unknown
Section 6 SW¼	189	68	121	Unknown
NE¼	196	71	125	Unknown
SE¼	177	59	118	Unknown
Section 32 NE¼	163	49	114	Unknown
Average of 12 samples	270	111	155	- - -

island. Some smaller intrusive outcrops occur at Desolate Point to the southeast, and two outcrops, the North and Sheepwagon stocks, each one mile by ¼ mile, are found to the northeast. The Paleozoic rocks are dominated by carbonates.

The mines and prospects of Crater Island are mostly scattered on the east side of the mountain mass. Anderson (1960, p. 160) notes that the mineralization is limited to (1) portions of the tactite zones between the granitic and Paleozoic rocks, (2) quartz and calcite veins, and (3) slight random occurrences in the highly jointed Swan Peak Quartzite. Some faults show local iron-staining and alteration. Mineralization has been noted in Ordovician, Cambrian, and Permian rock and to a slight extent in the granitic rocks.

Copper Blossom and Desolate Point Areas (Copper-Tungsten)

Most of the metal values for the Crater Island mining district have come from the Copper Blossom property, NE 22-4N-17W, which is located at the contact between the Crater Island stock and Permian limestones (figure 38). The last operation of the mine was in 1948 but some development work has followed. Presently (1974), the mine appears abandoned; there are ruins of an old ore chute and the foundation of a building that may have been a mill. The workings consist of a short adit which leads to a caved shaft, several cuts at right angles to the contact, at least 2 inclines and a few shallow shafts. The contact zone is 50 to 100 yards wide near the mine. The quartz monzonite is medium-grained, equigranular (each grain a millimeter or two in diameter) and contains inclusions or xenoliths of finer-grained igneous rock and marble. The identifiable minerals include pink orthoclase, gray plagioclase, some hornblende (or pyroxene), biotite, and the overall color is medium gray. Some fractures are epidotized. Small limonite pseudomorphs after pyrite are found in the fractures and a few thin aplitic dikes cut the rock. The monzonite appears to alternate with the marble; the latter is highly granular, but retains vestiges of its former bedding. In places there is altered (silicified) limestone of light (bleached) to dark (baked) color containing selective bands of epidotized or garnetized rock. Some limestone beds are heavily coated with limonite. Observed minerals include andradite garnet, azurite, malachite, chrysocolla, chalcopyrite, bornite, epidote and quartz. The sulfides are rare.

At Desolate Point are Ordovician quartzites, which in places appear extremely pure and gray white, in other places strongly limonitized along fractures. A least two pits have been dug where the limonite is prominent and there is some pyrite and copper stain. The limestones near the igneous contacts on Desolate Point are marbleized or bleached and, in a few places, epidotized. Here and there a speck of scheelite or powellite is visible.

East Central Crater Island Prospects (Copper)

These unmapped prospects explore calcite or quartz-filled fissures between the Copper Blossom mine and the northern end of the mountain mass. There are three prospect pits high on the west-facing slope of a ridge in the Garden City Formation in NE 12-4N-17W. The fissured rock trends north-south and dips 75-80 degrees east while the strata dip westerly about 30 degrees. The fissures are limonitized, showing stains of malachite and chrysocolla and minor azurite and a few specks of chalcopyrite and bornite. One fissure, about

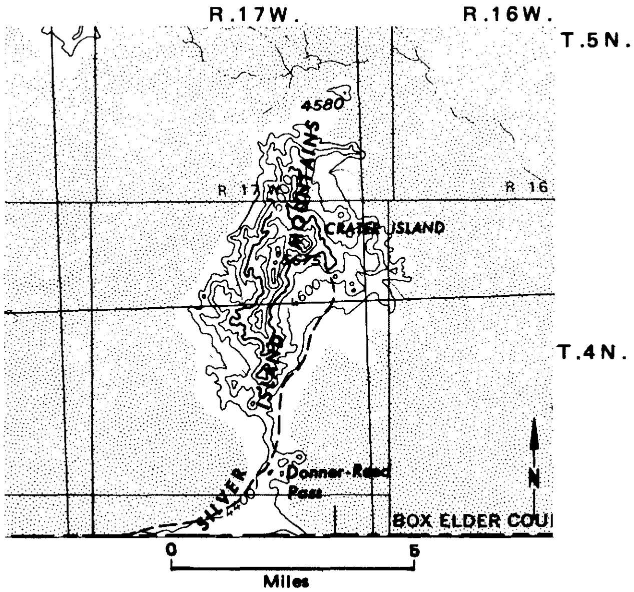


Figure 36. Crater Island mining district location map.

300 feet long, has two pits dug along it; they are 100 feet apart, the southernmost one is 15-20 feet deep, the other about 50 feet deep. An additional small pit is located near a saddle on the crest of the ridge in a less-well developed paralleling fissure 150-200 feet to the east. Copper stains are present.

Other workings examined in NW 1-4N-17W are in Upper Cambrian dolomite. A working is found on each of two paralleling fissures; the only observable mineralization is weak to moderate limonitization reminiscent of lead-silver deposits in the Lucin mining district. The northeasternmost pit consists of a steeply inclined shaft of undetermineable depth along with drifts extending along a level. The other pit is shallow.

Another limonitized calcite vein is located in SWNW 12-4N-17W in the Devonian Guilmette Formation. A few shallow adits and pits follow the copper staining.

Sheepwagon Stock Prospects (Tungsten, Molybdenum)

These mineralizations were discovered by a Mr. Taylor, Box 52, Wendover, Utah, and are found along the southwest boundary of the Sheepwagon stock. Minerals noted along the contact of the granodiorite with Ordovician limestone or dolomite consist of garnet, limonite, epidote, quartz, powellite, scheelite, and molybdenite. There are also small amounts of pyrite and copper minerals. The length of the contact zone may be half-mile in length; the interesting width is 5 to 15 feet. The tungsten is of low grade and Mr. Taylor planned to mill the rock near the diggings (1974). Samples were taken from two of the pits and channeled across the contact without the benefit of a black light. The northwesternmost pit contains much garnet and the 4-foot channel yielded 0.34 percent WO_3. A 3-foot channel taken at a pit to the southeast (where the road bends) yielded only 0.13 percent WO_3.

Newfoundland Mining District

The Newfoundland Mountains (figure 39) are located in the north-central part of the Great Salt Lake Desert, in the southern part of western Box Elder County. The mountain range is completely surrounded by mudflat, and the nearest paved road is 35 to 40 miles distant, but the Southern Pacific Railroad passes along its northern point.

Copper, gold, silver, lead, bismuth, tungsten, and molybdenum, are mentioned in reports concerning the Newfoundland Mountains. All of the important workings are in the northern half of the range, but small mineralized prospects are known to be scattered from one end of the 20-mile long mountains mass to the other (Paddock, 1956, p. 94).

The district was organized in 1872 and claiming and development work were the principal activity to 1900. The remote environment and lack of railroad made it almost impossible to ship ore. In 1904 the *Salt Lake Mining Review* reported that there were 10 shafts, 30 to 285 feet deep, and that a small lot of ore shipped to Salt Lake City by wagon team assayed 18.9 percent lead, 27 percent copper, 86.5 ounces silver and $1.20 in gold. As soon as the railroad was completed reports of activity ceased, and one might assume that after a small amount of high grade ore was shipped the balance proved too marginal to pay the cost of shipping. Several small shipments were made during World War I and more activity followed from 1927 to 1929. The marginal nature of the ore is exemplified by a U. S. Bureau of Mines' *Minerals Yearbook* (1919) remark: "According to the statement of the operator, lead ore containing copper and silver produced from the King Extension property and shipped to a smelting plant near Salt Lake City, did not pay transportation and treatment charges under the high rates for freight and smelting which prevailed in 1919."

Reports of mining activity since World War I are almost lacking, but some activity took place in the 1950's for copper and tungsten. In 1957, 1,800 pounds

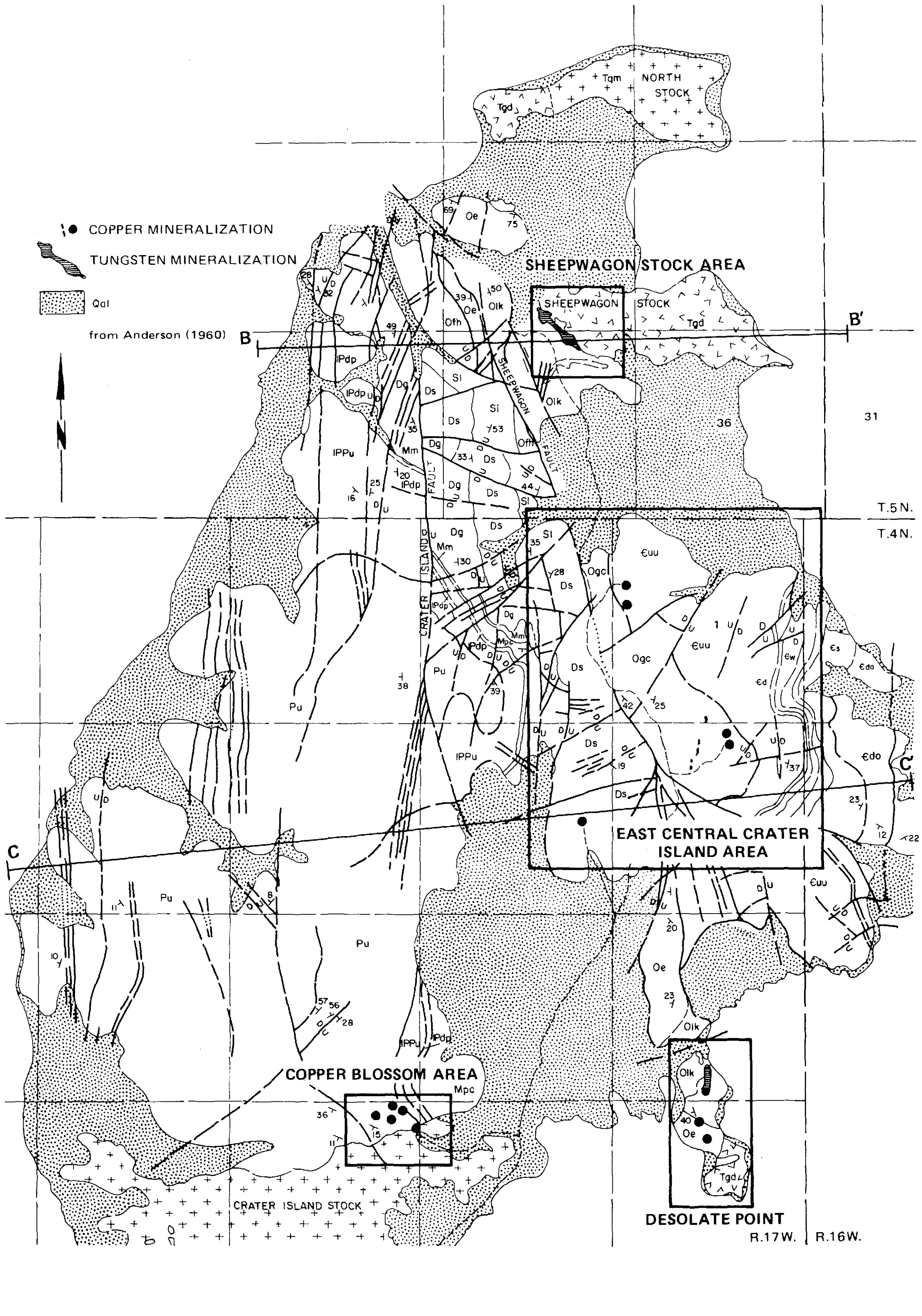


Figure 37. Geology and mineral deposits of Crater Island

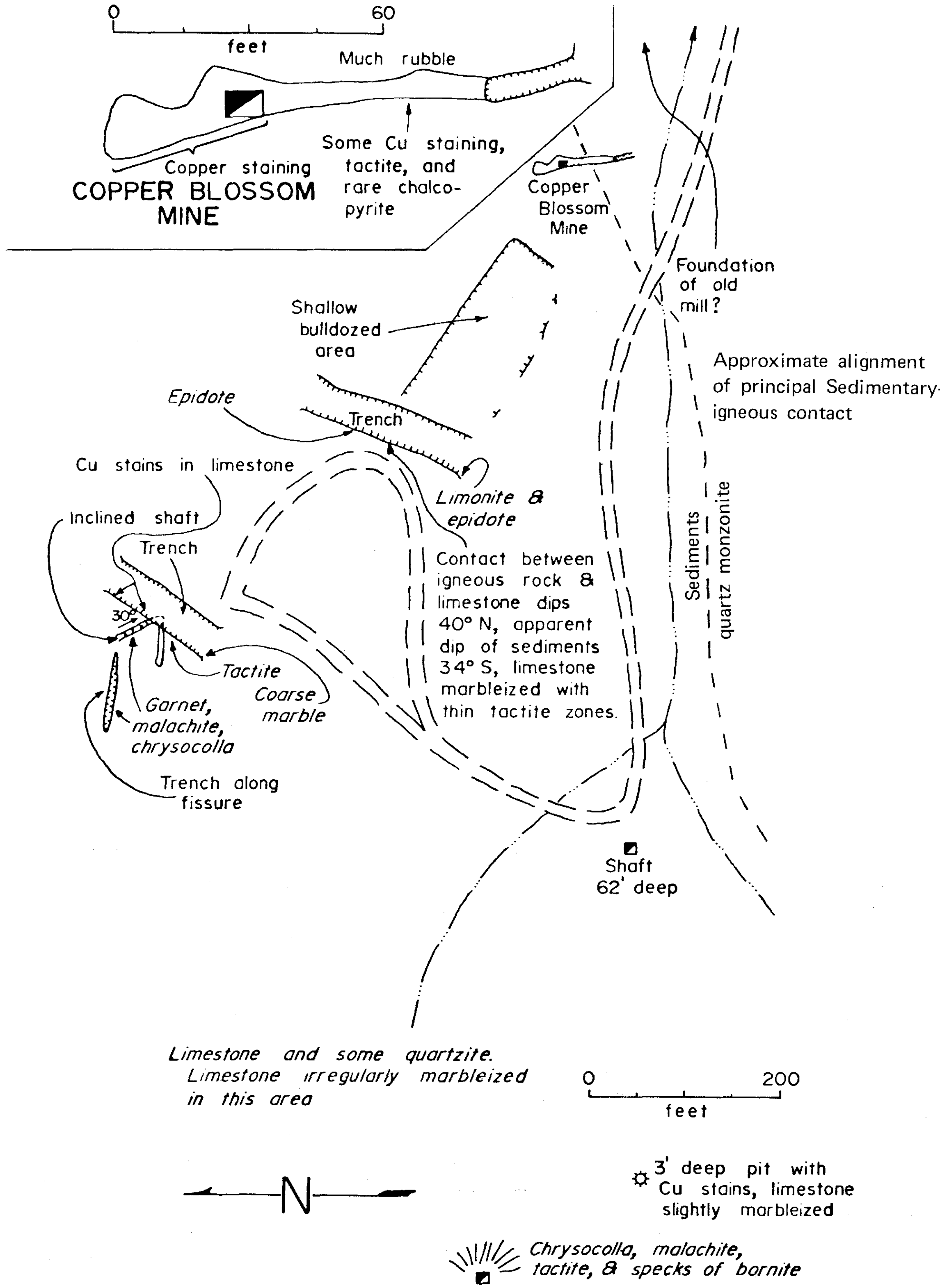
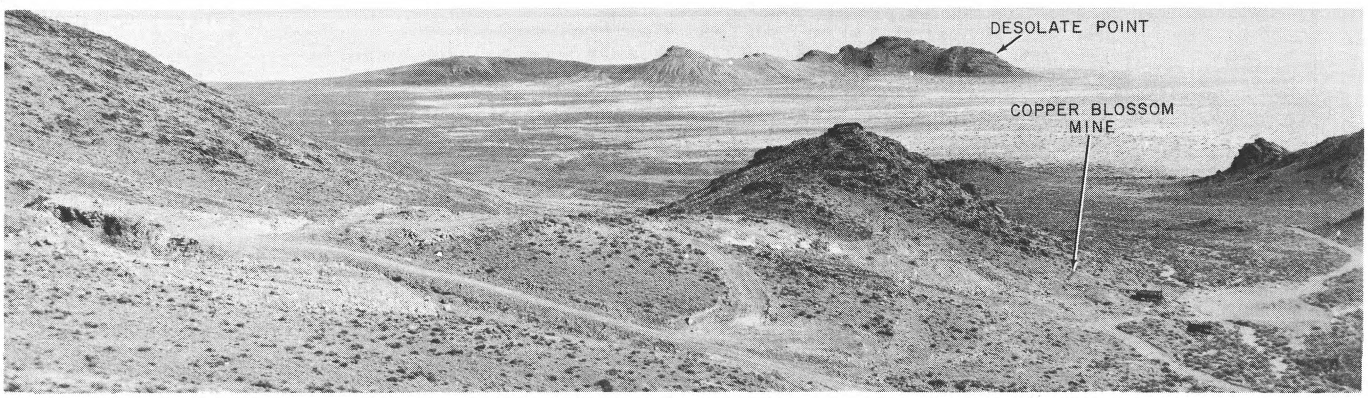


Figure 38. Sketch map of Copper Blossom area, Crater Island mining district.

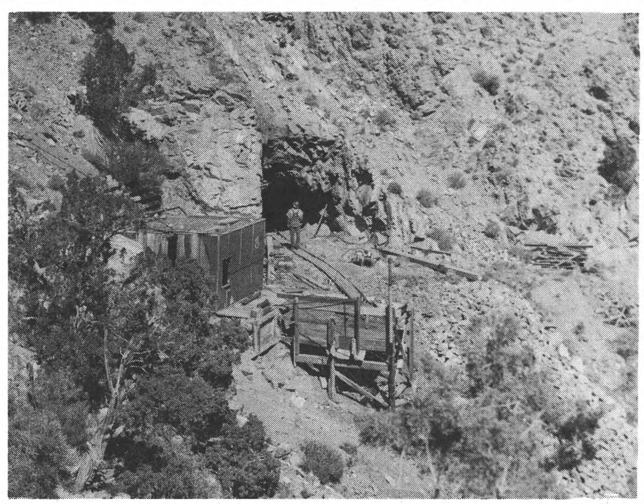
P 1. Lucin mining district; workings on west side of Copper Mountain.

P 2. Large opening just north of the Henry tunnel of the Tecoma Hill mine.



P 3. View looking easterly across the Copper Blossom area to Desolate Point, Crater Island mining district.

P 4. This cut is located just west of the main Copper Blossom mine workings and exposes a tactite zone, Crater Island mining district.



P 5. Desert Flower No. 1 tungsten mine in Pack Rat Canyon in the Newfoundland Mountains (Newfoundland mining district). Note the contact zone (see figure 46).

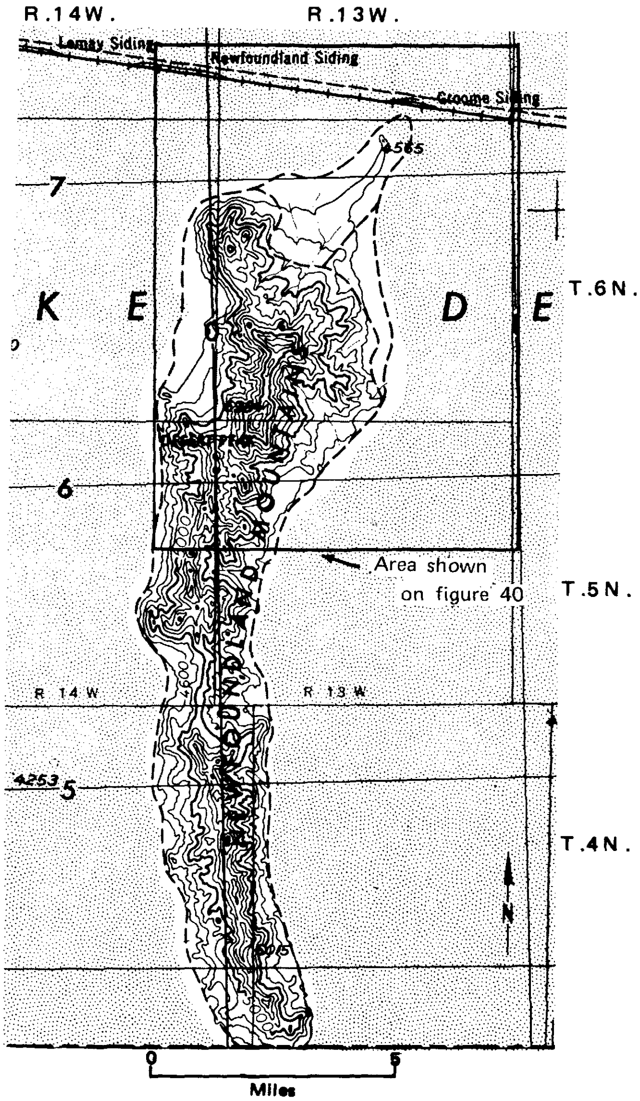


Figure 39. Location of Newfoundland mining district.

of copper worth $542 were produced and in 1955-56, 500 STU (short ton units) of tungsten were produced. A cumulative production and value figure for the Newfoundland Mountains is wanting; a rough estimate of the value of the 5 or 6 known shipments made after examining the principal mines and prospects is placed at less than $15,000.

The dominant geologic feature in the northern end of the mountain range is the Newfoundland stock (figure 40). It consists of a quartz monzonite with about nine square miles of outcrop. Some of the intruded Paleozoic rocks have been altered; bleaching, marbleization, and tremolitization of the carbonates is noticeable at many localities. Metals mineralization has occurred at the contact of the quartz monzonite and the Garden City Limestone and, more distantly, in the Swan Peak, Eureka Quartzite, Laketown and Guilmette formations.

Copper Flat Area (Copper-Molybdenum)

The Copper Flat area is located at the very north end of the Newfoundland Mountains (figure 40) scarcely two miles south of the Southern Pacific Railroad tracks in 9-6N-13W. The abandoned area includes two trailers, some collapsed mine buildings, areas for leaching the copper ore, and a small garbage dump containing many empty crates and bottles once containing sulfuric acid. A 1951 date on the sulfuric acid crates and a 1917 date on a powder box found within the mine emphasizes the intermittent activity. The main working (figure 41) consists of at least 1,000 feet of drifts and inclines and a shaft from the surface. The highly silicified cherty rock within the mine is intruded by thin dikes that are clayey and limonitized. Weak copper shows are along the incline that extends from the surface to the lower level. The mineralized zone in the incline varies from 6 inches to 7 feet in thickness and is thought to be a fault zone striking N. 60 degrees W. and dipping 15 to 40 degrees to the northeast. Minerals in the mine include malachite, azurite, chalcanthite, and chrysocolla. Minor quantities of pyrite, chalcopyrite, bornite and possible wolframite, limonite and garnet were seen. Considerable copper remains in the incline. The workings at the lower level are wet with seeping brine; the timbers are badly rotted.

Stone House Area Mines and Prospects (Copper-Lead-Silver-Bismuth?)

The Stone House area (figure 40) has the largest collection of mines in the entire mountain range and is located on the west side about 10 miles south by road from the railroad tracks. The mines are cut in several sedimentary units at least a mile removed from the nearest igneous outcrop. Mineralization, including minor copper shows, occurs in limestones or dolomites in fissures most of which trend north or northwesterly. The workings in section 1-5N-14W are in Permian rock and consist of short adits in rusty zones.

In the S½ 6-5N-13W (figure 42) there are two long tunnels and several shorter drifts, inclines and shafts. An ancient abandoned building, presumably a roasting and milling plant with adjoining cooling tower, is located between the main workings at the end of the access road. The adits are mostly cut in carbonate rock, but a few igneous dikes are intersected. These are clayey and stained brown. Except for the limonite there are no visible ore minerals in the main workings. The long

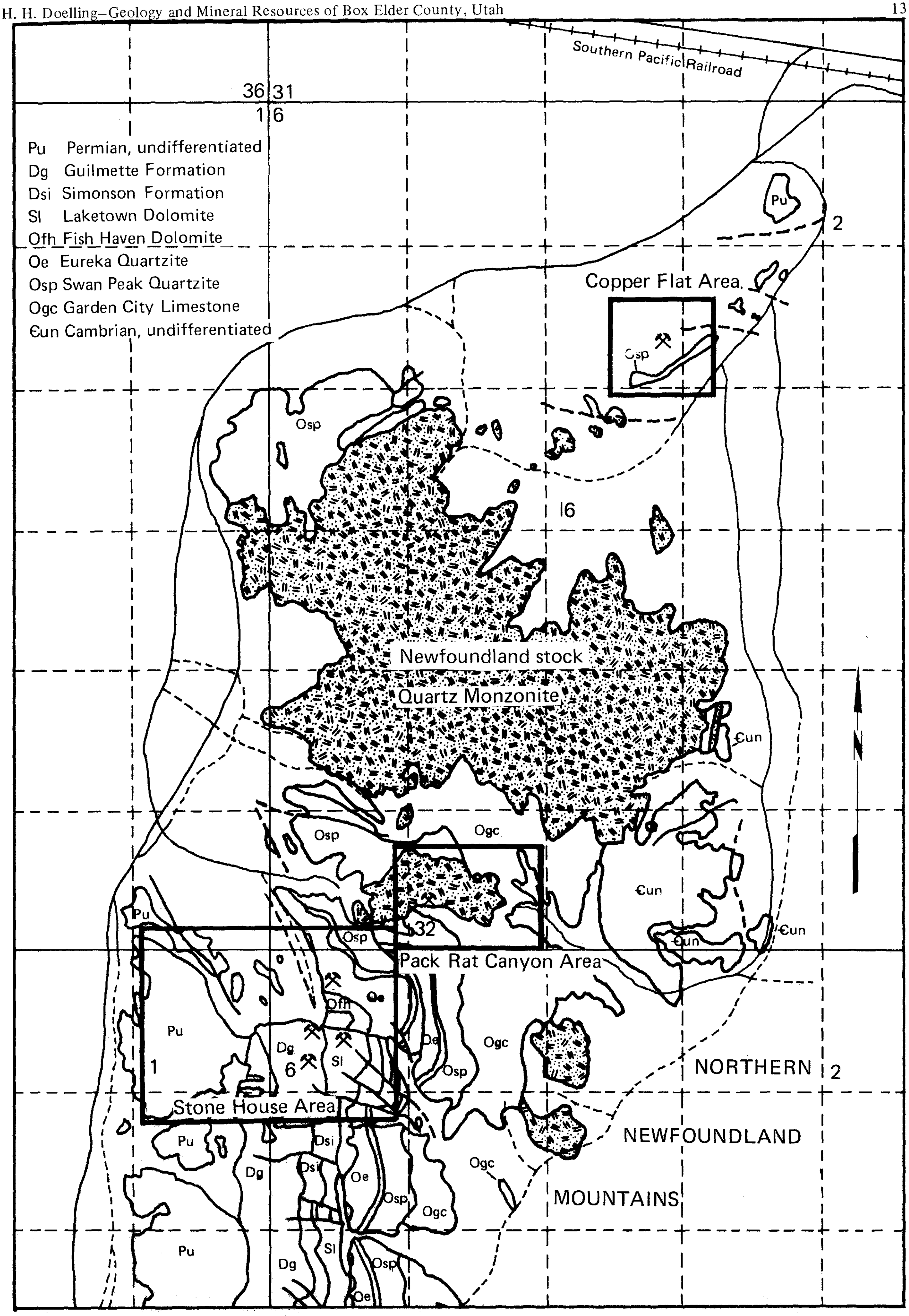


Figure 40. Mineral prospects in the northern Newfoundland Range (after Paddock, 1956).

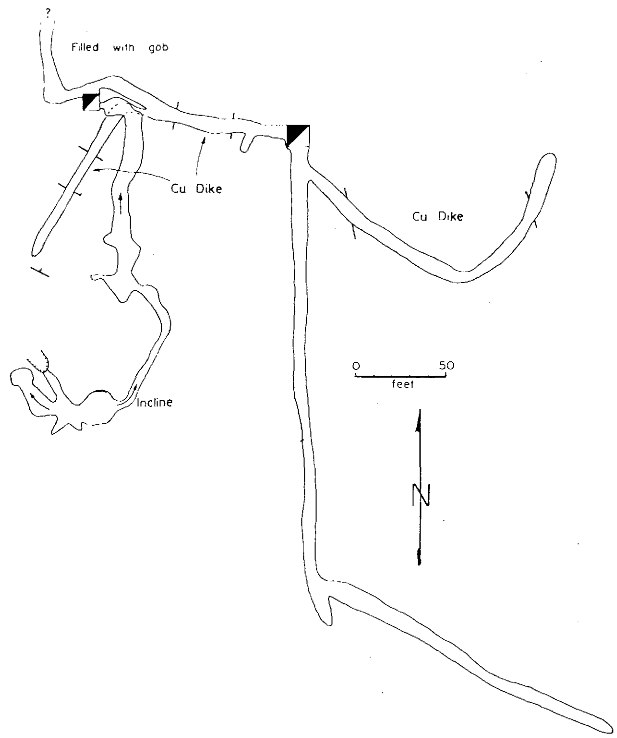


Figure 41. Newfoundland Copper mine, Copper Flat area.

straight tunnel to the west is cut mostly in unaltered rock and was driven to intersect a copper fissure exposed over a ridge to the south (figure 43). Several pits, inclines and short drifts exploit the fissure at the surface. A drift at the side of the long straight working turns southward and inclines sharply upward. This incline, not mapped because of its steepness and the general disrepair of the ladders, may connect with upper workings on the fissure.

The other tunnel, located in the gulch to the east of the cooling tower (figures 42 and 44) enters southward 200 feet into the mountain, then splits; one entry heads southeastward, the other eastward and northeastward. There are several limonitic zones, but much of the working has been cut in unaltered dolomitic limestone. The prospects above the main adit have copper shows as do the smaller workings over the ridge to the south. Malachite and chrysocolla are the most abundant ore minerals. Silver, lead, and perhaps bismuth, may have been present in small pockets in the limonitized zones of the east mine.

The mine above the stone house (Stone House Canyon mine) in the north part of 6-5N-13W is about 300 feet long and trends southeasterly (figure 45). It portals in limestone and breaks into brecciated rusty quartzite (Eureka?). Fracture surfaces in the quartzite are coated brown and have greenish to bluish casts that may carry minimal values of silver, lead, or copper. Near the end of the drift is a steeply dipping inclined shaft, estimated to extend downward at least 100 feet but not investigated. A few other minor workings are nearby.

Pack Rat Canyon Prospects (Tungsten-Copper)

At the head of Pack Rat Canyon, high on the east side of the mountain range, is a small tungsten operation (figure 46). The development is located in SW 32-6N-13W along the Garden City Limestone-quartz monzonite contact. The Desert Flower No. 1 consists of a short drift and side entry, a cable tram, and a dismembered mill. At the time of visit (1972) intermittent development work was being done. The walls of the mine show alternating limestone, quartz monzonite, and garnet skarn. The adit follows a limonitized fissure that cuts across all of the rock units. Identified minerals include limonite, chlorite, manganese coatings, muscovite, biotite, phlogopite?, grossularite, andradite, quartz, and a little scheelite, pyrite, and chalcopyrite. Around the mine tactite zones and quartz-filled fissures occur in varying widths, some to four feet. Another short adit is located lower in the canyon at the base of the tram. Paddock (1956, p. 94) reports:

> Mining operations were recently renewed in November 1955 and continue to the present time. The Sun Mining Company of Salt Lake City has located a scheelite property at the head of Pack Rat Canyon. Two adits are being driven in the canyon. To date, ore is being stockpiled at the property for shipment at a future date.
>
> The ore is of comparatively low grade, and occurs in spotty lenses, pods and irregularly shaped bodies in the quartz monzonite-limestone contact zone. On the west side of Desert Peak, an open-pit property was commenced during the summer of 1956, but has been abandoned temporarily. Specks of tungsten ore are found scattered throughout a garnetiferous contact zone in the basal Swan Peak Formation.

Everett (1961, p. 6) adds:

> Scheelite lenses in tactite have been found and developed in two places along the contact of the limestone and quartz monzonite of one outlier. Contacts between limestone and quartz monzonite can be traced about 5 miles, and claims have been located over much of this distance. The only appreciable development has been done by Sun Uranium Company in two adits. The area is extremely rugged, and exploration has been difficult and costly. Development has resulted in production of about 400 tons of ore, but operations were terminated in 1956 because of the abrupt decline in the price of tungsten. Small but significant reserves have been developed.

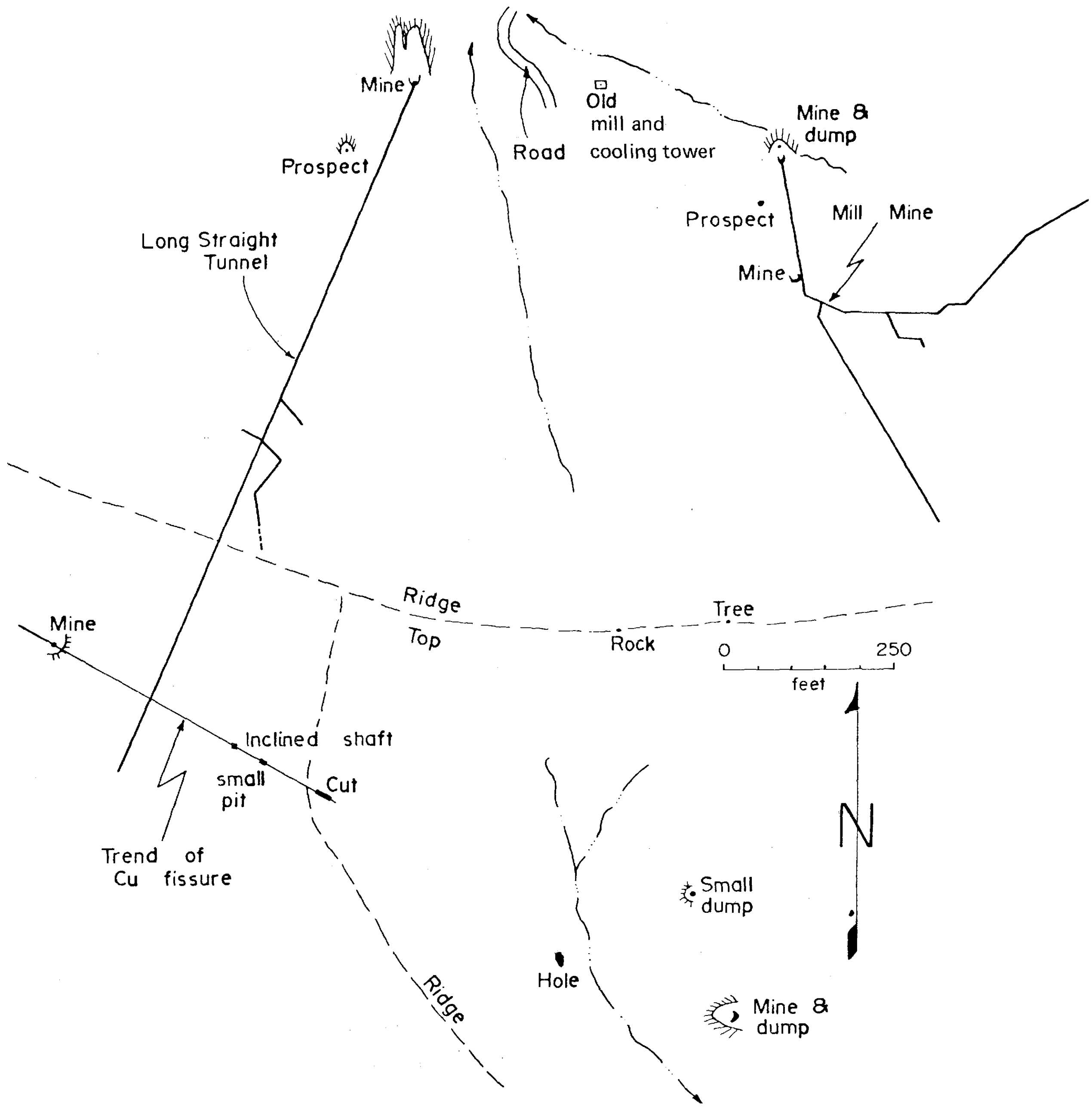


Figure 42. Stone House area, Newfoundland mining district.

He further adds that the ore ran 1.25 percent WO_3 indicating the production of about 500 STU of tungsten. (A short ton unit, STU , of WO_3 contains 15.862 pounds of tungsten and a ton of 1 percent WO_3 ore contains one STU).

Rosebud Mining District

The Rosebud mining district (figure 47) is located in the southern half of the Grouse Creek Mountains and is named after an easterly-flowing creek. Mineralization is sparsely scattered over a wide area and mines are found in 9, 10 and 11 N., 17 W and in 10N - 16 W. The principal mining area is 12 miles northeast of Lucin and 5 to 6 miles north of paved Utah Highway 30.

The metalliferous ores found in the Rosebud district contain tungsten, silver, lead, copper and gold. The first by far outranks the others in terms of production and value. The area has produced approximately

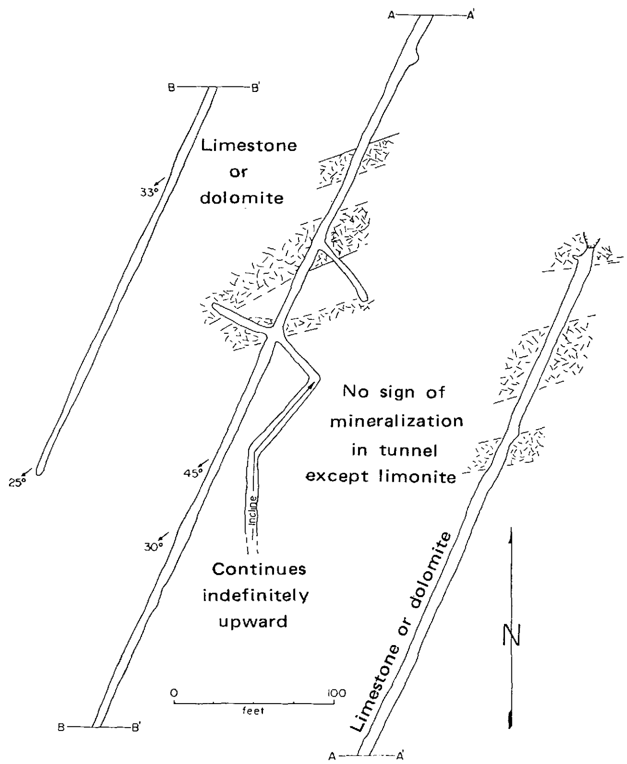


Figure 43. Long straight tunnel, Newfoundland mining district.

6,000 STU tungsten. According to Everett (1961, p. 19) there are 9,390 inferred tons of reserve remaining at 0.67 percent WO_3 or 6,292 STU of tungsten.

All of the tungsten mines of the Rosebud district are in the Rocky Pass area except for a new prospect (1978) located at the southeast end of Bovine Mountain. Small production of lead-silver ore may have come from the Rocky Pass, Mogul, and Ingham Canyon areas. Copper, lead, silver, and perhaps gold are found in the Silver Riddle area. The production and value of the mined precious and base metals for the district are unknown, but estimated to be small and comparable to that in the Newfoundland mining district.

Geologically the southern half of the Grouse Creek Mountains consists of Paleozoic formations (Devonian, Mississippian, Pennsylvanian and Permian), complexly faulted, into which granitic rocks have been intruded. The granitic rocks, with an outcrop area a little larger than ten square miles, consist of quartz monzonite and quartz diorite.

The tungsten deposits are found in the contact zones between the granitic and carbonate rocks. The potential length of such contact zones is five miles, but the tungsten mineralization is spotty. Base metal deposits are mostly in limonitized fissures. A few mineralized fissures are filled with quartz or calcite and some contain much pyrite. In the Silver Riddle area some of the mineralization has partly replaced a favorable carbonate horizon. Some of the fissures follow bedding planes, faults, fracture zones, or have invaded brecciated rock.

Records of mining activity are sparse and there was little activity prior to 1900. The tungsten deposits were actively mined during World War I. A *Salt Lake Mining Review* comment of May 30, 1916 notes that "The find was made some time ago and $40,000 in ore has been shipped to the Salt Lake market."

Everett (1961) reports that gravity mills operated from 1915 to 1917, 1941 to 1943, and in 1954. Production has been intermittent, and most active when the price of tungsten was high. During the late summer of 1972 the A & W mine was active. Prospecting the precious and base metal deposits may have begun earlier. Butler (1920, p. 496) states:

> North of the intrusive body at the south end of the range the quartz veins have been prospected at numerous localities, but most extensively at the Mogul mine and at Red Buttes. At neither locality, however, were operations in progress at the time of the visit, and few data concerning the deposits were obtainable. Specimens containing galena in a gangue of quartz and calcite were obtained on the dump of the Mogul mine and specimens composed of quartz and sulfides of iron and copper on the dump of the Red Buttes tunnels. Some of the black shale on the dumps of the Red Buttes tunnels was impregnated with iron sulfide. Both deposits are said to contain gold and silver.

The tunnels to which Butler refers are the Ingham Canyon mines in Ingham Canyon, a tributary to Red Buttes Canyon. The only significant copper shows are at the Silver Riddle prospects, which have been intermittently developed and may have produced small amounts of ore. The only comment in the literature is found in the 1923 U. S. Bureau of Mines' *Minerals Yearbook*, "In 1923 a small lot of lead ore containing silver was mined 12 miles northwest of Watercress." (Watercress is a ghost settlement located southeast of the Grouse Creek Mountains on the old Central Pacific railroad grade). Examination of the workings indicates that the claims are current and that development work has continued through the 50s and 60s.

Rocky Pass Area Mines and Prospects
(Tungsten, lead, silver, copper)

The principal mines of this area are for tungsten

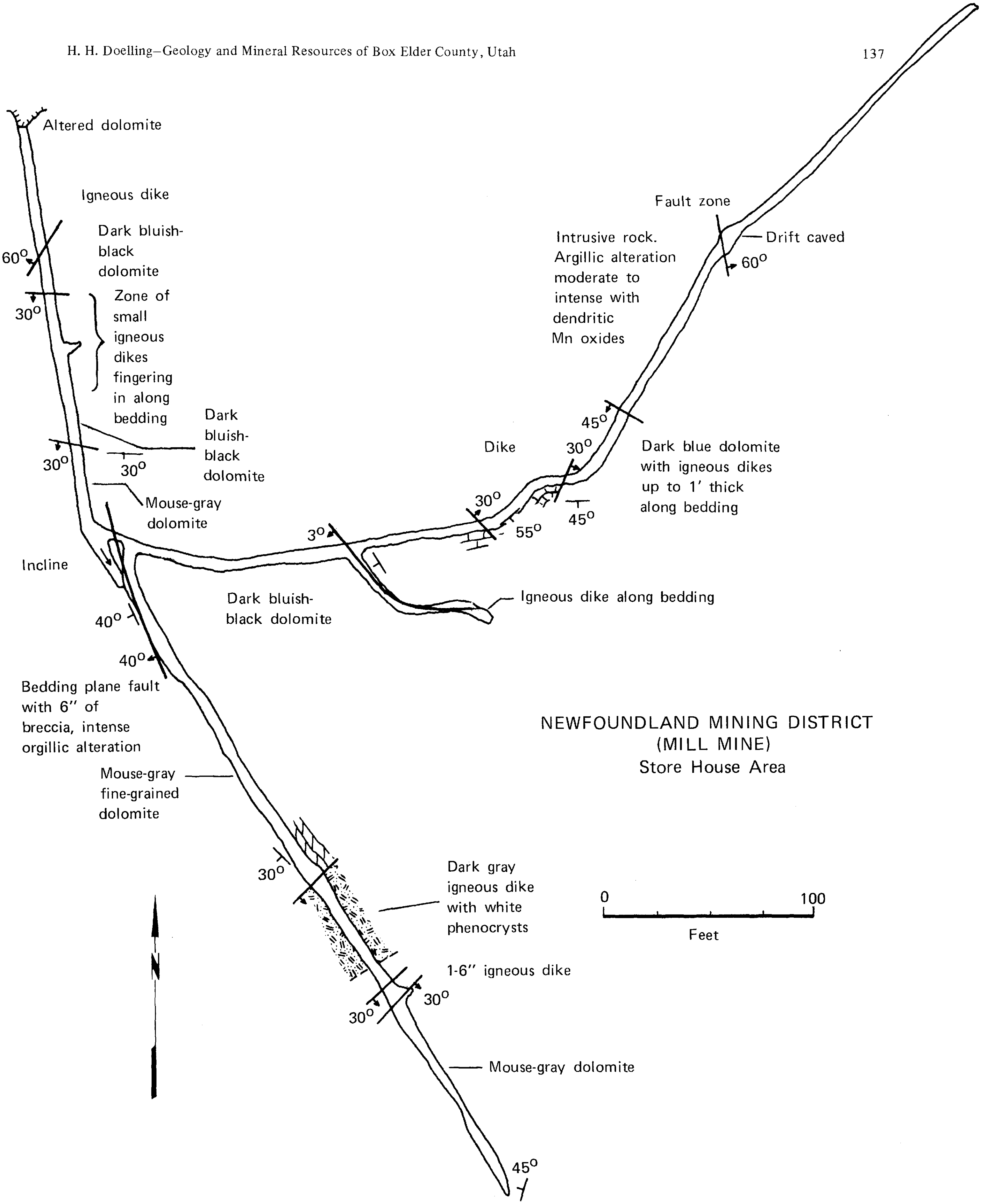


Figure 44. Mill mine, Newfoundland mining district.

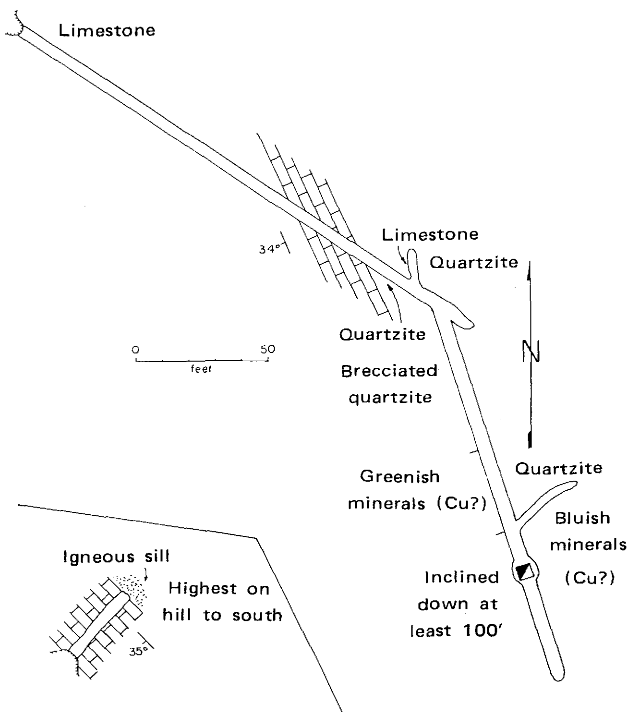


Figure 45. Stone House Canyon mine, Newfoundland mining district.

and are shown on figures 48 and 49. The most important mine in terms of production is the Lone Pine or A.M.W. in E½ 10 - 9N - 17W (figures 50 to 52). Everett (1961, p. 19) described the property:

> More than 1,300 tons of crude ore containing 4,475 units of WO_3 has been produced. The mine was worked by the owners in 1940-44 and 1954-56. A large part of the ore was shipped to the Metals Reserve Company at Salt Lake City.
>
> Scheelite occurs in tactite zones in limestone at and near contacts with quartz monzonite. Sills of quartz monzonite are common between the limestone and sandstone beds. The contact dips about 35° E. Scheelite is found in crystals up to 1 inch in diameter in a gangue of quartz, epidote, calcite, and garnet. Some of the tactite appears to follow fracture zones in limestone.
>
> The property has been developed by approximately 200 feet of inclined shafts and winzes, 900 feet of crosscuts and drifts, 50 feet of raises, and 200 feet of opencuts and trenches. Facilities include a cookhouse, dugout cellar, powder magazine, cap and fuse magazine, and two ore bins. Additional exploration might include driving drifts in tactite zones along the contact, crosscutting toward projected ore bodies at depth, and sinking along contacts from known mineralized zones.

The Lone Pine property is presently abandoned (1972); most of the facilities have been dismantled or have fallen into disrepair. A chip sample of remaining ore across a two-foot scheelite-bearing zone yielded 2.96 percent WO_3.

The only presently active (1972) mine in the Rosebud district is the A & W located in NE 11 - 9 N - 17 W (figure 53). The contact zone strikes northeasterly and dips 12 to 25 degrees southeast along a quartz monzonite sill. As at the Lone Pine mine, scheelite occurs in garnet and epidote zones in quartz and calcite. The crystals of scheelite are of comparable size. The inclined shaft is currently 140 feet in length and the ore zone is 1 to 4 feet thick. The total production is unknown but 500 to 1,000 STU of tungsten could easily have been mined here. A chip sample across a 4-foot ore zone at the far end of the inclined shaft contained 0.61 percent WO_3. The sampling site was at one of the poorer showings of scheelite, but at the thickest part of the zone.

A small open cut around the ridge to the southwest of the A & W mine is unofficially called the "Compressor" mine. The contact zone is 6 feet wide and dips steeply; the limestone is marbleized and garnet and epidote are prevalent. The entire 6 - foot zone was channel sampled and yielded 0.18 percent WO_3. Scheelite crystals were much smaller, and not everywhere visible. Very weak copper mineralization is present.

The Magnitude mine is in N½ 14 - 9 N - 17 W and is an older tungsten working. It consists of many caved adits, pits, and cuts (figure 54). The description by Everett (1961, p. 21) reads:

> Several mine workings around the Magnitude mine were included with property known as the Frank Edison mine during World War I. Scheelite occurs in a tactite zone at the contact of quartz monzonite and limestone. The limestone is a thin member of a thicker sandstone-quartzite bed. Mine workings consist of several open cuts and a shaft 25 to 50 feet deep. Total production has been about 300 tons of ore containing an estimated 250 units of WO_3. . . . . .No reserves have been developed, but ore has been obtained from the mine when the price was especially attractive, but probably small quantities of additional ore could be produced under favorable economic incentives.

A chip sample of tungsten-bearing intrusive rock was taken in a small mine on the ridge to the east overlooking the larger Magnitude workings that yielded 0.55 percent WO_3. The scheelite appears to be irregularly distributed in the intrusive rock near the edge of the contact with the limestone. Some minor copper shows were evident as well.

The Rocky Pass property is west and south of the Magnitude mine. Everett (1961, p. 21) remarks:

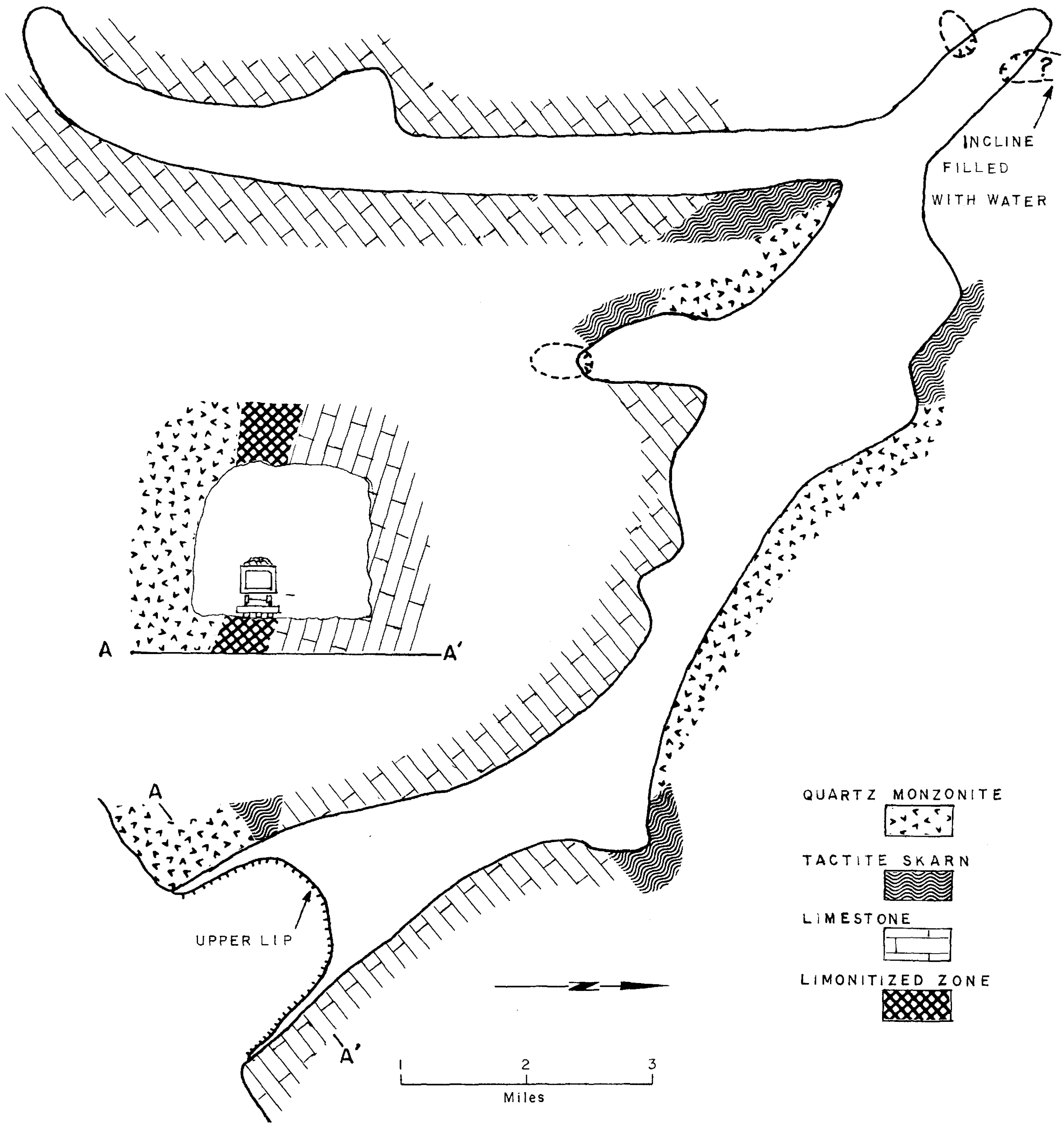


Figure 46. Desert Flower No. 1 mine, Newfoundland mining district.

Scheelite occurs in tactite zones near or at quartz monzonite-limestone contacts. Workings consist of several open cuts and shallow inclined shafts and a 200-foot adit. The property has not been mapped in detail. The property has several exposures of scheelite, but no reserves have been developed. This property is in a geologically favorable area, and additional exploration might result in a discovery of small ore reserves.

The lead-silver mines of the Rocky Pass area are found near the common corner of sections 11, 12, 13 and 14 - 9 N - 17 W, about ½ to 1 mile east of the tungsten workings (figure 55). The area and the Rocky Pass tungsten mine are controlled by the Rocky Pass Mining Company. These are accessible by a short jeep trail leading northwest from Emigrant Pass (figure 48)

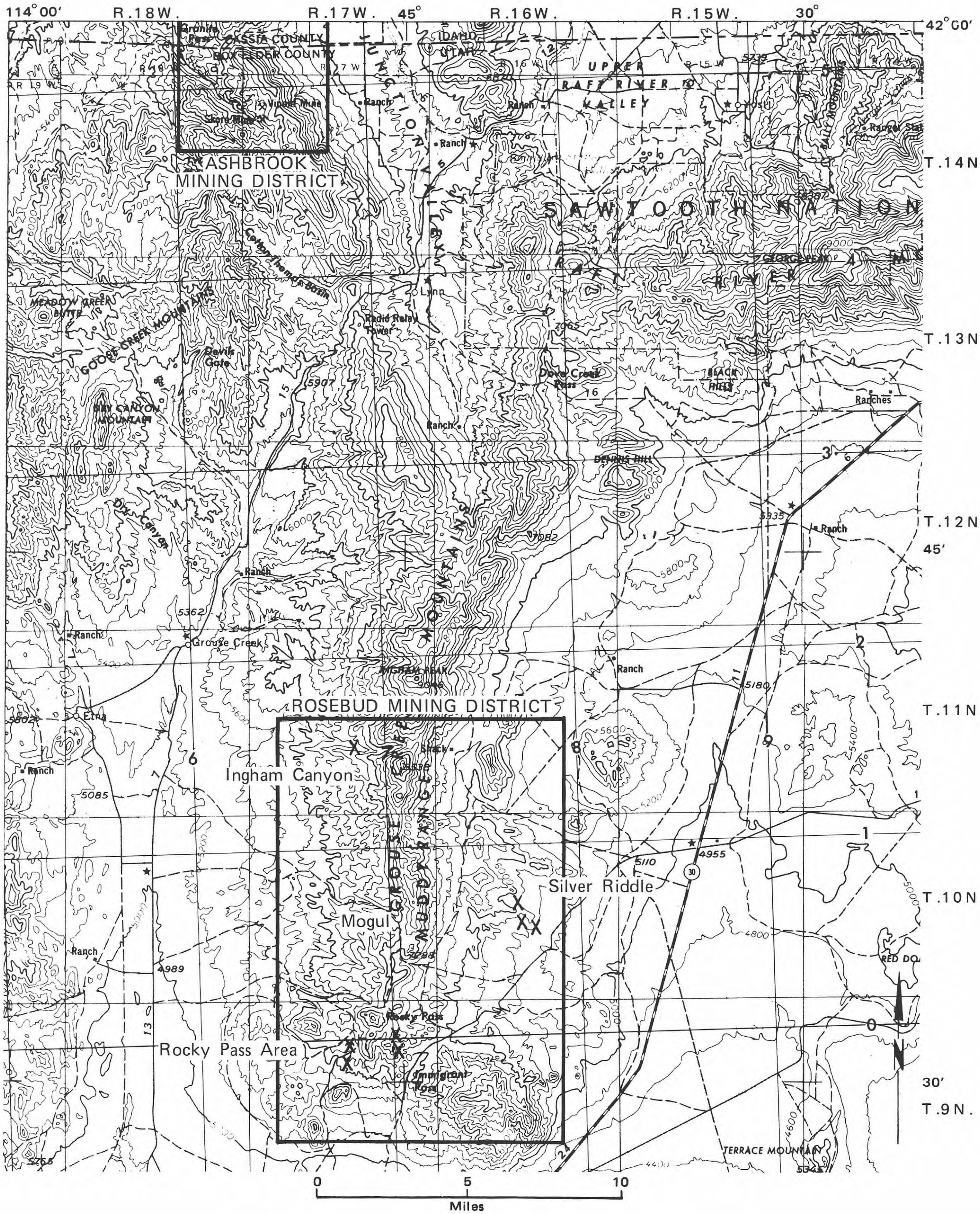


Figure 47. Location map of Rosebud and Ashbrook mining districts.

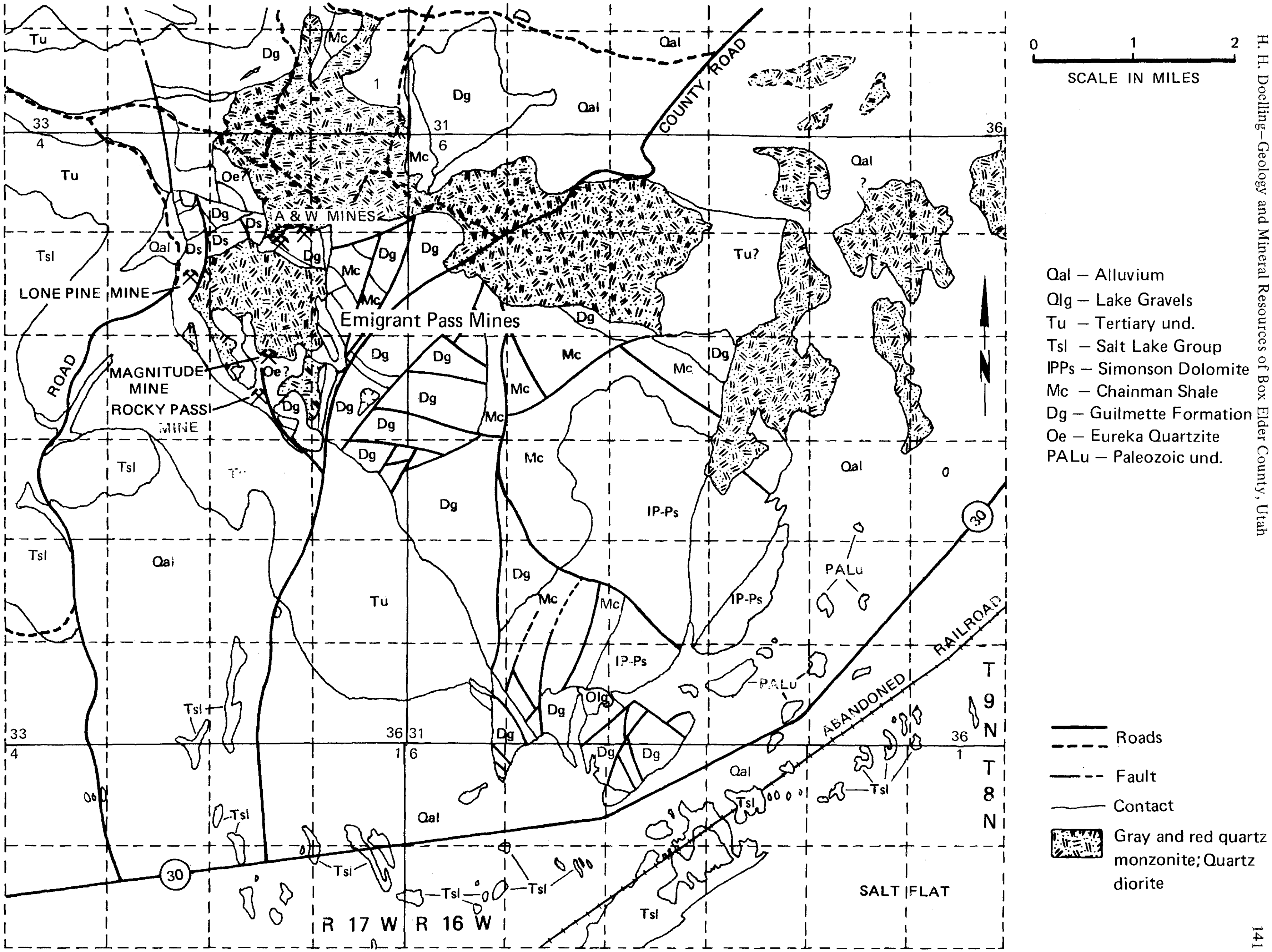


Figure 48. Rocky Pass area, Rosebud district, Grouse Creek Mountains (from Everett 1961).

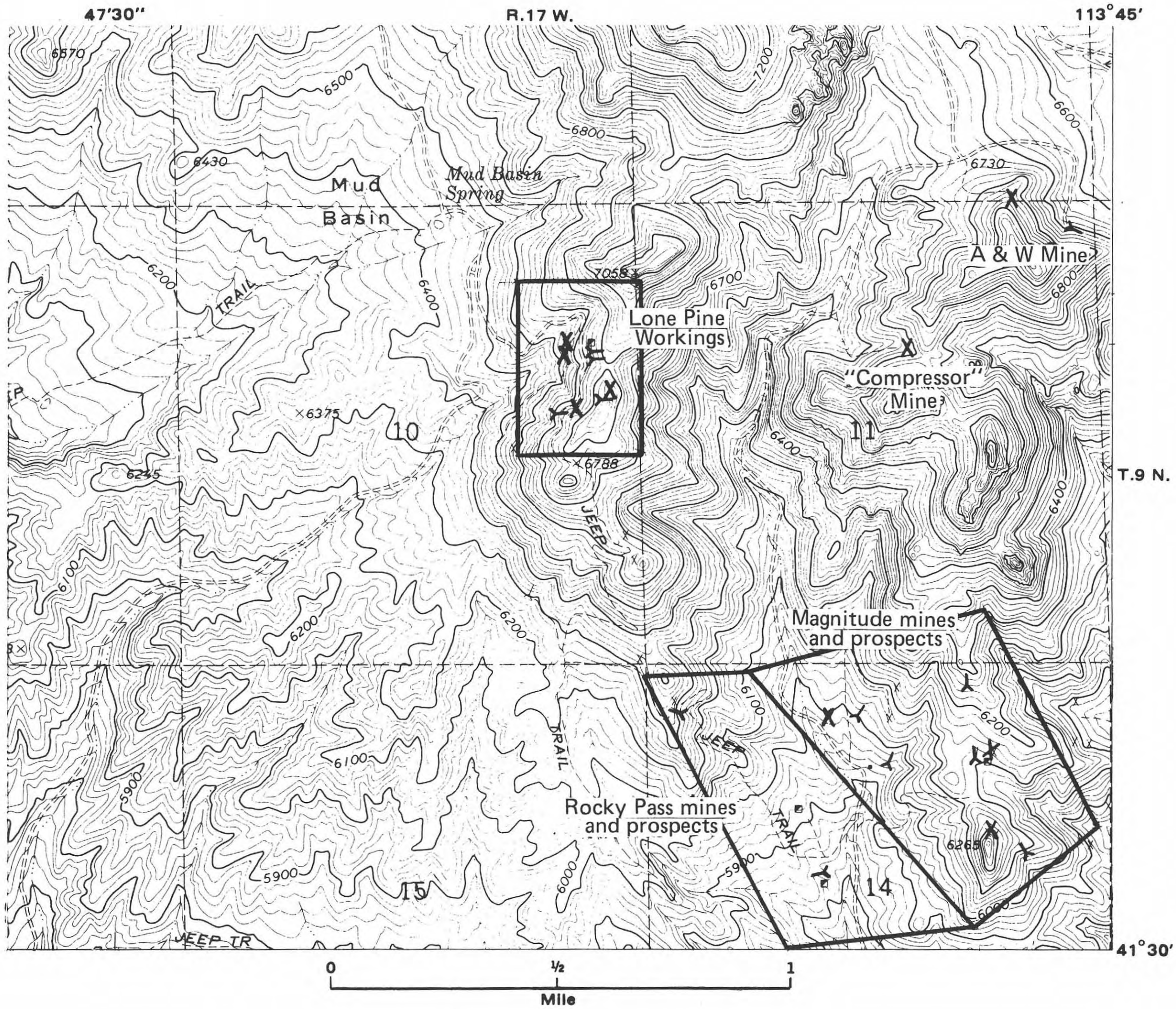
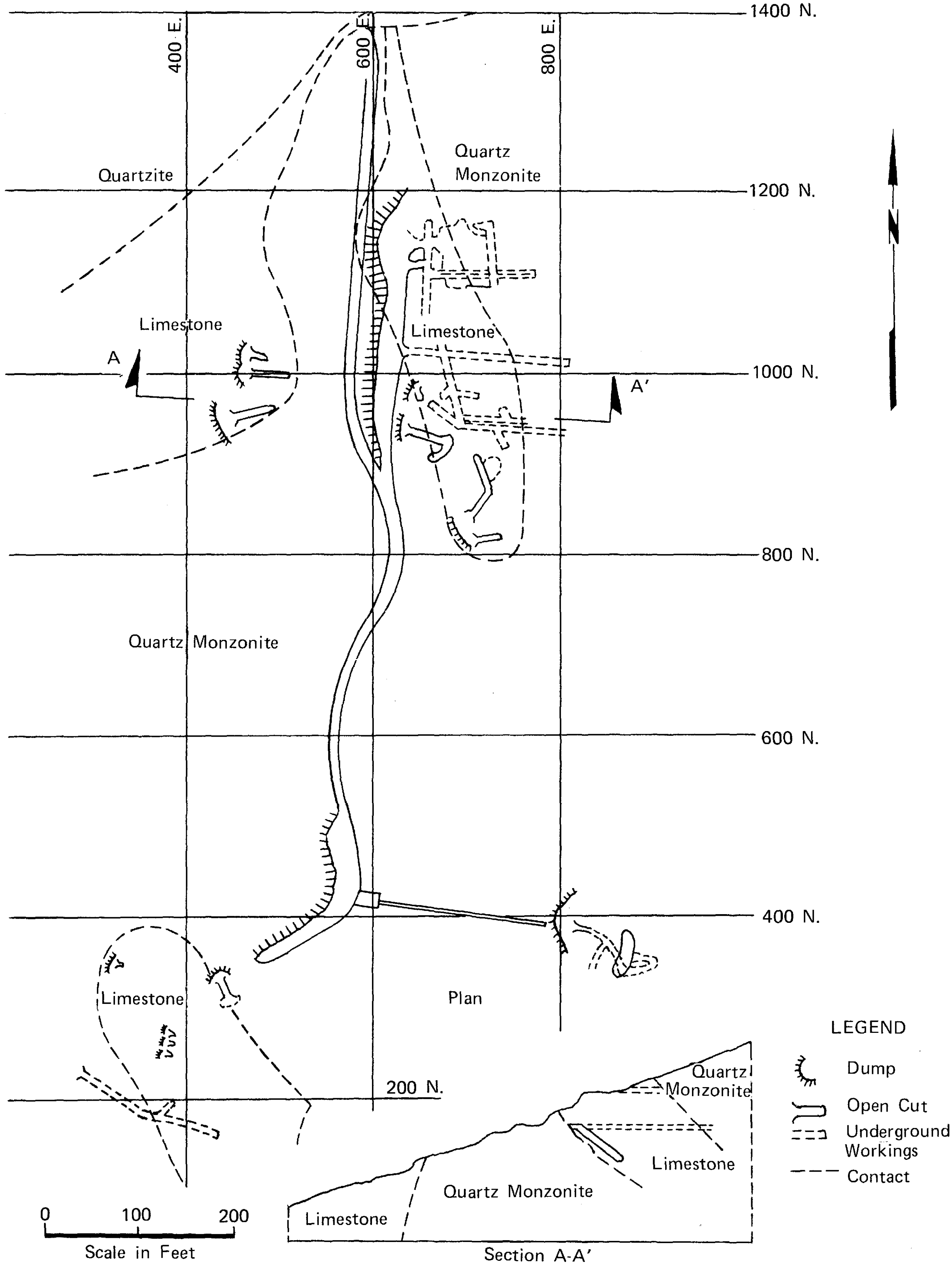


Figure 49. Rocky Pass mines and prospects, Rosebud district.

and are here labelled the "Emigrant Pass" mines. The mines and prospects are confined to a ¼ - mile area near the intrusive outcrop. Host rocks include the Simonson Dolomite, perhaps the Guilmette Formation, and the Mississippian Chainman Shale. The limestones adjacent to the intrusive rocks are bleached, marbleized and often brecciated. Rusty fissures appear to be the only mineralization close to the intrusion. The larger workings are about 1,000 feet from the contact and are cut in limestone, dolomite, and silicified black shale (figure 56). These consist of two tunnels (mines A & B), the lower with 800 feet of workings, the upper with 250 feet.

There are some prospect pits and a 20-foot shaft above the tunnels, presumably in northwest-trending fissures; the objective for the tunnels was to intersect the fissures and this appears to have been done. Mineralization consists of rusty fissures or quartz-filled fissures. What appears to be a dike or sill of intrusive rock is also present in the rear of the principal crosscut. Some scheelite was noted in this part of the working. Except for the scheelite no identifiable ore minerals were seen and most of the main tunnel is cut in unaltered rock. Some ore was taken from small pockets along the fissures in the mine crosscuts and probably consisted of argentiferous cerussite and anglesite. Small specks of pyrite are in places disseminated in the silicified shale. The "Emigrant Pass" mines were abandoned at the time of visit (July, 1972), but appearances indicate that they are intermittently subjected to development work (figure 57).



Rocky Pass Area, Rosebud District
(From U. S. Bureau of Mines Information Circular 8014, by Everett, 1961)

Figure 50. Workings at the Lone Pine property.

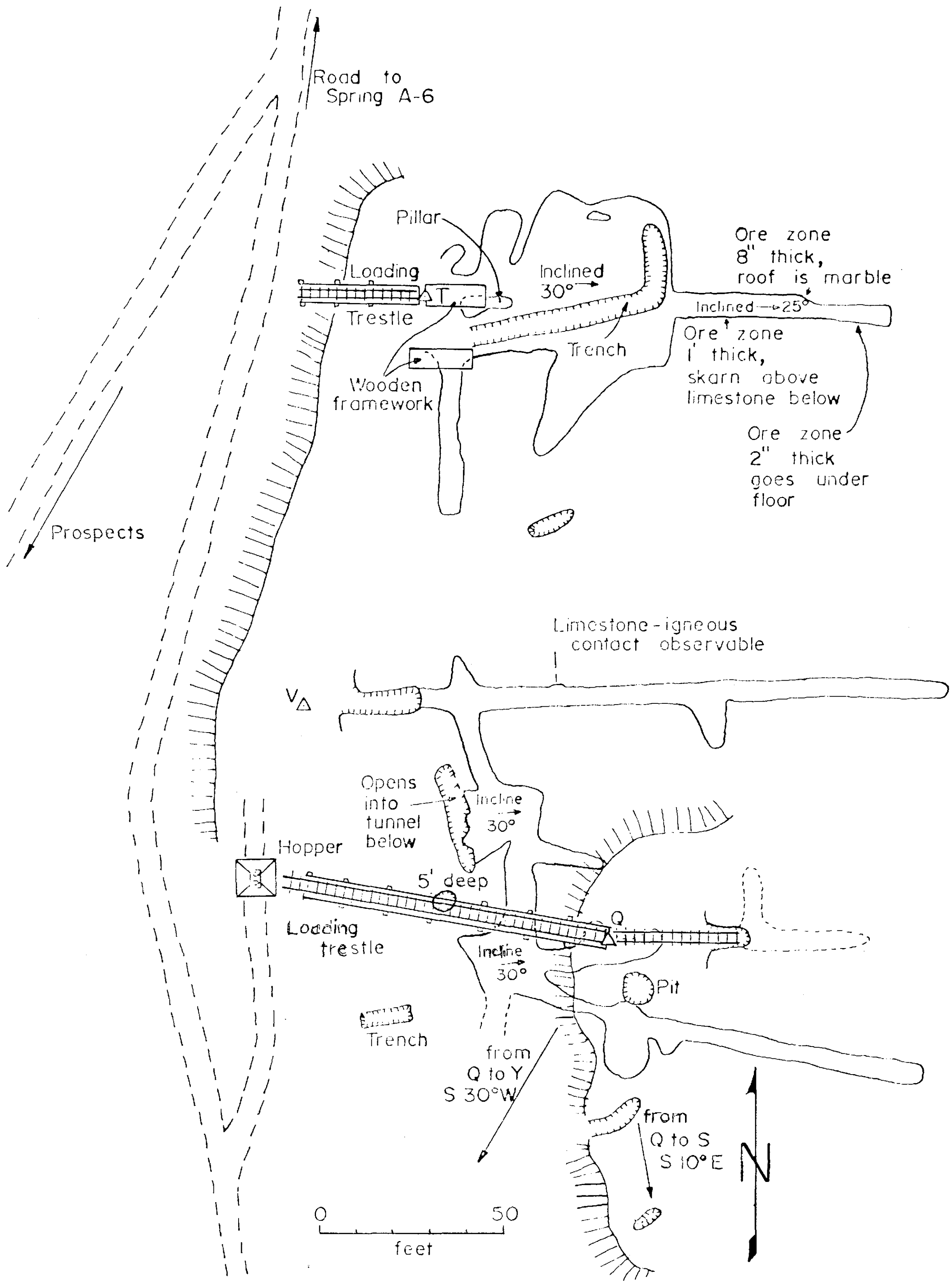


Figure 51. A. M. W. mining area (Lone Pine mine), Rocky Pass area, Rosebud district.

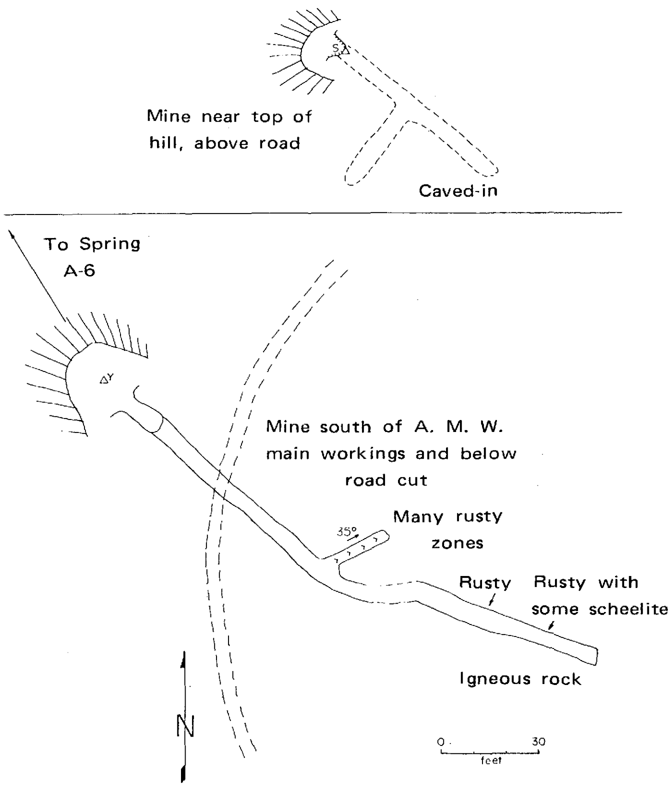


Figure 52. A. M. W. mines, Rosebud district.

Silver Riddle Area Workings
(Copper, Lead, Silver, Gold?)

The Silver Riddle area consists of a hillside of shallow workings in limestone and silicified black shale or phyllite (figures 58 to 60). The workings are located in NW 21 - 10 N - 16 W in the Guilmette Formation and Chainman Shale outcrops. The mineralization occurs in fissures or as partial replacements along fractures, faults, and bedding planes. Copper and iron are immediately evident and local prospectors indicate that lead-silver and gold values were recovered. Minerals megascopically identified were limonite, malachite, chrysocolla, pyrite, minor chalcopyrite, copper pitch, calcite, quartz, and a little galena. Small amounts of ore may have been shipped from the Silver Riddle group. The mines are abandoned, but claims are held current.

Mogul and Ingham Canyon Mines and Prospects
(Lead - Silver - Gold)

The Mogul mine, (figures 47 and 61) is very old and located almost on the ridge line of the Grouse Creek Mountains in SE2 - 10N - 17W. A mountain road follows the crest northward from Rocky Pass and the mine is slightly west of the divide. The workings consist of a shaft 55 feet deep, an open tunnel with 155 feet of workings which include an interior 25-foot shaft and a caved adit. In addition there are a few cuts and shallow diggings. The workings are cut in argillaceous limestone that is locally brecciated. Mineralization is in fissures with limonite and hematite being the chief minerals. Cerussite and anglesite were noted in sparse quantities.

The Ingham Canyon mines and prospects (figure 47) are located in 23 - 11 N - 17 W along a canyon which is a west side drainage of the mountain range. The road passes near the workings and crosses the range to the east; it is passable with a truck during good weather. There are several collapsed adits on the north side of the road and one open 30 - foot drift cut mostly in quartzite. On the south side is an open mine and a cut which may have caved a second tunnel. The open mine is cut in siliceous shale or meta-argillite (Chainman Shale), which is locally pyritiferous and cut by quartz fissures. At the time of visit (August, 1972), the floor was covered by six inches of water. A short distance into the tunnel the drift forks. Many of the quartz-argillite contacts are rusty and edged with a black clayey material which may contain finely divided galena that is presumably argentiferous. Clayey zones no thicker than ½ inch are remnants of ore left by the miners. From appearances these mines are permanently abandoned and very old.

Ashbrook Mining District

The Ashbrook mining district (figure 47, 62) is located at the north end of the Grouse Creek Mountains in the northwest Vipont Mountains branch. The principal mining area is near the Idaho line and one mine is partly in that state. The district is old; the *Salt Lake Mining Review* hints that a mine existed in 1860, but property was first properly located in 1872 and the district was organized on July 1, 1874. It is the second most important district with respect to production and value in the county.

The principal metals of the Ashbrook district are silver with a little gold. Some lead and copper have been produced and U. S. Bureau of Mines' *Minerals Yearbooks* and other pertinent publications indicate that about $3.35 million worth of metals has been recovered. Mining activity was slow and intermittent at first and through 1904 about $36,000 worth of silver had been extracted. There was a period of inactivity until 1917 and peak production was achieved 1920 to 1923. On August 1, 1923, buying of silver under the Pittman Act ceased and the price of silver dropped from $1.00 to $0.64 per ounce. Only small production was maintained

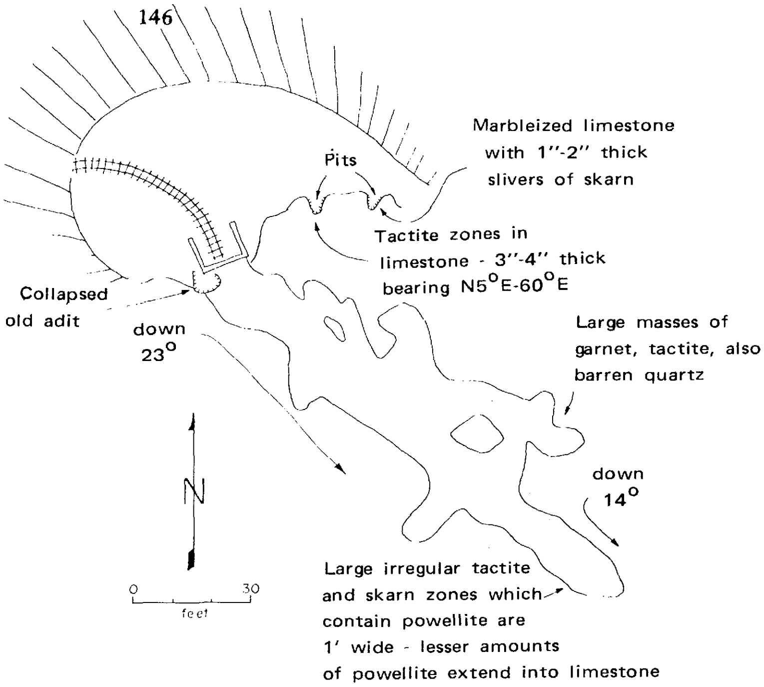


Figure 53. A & W mine, Rosebud district

through 1926 and in 1929 the mining and milling machinery was sold. The operations were revived in 1934 and this time they lasted until 1941. A small amount of ore was again produced in 1955 and some developmental and exploratory work on the properties, including a U. S. Bureau of Mines drilling program, was conducted during the 1950s. Unconfirmable reports indicate new reserves were blocked out, but that the costs of mining and milling could not be recovered at the current price of silver. Peterson (1942, p. 474) states that from 1934 to 1942 some 300,000 ounces of silver and several hundred ounces of gold had been produced. The U. S. Bureau of Mines' *Minerals Yearbooks* for the same years record a production of only 105,000 ounces of silver and 288 ounces of gold. The overall recorded production of metals from the Ashbrook district is estimated as shown in table 4.

Peterson 1942, p. 472 - 473) describes the mineralization as follows:

> All the ore deposits thus far found in the district are replacements in limestone and all have an irregular, patchy distribution, whether oxides or sulfides. Deposits are similar in shape and form in each of the three limestone formations recognized in the district, but deposits in the Vipont Limestone are much more abundant and widespread. The irregularity and bunchy distribution of the ores has in part accounted for the delayed and sporadic development of the district. It has never been possible to block out ore with any success in any of the mines, nor to predict the character or size of a single, small orebody.
>
> The distribution of the mines and prospects within the district is clearly related to the distribution of the late intrusives. Extensive prospecting has revealed that ore values are almost invariably associated with limestone in close proximity to the porphyries and that the values in general diminish with distance from these rocks. Replacements have not been general, but in all cases have been localized by structural features within the limestones. Most notable of these features are the small crenulations in the limestone, along the bedding planes of which abundant secondary calcite has developed.

Table 4. Metal production from Ashbrook district.

Metal	Amount	Value
Silver	3,368,137 oz.	$3,183,074
Gold	7,762 oz.	164,898
Lead	6,160 lb.	431
Copper	3,001 lb.	510
	Total value	$3,348,913

The geology is shown on figure 63. Peterson, in mapping the area, named the stratigraphic units that are mineralized at Ashbrook. Actual correlations and age assignments await further work, but Peterson's informal units are useful in understanding the geologic and structural relationships of the area. Precambrian rocks crop out to the east and northeast of the Vipont and Skoro mines, the two most important of the district. The Sentinell Formation, once considered Cambrian?, is now regarded as metamorphosed Ordovician sediments (Pogonip and Eureka?) and is named after the Sentinell group of prospects. The lower part is white to tan sugary quartzite and the upper part is light gray, thin-bedded limestone. Each part is 100 feet thick. The limestone is mineralized in many places; the Sentinell and Skoro mines exploit it. The overlying Vipont Limestone, Wardlaw Shale, and Phelan Limestone, in ascending order, are considered Carboniferous in age. The Wardlaw Shale is probably correlative to the Chainman Shale that is exposed in the southern Grouse Creek Mountains and elsewhere in the county. The Vipont Limestone is the principal ore host and is a fine-grained crystalline thin-bedded limestone. The unit is thin, 50 to 100 feet thick. The 400 - foot Wardlaw Shale is a black to gray pyritic shale in which a few dolomitic limestone lenses may be found. It is either shaly or massively bedded. The Phelan Limestone (Oquirrh or Pequop) is a light blue gray, often cherty, massive limestone more than 1,000 feet thick.

The strata are intruded by rhyolite porphyry, divisible into two subunits; a lower coarse-grained porphyry sill and an upper fine-grained unit. The outcrop of the lower porphyry is extensive and surrounds

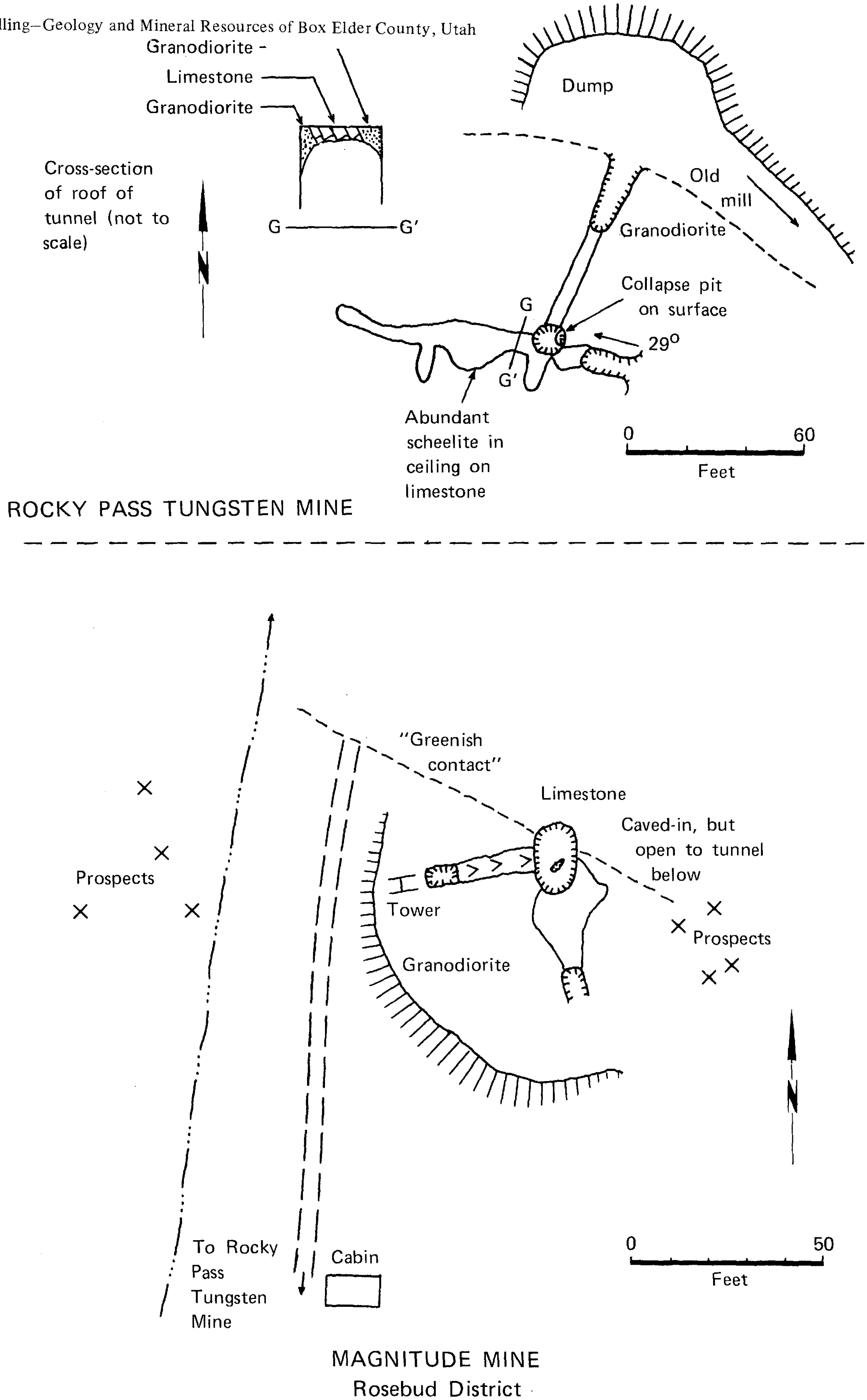


Figure 54. Rocky Pass Tungsten and Magnitude mines.

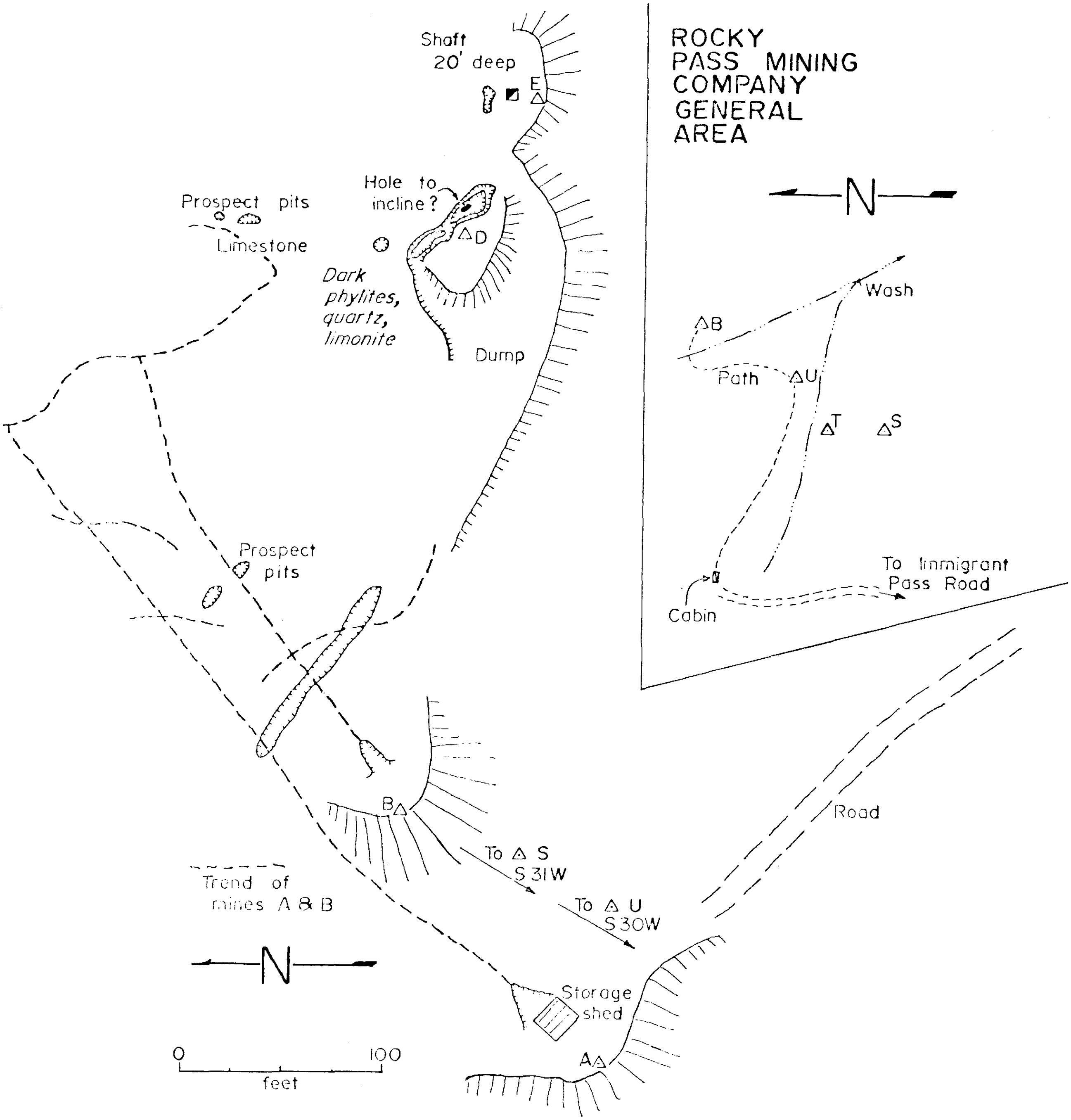


Figure 55. Rocky Pass mining company area (lead-silver mines), Rosebud district.

the area; the upper crops out as small pipes or as thin dikes and sills.

The sedimentary beds strike northwesterly and dip to the southwest. Structurally the area may be described as a shallow syncline gradually plunging southwestward. Several faults, principally trending north-south, cut the strata. These appear to have had little influence on ore deposition.

Ashbrook Mines and Prospects (Silver-Gold-Lead-Copper)

Most of the entrances to mines in the Ashbrook district are caved or otherwise impassable (1972). Most of the ore has come from the Vipont mine and fortunately Peterson (1942) was able to study it in some detail during its last stages of activity. Highlights of his discussion are repeated here:

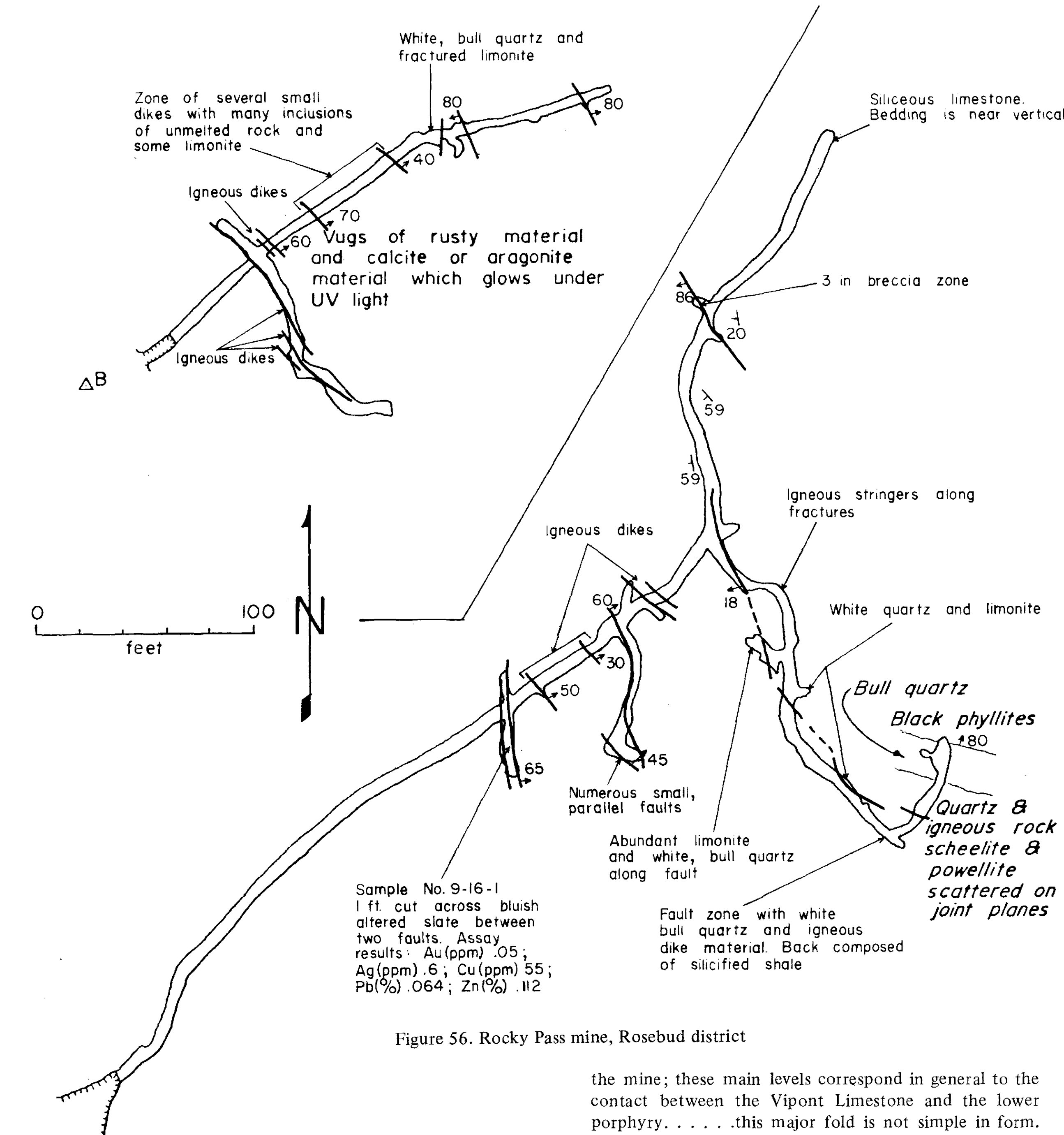


Figure 56. Rocky Pass mine, Rosebud district

The orebodies of the Vipont mine occur in the Vipont Limestone, between the overlying Wardlaw Shale and underlying lower porphyry. They are not confined to a particular horizon within this formation, but are distributed from the porphyry footwall to the shale hanging wall, and usually conform to bedding planes. Structural features within the limestone, though not clearly discernible in all cases, appear to have been the most important factors in localizing the ore deposits. The workings of the mine are along the northeastern flank of the synclinal fold forming the major structure of the district. Reflection of this fold is seen in the outline of the main levels of the mine; these main levels correspond in general to the contact between the Vipont Limestone and the lower porphyry. . . . . .this major fold is not simple in form. Superimposed upon it are numerous small crenulations, the largest of which have a roughly radial distribution with respect to the major fold. . .

. . .In conjunction with these crenulations, the structure is further complicated by minor slips and localized zones of fracture. These zones of fracture, like the apical portions of the crenulations, in which there has been extensive development of secondary calcite, have formed the most vulnerable areas of replacement by mineralizing solutions. Their intricate form and complex relation to each other account to a large extent for the great variations in the size and continuity of the ore-

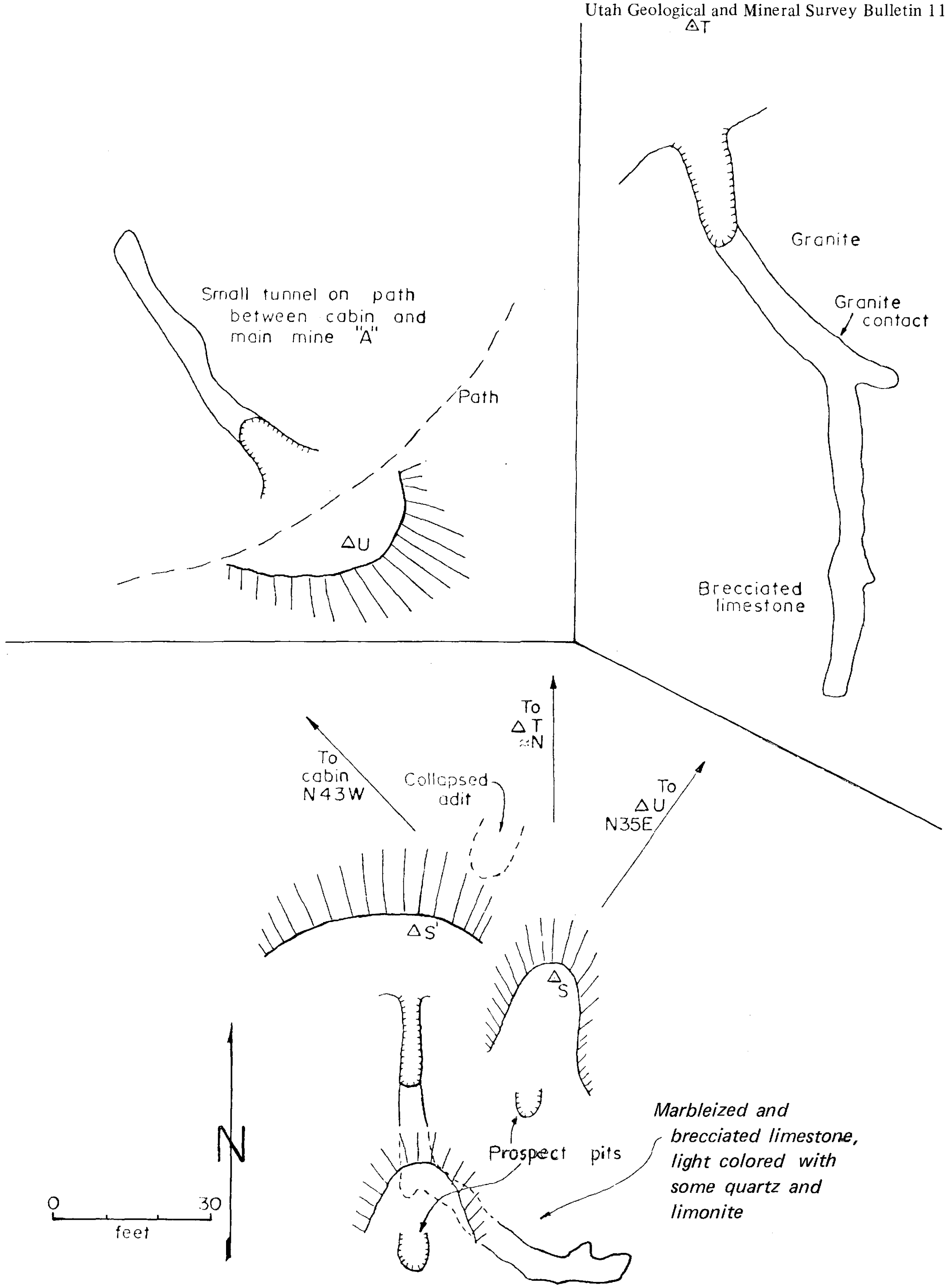


Figure 57. Rocky Pass lead-silver mines, Rosebud district.

bodies. However, replacement by ore-bearing solutions is not limited to these fractured areas. At present it is not possible to predict the extension of particular fractured zones beyond the known orebodies, or to determine in advance their relation to each other, though it seems possible that through detailed study this might be accomplished.

The ore occurs generally in small patches and pockets of irregular form, connected by small stringers.

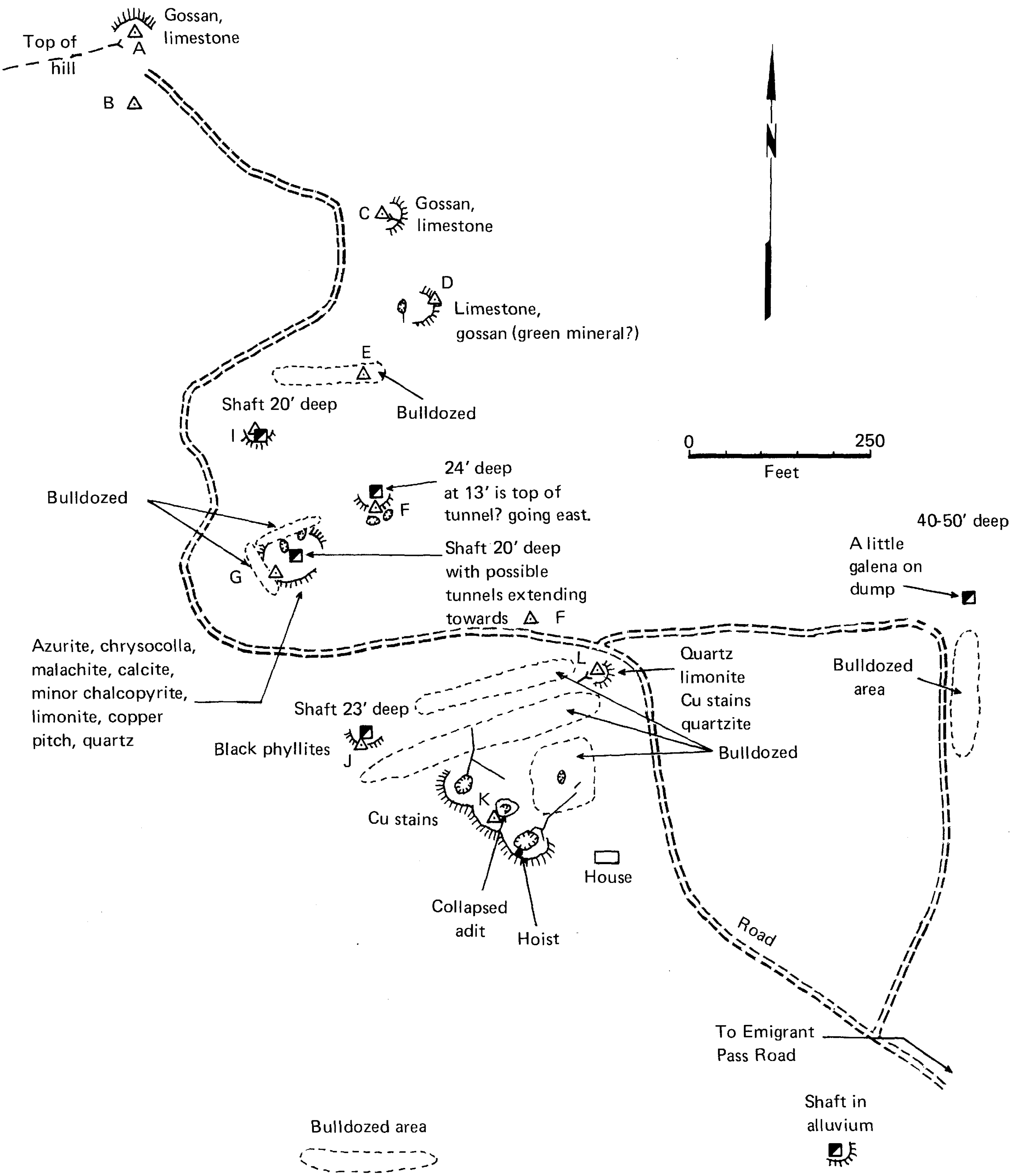


Figure 58. Silver Riddle Group, Rosebud district.

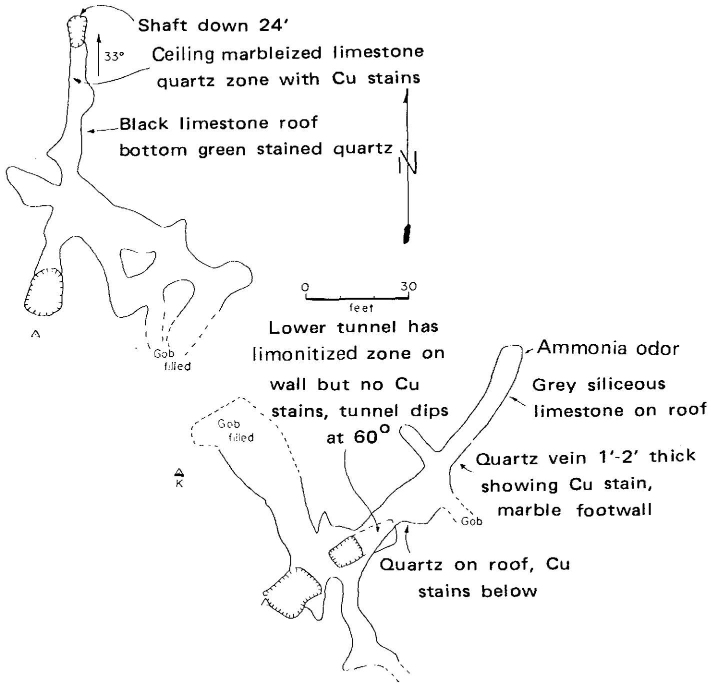


Figure 59. Silver Riddle Group No. K, Rosebud district.

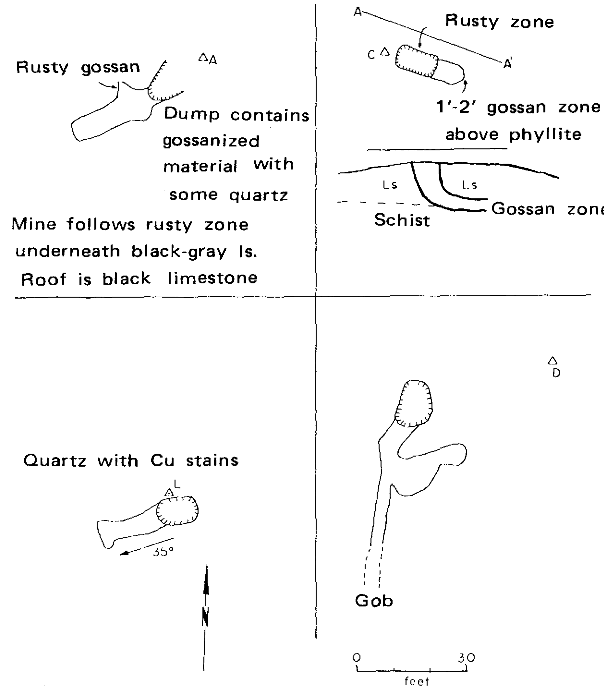


Figure 60. Silver Riddle prospects, Rosebud district.

Commonly they are elongated parallel to the bedding planes in the limestone, and have a roughly lenticular form across their shorter dimensions. The size of the orebodies is extremely variable. An orebody several feet in diameter may in the course of a few feet connect with a scarcely visible stringer; this stringer may again expand into a sizable orebody. . .

. . .The minerals that are considered primary or hypogene in origin are those formed prior to or overlapping with the deposition of galena, which is apparently the latest of the primary minerals. The primary minerals include: rhodochrosite, sericite, quartz, pyrite, arsenopyrite, gold, sphalerite, chalcopyrite, argyrodite, tennantite, pearceite, pyrargyrite, an unidentified mineral, and galena. . .

. . .Gold in the Vipont ores is known only from assays with widely divergent values of this metal. Gold has never been recognized in the hand specimen of these ores, and it is only doubtfully recognized in polished section. . .

. . .The hypogene ores of the Vipont mine have been extensively modified by supergene processes. . . . . It is not possible to divide the Vipont mine into zones in which either primary, enriched, or oxidized ores predominate. Oxidized and enriched ores are not uncommon in the lowest workings of the mine, and essentially primary ores are not unknown in the highest levels of the mine. . . . . .The following minerals have been noted as alteration products of the primary ores resulting from processes of downward enrichment: undetermined lead silver salt, intermediate between galena and argentite; argentite, covellite, chalcocite, cerussite, and possibly native silver. .

. . .Two hundred composite analyses, each composed of ten grab-samples from freshly blasted high grade ore at different localities throughout the mine, show an average silver content of 27.06 fine ounces, and an average gold content of 0.078 ounce per ton. Individual orebodies have been known to carry as much as 10,000 ounces of silver and 4 to 5 ounces of gold per ton. The ratio of gold to silver is highly variable and there seems to be no consistent relationship of tenor or locality. Out of 63,710 tons of ore mined during 1922, the average recovery per ton was 0.046 ounce of gold and 16.3 ounces of silver.

The mine is rather extensive in its development, evident by the many adits, shafts and dumps at the surface. The Vipont workings were re-opened in 1977 or 1978 and two new adits driven. A mill was constructed to handle the ore and to rerun the tailings of the old mill.

Other mines of the area include the Skoro, Sentinell Group, Francis X, Midway, Lexington-Argenta, Dolly Clark, and Peg Leg.

The Skoro is southeast of the Vipont and has tapped ore in the Cambrian? (Ordovician?) Sentinell Limestone. The main tunnel was driven through the lower porphyry to the producing horizon. The mineralization was not as prolific nor as rich as in the Vipont mine; no very large shipments of ore were made. How-

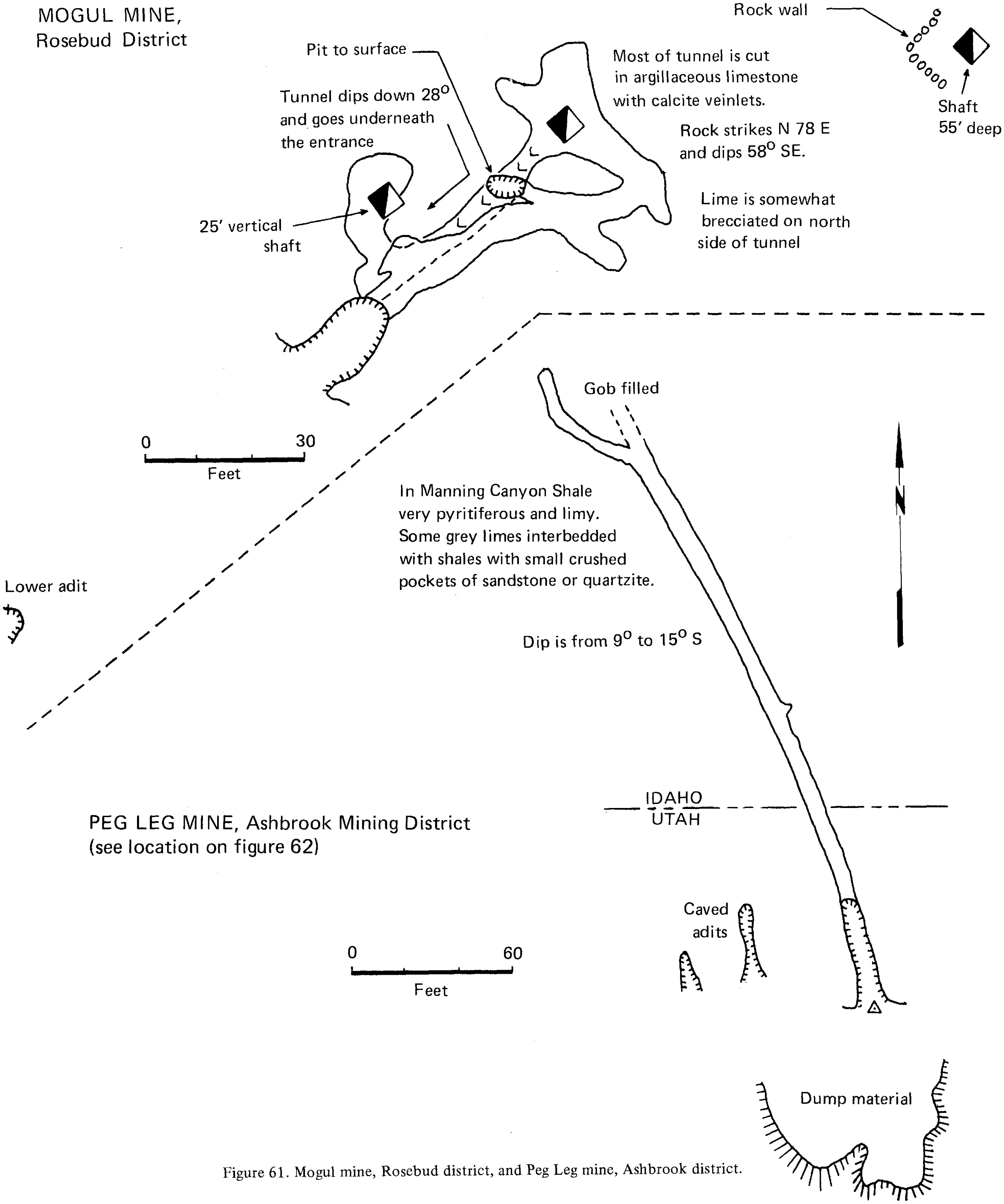


Figure 61. Mogul mine, Rosebud district, and Peg Leg mine, Ashbrook district.

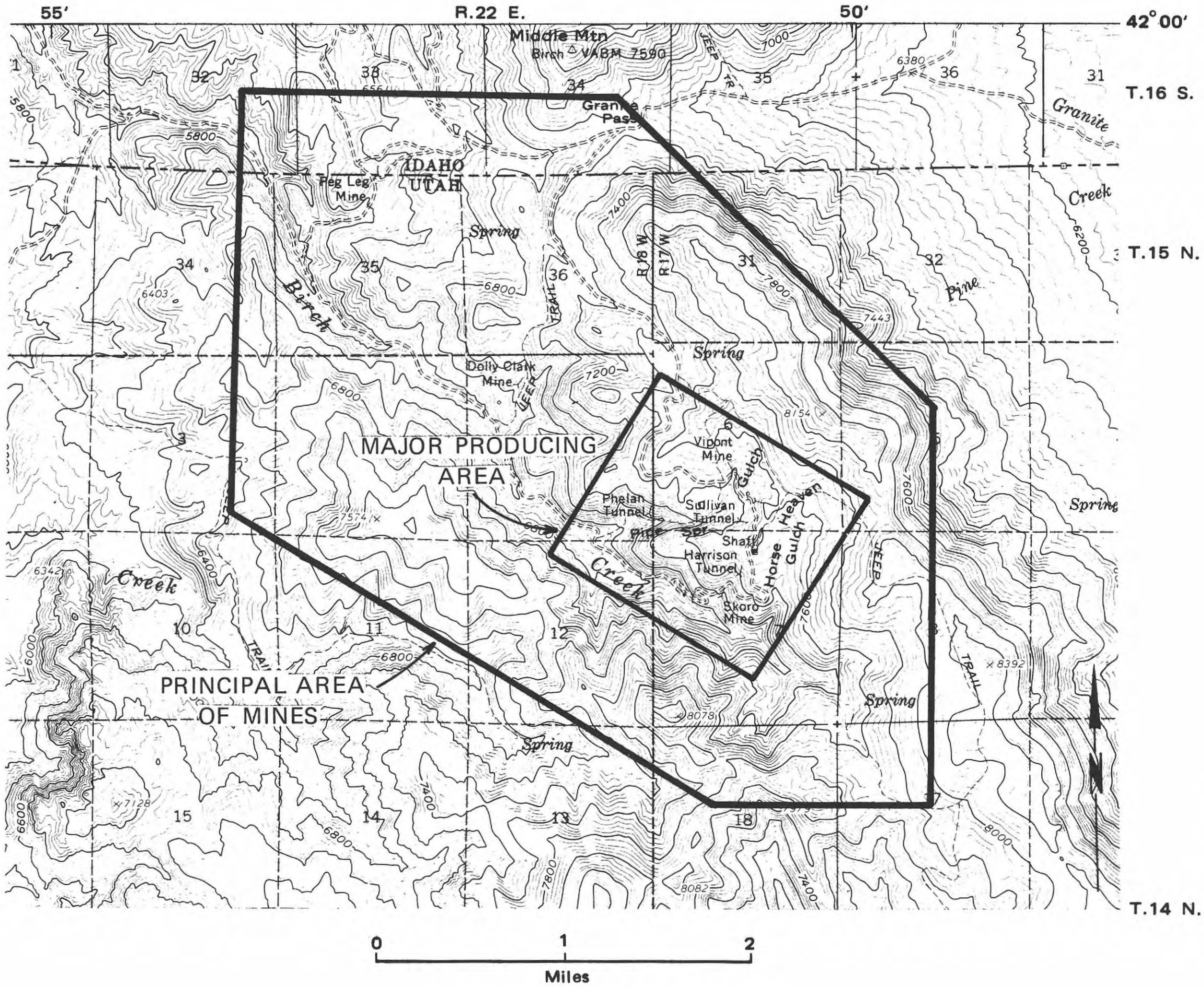


Figure 62. Ashbrook mining district

ever, the mineralogy and the nature of mineralization is similar to that in the Vipont.

The Sentinell Group mines are shallow workings cut in the Sentinell Formation north of the Skoro mine. Some of the prospects are still accessible, but most are caved. Small amounts of ore were produced here and are reported to have been richer in gold than at the other two more important mines.

The Francis X is a caved mine that was driven to intersect the Vipont Limestone. The tunneling got as far as the Wardlaw Shale and there was no ore production. The Midway tunnel starts in the Phelan Limestone and reaches the Vipont Limestone; supposedly a small amount of ore was found, but has not yet been extracted. The tunnel is presently caved.

The first mines of the district were discovered and opened at the Lexington-Argenta property located in the western part of the major producing area. These mines, consisting of at least three workings, are all caved and probably have not been worked since 1910. The Dolly Clark mine is located northwest of the major producing area and consists of a 600-foot open tunnel, presently producing a small stream of water. There are some short side drifts but little ore has been produced.

The Peg Leg mine (figure 61) consists of a tunnel 260 feet long and two other caved adits cut into the Wardlaw Shale. One-hundred-ninety feet of the tunnel are in Idaho. The shale is very pyritiferous and there are interbedded gray limestones and irregular pockets of crushed quartzite. The dip is southerly 9 to 15 degrees and the objective of the mine may have been to intersect

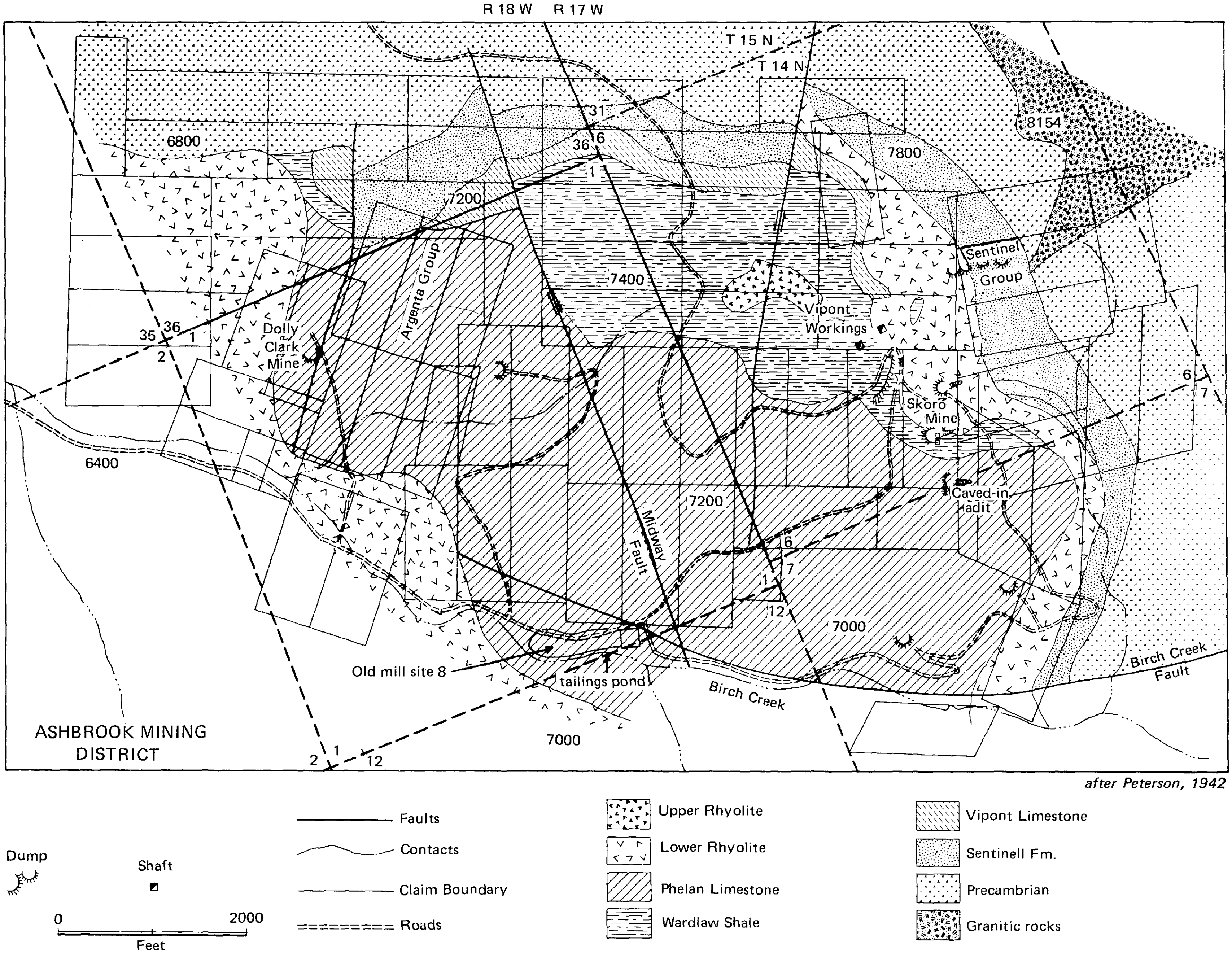


Figure 63. Geology, claim boundaries and surface workings of Ashbrook mining district

the Vipont Limestone. No interesting mineralization is present and no ore was produced.

On December 15, 1900, the *Salt Lake Mining Review* mentions that the Grouse Creek Mining Company had mined a tunnel 150 feet in length 4 or 5 miles south of the Vipont mine in Cotton Thomas Basin. Occasional kidneys of pyritic mineralization had been encountered. The mine was not located for this study.

Park Valley Mining District

The Park Valley mining district (figure 64) is located in the western part and south flank of the Raft River Mountains. Prospects and mines are known from Duncan Canyon westward to Corner Creek, but the most intensive activity and greatest production were realized at the west end of the area. Heikes (in Butler, 1920, p. 497) notes that about $400,000 had been produced in gold, silver, and copper and that $35,000 had been paid to stockholders of the Century Company. Compton (1972, p. 5) quotes the *Salt Lake Mining Review* papers of 1909 that about $500,000 in gold had been produced and that ore tenor ranged from $8 to $100 per ton. This production value may be a little high and stems from MacFarren (1909, p. 18, col. 1).

The southwestern Raft River Mountains are made up of Precambrian quartzites, schists, gneisses, and coarse-grained porphyritic granite (adamellite). The rocks can be subdivided into two groups: an underlying complex of quartzite, schist, gneiss and adamellite and an overlying bedded quartzite (Elba Quartzite). The upper quartzite dips gently to moderately to the south. The lower complex is intruded by quartz veins which terminate against the upper quartzite, and are mineralized with native gold, galena, sphalerite, pyrite and chalcopyrite. Secondary minerals such as limonite and hematite are plentiful; malachite and azurite are occasionally seen. Pyrite is common in the dark micaceous

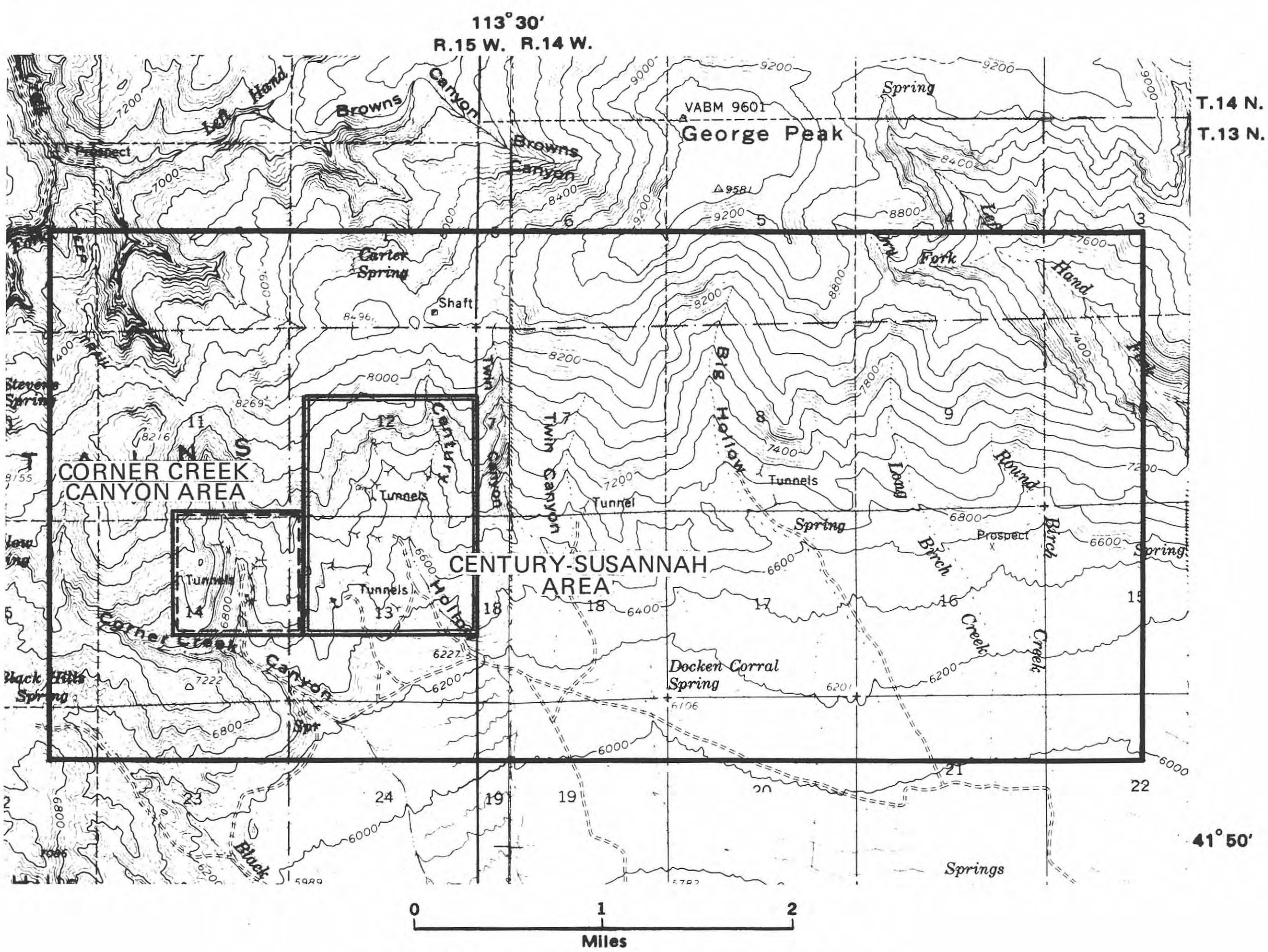


Figure 64. Principal area of Park Valley mining district

schists. The upper parts of the quartz veins had richer mineralization; the ore varied greatly in tenor, some very rich and much almost barren. The veins strike eastwardto northeastward and dip steeply southward.

Century-Susannah Area Mines and Prospects Gold-Lead-Silver-Copper

The *Salt Lake Mining Review* lists numerous properties which can be assigned to the vicinity of the Century mine, but only the Century and Susannah have been located and identified (figure 64). The area is completely abandoned and probably mined out; practically all the workings are caved. Century Hollow is located in sections 12- and 13- 13N 14 W. The Century mine dump is on the west side of the hollow and the Susannah is to the southwest over a ridge in the next gulch. Figures 64 and 65 show these and satellite workings. Both mines produce a small amount of water of startling purity (less than 100 ppm total dissolved solids). Other than rusty quartz and a little malachite, no megascopic ore minerals were found. In the northeast fork of Century Hollow is a mine dump with galena and pyrite.

Corner Creek Area Mines and Prospects (Gold-Lead-Silver-Copper)

Corner Creek Canyon (figure 64, 65, 66) is a mile west of Century Hollow and its workings are mostly located in NE 14- 13N- 15W. Most of the mines are caved. One mine, open in 1972, appeared only recently abandoned and may have been the last to operate. The name is unknown; it may be the Deer Trail mine mentioned in various issues of the *Salt Lake Mining Review*, but on figure 66 it is simply called the Corner Creek mine. There are at least 700 feet of workings that follow a rusty brecciated quartz vein; upper levels may be present. Some light copper stains are found near the vein. The country rock is adamellite and/or augengneiss. At least six other mines or adits and the foundation of an old mill are found in the vicinity.

Other Park Valley Mining District Mines and Prospects (Gold-Lead-Silver-Zinc)

On the crest of the Raft River Mountains above Century Hollow in SE 1-13N-15W are a shaft, dump, a broken hoist and foundation. The shaft, 8 x 8 x 20 feet deep in a black-brown mica schist, becomes an east-trending incline near the bottom. Mineralization includes limonite, pyrite and quartz.

There are at least three adits in the east fork of Twin Canyon, one mile east of Century Hollow. A lower mine, SE 7-13N-14W, is caved, the adit trending N 24 degrees E. The dump consists of gneissic adamellite, dark greenish mica schist, and quartz. The schist contains cubic crystals of pyrite with diameters to 1/2 inch. Some limonite and a small amount of galena were noted, principally in the quartz. Farther up the canyon are two additional caved adits and dumps. Gneissic adamellite and dark schist are also the dominant material in the dumps. Quartz and carbonate rock containing galena, pyrite and sphalerite was collected and assayed, yielding a trace of gold, 0.5 ounces silver, 1.4 percent lead, and 1.2 percent zinc. There was no copper present.

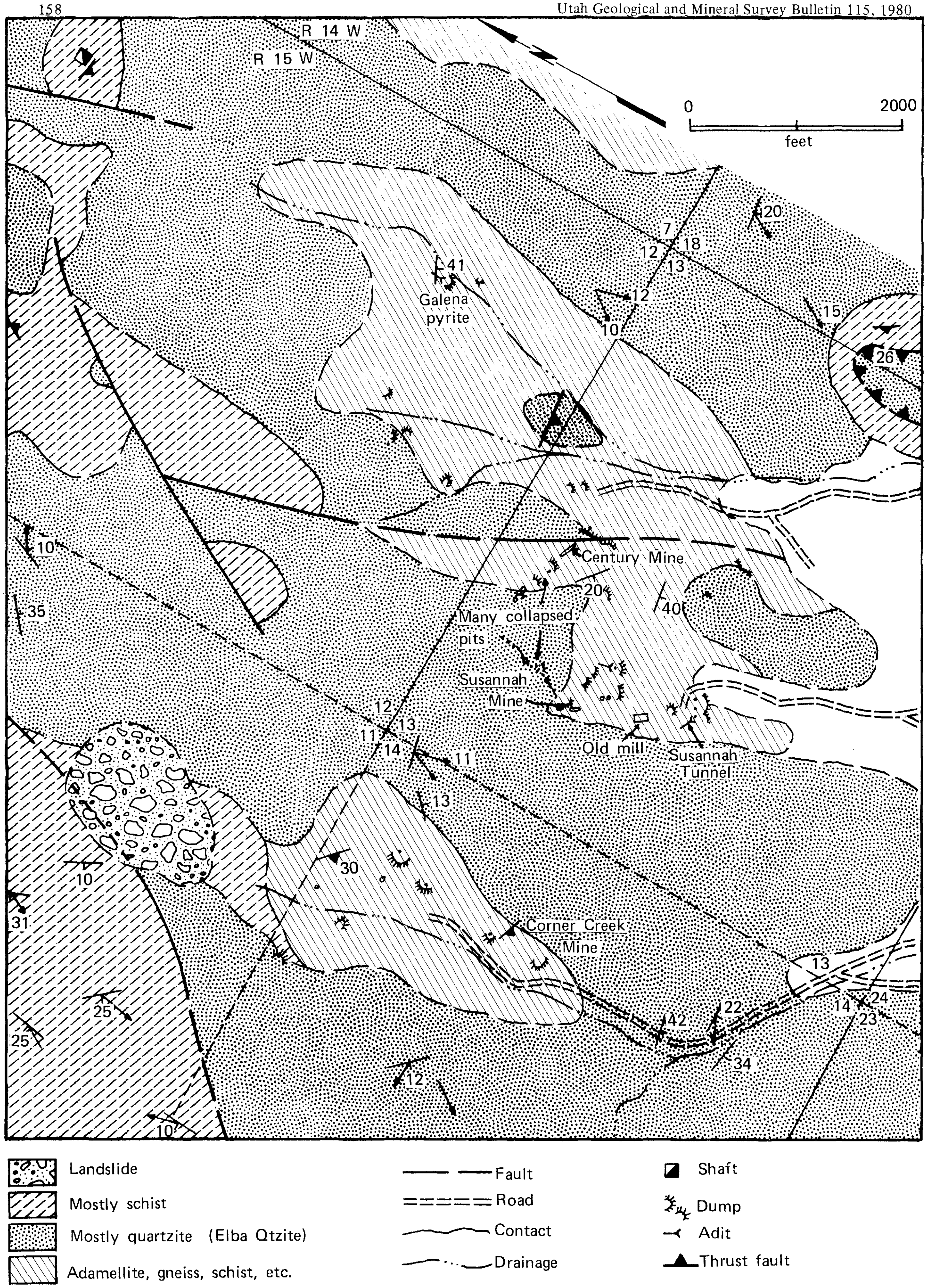
Yost Mining District

The Yost mining district is located on the north flank, west half of the Raft River Mountains. The mines and prospects are sparsely scattered across a seventeen-mile distance between Wildcat Creek and Onemile Creek south of the village of Yost (figure 67). There are no available production records but examination of the workings shows that a small amount of lead-silver ore was produced with a total value amounting to a few thousands of dollars. The geology in most of the mines is similar. The host rocks are Precambrian and Cambrian schists and quartzites in which rusty quartz veins and dikes are found.

Yost Mining District Mines and Prospects (Lead-Silver-Tungsten)

A tunnel and a few prospects are located along the west side of Wildcat Creek in about the center of 30-14N-15W (Mine No. 1, figure 67). The tunnel is caved, but the dump indicates that the workings may have been about 50 feet in length. The country rock is gray-green-brown mica schist; the tunnel follows a north-trending quartz vein about 6 feet in width. The vein is quite rusty and some pyrite is noticeable. There are several prospects on the east side of the canyon; one pit 8 feet deep has been dug into a rusty quartz vein.

There are some diggings in a small knoll adjacent to some farm buildings in SW 17-14N-15W (Mine No. 2). There is a pit on the southwest side of the knoll about 8 feet deep into a vein of hematitic and limonitic quartz. A 25-foot adit is on the southeast side of the knoll, following a rusty quartz vein. Additional rusty veins are noticeable on the boundary of sections 17 and 18, north of the road intersection.


R 14 W
R 15 W
0
2000
feet
Galena
pyrite
Century Mine
Many collapsed
pits
Susannah
Mine
Old mill
Susannah
Tunnel
Corner Creek
Mine
Landslide
Mostly schist
Mostly quartzite (Elba Qtzite)
Adamellite, gneiss, schist, etc.
Fault
Road
Contact
Drainage
Shaft
Dump
Adit
Thrust fault

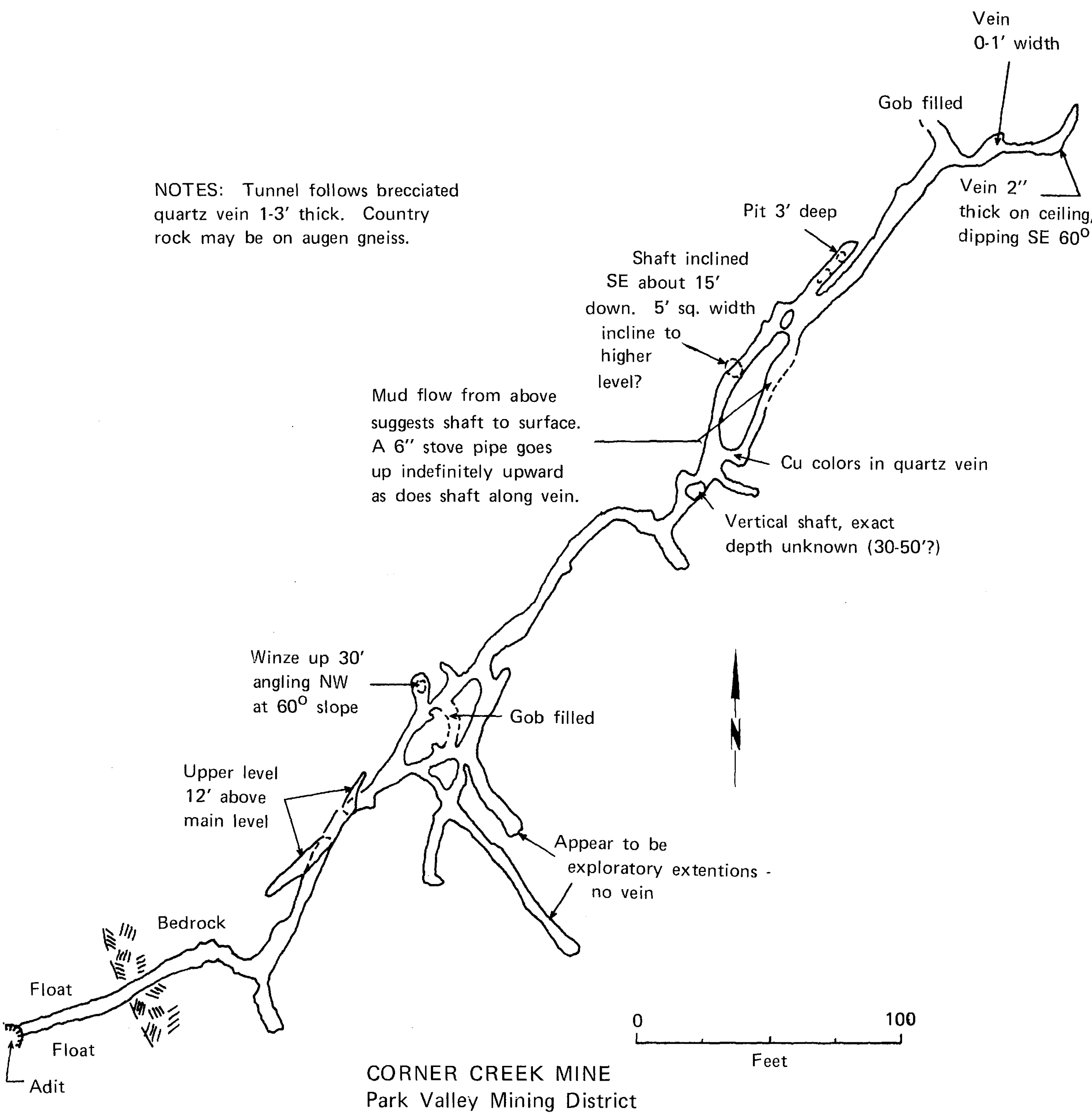


Figure 66. Corner Creek mine

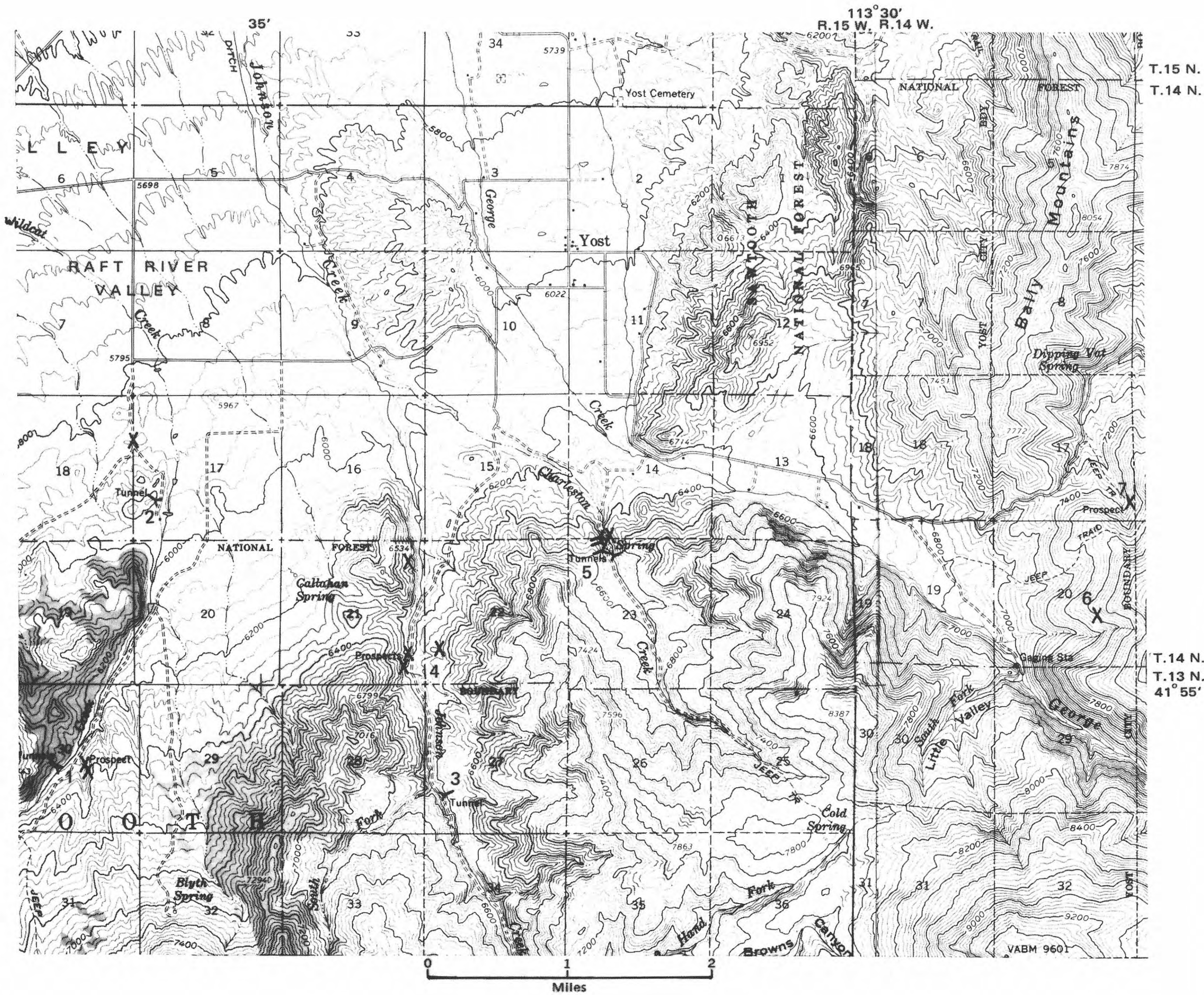


Figure 67. Yost mining district

There are several workings in Johnson Creek Canyon. At Mine No. 3, SW 27-14N-15W, is an open tunnel about 130 feet long on the east side at road level (figure 68). The dump is mostly dark mica schist and gray quartzite (schist of Stevens Spring and quartzite of Clarks Basin). Some pockets and irregular veins of rusty quartz were encountered in the mine, and a little pyrite was observed. About a mile down-canyon and on the west side are three or four workings, one of which is 135 feet in length, another 40 feet. These also follow rusty quartz veins in dark mica schist, presumably for lead-silver. A little side road leads east about 0.2 miles to the north to a rather fresh, deep cut and an older short adit (Lucky Boy No. 1). The dumps consist of gray micaceous quartzite, rusty mica schist, and a smaller amount of rusty quartz. The strike of the rocks is N. 35 degrees E. and the dip is 41 degrees southeast. The deep cut is mostly in thin-bedded quartzite with no mineral exposed. The short adit is 22 feet long with the last 15 feet declined 35 degrees northward. To the north, above both workings, is a north-trending bulldozer cut, quite shallow and about 150 feet long, following a brownish limonitic zone in schist. Part of this cut and the adit are in brownish sandstone or quartzite.

The Charleston Creek mines (No. 5) are located very near the mouth of the canyon in NW 23-14N-15W. These pits, tunnels, and prospects are found on both sides of the canyon (figure 69). Those workings on the east side of the canyon are shown on figure 70 and those on the west side are shown on figure 71. They have recently produced a little lead-silver ore; the mines were finally abandoned in the summer of 1972. At least 9 adits cut in schist or quartzite follow rusty quartz veins. Some galena was noted in the quartz and along the rusty contacts within thin clayey zones especially in the schist. Some white and gray encrustations carry a little cerussite and anglesite and some pyrite.

In a letter to Dr. W. P. Hewitt, Director of the Utah Geological and Mineral Survey, dated August 3, 1971, Joseph Dolanski, formerly with the U. S. Bureau of Mines in Salt Lake City, reported the following:

> I wish to report what I consider to be a new scheelite deposit in the Yost area. . . . . .These are in Box Elder County, T. 14 & 15 N., R. 14 W., sections 16, 17, 20 and 21. The occurrence was brought to my attention by a prospector, who submitted a sample on 6th May, 1969. . . . . . for mineral identification. This was essentially quartz with flakes of molybdenite. With this mineral association I suspected scheelite and/or powellite and found these to be present.
>
> A subsequent visit to the prospect revealed two quartz veins heavily mineralized with scheelite and some powellite. . .

A visit was made to fresh workings in 20-14N-14W (Mine No. 6). In a cliff-side road cut many white steeply dipping quartz dikes are exposed in dark schist. Some of these dikes are rusty; minor pyrite, much of which is altered to limonite, is noticeable. Minor shows of green (malachite) copper staining and galena were found. In a short 20-foot northward-trending adit a black light examination revealed spotty distribution of scheelite crystals, up to ¾-inch, in two of the quartz veins. The best shows were across one 14-foot quartz vein and a chip sample produced an analysis of 24.62 percent WO_3. The sample was taken across the best-looking part and does not reflect the average tenor of the ore. Reportedly some production was achieved in 1976-77. More prospecting is necessary to investigate the full potential of the area.

A southeastward trending tributary gulch of One-mile Creek in SE 17-14N-14W leads to the Blue Bird workings, some of which are open (figure 71a). These were developed during the 1930's. Fresh pyrite, galena, and limonite pseudomorphs after pyrite, up to ¾ inch in diameter, were noted. A grab-sample collection taken from ore remnants from several of the workings and dumps yielded a trace of gold, 13.5 ounces silver, 5 percent lead and no copper or zinc.

Clear Creek Mining District

The Clear Creek mining district lies on the north-east flank of the Raft River Mountains; most of the mines are in 12-14N-13W. The mineralization is primarily copper, silver, and lead. The mines are located on figure 72. At Mine No. 8 there is a small knoll into which a short adit (15 feet) has been driven into the Pennsylvanian-Permian Oquirrh Formation. The limestone is marbleized and there is considerable gossan. Brecciated marble and limonite make up a zone 3 to 4 feet thick. Iron oxides were noted as the only mineralization.

All of the remaining prospects are in 12-14N-13W. At Mine No. 9 are two adits on the east side of a gulley, near stream level, cut in shaly schist underneath quartzite and limestone beds. The two workings may connect under-ground. The overlying quartzite and limestone beds dip 5 to 10 degrees northward. The length of each adit is at least 50 feet. Except for the limonite and hematite no significant mineralization was observed. There are numerous surface pits in the vicinity.

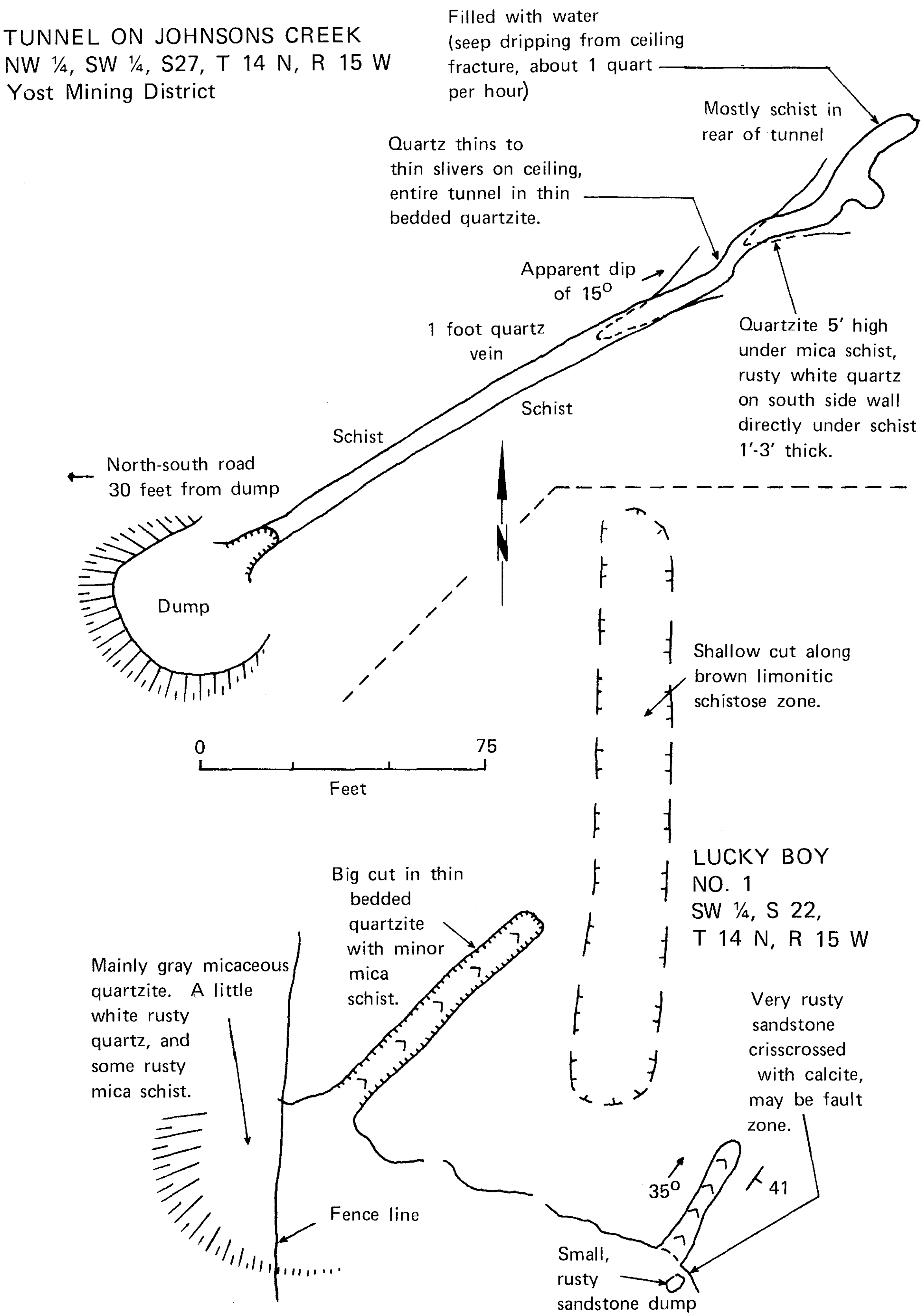
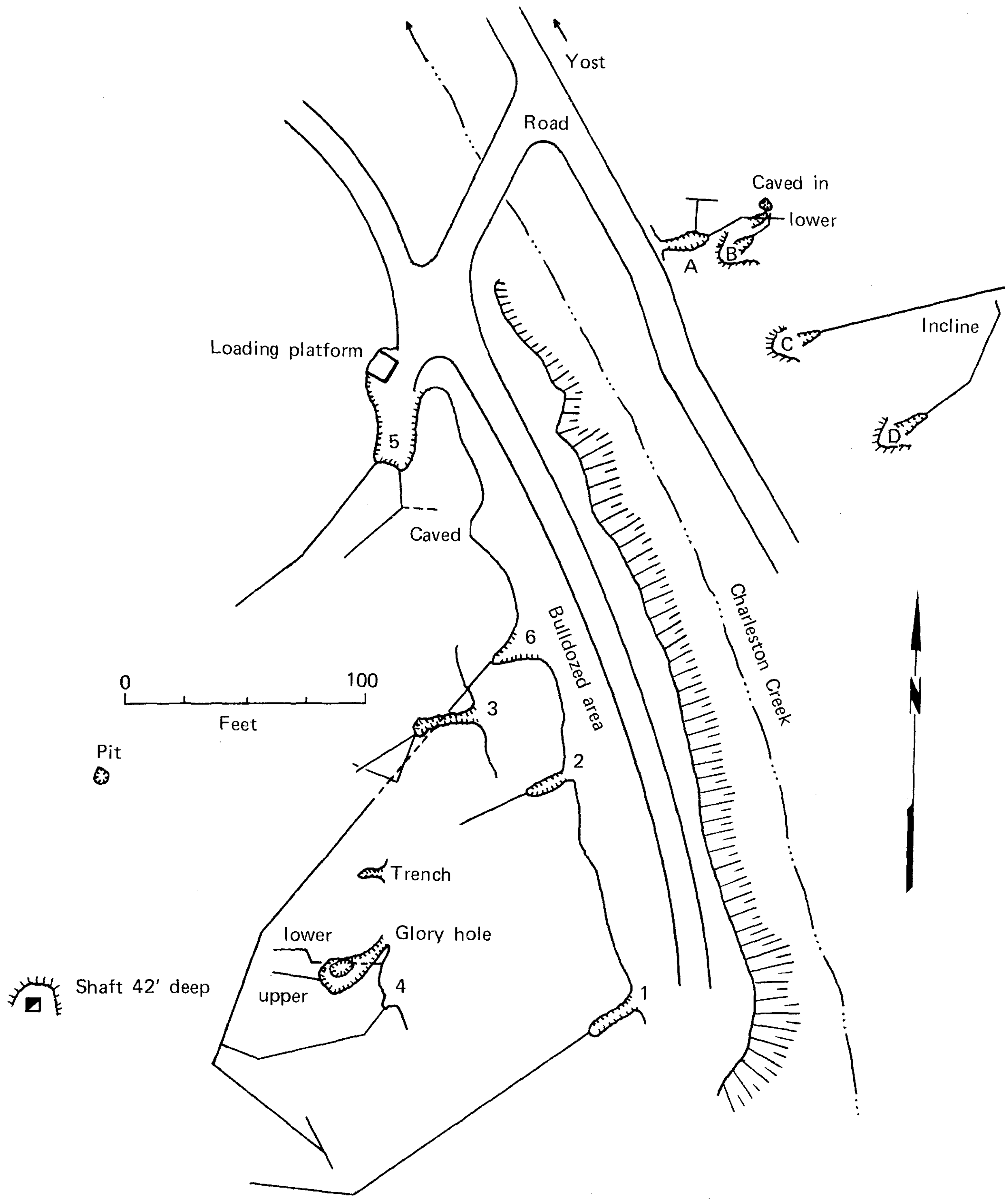


Figure 68. Tunnel on Johnsons Creek and Lucky Boy No. 1.



CHARLESTON CREEK AREA, Yost Mining District

Figure 69. Charleston Creek area

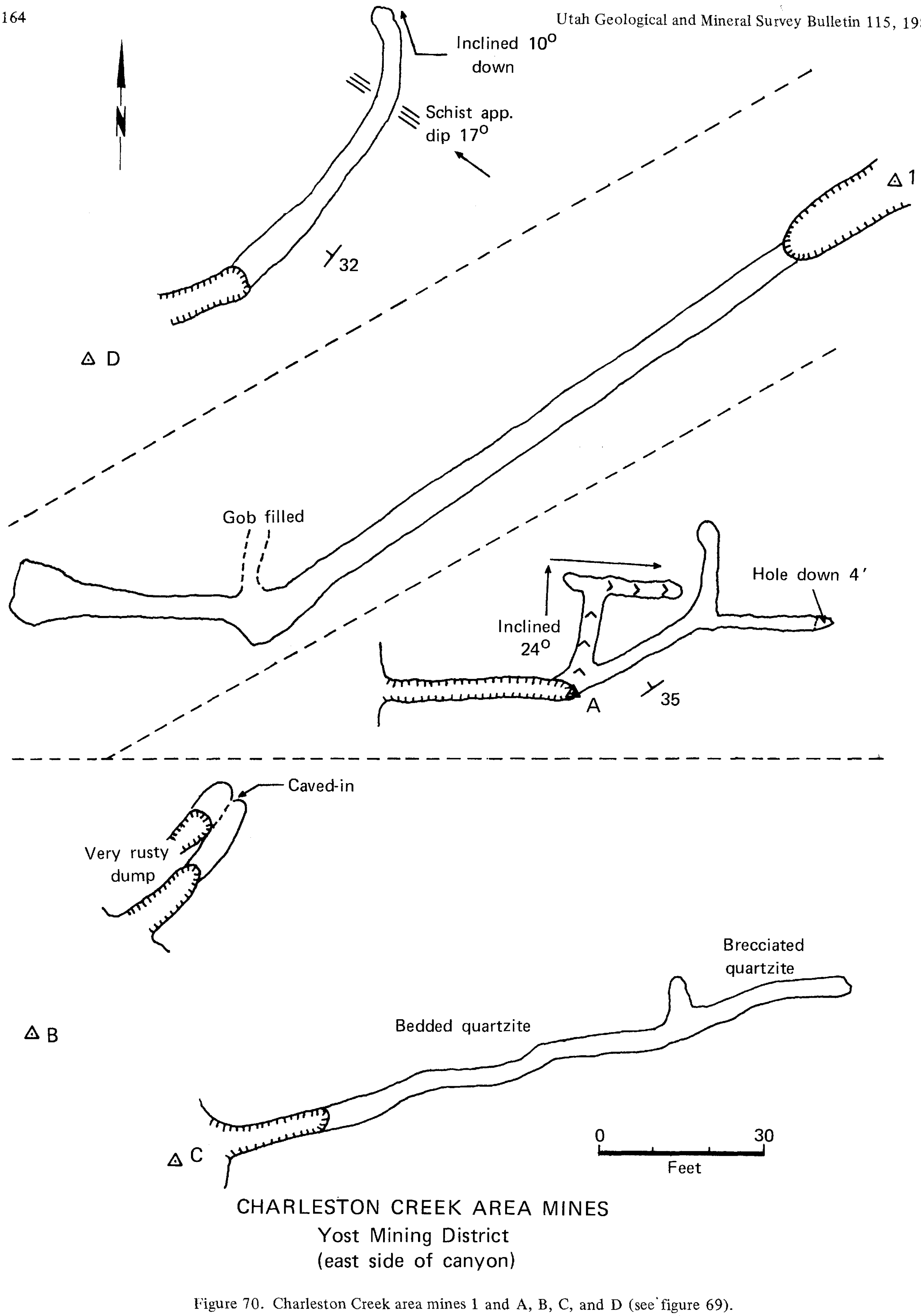
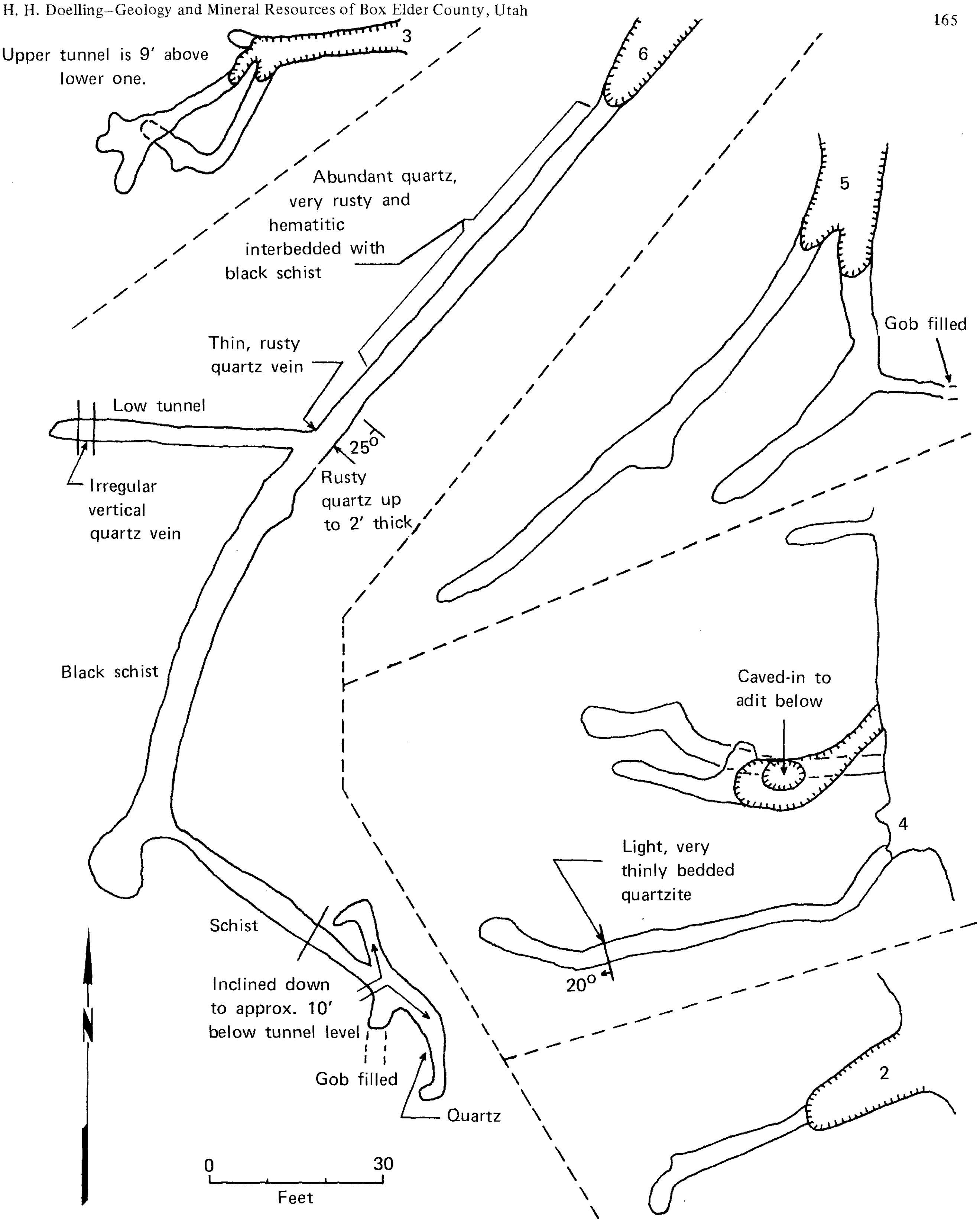


Figure 70. Charleston Creek area mines 1 and A, B, C, and D (see figure 69).



CHARLESTON CREEK AREA MINES, Yost Mining District
(west side of canyon)

Figure 71. Charleston Creek area mines 2 to 6.

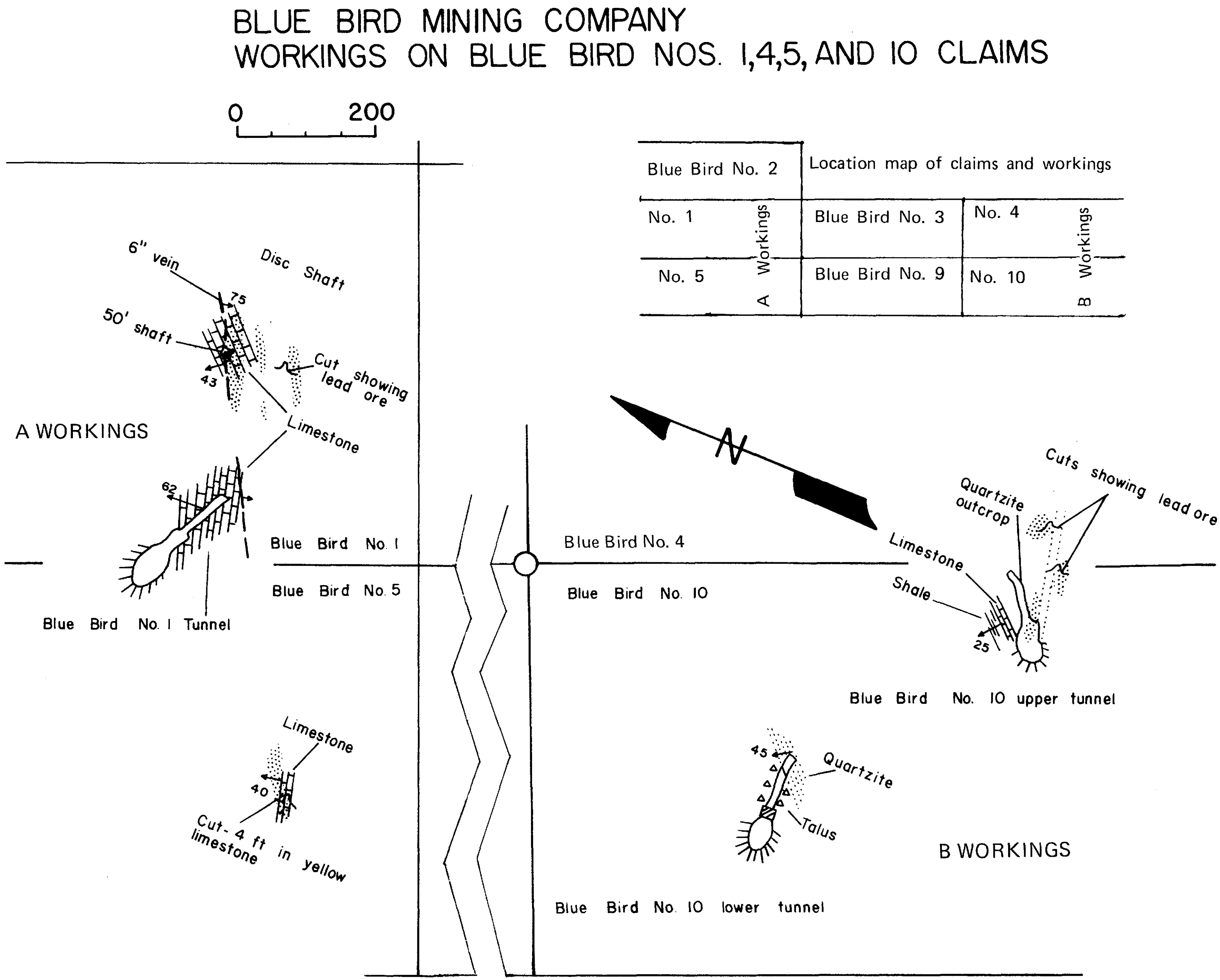


Figure 71a. Blue Bird Mining Company workings, Yost mining district

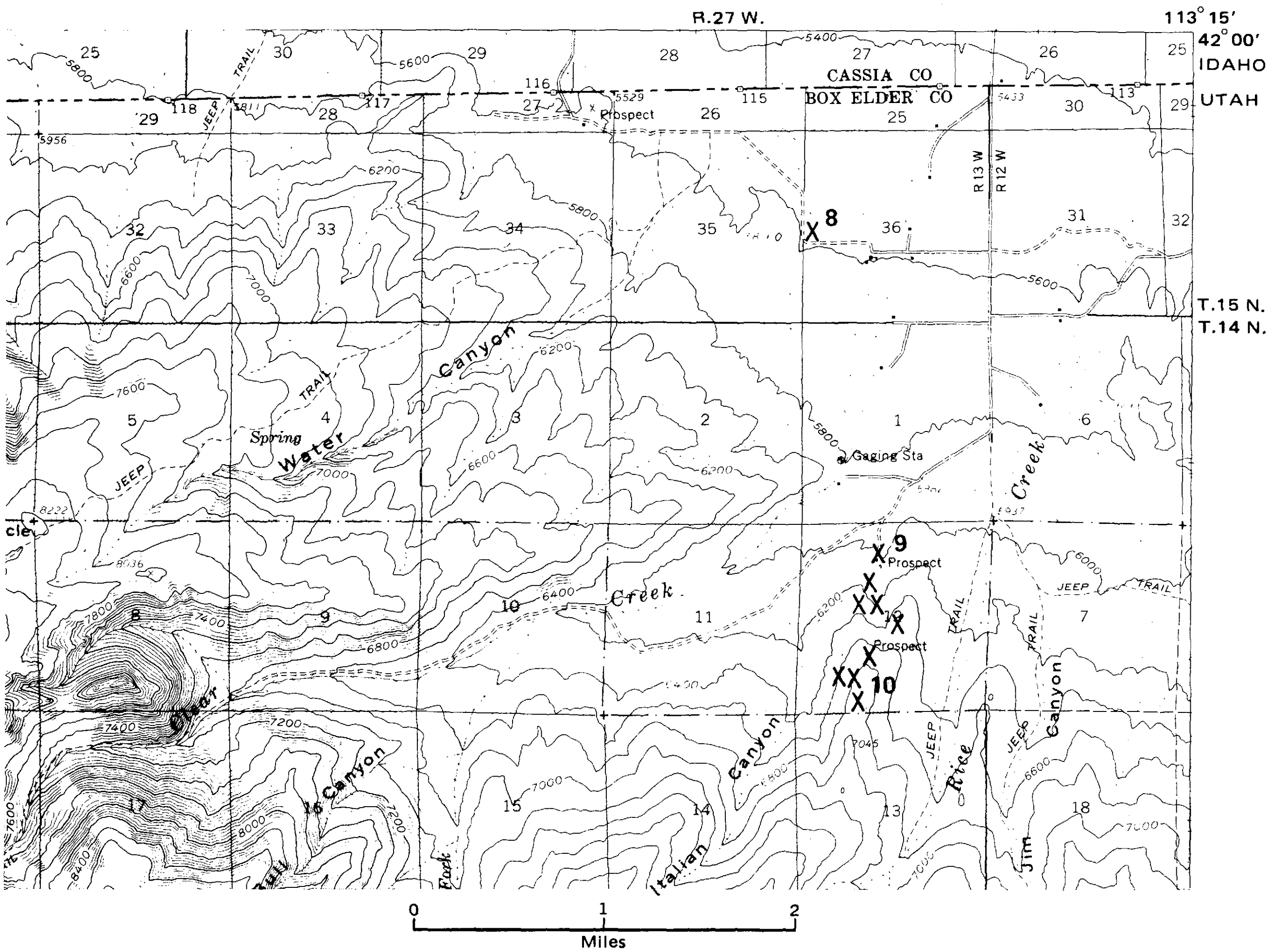


Figure 72. Clear Creek mining district

Several small mines are found farther up the hill between Rice Creek and Italian Canyon. The prospect marked No. 10 on the map (figure 72) is a tunnel entering westward into the hillside. The portal has collapsed, but the size of the dump indicates at least 100 feet of workings. The material on the dump consists of dark schist and hard white quartzite, much of which is coated with muscovite mica. Hematite and limonite make up the dominant mineralization; chalcopyrite, bornite, malachite and minor azurite are present. A little farther south on the east side of Italian Canyon are several prospects cut in rusty schist and quartzite. The size and nature of the dumps of the largest indicate that most of the working is cut in schist and consists of no more than 50 to 100 feet of drifts. Strong limonitization is evident and occasional pieces of copper-stained white quartz are to be found. The workings are thought to be part of the Ginza Copper Company holdings which were active in 1913 and perhaps as late as 1932. The *Salt Lake Mining Review* of May 15, 1913 noted that the company had 2 cars of $50 ore ready for shipment. On September 15, 1913 these notations appeared:

> . . .The Ginza vein is a contact between quartzite and granite, almost in blanket formation. The ledge is a wide one with a 3½ foot zone hanging wall averaging $27 to the ton in copper, gold, and silver, with copper values predominating. Development consists of a tunnel 160 feet in length with drifts both ways from the face to 12 and 15 feet. The company now has about 4 carloads on the dump ready for market. Besides the paystreak in the vein a large amount of ore of lower values is being opened up, as a winze has been sunk in the tunnel, on the vein to a depth of 18 feet.

Promontory Mining District

by Lee I. Perry

UGMS Staff Geologist, Economic Geology section

The Promontory mining district is located a few miles north of the salt plant at Saline, near the southern end of the Promontory Range. The principal mineralization was discovered later than that of the other mining districts in the county. In 1907 it was reported that the Lakeside Mining Co. shipped a test lot of siliceous copper ore carrying a little silver and that their property was developed by a 120-foot shaft and 40 feet of drifts. A few claims were held on a bed of marbleized limestone. In the latter part of 1914 some men doing assessment work found boulders of lead-zinc carbonate northeast of the claims. The source of the boulders was traced to the outcrop. The Lakeview Mining Company became the largest producer of zinc ore in the county. The company began development work in April, 1915, and by the early part of June had paid all pre-production expenses and declared a dividend to the stock-holders. Jessup (1916, p. 576) states that through September, 1916, the Lakeview Mining Company had paid $150,000 in dividends. Production tapered off after 1918; intermittent shipments were made through 1928, when production ceased. During World War II production was reported from 1942 to 1947; the last shipments were made in 1956 (Table 5). The Promontory district has produced more than 90 percent of the county's zinc and 23 percent of the lead (figure 73).

Ore deposits in the Promontory mining district are of two types: disseminated copper, found in the Prospect Mountain Quartzite, and zinc-lead replacements of limestone along faults and in selective beds in Middle Cambrian rock. The copper deposits are on the west side of the mountain range, about 1½ miles (2.4 km) north of Saline. In 1907, 14 tons of hand-sorted ore averaging 3.85 percent copper and 1 ounce of silver per ton were shipped (Butler and others, 1920, p. 502). Butler describes the deposits as disseminated chalcopyrite and possibly bornite altered to carbonates at or near the surface. When Butler examined the deposits there were two shafts, an incline shaft, and two tunnels developing the ore. Only one shaft remains; the other workings were destroyed in a rock quarry. The dump of the shaft reveals chalcopyrite, malachite, bornite, and limonite. The copper mineralization is localized and is not of commercial interest at the present time.

The limestone replacement ore bodies of the district are the most important and account for all of the zinc-lead production. All of the ore deposits, with the exception of one in Little Valley, lie between the Cambrian Lyndon equivalent (Millard Formation of Olson, 1960) and the base of the "Wheeler Shale". The mineralization is associated with favorable beds in the interbedded carbonate and shale section overlying the Prospect Mountain Quartzite. The "Wheeler Shale" may have acted as a barrier to rising metal-bearing solutions (Olson, p. 235). The "middle limestone bed" host rock of Butler and others (1920, p. 502) and Siegfus (1924, p. 102) is probably Unit 7 of Olson's (p. 279) Burrows Limestone (Dome equivalent). Marbleization is evident near the deposits and dolomitization is prevalent at distances of several thousands of feet from the deposits. No sulfide ore has been observed by any of the investigators who have inspected the mines, but all maintain that the carbonate ores were derived from the alteration of sulfides.

The ore bodies are completely oxidized and the principal ore minerals are hemimorphite, smithsonite, and cerussite. The ore generally contains less than an ounce of silver to the ton and practically no copper or gold. The gangue minerals are limonite, hematite, calcite, dolomite and possibly barite. Hemimorphite is the most common zinc mineral; crystals up to 1/16 inch (1-2 mm) can be seen in most of the Lakeview workings. Smithsonite and cerussite are mostly massive and intermingled with the iron oxides, making field identification difficult. The mineralization in the main Lakeview workings on the south side of Lakeview Ridge is predominantly zinc with a little lead; lead increases in the lower workings. The workings across Cedar Ridge Gulch to the south (Lead Mountain) are high in lead and low in zinc.

Lakeview Workings (Zinc-Lead)

The major mines of the Promontory mining district are on patented claims; the workings are located on figures 74 and 75. The principal Lakeview mine portals are located on the south side of Lakeview Ridge and are numbered starting with the lowest working: Nos. 1, 2, 3, 4, 5, and the Skyline tunnel (figure 76, 76a-76f).

Lakeview No. 1 is the most extensive working and was driven to develop the down-dip extension of the "middle limestone member" or "ribbon bed" and to provide a haulage level for the higher workings. This level has about 1,300 feet (396 m) of drifts, several winzes exploring the down dip of the "middle limestone" or "ribbon bed", and several raises connecting with higher levels. Several raises from Lakeview No. 1 connect with the workings on the Volunteer Gulch side of Lakeview Ridge. Most of the stoping on the No. 1 level was done near the southern end of the level which is connected by stopes with the surface workings of the No. 2 level. The winzes below No. 1 did not develop the ore as expected and were abandoned. A 340-foot rock tunnel connected the working level with the portal.

Table 5: Production of Precious and Base Metals, Promontory mining district, 1907-1976

Year	Tons	Gold ozs.	Silver ozs.	Copper lbs.	Lead lbs.	Zinc lbs.	Lead Avg. Grade	Zinc Avg. Grade	Value
1907	14	---	14	1,078	---	---	---	---	$225
1908-1914	probably no production								
1915	4,788	---	---	---	?	2,482,578	?	30.5%	322,735*
	94	---	---	---	34,174*	?	18.18%	?	1,708*
1916	?	---	---	---	1,089,600√	2,688,401	?	?	423,164*
1917	?	---	---	---	265,826√	574,357	?	?	75,616*
1918	?	---	---	---	30,000√	300,000√	?	?	26,100*
1919	?	---	---	---	5,000√	20,000√	?	?	1,700*
1920-1924	no production								
1925	12	?	?	?	?	?	?	?	?
1926	no production								
1927	one lot of oxidized lead ore shipped								?
1928	two cars of oxidized lead ore shipped								?
1929-1941	no production								
1942	77	---	21	---	17,300	16,000	11.2%	10.4%	2,662
1943	580	---	104	1,500	103,200	119,000	8.9%	10.3%	20,861
1944	403	1	90	---	82,400	105,500	10.2%	13.1%	18,718
1945	600	1	111	600	88,500	155,000	7.3%	12.9%	25,631
1946	368	1	78	500	68,000	90,000	9.2%	12.2%	18,571
1947	129	---	22	200	15,600	29,800	6.0%	11.6%	5,914
1948-1951	no production								
1952	130	---	22	---	18,000	14,000	6.9%	5.3%	5,242
1953-1955	no production								
1956	4	---	2	---	400	500	5.0%	6.3%	133
1957-1976	no production								
Totals	7,199+	3	464	3,878	1,818,000	6,575,136			$948,980

*Calculated values
√Author estimates
Most data from U.S. Bureau of Mines' Minerals Yearbooks

Lakeview No. 2 was the site of first development on the property and consisted of glory-holing and later stoping underground along the "middle limestone bed." These stopes were finally connected with the stopes above the southern end of No. 1.

In Lakeview No. 3 stopes extend to No. 4 level and below, connecting with two raises from No. 1. The "middle limestone bed" was followed northward into the middle of the ridge. Stopes above the level in the deeper parts of the mine connected with Lakeview No. 5 above.

The workings of Lakeview No. 4 are not extensive and served mainly as a transfer level, pulling the ore from No. 5 to the levels below. The large stope near the portal of the Lakeview No. 5, partially caved, indicates the large block of ore that was present here. The workings extend along the "middle limestone or ribbon bed" for approximately 350 feet (107 m) and include stopes in the first 180 feet (55 m). Approximately 300 feet (91 m) from the portal a winze was sunk connecting with stopes of the Volunteer workings. Near the top of this winze a raise was driven and a small amount of ore mined.

The uppermost main working is the Skyline tunnel, so named because it is close to the Lakeview Ridge summit and extends through the ridge, opening into Volunteer Gulch. The length of the tunnel is about 560 feet. From the portal on the south side of the ridge the drift was driven northwesterly until the "ribbon bed" was encountered, which was then followed along strike. About 300 feet north of the portal, stoping began. From this point to the Volunteer Gulch portal stoping is continuous above and below the level. The stopes above the level connect with a winze from the Volunteer No. 3 level. Complementary workings in Volunteer Gulch consist of three levels (Volunteer Nos. 1, 2, and 3). Volunteer Nos. 1 and 2 are below the portal of the Skyline tunnel and No. 3 is above. Stoping below the Skyline level connects with the Volunteer No. 2 in two places. Ore was transferred down through the stopes until it was pulled on the Lakeview No. 1 level.

Volunteer No. 1 is the most extensive working on the south side of Volunteer Gulch and extends into the ridge about 400 feet (122 m). There are numerous stopes both above and below the level. Volunteer No. 1 is connected by a winze to Lakeview No. 1 very near the

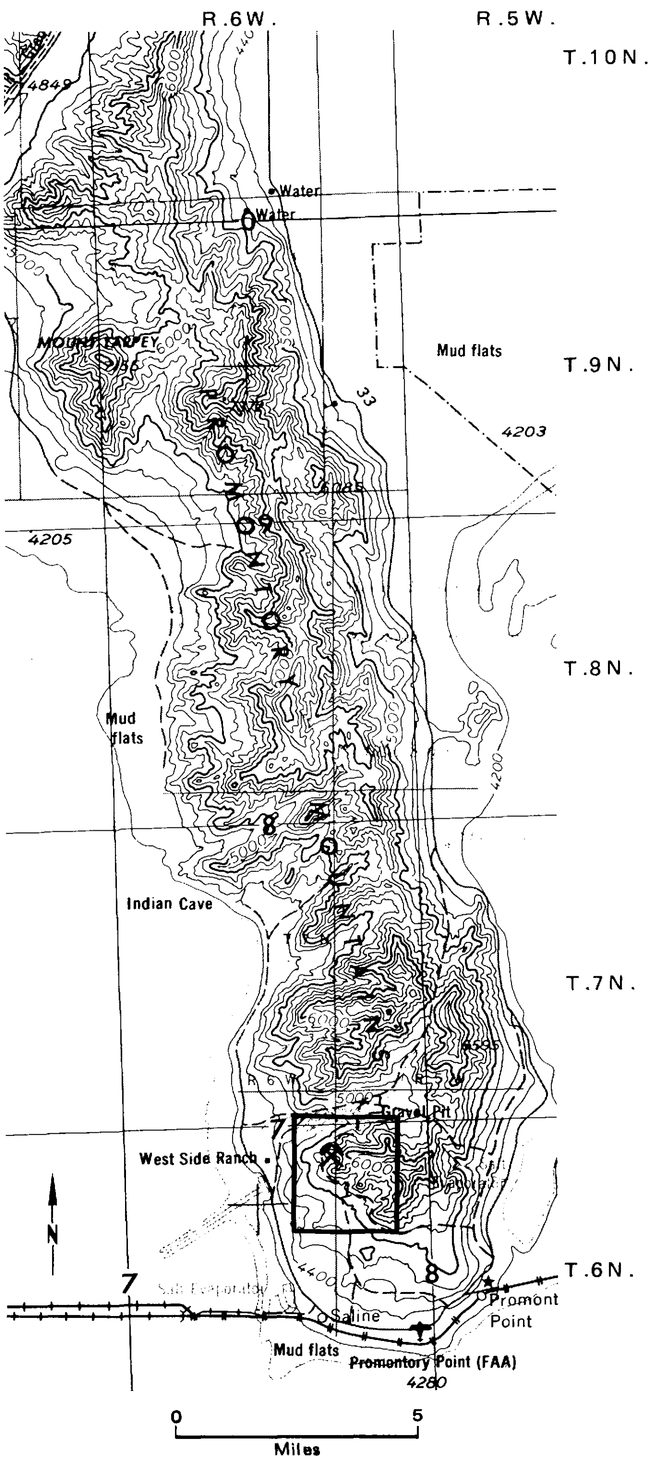


Figure 73. Promontory mining district, showing area of principal mines.

Volunteer portal. Below Volunteer No. 1 and above Lakeview No. 1 are two sublevels that have no external connections with the surface, but have stope and winze connections with each other. The ore mined in Volunteer No. 1 stopes and in the sublevels is replacement ore in and around the "middle limestone bed"; the ground was prepared by small faults and fractures providing access for the mineralizing solutions (figure 76b).

The Volunteer No. 2 workings extend into Lakeview Ridge approximately 220 feet (67 m). Stopes below the level connect with Volunteer No. 1 and the stopes above the level connect with the Skyline tunnel. The next higher workings are the Skyline tunnel and the Volunteer No. 3. The No. 3 workings are the smallest and are connected with the Skyline tunnel via a winze.

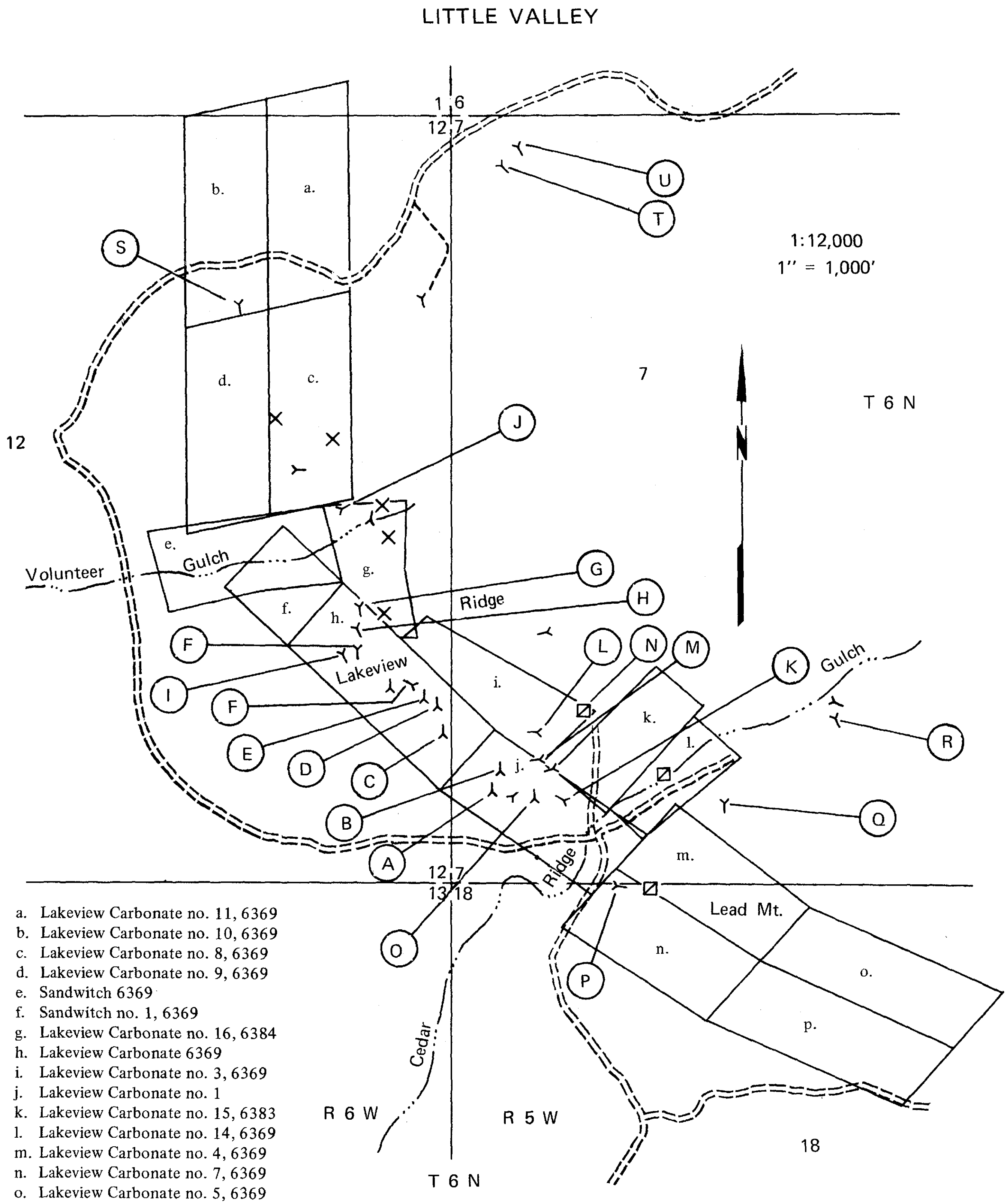
Near the head of Volunteer Gulch is an inclined shaft, listed as J in figure 75 and arbitrarily named the "Harbor Gulch" incline. The shaft is inclined 35 degrees and follows the mineralization along the "ribbon bed". Two levels are turned off the shaft to the southeast, the longest one about 110 feet (34 m) long. No large amount of ore appears to have been stoped from this working (figure 77). Several other small workings consisting of prospect pits and short adits are located in Volunteer Gulch, all cut in the "ribbon bed".

Other Workings on or near Lakeview Ridge (Zinc-Lead)

East of the Lakeview portals are the Complex tunnel, Petes tunnel, the Shaft, and several less important prospects and adits. The Complex tunnel, listed as K in figure 75, was driven to intersect the "ribbon bed" at depth. This bed, intersected 90 feet from the portal, was followed to the northwest. There are about 800 feet (244 m) of workings and stopes in the tunnel (figure 78). Siegfus (1924, p. 110) states that ore was shipped and that an assay of ore on the dump showed 1.1 percent lead and 17.12 percent zinc.

Petes tunnel, listed as L in figure 75, is higher in elevation than the Complex tunnel and is located southwest of the Shaft. It contains several hundred feet of workings along the " middle limestone bed". There are several stopes in the mineralized area, but the amount of ore extracted is unknown (figure 79). An adit 160 feet to the south of the portal is driven along the ore zone, which is up to 14 inches thick, strikes N. 70° W. and dips 55 degrees to the southwest. The ore zone has been stoped above the level for approximately 100 feet (30 m) and is connected by stopes to Petes tunnel.

The Shaft, listed as N in figure 75, in the northeast corner of the Lakeview Carbonate No. 3 claim, was sunk to a depth of 512 feet (156 m). Two levels were cut from the shaft at 128 feet (39 m) and at 350 feet



a. Lakeview Carbonate no. 11, 6369
b. Lakeview Carbonate no. 10, 6369
c. Lakeview Carbonate no. 8, 6369
d. Lakeview Carbonate no. 9, 6369
e. Sandwitch 6369
f. Sandwitch no. 1, 6369
g. Lakeview Carbonate no. 16, 6384
h. Lakeview Carbonate 6369
i. Lakeview Carbonate no. 3, 6369
j. Lakeview Carbonate no. 1
k. Lakeview Carbonate no. 15, 6383
l. Lakeview Carbonate no. 14, 6369
m. Lakeview Carbonate no. 4, 6369
n. Lakeview Carbonate no. 7, 6369
o. Lakeview Carbonate no. 5, 6369
p. Lakeview Carbonate no. 6, 6369

Figures 74 and 75. Patented claim map and location of workings, Promontory mining district.

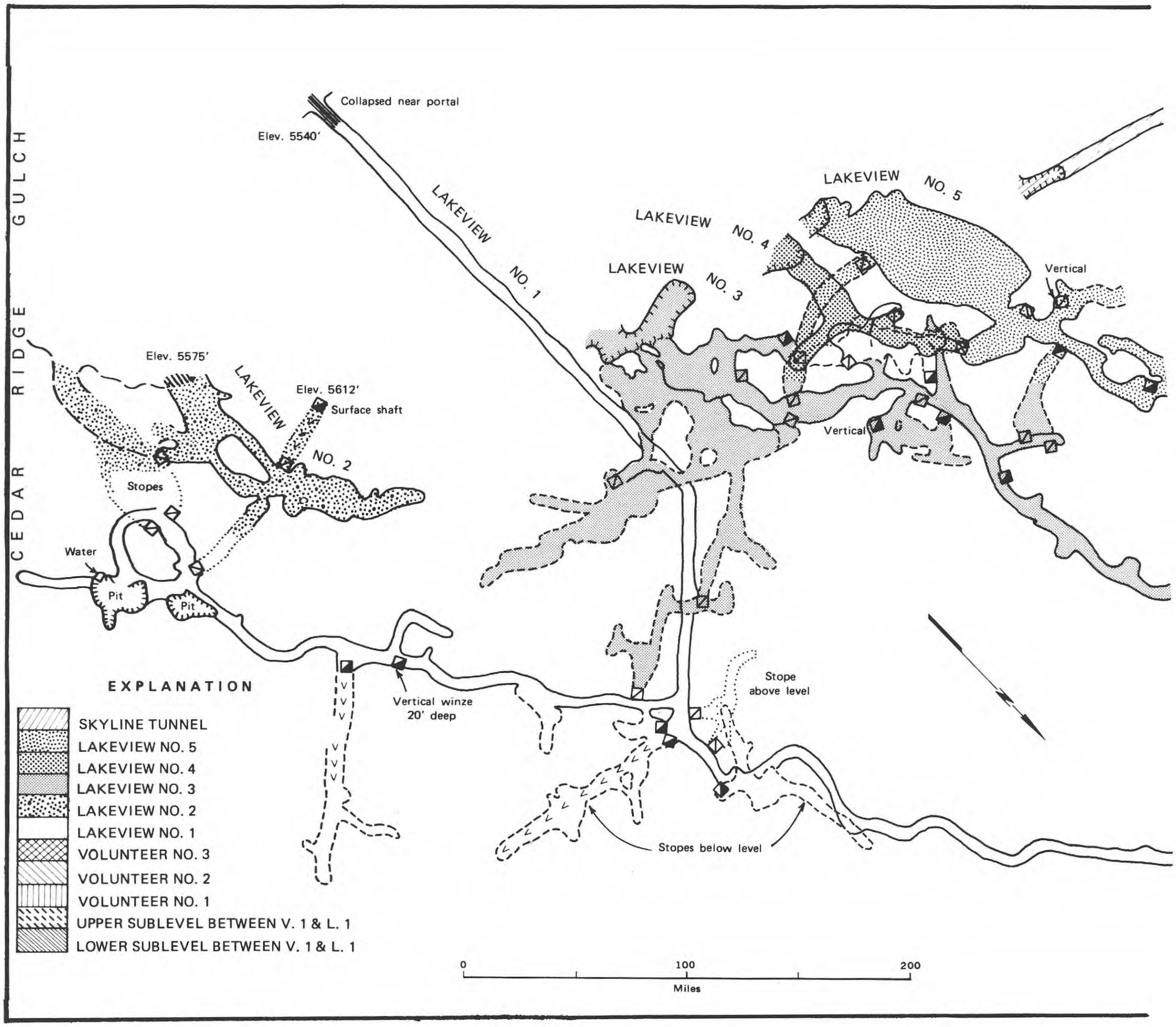
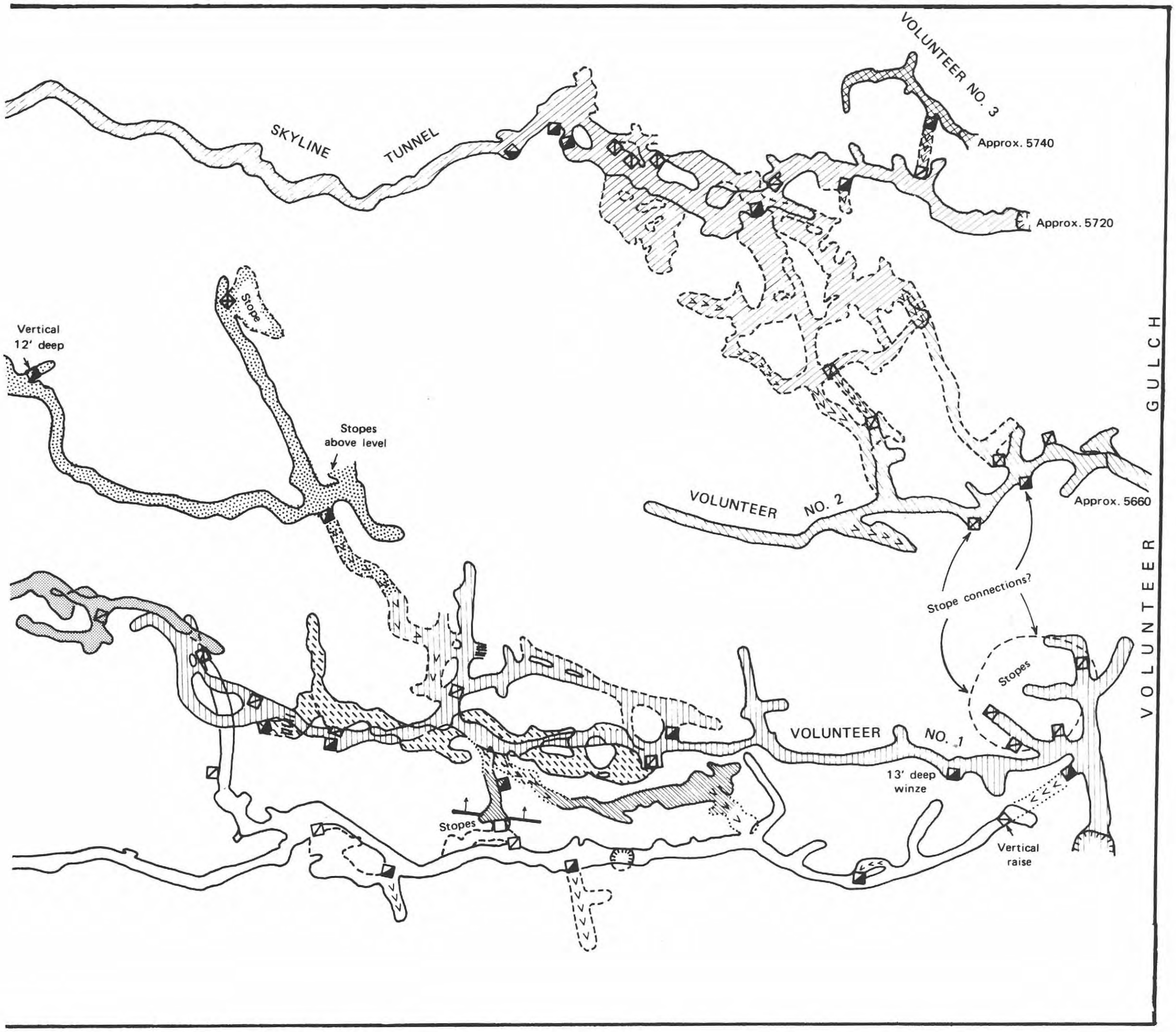


Figure 76. Lakeview workings and Volunteer workings, Promontory Mining district.


VOLUNTEER NO. 3
SKYLINE TUNNEL
Approx. 5740
Approx. 5720
Stope
Vertical
12' deep
Stopes
above level
VOLUNTEER NO. 2
Approx. 5660
VOLUNTEER GULCH
Stope connections?
Stopes
VOLUNTEER NO. 1
13' deep
winze
Stopes
Vertical
raise

(107 m) below the collar. The 128-foot level followed a water course after being opened by a short drift. The water course was of such size that it was possible for a man to crawl easily in the natural opening, which was inclined 45 degrees for a short distance and then extended 25 feet horizontally to the north, where it is no longer passable. The 350-foot level drift follows a fairly well defined contact for 100 feet (30 m) to the northwest. A sample taken by Siegfus (1924, p. 111-113) from various places along this drift assayed 1.15 percent lead and 23.28 percent zinc. Siegfus reports a black carbonate of lead ore was found on this level and a large sample of this material showed a composition of 1.08 ounces of silver, 41.52 percent lead and 0.36 percent sulfur.

Midway between the Lakeview No. 1 portal and the Complex tunnel along the strike of the "middle limestone bed" is a small working listed as 0 in figure 75. The adit intersects an area of brecciated limestone that has zinc-lead ore associated with it (figure 80).

Lead Mountain workings
Lead-Zinc

The workings on Lead Mountain consist of a shaft, open-cut, and two adits. The first work was done on the common line of patented claims Lakeview Carbonate No. 4 and Lakeview Carbonate No. 7 (figure 74). An open cut extended into underground stoping and a shaft was sunk about 50 feet (15 m) before an adit was driven under the surface workings and shaft to make it easier to extract the ore (figure 81). The surface workings extend into the mountain approximately 100 feet (30 m) and are connected with the adit driven under them in several places. The surface workings and the shaft were not mapped.

Farther east in Cedar Ridge Gulch another adit (Lead Hill incline) is listed as Q in figure 75 and is represented in figure 82. Approximately 20 feet (6 m) in from the portal of the adit is the top of an inclined winze which leads to a sublevel that is 40 feet (12 m) long. Little ore was mined from this working. Still farther east on the south side of the gulch are two small adits, one listed as R in figure 75 and mapped in figure 83. Some limonite and hematite is present, but no ore minerals were observed.

Little Valley workings
Lead-Zinc

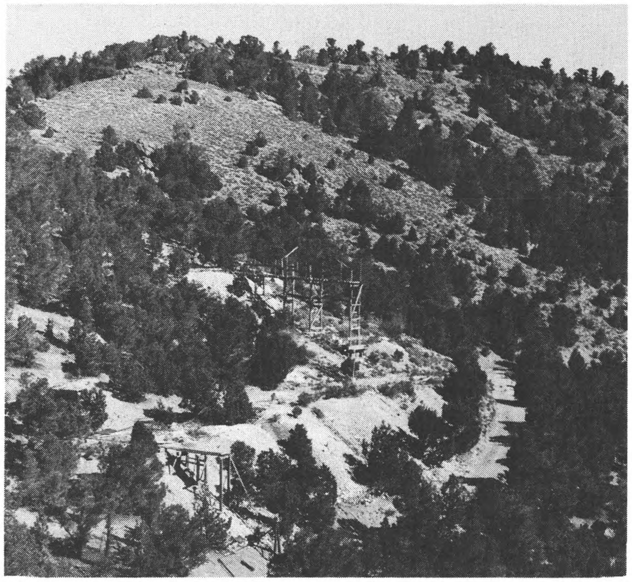
About ½ mile (0.8 km) north of the main Lakeview workings on the south side of Little Valley are three adits open at the time of visit (Mines S, T, and U, figure 75) and a fourth caved at the portal. The western most adit, the Spelter tunnel, is located near the southern end of Lakeview Carbonate No. 10 patented claim (figure 84). The adit, driven to the south, encountered lead-zinc mineralization. Some stoping was done in the mineralized zone, but the amount of ore produced was small. Farther east, in NE Section 7, two adits were mapped (figures 85 and 86). The western most of these adits consists of approximately 200 feet (61 m) of workings. The portal is in limestone and a shale bed is encountered and followed for a short distance. The shale contains much limonite and may contain lead-zinc minerals. Mine U is a 700 foot (213 m) adit following a N. 70 degree W. fracture containing a small amount of limonite; no ore minerals were identified.

Sierra Madre Mining District

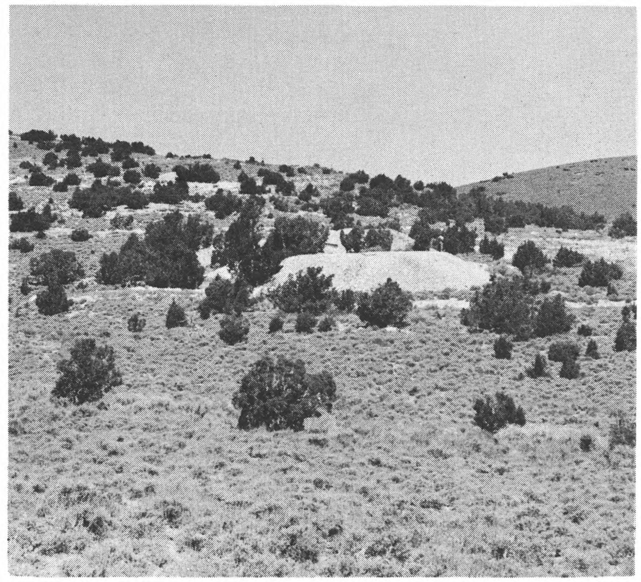
by Lee I. Perry
UGMS Staff Geologist, Economic Geology section

The Sierra Madre mining district, located in the Wasatch Mountains between Utah Hot Springs and Willard, extends from the foothills on the west side of the range eastward into Weber County; the Box Elder County portion extends to the crest of the range (figure 87). The first discoveries in the district occurred on the King Solomon vein in 1897 and the district was organized in February, 1902.

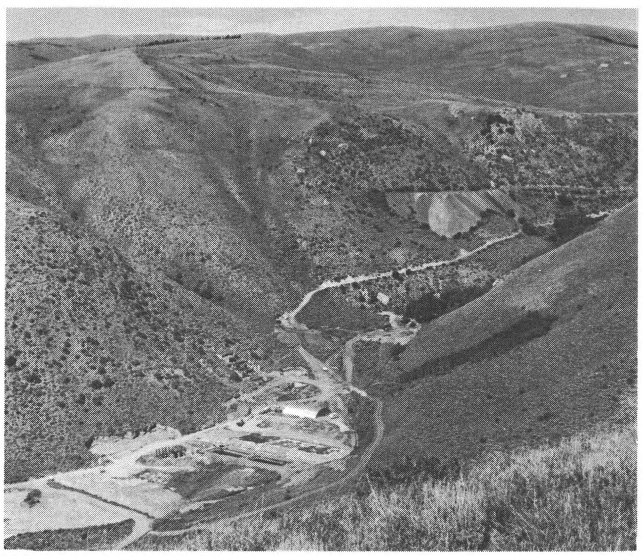
From 1897 to 1910 considerable development work was done in the district. Thousands of feet of tunnel were driven on several properties; the main goal was to intersect fissures at depth. Several mule trails were constructed to deliver the necessary supplies to the prospects. Two aerial trams were built to service the Napoleon-Magera and Eldorado (Alvarado) mines, which, along with the Santa Maria and Prince of India, were the principal workings. The development found only low grade mineralizations that were not large enough to be economic. Sporadic development work was carried out in the 1920s and 1930s and the district was abandoned thereafter. Records are incomplete, but production is assumed to have been small. Butler and others (1920, p. 223) report that 205 tons of ore containing \$100 in gold, 152 ounces of silver and 3,387 pounds of copper were produced between 1901 and 1905. The value of this ore was set at \$996. Walter Clay (1968, p. 2) reports that two cars of lead-zinc-silver ore shipped from the Eldorado mine did not pay the freight and smelter charges.



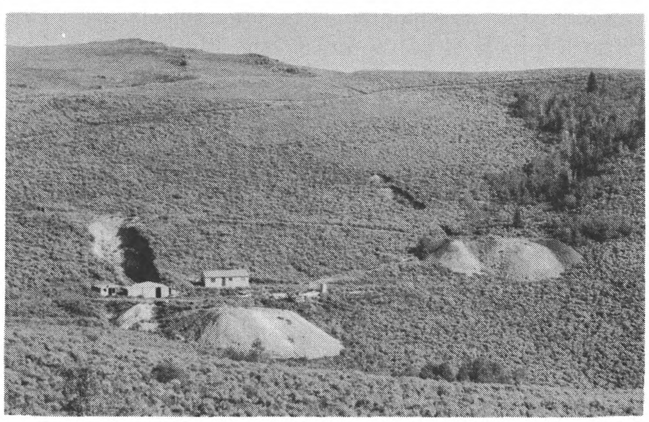
P 6. View of Lone Pine workings, Rocky pass area, Rosebud district, in the southern Grouse Creek Mountains.



P 7. Silver Riddle workings on the east side of the Grouse Creek Mountains. The copper-lead-silver-gold? mineralization is probably in the Devonian Guilmette limestones and the Mississippian Chainman Shale.



← P 8. The Vipont area in the Ashbrook district in 1978. The Phelan tunnel dump is shown in the right-central area of the picture The new mill building can be seen below the two new adits (arrows) and the mill-tailings area is located in the lower left. The Sentinell workings are shown as three or four white patches in the background in the upper right. These workings are in the Quartzite of Clarks Basin.



P 9. Skoro mine dumps, Ashbrook District, Vipont Mountains, northwestern Box Elder County.

P 10. Surface expression of mine workings in the Park Valley district. Photo shows the dump of the Corner Creek mine. The district produced gold in the early 1900's.

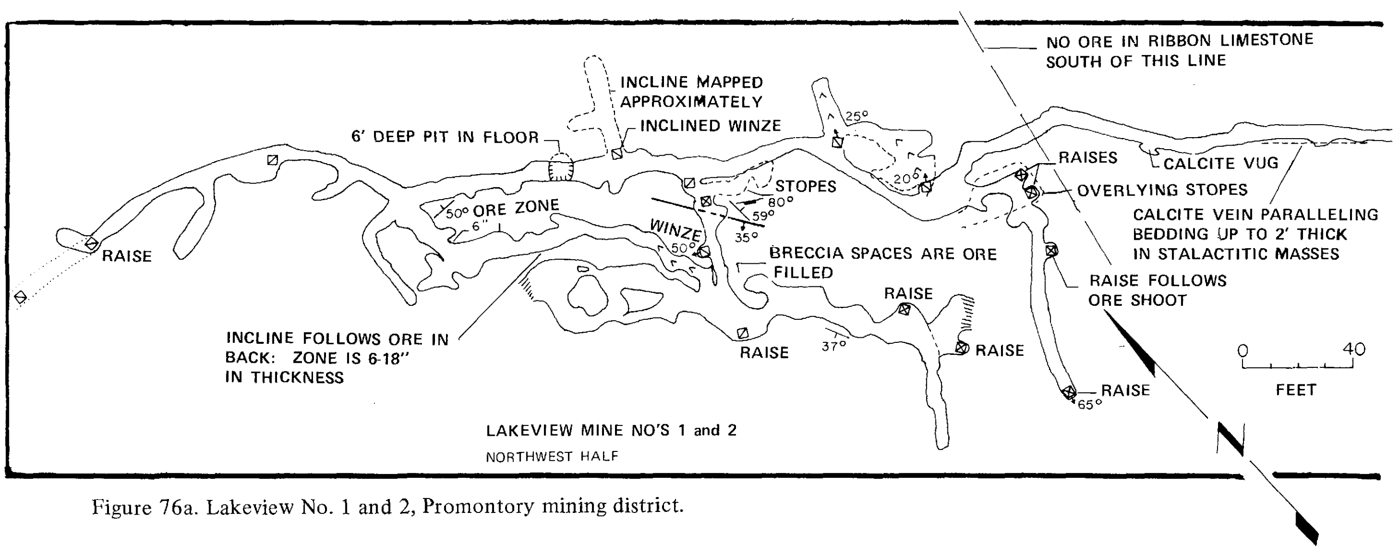


Figure 76a. Lakeview No. 1 and 2, Promontory mining district.

The western slope of the range exposes the Precambrian Farmington Canyon Complex and the Cambrian Tintic Quartzite, Ophir Formation and Maxfield Limestone in the autochthon below the Willard thrust. Above the thrust the Precambrian metaquartzite and schist of Facer Creek and the formation of Perry Canyon are exposed. The mineralization in the district is of two types: veins in the Farmington Canyon Complex and replacements in the Cambrian carbonate rocks. The lower formation in this area consists of medium- to coarse-grained gneissic quartz monzonite. The mineralized fissures and veins that cut the quartz monzonite have a general east-west strike and dip steeply to the north; a few strike northerly. In the fissure zones fine grains of pyrite replace hornblende or biotite in the gneissic quartz monzonite. Chalcopyrite accompanies the pyrite discontinuously; its presence in surface exposures is represented by secondary copper minerals. Rare galena and sphalerite grains are found in the fissures where the copper is present. Gangue minerals include pyrite, quartz, calcite and sericite. A little ore was produced from these fissures, principally from the Napoleon-Magera property.

The replacement deposits are found principally in the dolomite members of the Ophir Formation. The mineralized veins in the Farmington Canyon Complex can be traced upwards through the Tintic Quartzite into the Ophir. Replacement bodies were formed at the intersections of the dolomite and fissures. In these areas the dolomite is bleached from dark blue to white. The mineralization ends abruptly against the overlying shale. The ore grade mineralization consists of varying quantities of fine-grained galena, sphalerite and pyrite accompanied by quartz, calcite, sericite and coarsely crystalline dolomite. The replacements are irregular in shape and vary considerably in composition. At the Eldorado mine an ore body was followed 100 feet (30 m) along strike and a similar distance down-dip. Loughlin reports (in Butler, 1920, p. 225) that samples taken from this ore body ranged from 56 percent lead and 3.2 percent zinc to no lead and 46.5 percent zinc. In some places the mineralization is oxidized.

There are two groups of patented claims in the Sierra Madre district; four at the Eldorado workings, and twelve at the Napoleon-Magera workings. A single patented mill site lies west of the Napoleon-Magera group at the base of the mountain at the lower end of the Eldorado and Napoleon-Magera tramways.

Napoleon-Magera Mine (Copper-Silver)

The Napoleon-Magera is one of the larger mines and is located on 12 patented claims in 5 and 6-7N-1W. The mine was once serviced by a gravity operated Broderick & Bascome tram, 2,700 feet (823 m) long. The lowest level of the mine, the Illinois tunnel, has approximately 1600 feet (488 m) of workings (figure 88). It was driven into the Precambrian Farmington Canyon Complex for 400 feet (122 m) on a bearing of N. 20 degrees E. before intersecting the Napoleon lode. Here the tunnel was turned to the east and followed the vein 1200 feet (366 m) to a fault. The fault was followed 30 feet (10 m) to the north and 35 feet (11 m) to the south without finding the continuation of the vein and work was abandoned. The No. 1 tunnel was driven 450 feet (137 m) higher in elevation and somewhat east of the Illinois portal. When the No. 1 portal was visited in 1974 it was caved, but according to the *Salt Lake Mining Review* (Oct. 30, 1909, p. 21) the tunnel:

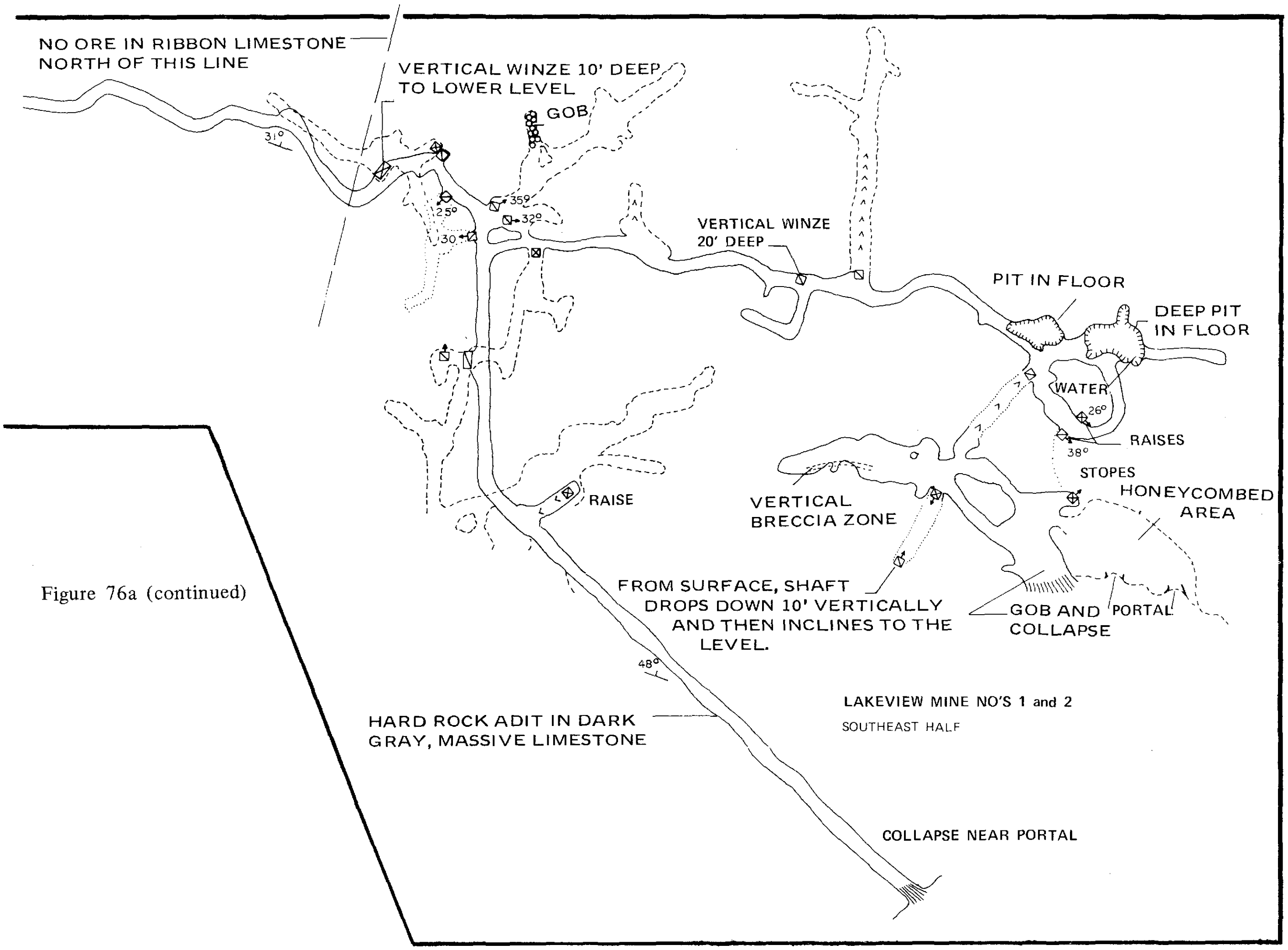


Figure 76a (continued)

. . .is 1200 feet in length, 950 feet of which follows the vein and is in ore the entire distance. A winze, on the ore-body in No. 1 tunnel, has been sunk to a depth of 100 feet, all in ore, towards the Illinois tunnel level.

The No. 1 dump contains pieces of ore containing chalcopyrite, bornite, malachite, and hematite in a quartz gangue. An open-cut exposes 6 feet (2 m) of mineralization on the vein 600 feet (183 m) east of the No. 1 portal which consists of chalcopyrite, chrysocolla, limonite and hematite in a gange of quartz. The Napoleon lode is a vein with a distinct hanging wall and foot wall. It strikes easterly and dips 65 to 70 degrees to the north where measured in the Illinois tunnel. The vein is about 6 feet (2 m) thick and contains discontinuous lenses of quartz. Quartz becomes more abundant 460 feet (142 m) from the face in the Illinois tunnel and epidote is present. Argillic alteration is evident in the hanging wall. A 2-foot (.6 m) sample taken of the hanging wall 140 feet (44 m) from the face showed epidote-stained quartz, feldspar, and clay that assayed 0.2 ounces in silver, 0.006 percent copper and no gold, lead or zinc. Loughlin (in Butler, 1920, p. 224) reports that samples taken in 1913 from the Illinois tunnel assayed nil to 2.51 percent copper, nil to 0.32 ounces of silver and nil to a trace of gold. The ore produced from 1901-1905 averaged \$0.50 in gold, 7.5 ounces silver to the ton, and 0.85 percent copper.

Eldorado (Alvarado) Mine (Lead-Zinc)

The Eldorado or Alvarado mine is in SESESW 32-8N-1W at an elevation of 8,850 feet (2,615 m) above sea level. The first work on the property was done in 1898 and the property was patented shortly thereafter; the four claims are the Western Bonanza, Eldorado, Creole, and Sierra Madre. Mine workings consist of three adits, one of which was caved at the portal and filled with water in the fall of 1973. The upper two adits were originally serviced by mule trail and later by the tram, constructed in 1900, that extended to the base of the mountain. After two cars of ore shipped over the tram did not pay freight and smelter charges, shipments were suspended.

The upper two adits are in the lower part of the Ophir Formation. The lower of these two is located immediately above the quartzite-shale contact and the upper is about 100 feet (30 m) above it. The upper adit contains about 440 feet (134 m) of workings and is driven northeasterly into the mountain. Three sets of crosscuts have been driven at right angles to the adit, but there are no stopes. Mineralization is associated with a north-south striking fracture system in the shale. The dolomite encountered in the mine is essentially barren, excepting pyrite and limonite. Two winzes were sunk; one connects with the lower adit which is caved at the portal and flooded. The third adit, much lower in elevation, is driven northeasterly into the Tintic Quartzite for 860 feet (262 m). With the exception of limonite staining along fractures there is no mineralization in the working. The adit has no crosscuts and was driven as a drain tunnel for the upper workings, but was never connected. The Eldorado mine contains mineralization high enough in grade to be interesting, but the lack of appreciable tonnage is discouraging (figures 89 and 90).

Santa Maria Mine (Copper-Silver)

The Santa Maria mine is in Maguire Canyon near the north line of 8-8N-1W. The main working is the Clara Belle tunnel with its portal near the bottom of Maguire Canyon at an elevation of 6,700 feet (2,042 m). The portal was partially caved and flooded with three feet (0.9 m) of water in 1975; in 1977 it was completely caved. The tunnel is driven into the Farmington Canyon Complex on a N. 5 degree W. bearing and, according to the *Salt Lake Mining Review* (Feb. 28, 1910, p.1), extends more than 1800 feet (549 m) and cuts eight veins. Almost 5,000 feet of workings were completed. It is not known whether any minerals were produced.

The more important of the remaining workings in the district are found on the Prince of India, Great Northern, Midland, Southern Pacific, Wisconsin, and Chicago groups of claims. The Prince of India group is located northwest of the Napoleon-Magera mine in Pearson Canyon, and according to the *Salt Lake Mining Review* (July 15, 1910, p. 40) the property is developed by a 700 to 800-foot tunnel in which large bodies of fine concentrating ore are exposed. The Great Northern group is located on the west slope of Sierra Madre Mountain, 5 miles from Utah Hot Springs in Sylvania Canyon and is developed by a tunnel reported to be over

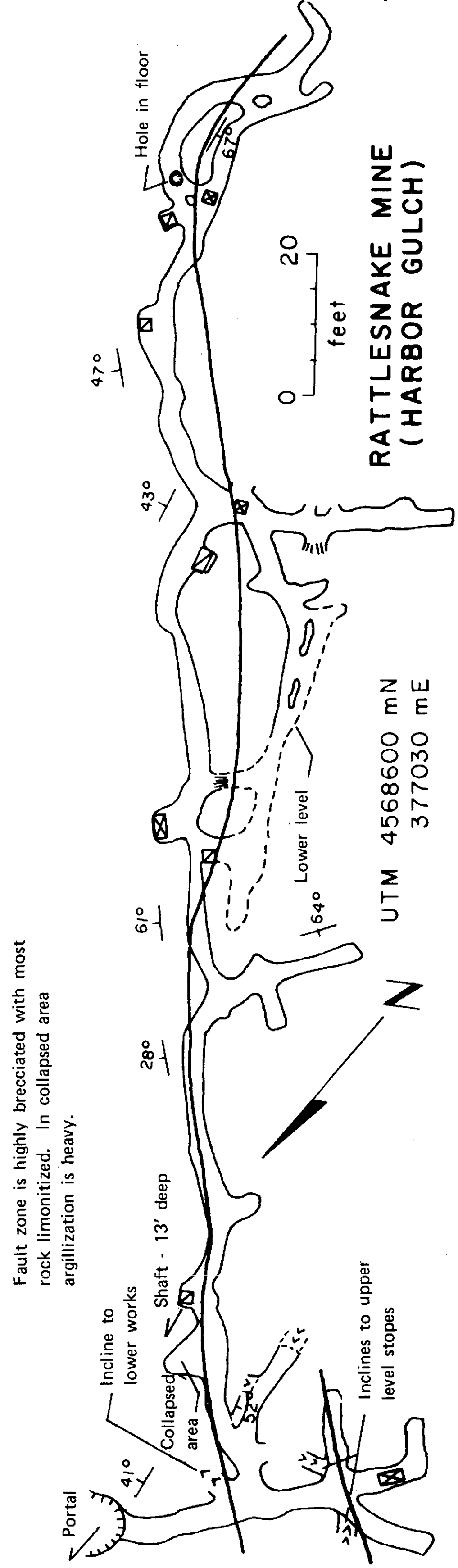


Figure 76b. Volunteer No. 1 (Rattlesnake, Harbor Gulch), Promontory mining district.

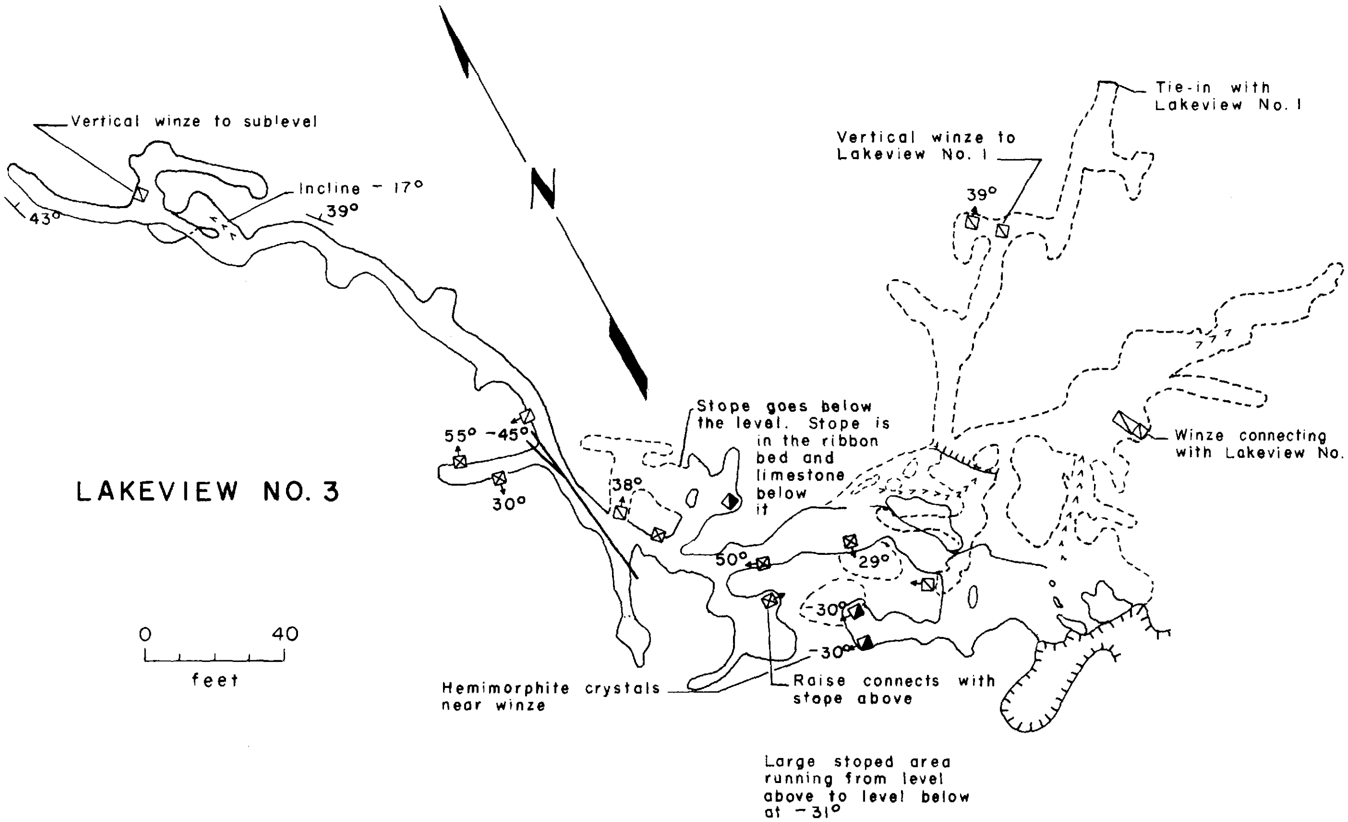


Figure 76c. Lakeview No. 3, Promontory mining district.

100 feet (30 m) long (*Salt Lake Mining Review*, July 30, 1904, p. 13-14 and Feb. 28, 1907).

Willard Mining District

by Lee I. Perry

UGMS Staff Geologist, Economic Geology section

The Willard district (figure 87) lies to the north of the Sierra Madre mining district and along the western slope of the Wasatch front. The northern boundary of the district is along Box Elder Creek (Highway 89 between Brigham City and Mantua). The eastern part of the district extends into Weber County, but only the Box Elder County portion is considered for this report. As in the Sierra Madre district, much money was invested with little or no return in ore produced. The district has seven patented mining claims divided into three groups. The eastern group, composed of the Golden Ring, Iron Chief, and Annie Elizabeth claims, lies in the bottom of Willard Basin near the common boundary of 19 and 20-8N-1W (figure 87). The western group, consisting of the Atlantis, Red Bonanza and Sunbeam claims, is located at the confluence of Willard Creek and the West Fork of Willard Creek. A single patented claim, the Diamond, lies near the common corner of 13, 14, 23 and 24-8N-2W.

The geology of the Willard mining district is complex, exposing faulted and folded Precambrian rocks and smaller areas of Cambrian rocks. The Willard thrust extends into the area. Most of the mineralizations are associated with the Precambrian units. Several small mines and prospects are found in the district. The three patented claims of the eastern group (figure 87) are developed by underground workings, now caved and inaccessible. M. R. White (1975, oral communictaion) reports that there are about 1,500 feet (457 m) of workings and that lead-silver ore was encountered as pods and bunches, too small and scattered to be successfully worked.

The western group of patented claims was prospected in the early 1900's and developed by at least 100 feet (30 m) of underground workings. In the southern part of 17-8N-1W the American and Workman mines, now caved and inaccessible, were driven along zones of mineralization in Precambrian rocks. Several prospect pits, showing copper staining, are located in 13-8N-2W.

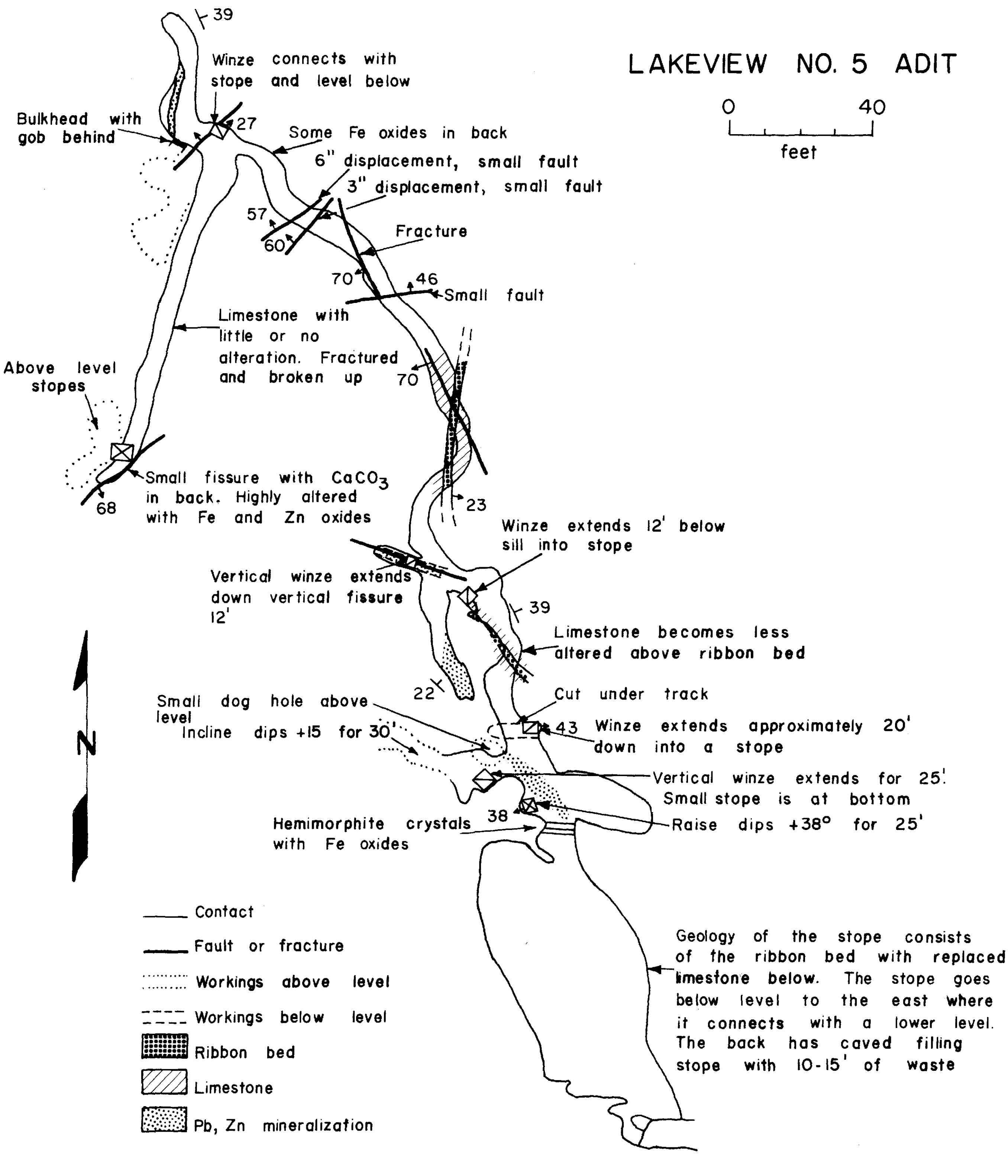


Figure 76d. Lakeview No. 5, Promontory mining district.

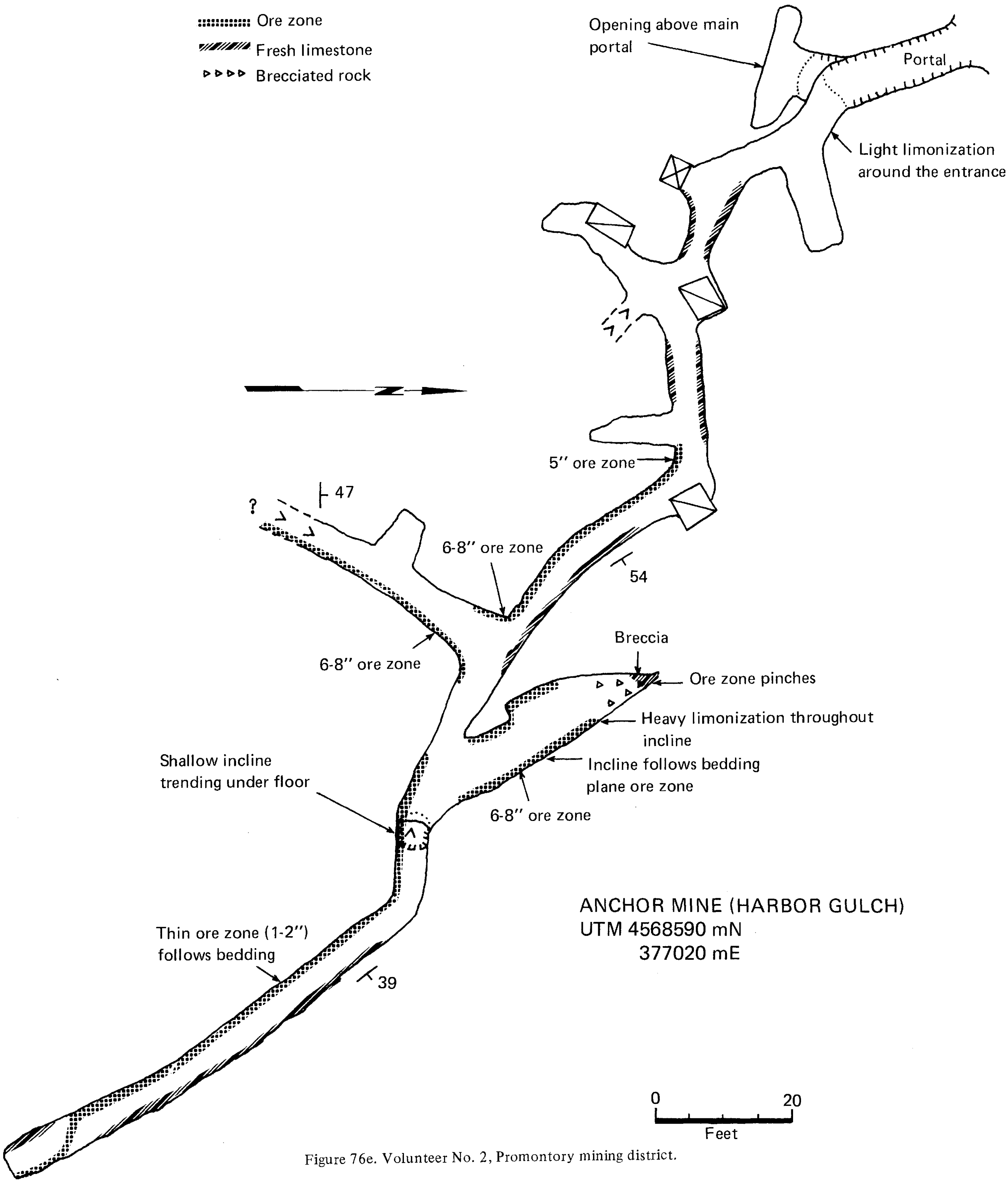


Figure 76e. Volunteer No. 2, Promontory mining district.

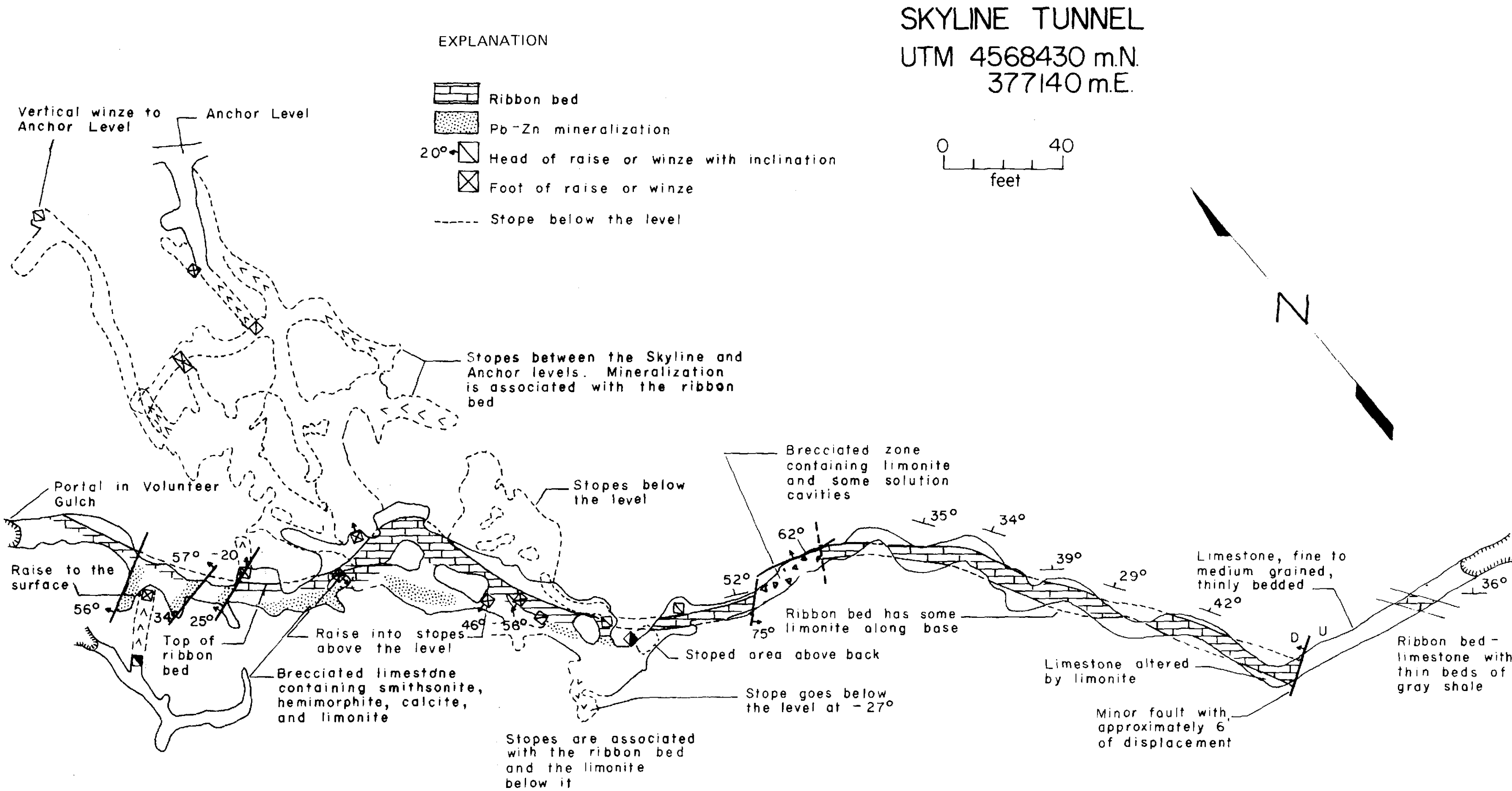


Figure 76f. Skyline tunnel, Promontory mining district.

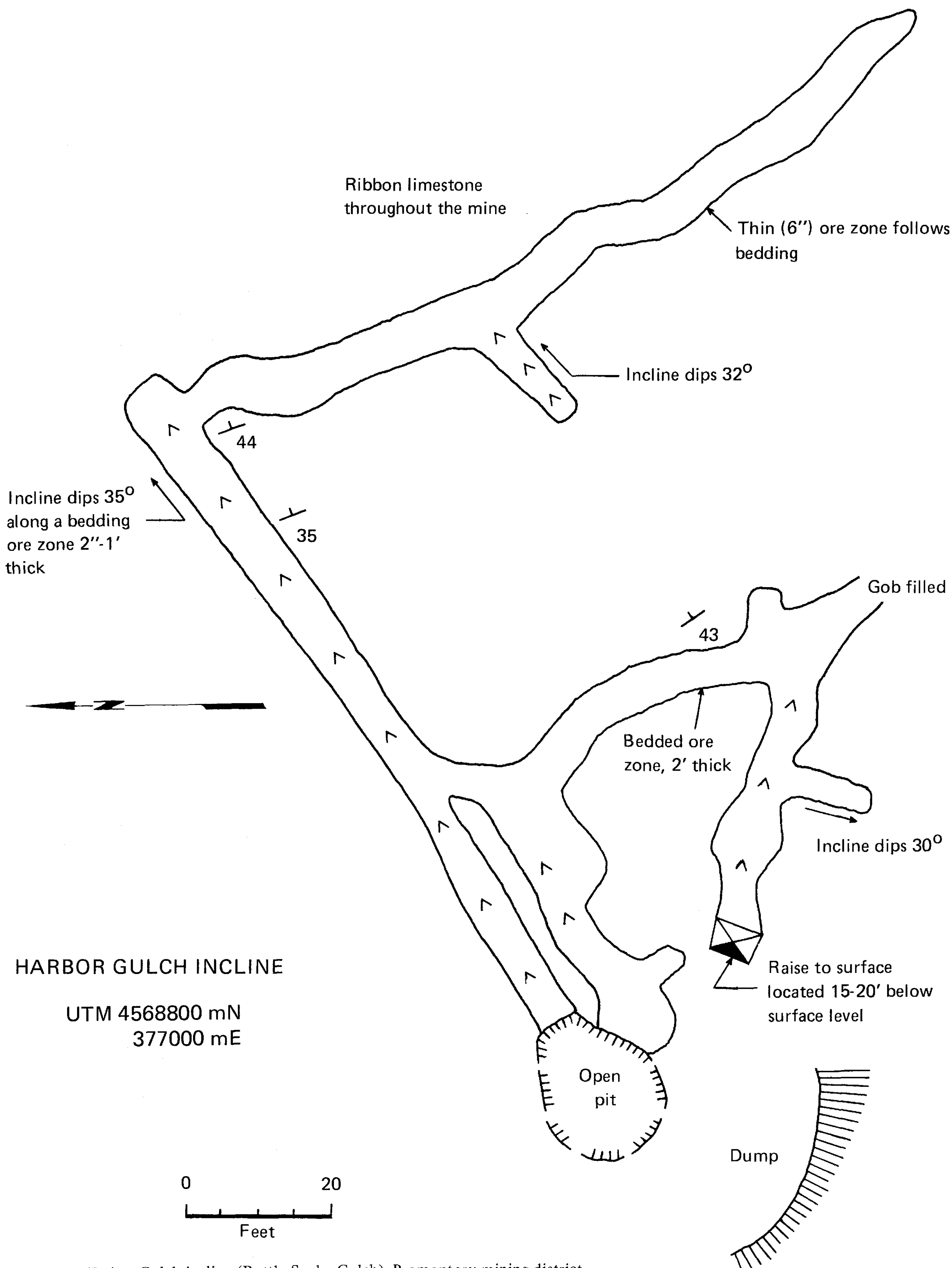


Figure 77. Harbor Gulch incline (Rattle Snake Gulch), Promontory mining district.

To the north, in SW 6-8N-1W, on the north side of Threemile Creek, the workings of the Homber Mining Co. include three adits and several hundred feet of workings. The mineralization is associated with quartz lenses containing lead oxides and sulfides, minor copper carbonates and abundant limonite (figure 92).

The Holton mine is in NW 32-9N-1W on the south side of Dunns Canyon at an elevation of 7,120 feet (2170 m). The shaft collar is near the top of the ridge that separates Dunns and Mathias Canyons. The mine consists of a 41 degree inclined shaft going down approximately 100 feet (30 m) into the Precambrian Caddy Canyon Quartzite. The shaft follows a clay layer, up to 1 foot thick. A drift was run about 10 feet (3 m) below the shaft collar for approximately 25 feet (8 m). The only observable mineralization in the mine workings is limonitization in the clay layer.

The Silver Eagle mine, located about 1 mile (1.6 km) south of Mantua on the east bank of Box Elder Creek in NW 34-9N-1W at an elevation of 5,440 feet (1658 m), is cut in the Cambrian Ute and Langston limestones which strike N. 10 degrees W. and dip 30 degrees NE at the surface. The dark bluish gray rock is mostly dolomitic limestone. The portal is located on the south side of a hill; the adit extends about 450 feet (137 m) in a northeasterly direction (figure 91). The mine has three inclined winzes, one major and two minor. The first winze, about 50 feet (15 m) from the portal, has three sublevels driven from it at 8, 42, and 90 feet (0.3, 13 and 27 m) vertically below the sill. This winze is inclined minus 42 degrees and is approximately 120 feet long. At the bottom of the winze the main sublevel extends about 600 feet (182 m) to the southeast. Mineralization is associated with northwest-trending fissures dipping to the northeast. The mineralizing solutions altered and replaced the limestone along the fissures to form thin zones to one foot in width. Buranek (1942) reports samples of copper and silver-lead ore on the dump containing chalcocite, covellite, malachite, azurite, and limonite, along with galena with rims of anglesite. Copper carbonates were found by the present author, but no lead-silver minerals. No copper or lead-silver mineralization was observed in mapping the underground workings.

Box Elder Mining District

by Lee I. Perry

UGMS Staff Geologist, Economic Geology section

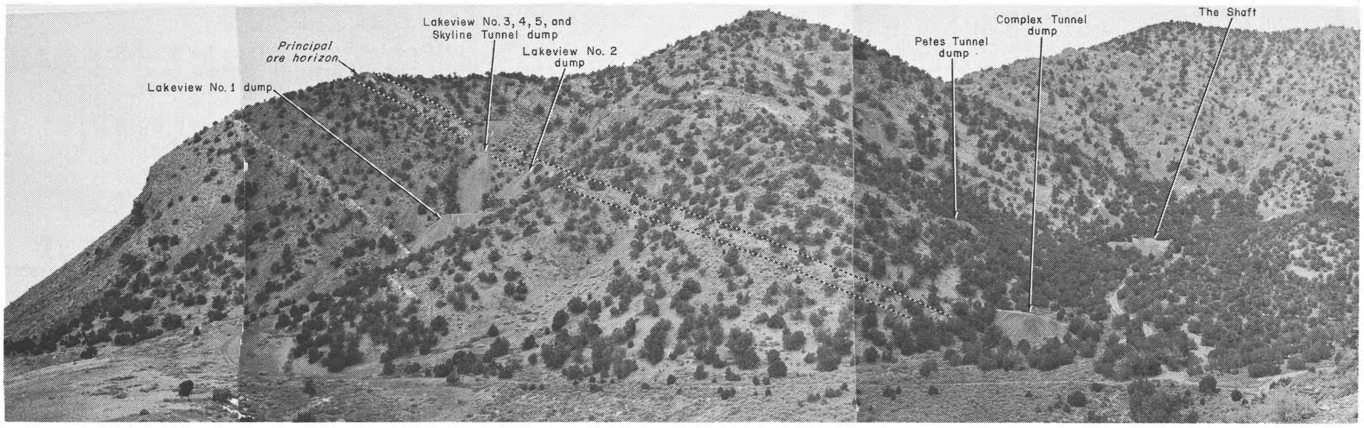
The Box Elder mining district (figure 93) is located along Wellsville Mountain, northeast of Brigham City. The district was organized on October 2, 1889 and work was done intermittently until World War II, after which the area was abandoned. The principal area of interest is in Baker and Antimony canyons although there are small prospects in other canyons. Copper, gold, silver and antimony have been produced from the district in unknown quantities, but the values are presumed to be relatively small. A small production of copper ore containing gold and silver was reported from the district in 1908 by Butler and others (1920, p. 222). In 1955, the U. S. Bureau of Mines *Mineral Yearbook* reported the production of 400 pounds of copper and 17 ounces of silver from the Box Elder district.

Baker Mine (Copper-Silver-Gold)

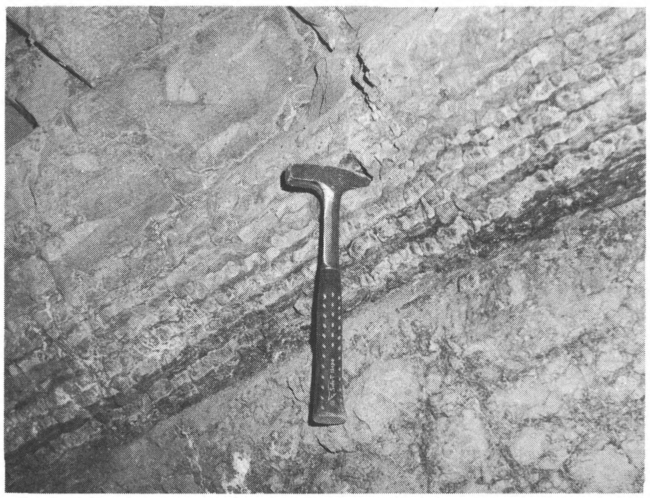
The Baker mine can be considered the major mine of the area and is located near the head of Baker Canyon. The mine, worked intermittently under several names, was first served by a mule trail. The construction of an aerial tram to transport ore to the base of the mountain and carry supplies in return made it easier to work the mine. The *Salt Lake Mining Review* (May 30, 1906, p. 25) reports the completion of a 150-ton concentrating plant in the Fall of 1905.

The portal of the mine is on the north side of Baker Canyon at an elevation of 6,700 feet (2042 m) in Cambrian limestone. The adit is driven in a northeasterly direction and encounters a northeast-trending fault system about 300 feet (91 m) from the portal. This fault system was followed to its intersection with an east-west fault system; the mineralized intersection was stoped above the level and a winze was sunk to explore the structure at depth. The stoped area indicates a maximum of 3,500 tons of ore was mined. Ore from a stockpile was assayed and showed 7.9 percent lead, 0.10 percent zinc and 0.5 ounces of silver per ton. No sulfides were found in the ore, which contained much limonite. Approximately 1,800 feet of workings are accessible (figure 94).

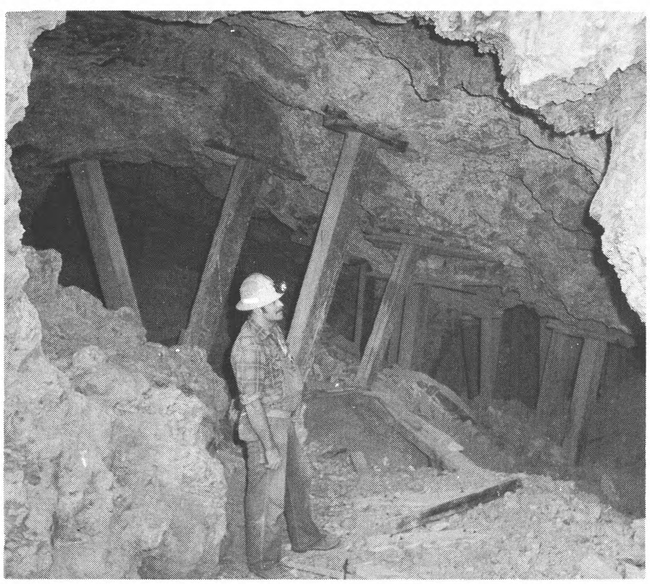
Water encountered while drifting was piped to the portal for camp and mine use. In November, 1973 the flow was estimated to be 5 to 10 gallons per minute. Water has flowed from the drifts into the winze and the water level in 1973 was about 20 feet (6 m) below the track level. Surface buildings at the mine consist of a log boarding house, a blacksmith shop, and a small cabin. These buildings have been caved by snow and are no longer serviceable. A service trail leads from the portal around the south side of Baker Canyon for 450 feet (137 m) to the upper terminal of the tram.



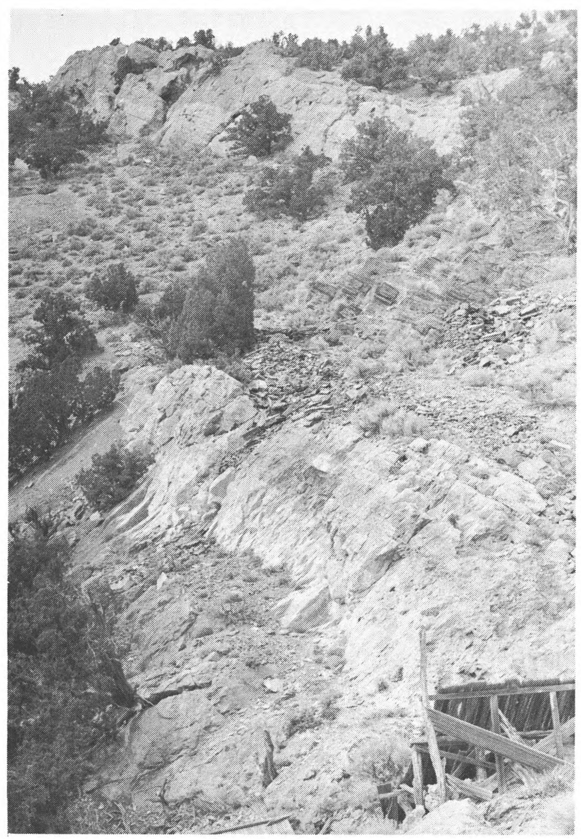
P 11. Lakeview Ridge, showing the principal workings of the Promontory Mining District. The host rocks are Middle Cambrian.



P 12. Unmineralized ribbon limestone in the Lakeview No. 1 workings.



P 13. Mined out stopes, Lakeview No. 5 workings.



P 14. Surface outcrop of ore host on Lakeview Ridge, Promontory Mining district near the No. 2 portal.

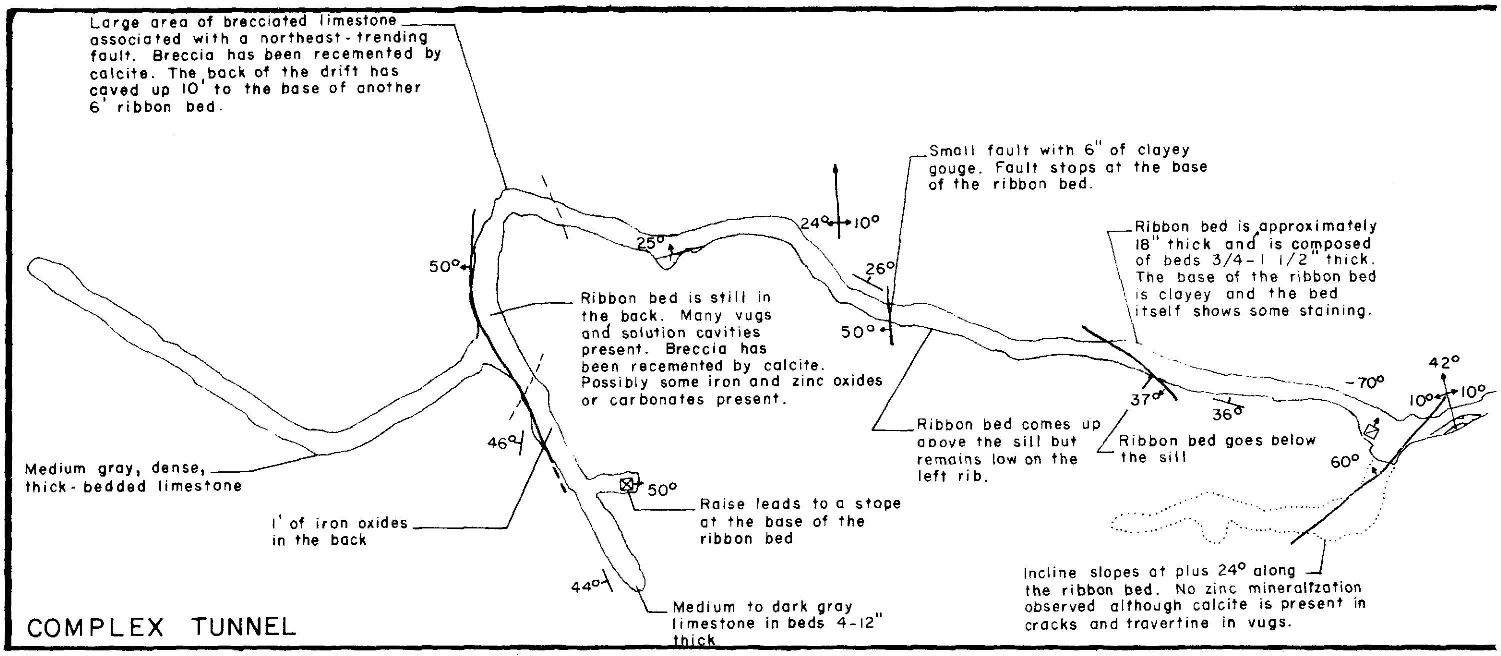


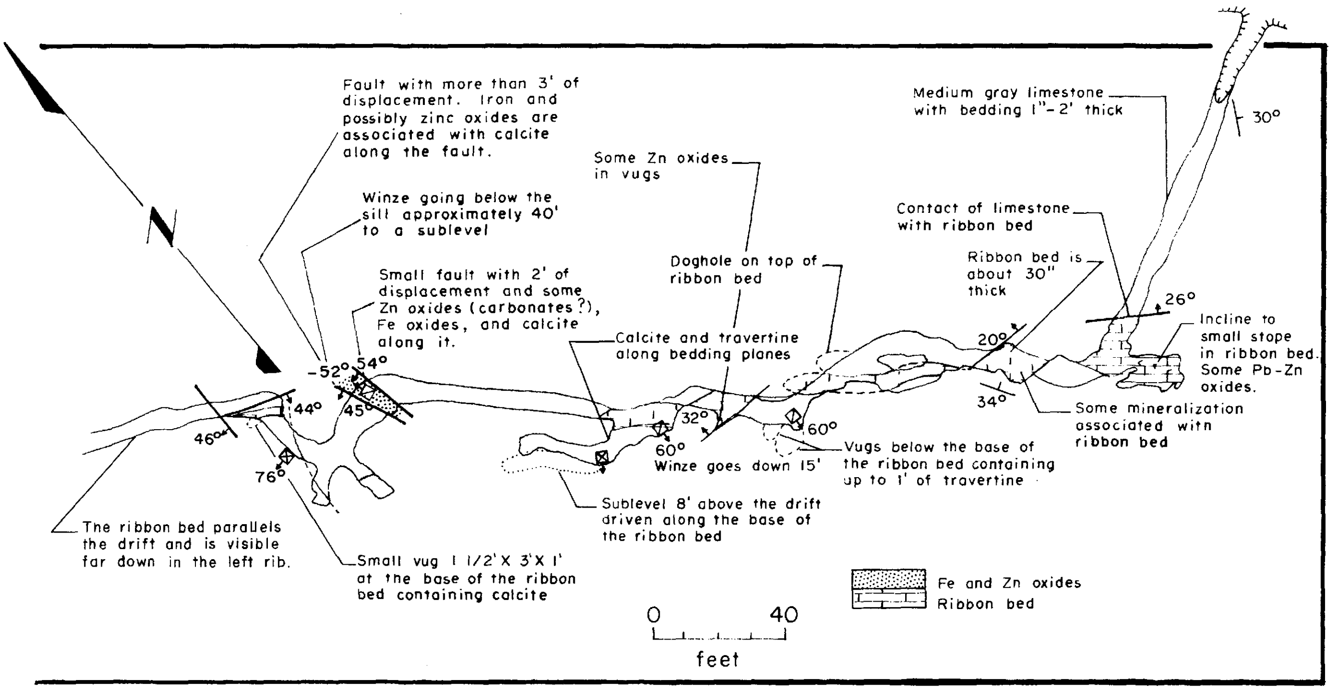
Figure 78. Complex tunnel, Promontory mining district.

Copper Blossom mine
(Copper-Lead-Zinc-Silver)

The Copper Blossom mine is found on the south side of Baker Canyon below the Baker mine (figure 93). The workings are on the Baker mine mule trail at an elevation of 6,250 feet (1905 m). Mineralization is associated with a brecciated zone in Cambrian limestone striking N. 60 degrees E. and dipping 45 degrees to the south. It consists of a limonite-rich gossan with lead, zinc, silver, and copper values. Mining consisted of glory-holing along the breccia zone which was followed by mine workings for approximately 200 feet (61 m) along strike. The glory holes were caved in 1973, preventing examination of the mineralization in the deepest parts of the workings. The amount of rock on the dumps suggest the breccia zone was explored to possibly 100 feet (30 m) in depth. No production figures are available and a small tonnage may have been mined. The failure to develop adequate ore probably led to the abandonment of the mine.

Dry Lake Antimony mine
(Antimony)

The Dry Lake antimony mine is 4 miles (6.4 km) north of Brigham City on the north side of Antimony Canyon and is incorrectly labelled the Copper Blossom mine on the Brigham City 7½ minute quadrangle. The mine workings consist of a glory hole and two adits. The glory hole is on an east-west quartz vein in Cambrian limestone. The vein in the glory hole is up to 10 feet (3 m) wide and composed of white quartz containing limestone fragments and pockets of stibnite. The glory hole measures 50 x 10 feet (15 x 3 m) and is at least 20 feet (6 m) deep. An adit was driven approximately 50 feet (15 m) below the top of the glory hole to cut the vein (figure 95). At the intersection with the vein, drifts were run both east and west for a total of 80 feet (24 m). From the east drift a raise was run to the glory hole and later gob-filled. The ore mined before World War I was transported from these workings to the bottom of the canyon via a 600-foot (183 m) tram and then hauled by wagon to the railroad. During World War II a better road was constructed into Antimony Canyon and another adit driven to test the vein at greater depth. The portal of this adit is approximately 600 feet (183 m) lower and to the east of the glory hole at an elevation of 5,450 feet (1661 m). The adit was driven in a northeasterly direction and cut the vein 660 feet (201 m) from the portal. A drift followed the vein eastward for about 300 feet (91 m) but was abandoned due to failure to find ore. The vein (figure 96) consisted of quartz, calcite, limestone fragments and clay, and a small amount of malachite. To the east the proportion of calcite and limestone fragments in the vein increased and quartz decreased. The adit was driven by the Dry Lake Mining Company with a Reconstruction Finance



Corporation loan during World War II. 6 tons of ore, averaging 50 percent antimony, were produced from the glory hole. The mine operated in 1943 and 1944. About 100 tons of antimony have been produced since the mine was opened in 1897 (Dasch, 1964, p. 138).

Prospects in Cataract Canyon (Lead-Zinc)

There are two adits in Cataract Canyon, which is located between Brigham City and Honeyville. The upper adit is found just east of the line between Sections 13 and 14-10N-2W at an elevation of 6,020 feet (1835 m). The adit is caved and is accompanied by a small prospect. The dump suggests a maximum of 100 feet of workings which are along a northeast-trending fracture zone in the limestone. About 1500 feet (457 m) south of the adit and 100 feet (30 m) up the other side of the canyon is another adit driven into the limestone. The portal is caved and the amount of dump material suggests another 100 feet of underground work. The mineralization associated with both of these adits indicates weak lead-zinc values. Little if any ore was produced.

Plymouth Prospect

A small shaft is found 2½ miles (4 km) north of the town of Plymouth in the mouth of Mine Hollow. The shaft collar is in SW 36-14N-3W at an elevation of 5,180 feet (1579 m). The shaft is collared in a shaly silty limestone of the Salt Lake Formation that weathers like a shale, forming steep clay banks. No mineralization or alteration was found in and around the shaft.

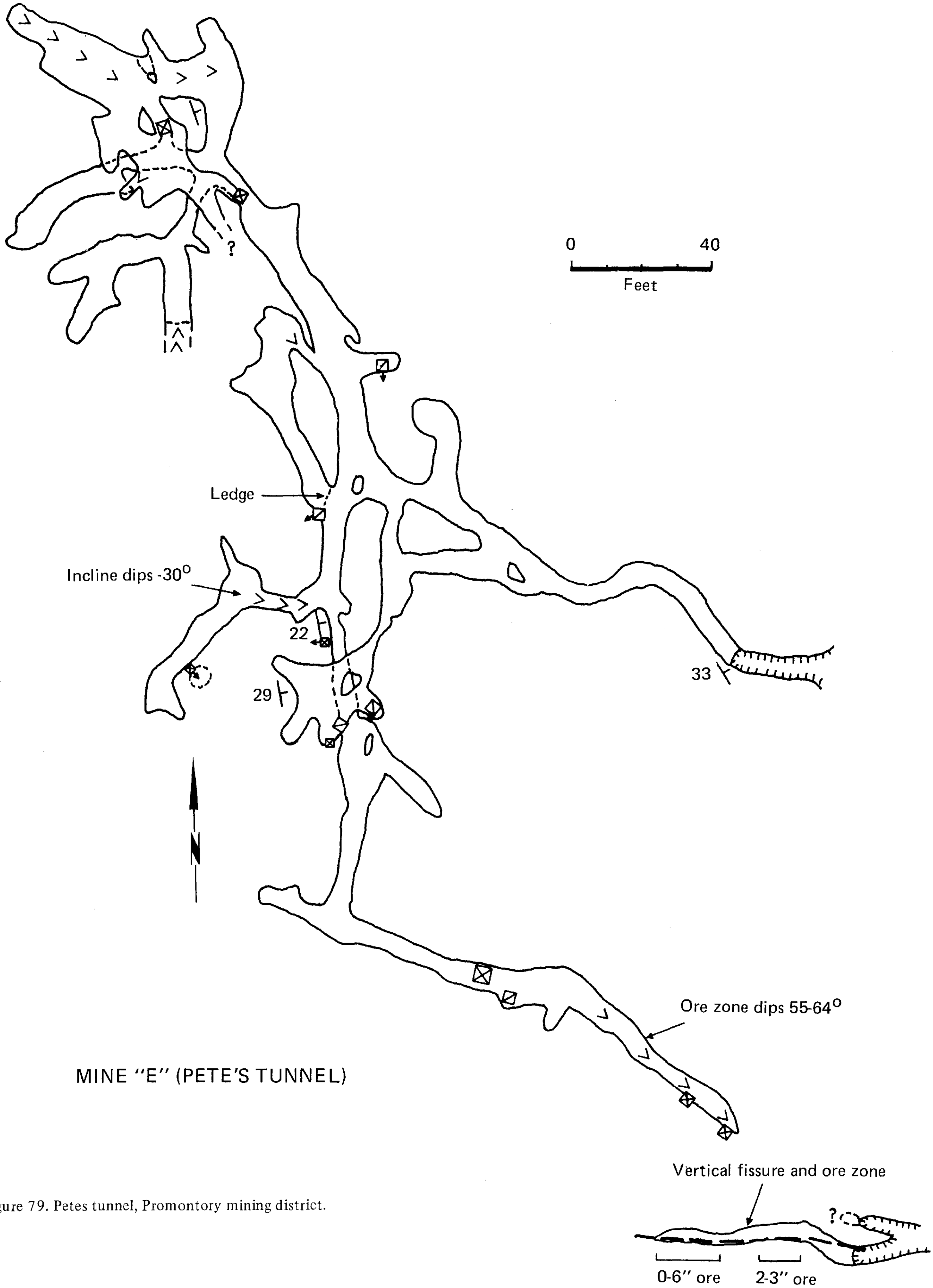


Figure 79. Petes tunnel, Promontory mining district.

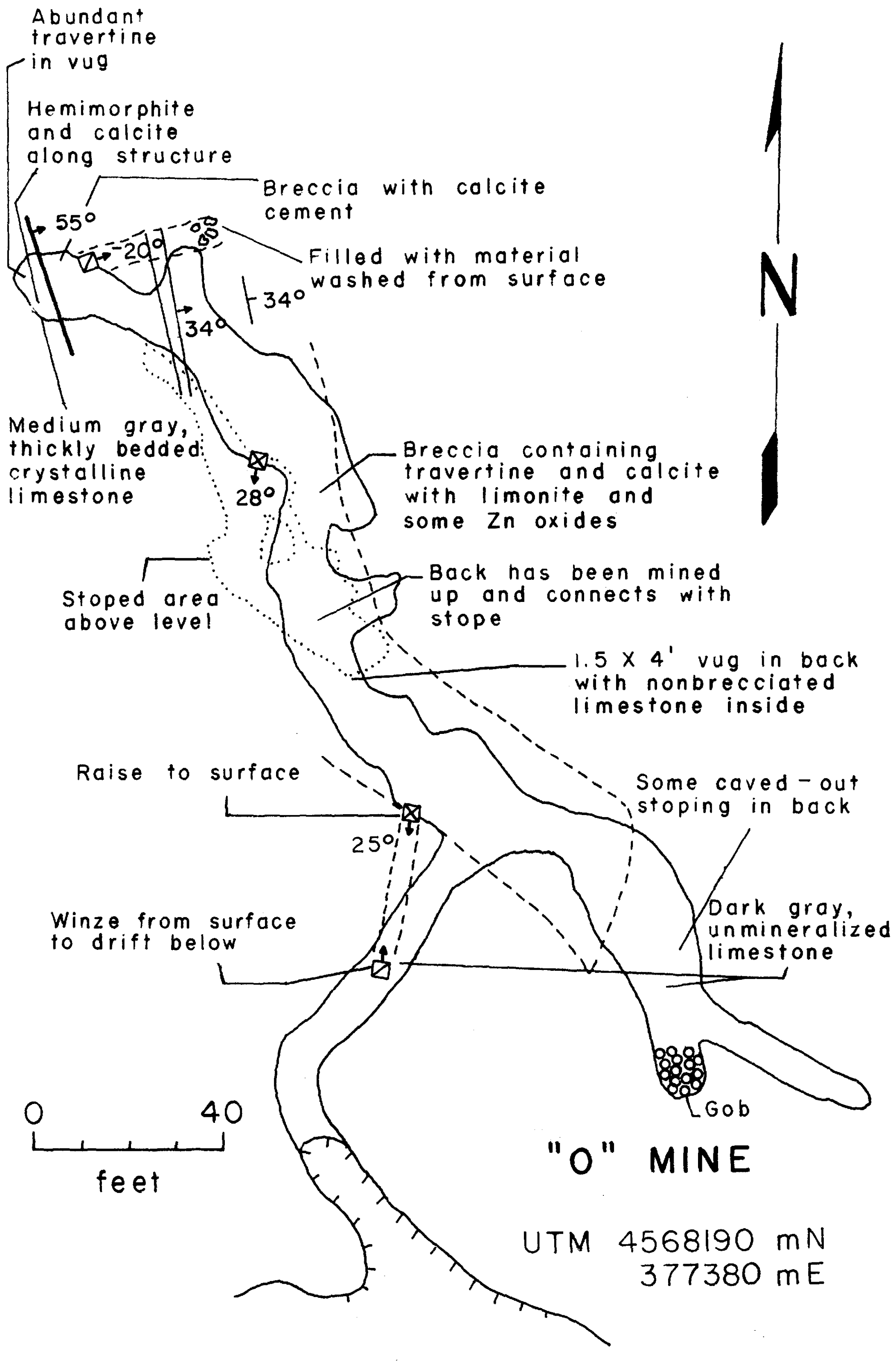


Figure 80. "O" mine, Promontory mining district.

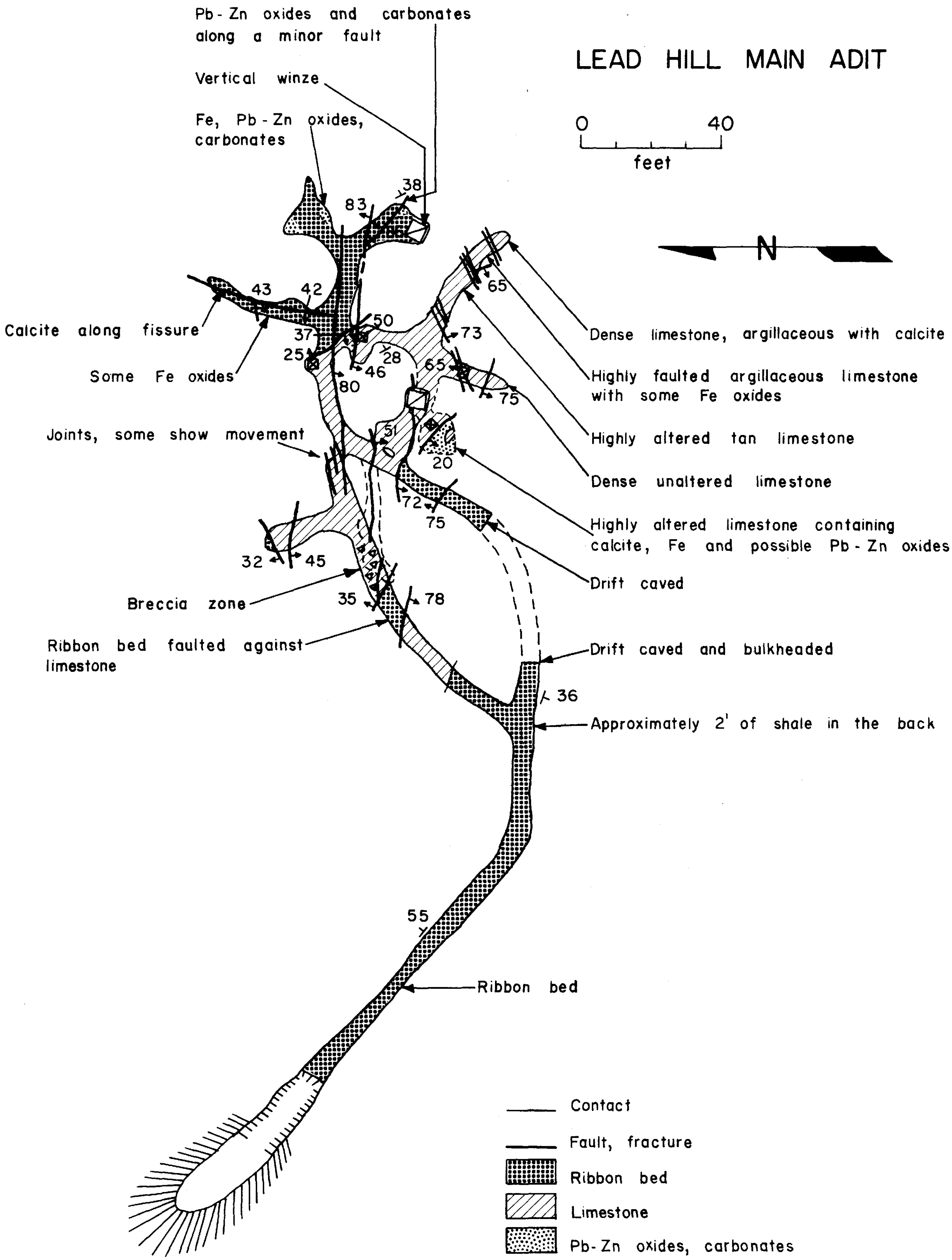


Figure 81. Lead Hill main adit, Promontory mining district.

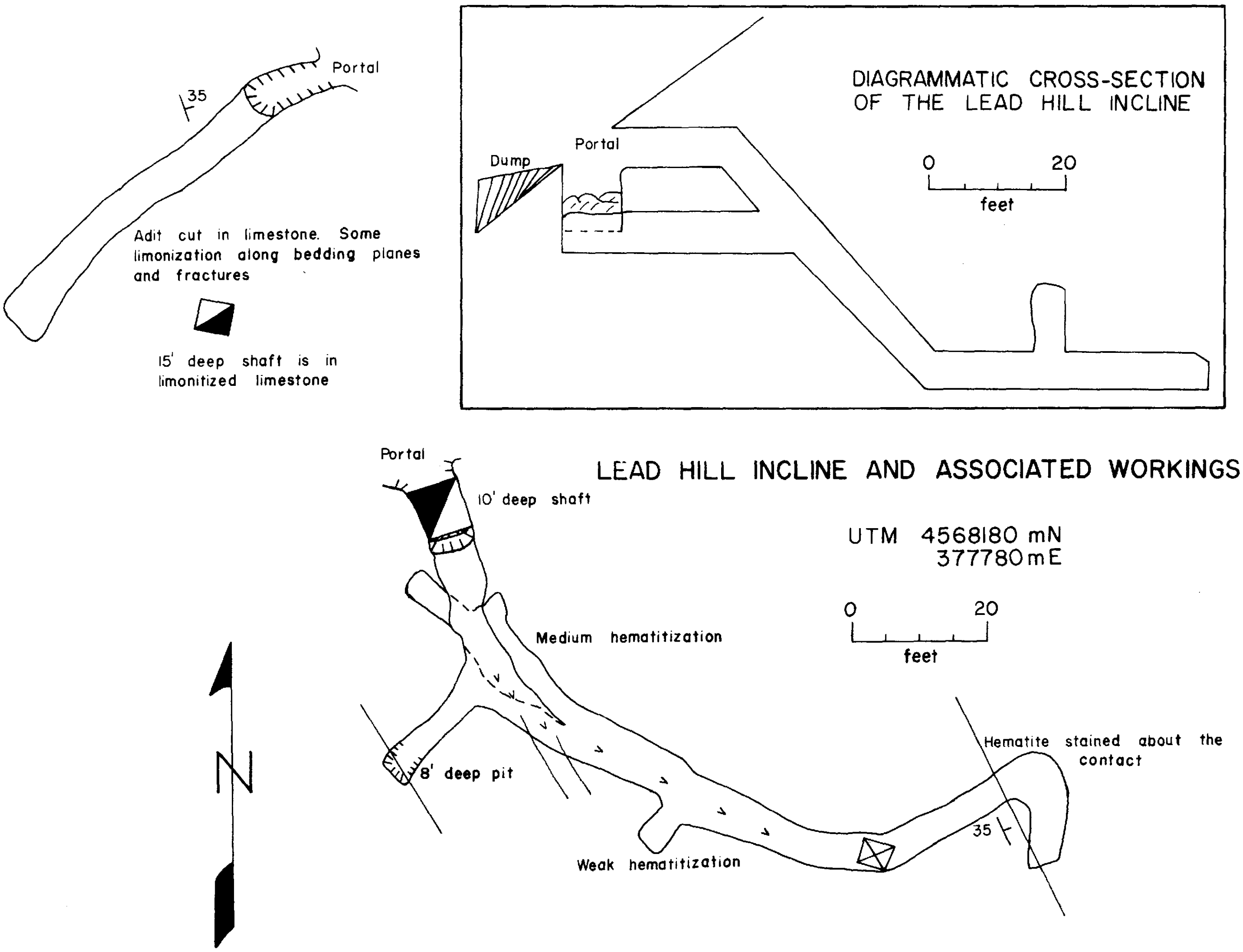


Figure 82.Lead Hill incline and associated workings, Promontory mining district, ("Q" on figure 75).

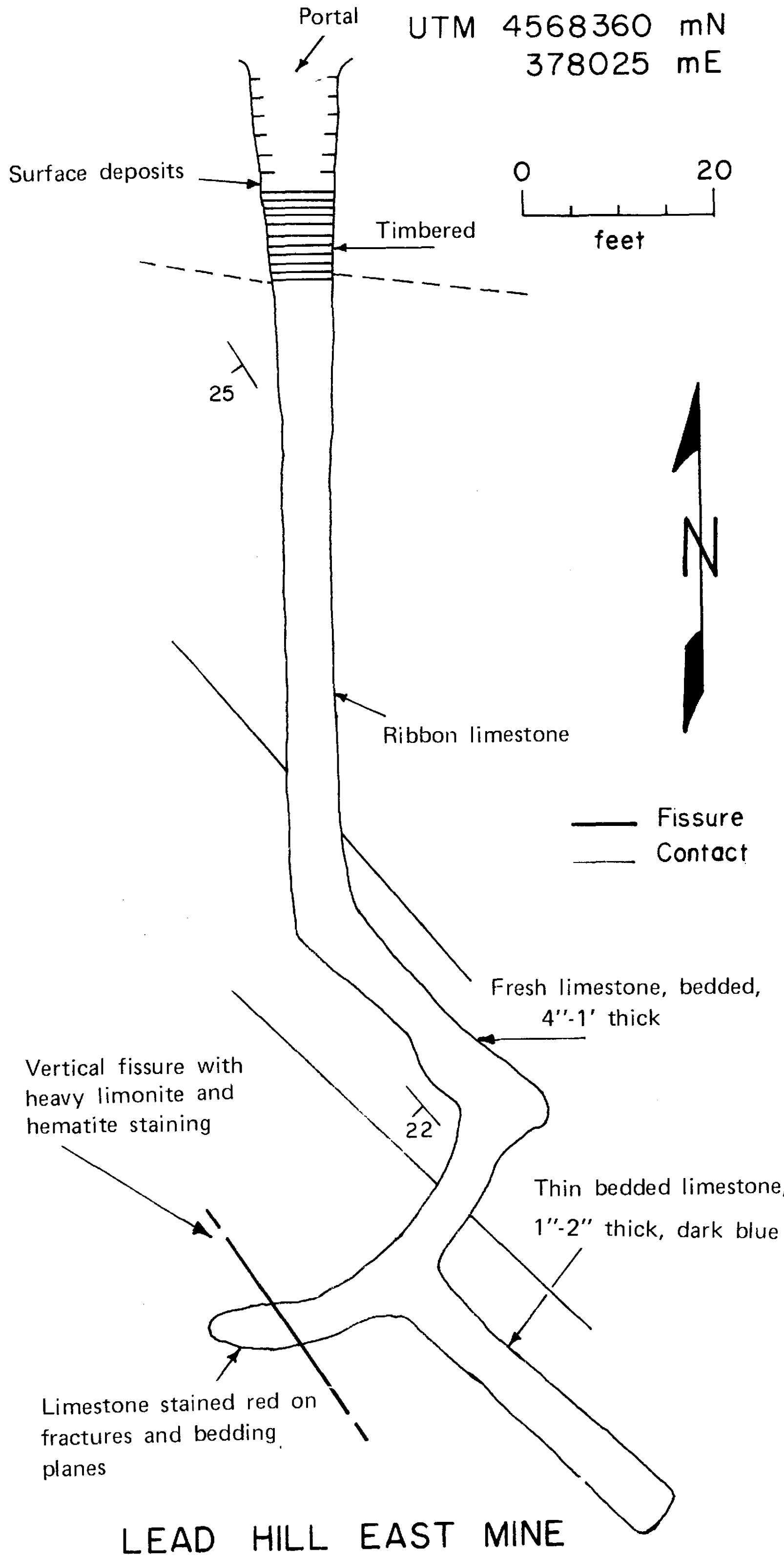
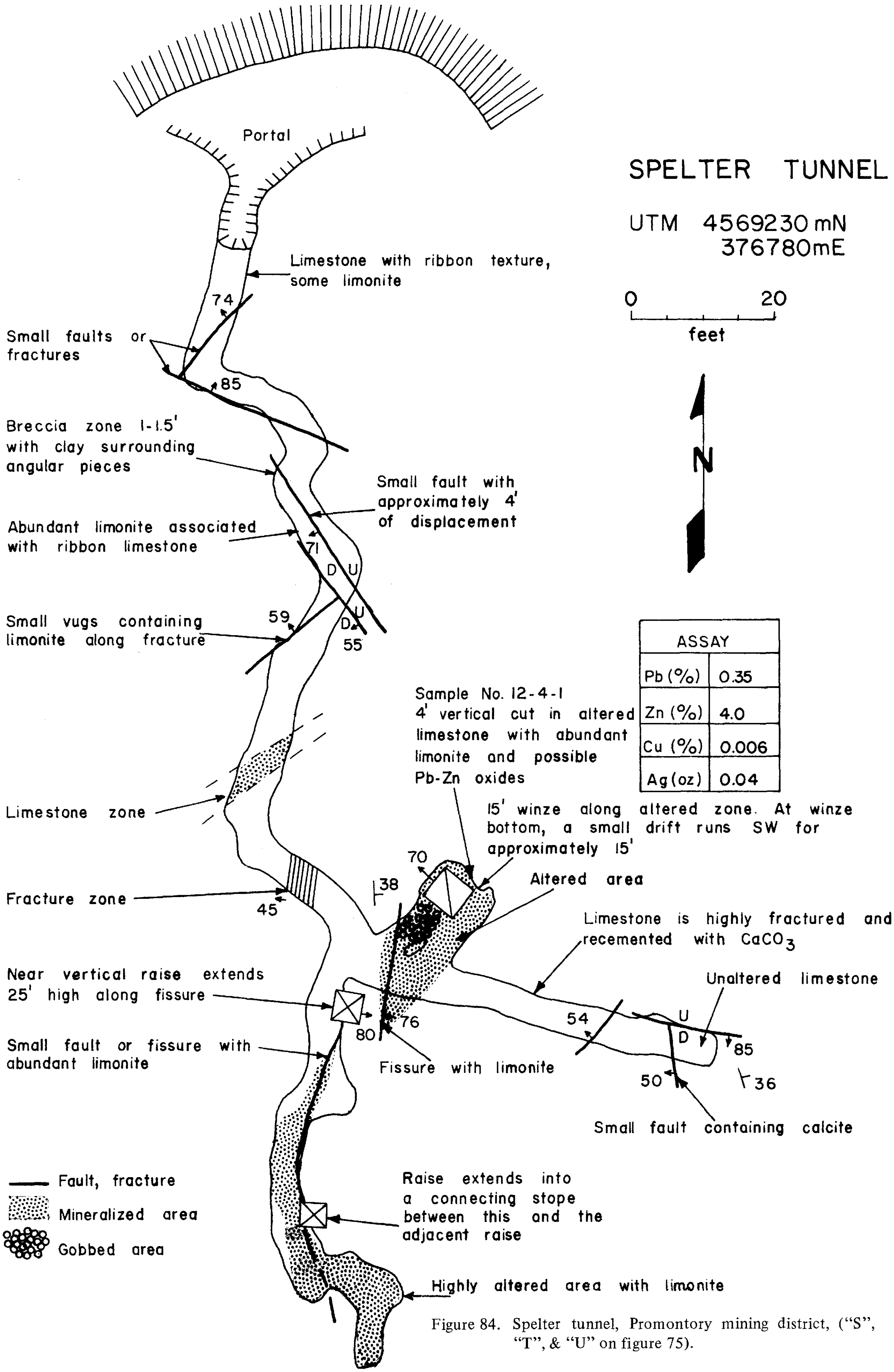


Figure 83. Lead Hill East mine, Promontory mining district, ("R" on figure 75).



ASSAY	
Pb (%)	0.35
Zn (%)	4.0
Cu (%)	0.006
Ag (oz)	0.04

Figure 84. Spelter tunnel, Promontory mining district, ("S", "T", & "U" on figure 75).

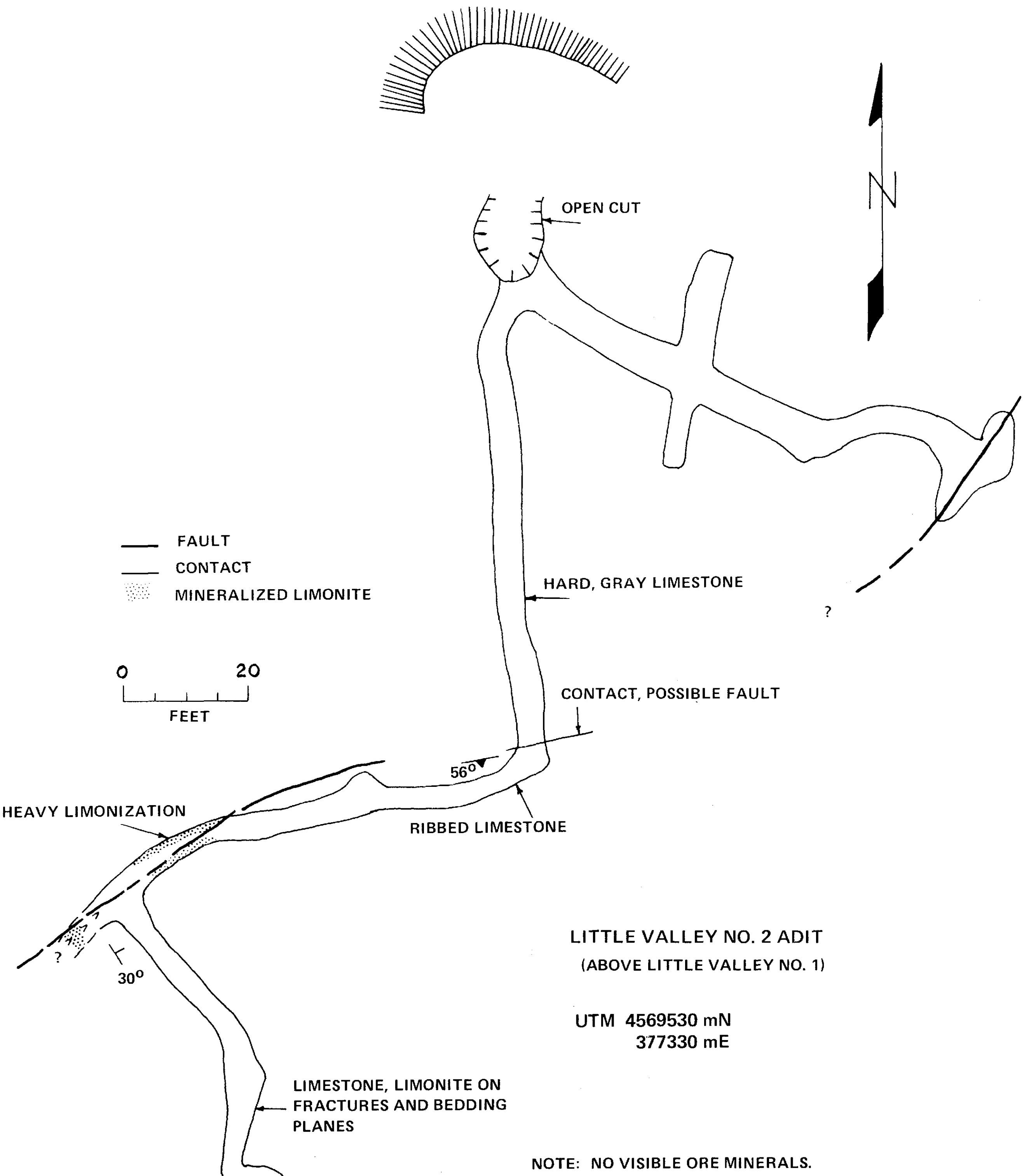


Figure 85. Little Valley No. 2 adit, Promontory mining district.

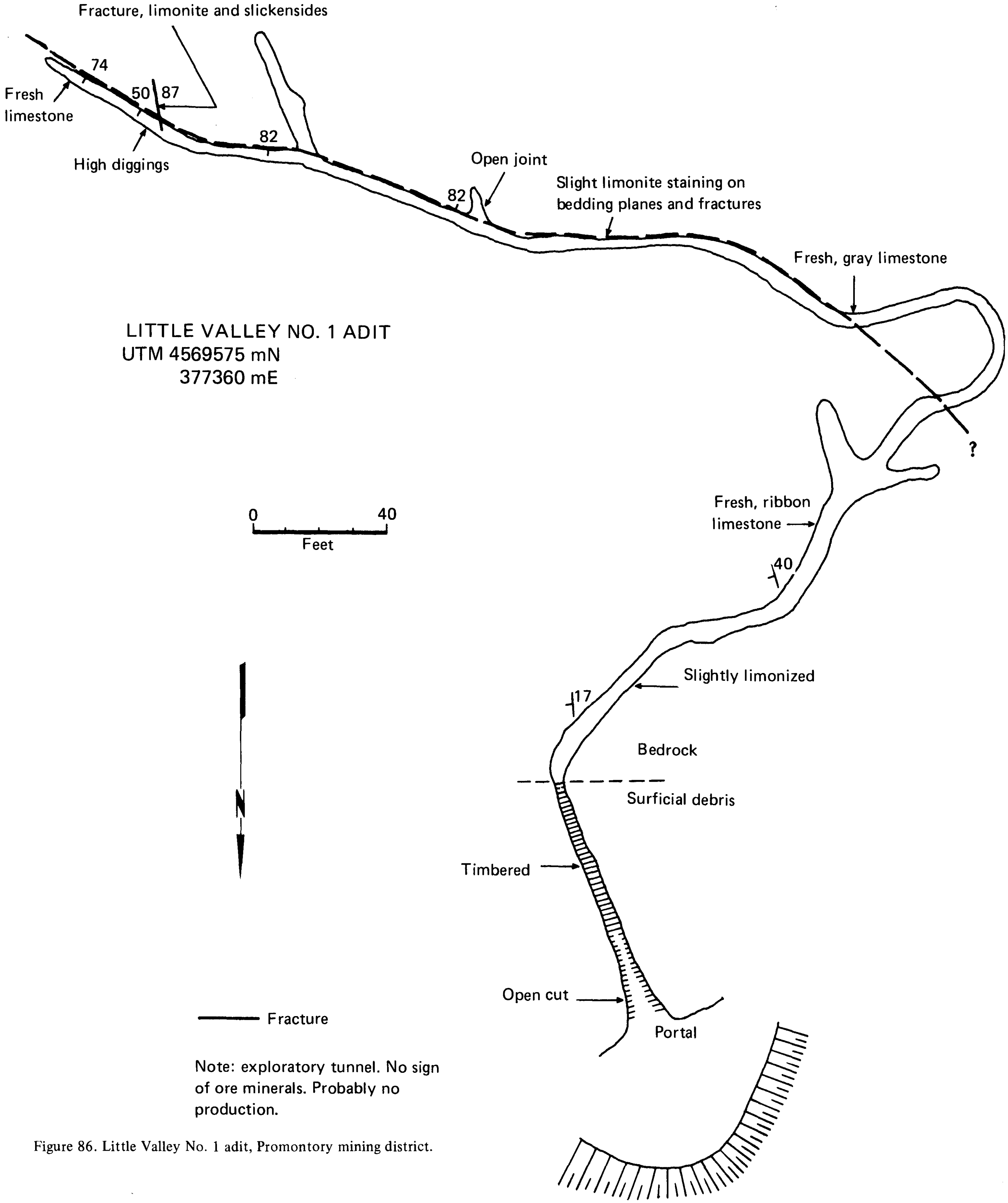


Figure 86. Little Valley No. 1 adit, Promontory mining district.

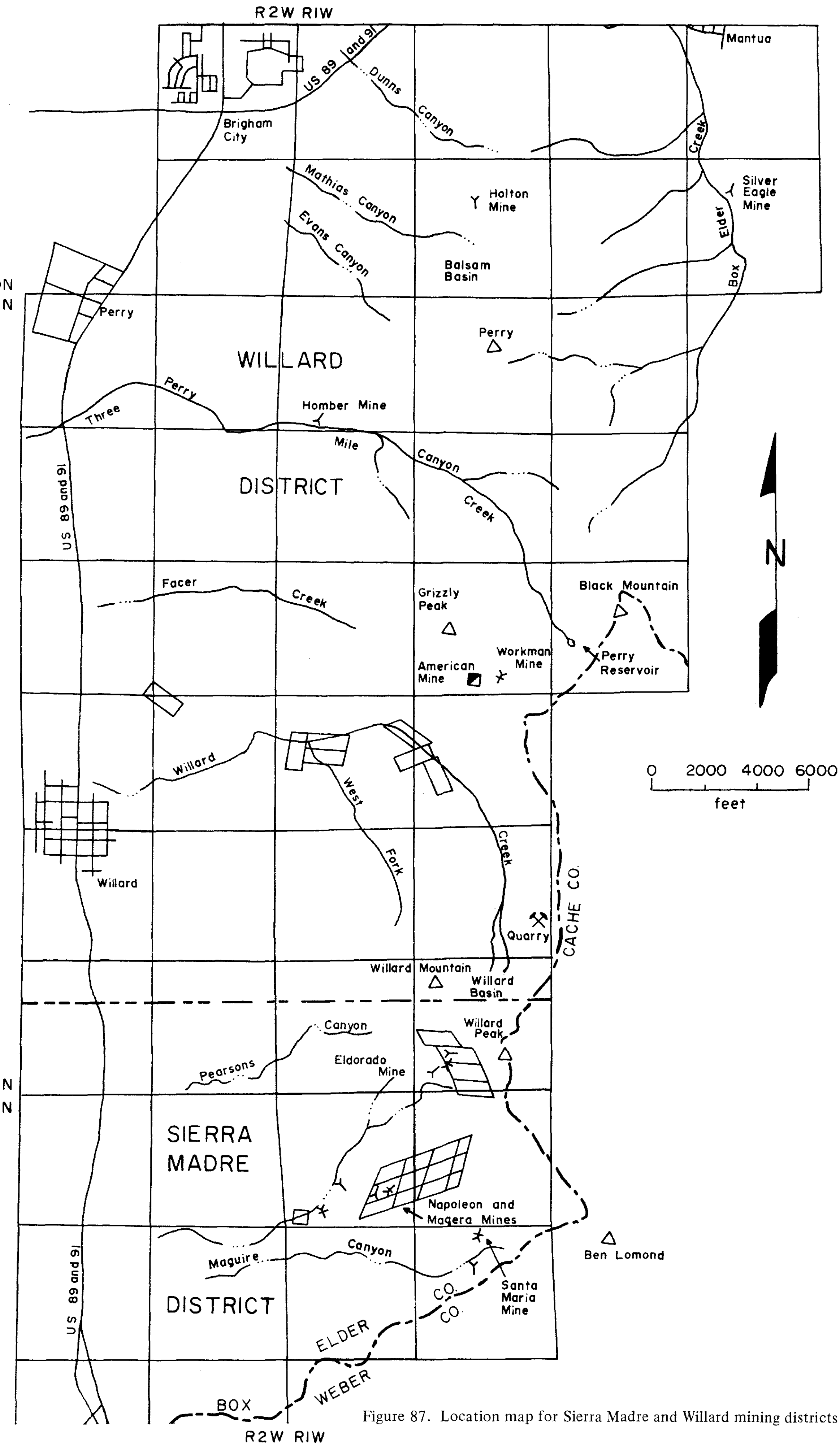


Figure 87. Location map for Sierra Madre and Willard mining districts

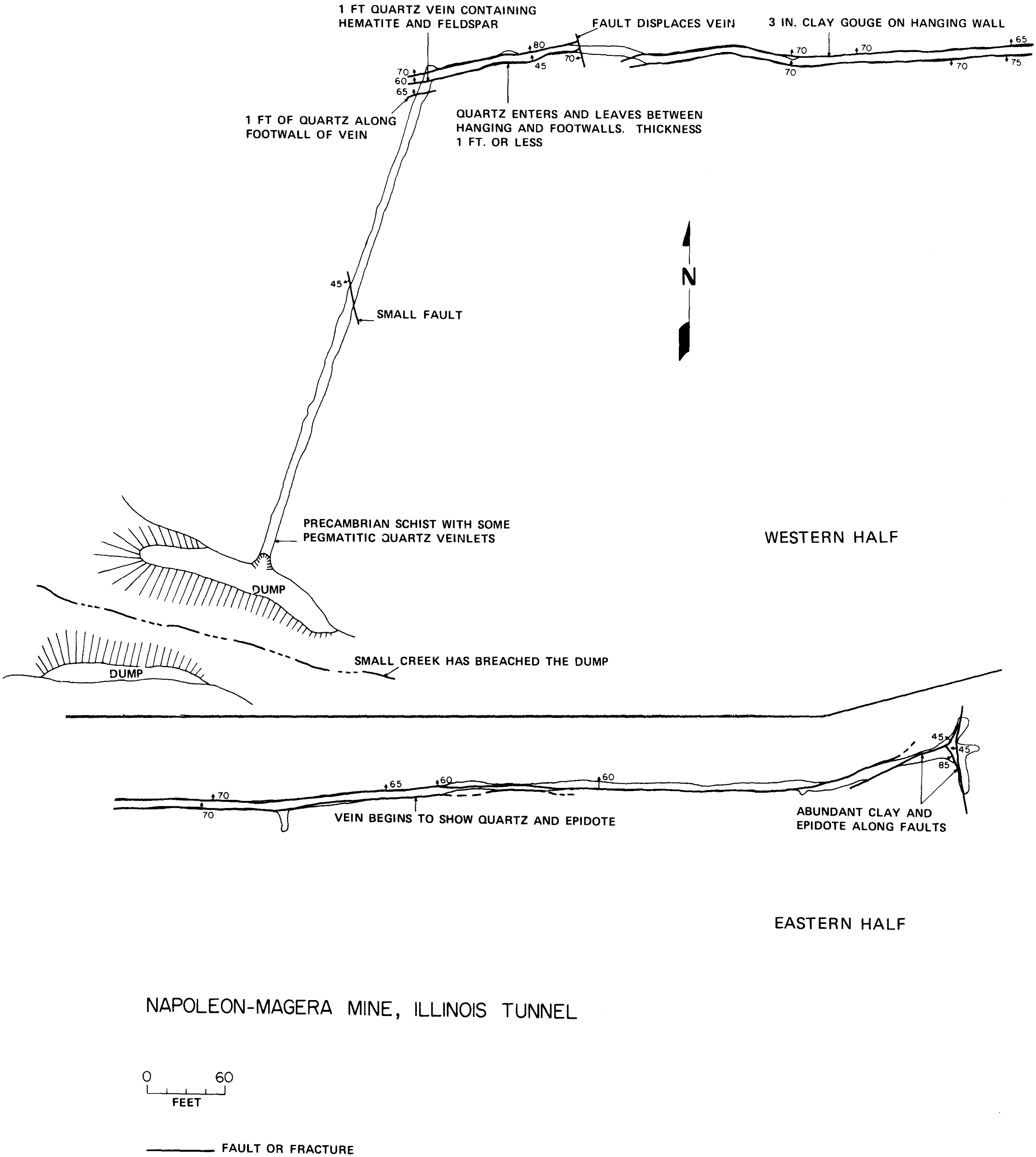


Figure 88. Napoleon-Magera mine; Illinois tunnel, Sierra Madre mining district.

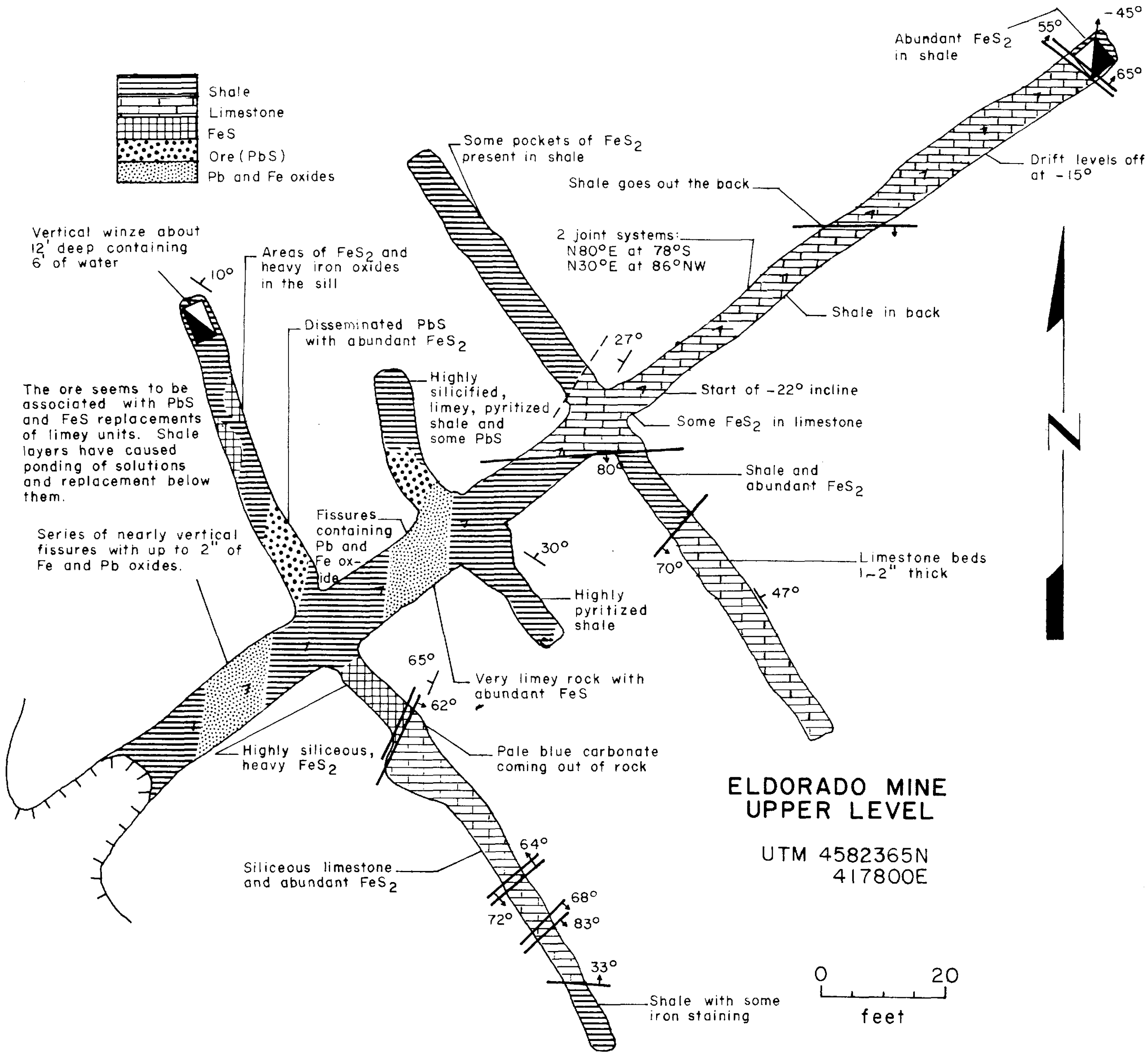


Figure 89. Eldorado mine, upper level, Sierra Madre mining district.

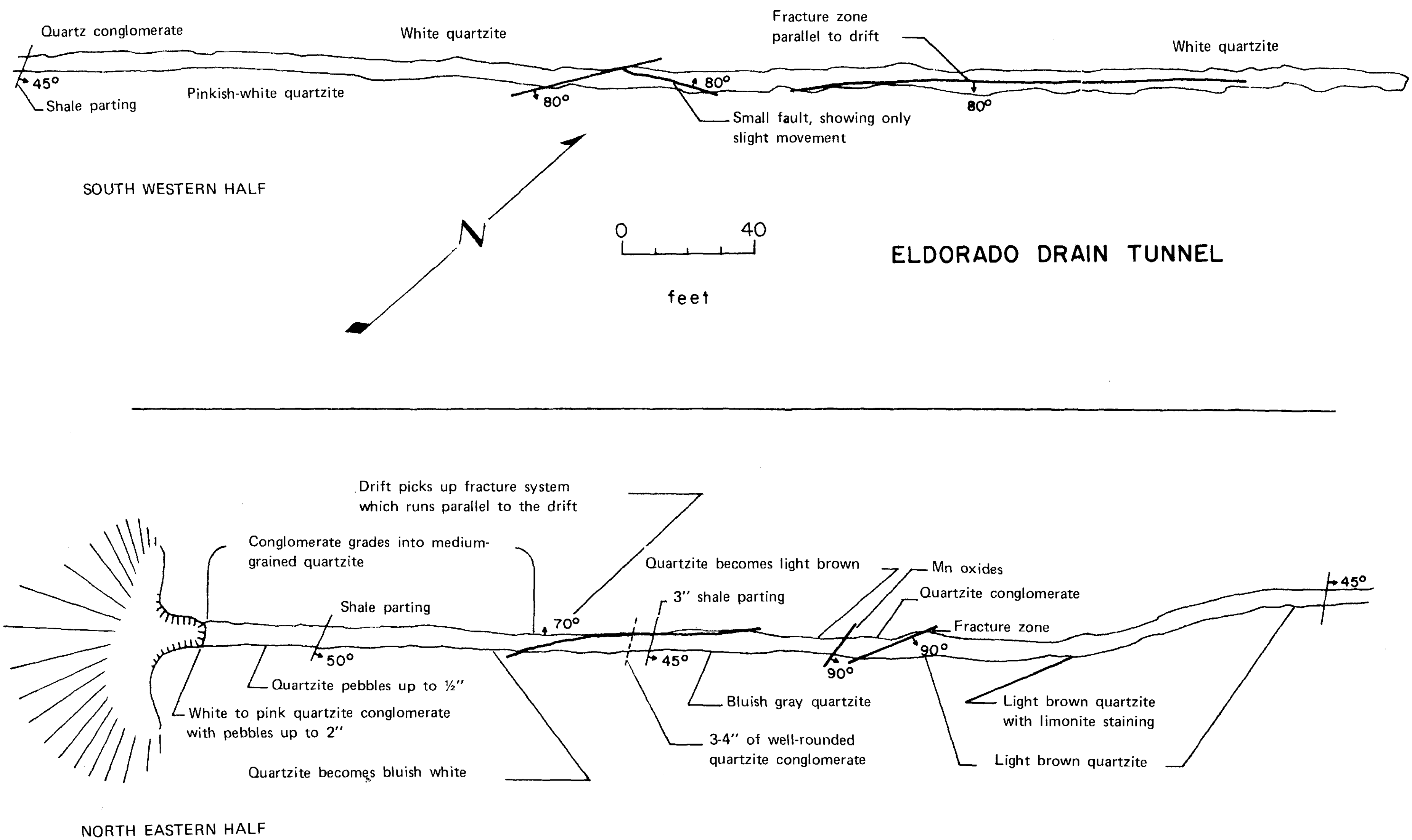


Figure 90. Eldorado drain tunnel, Sierra Madre mining district.

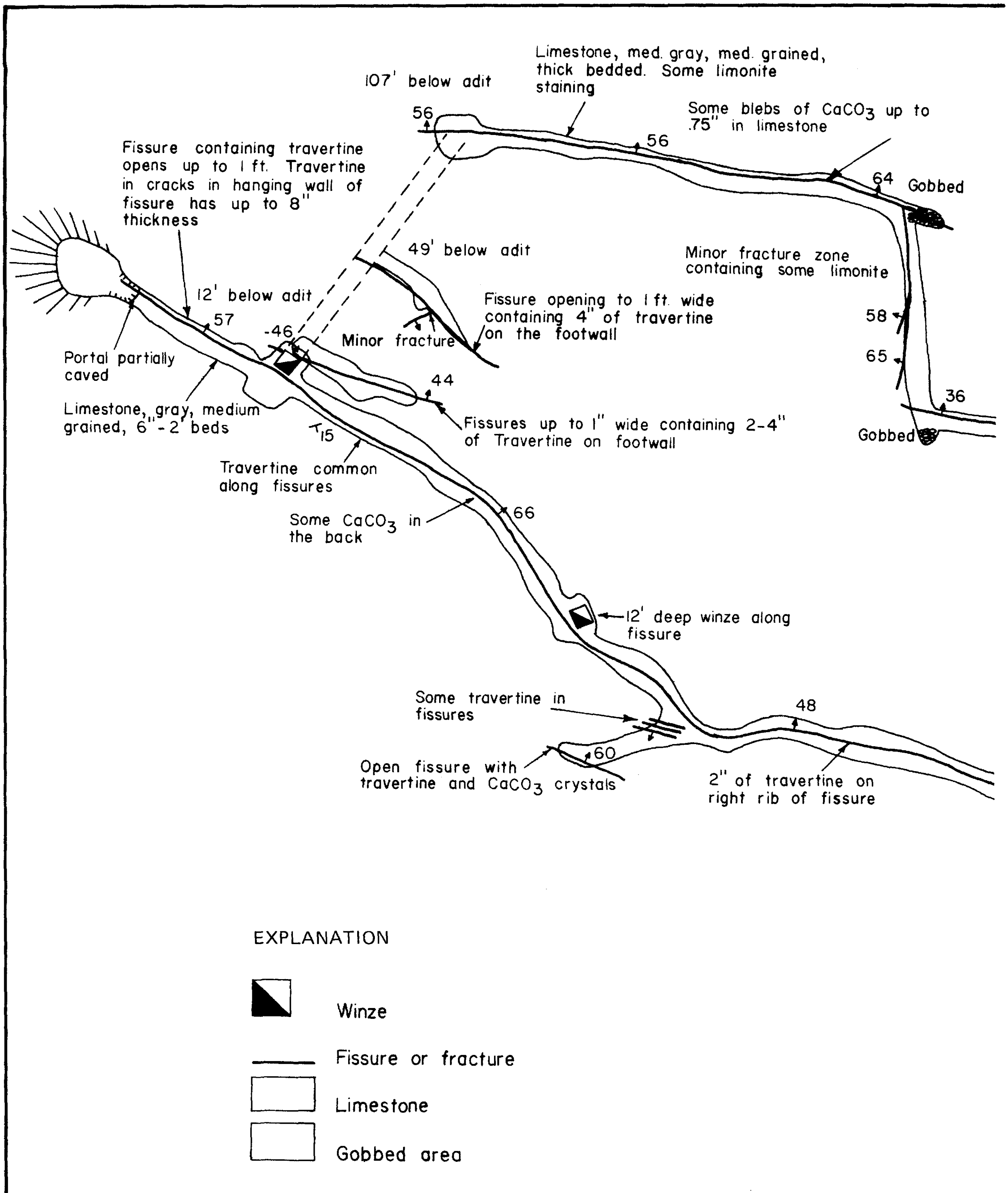
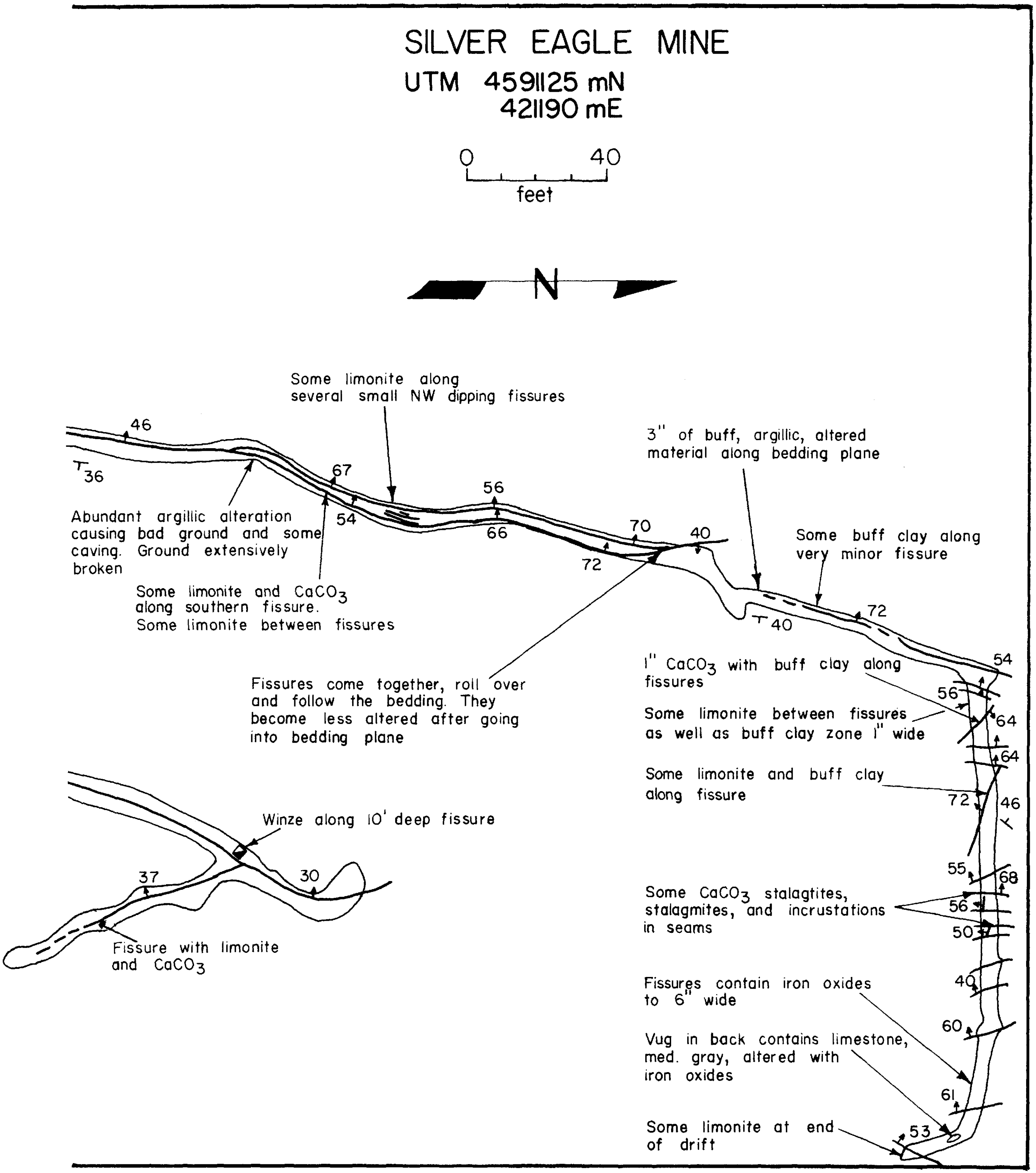
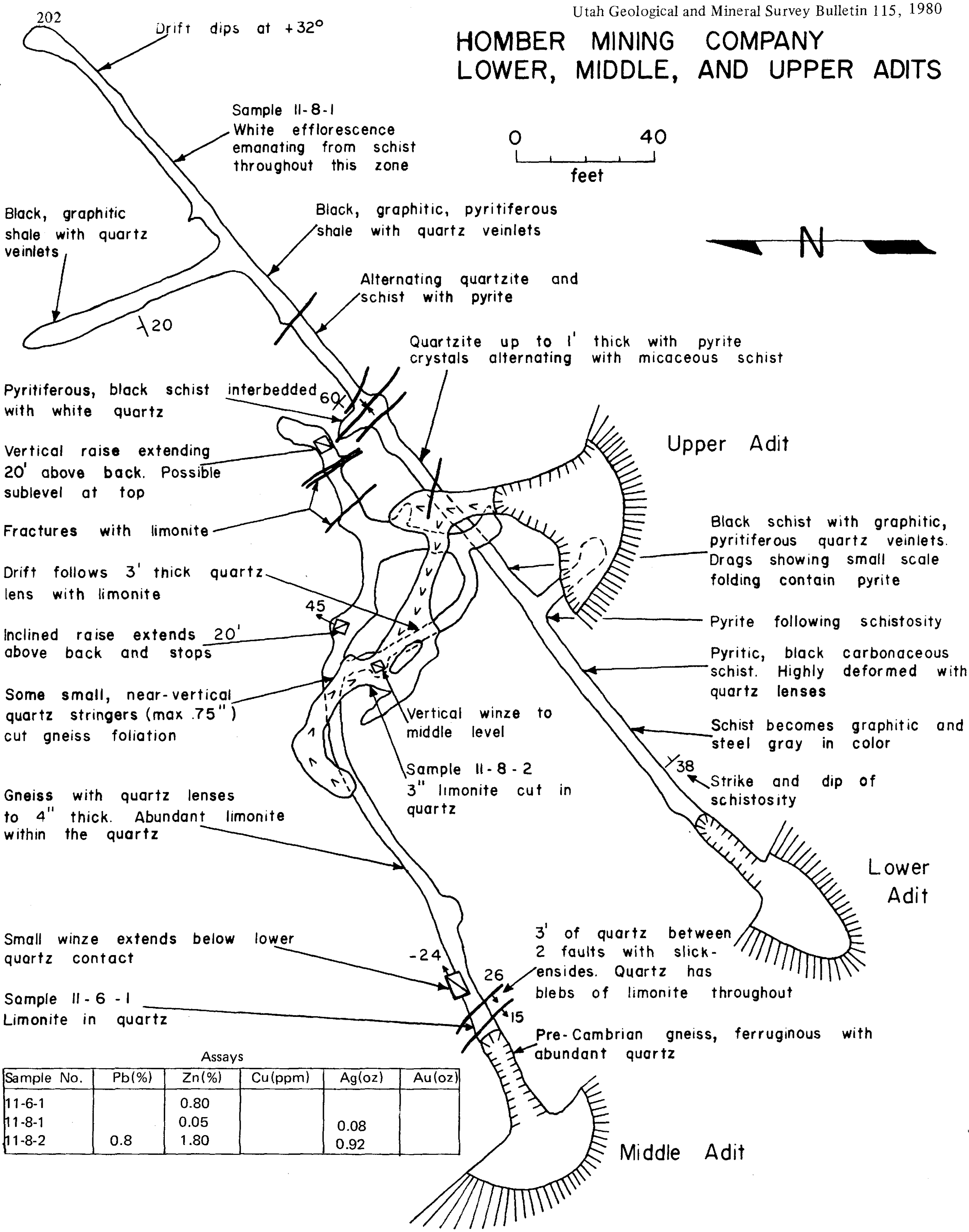


Figure 91. Silver Eagle mine, Willard mining district.


SILVER EAGLE MINE
UTM 4591125 mN
421190 mE
0 40
feet
N
Some limonite along several small NW dipping fissures
3" of buff, argillic, altered material along bedding plane
Abundant argillic alteration causing bad ground and some caving. Ground extensively broken
Some limonite and $CaCO_3$ along southern fissure. Some limonite between fissures
Some buff clay along very minor fissure
Fissures come together, roll over and follow the bedding. They become less altered after going into bedding plane
1" $CaCO_3$ with buff clay along fissures
Some limonite between fissures as well as buff clay zone 1" wide
Some limonite and buff clay along fissure
Winze along 10' deep fissure
Some $CaCO_3$ stalagtites, stalagmites, and incrustations in seams
Fissure with limonite and $CaCO_3$
Fissures contain iron oxides to 6" wide
Vug in back contains limestone, med. gray, altered with iron oxides
Some limonite at end of drift



Assays

Sample No.	Pb(%)	Zn(%)	Cu(ppm)	Ag(oz)	Au(oz)
11-6-1		0.80			
11-8-1		0.05		0.08	
11-8-2	0.8	1.80		0.92	

Figure 92. Homber Mining Co., lower, middle, and upper adits. Willard mining district.

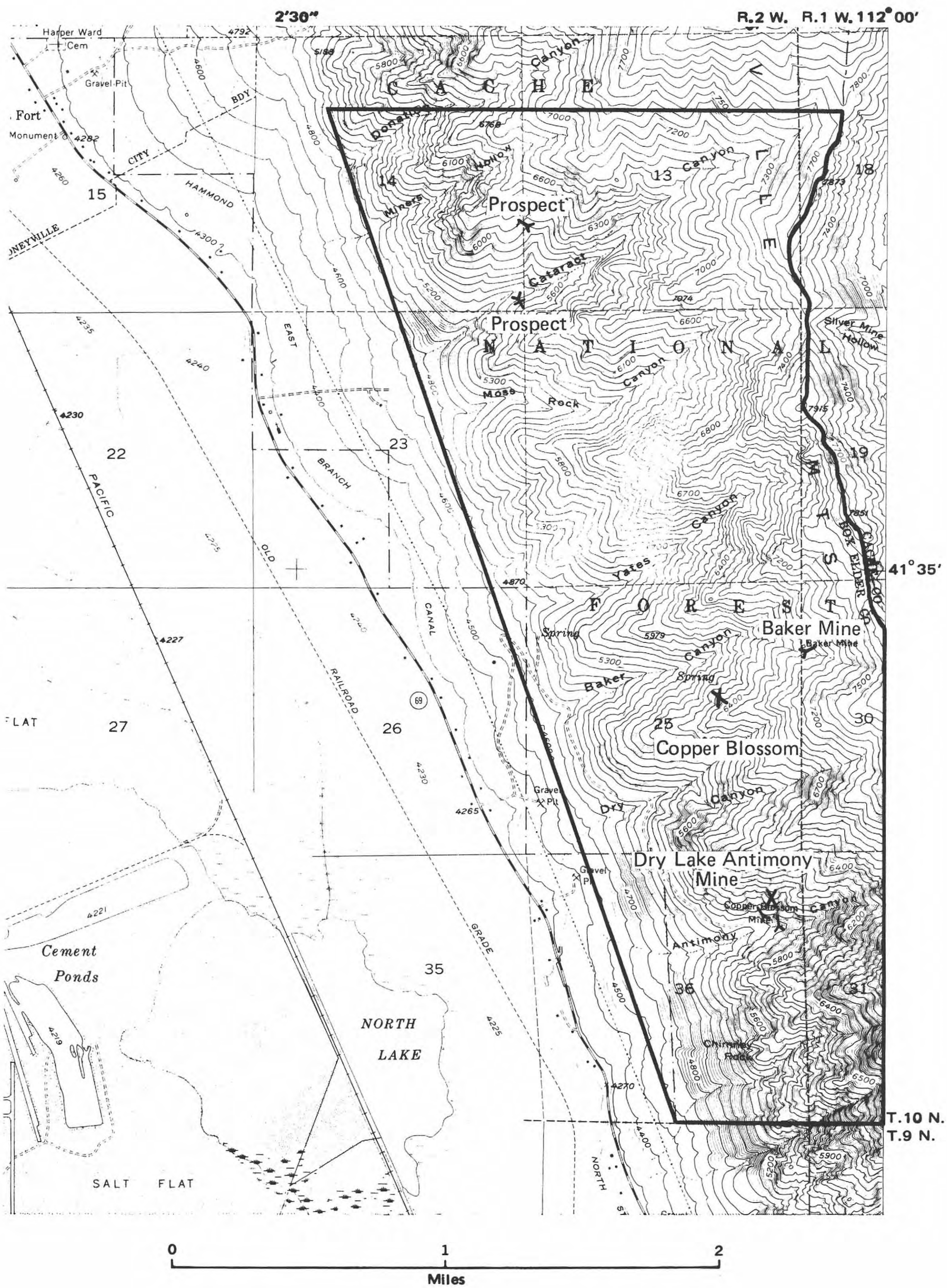
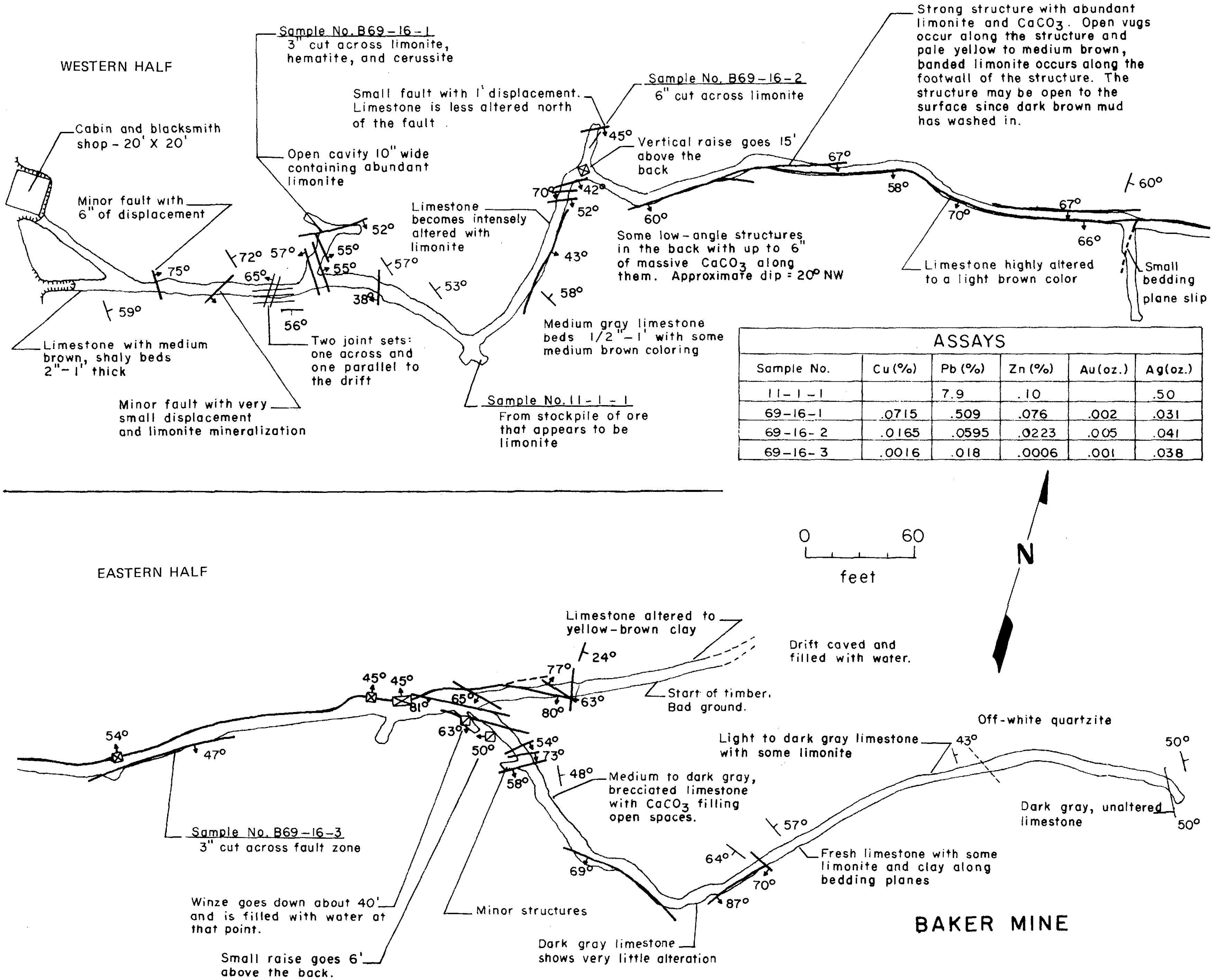


Figure 93. Location map of Box Elder mining district.



ASSAYS

Sample No.	Cu (%)	Pb (%)	Zn (%)	Au (oz.)	Ag (oz.)
11-1-1		7.9	.10		.50
69-16-1	.0715	.509	.076	.002	.031
69-16-2	.0165	.0595	.0223	.005	.041
69-16-3	.0016	.018	.0006	.001	.038

Figure 94. Baker mine, Box Elder mining district.

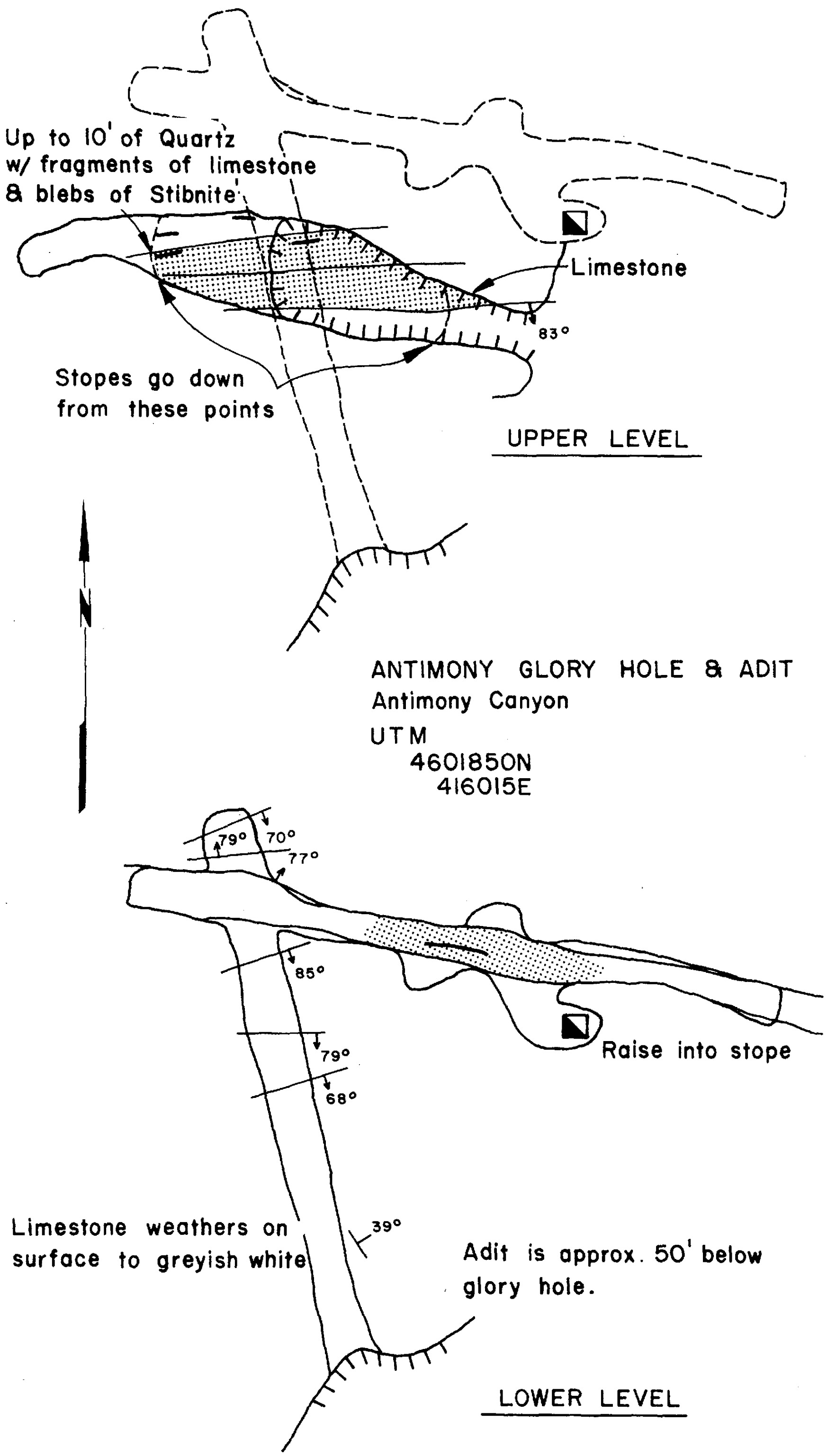


Figure 95. Antimony glory hole and adit, Box Elder mining district.

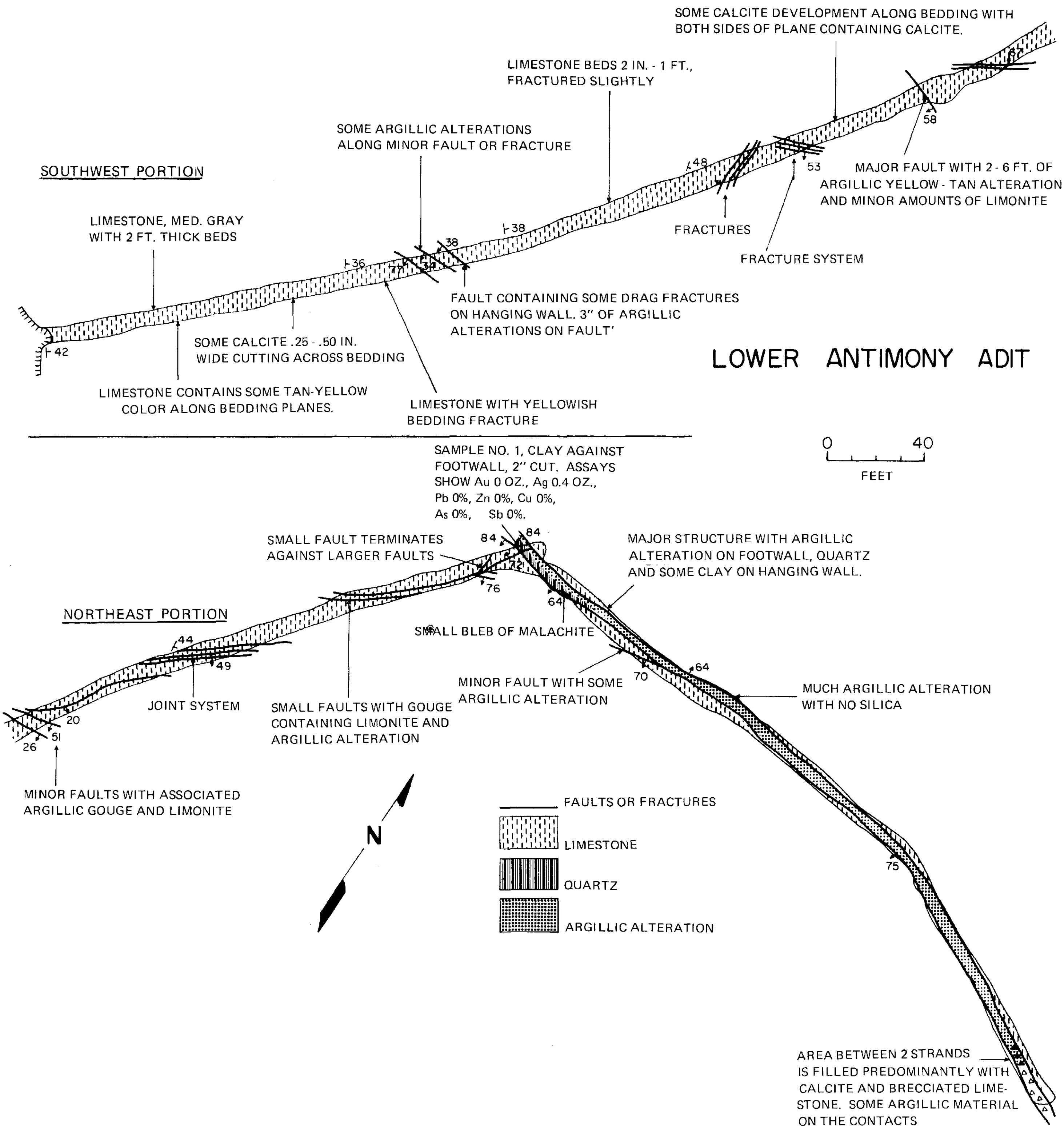


Figure 96. Lower Antimony adit, Box Elder Mining district.

MINERAL FUELS

Box Elder County has had little production of mineral fuels. A small amount of petroleum was produced at Rozel Point on the north shores of Great Salt Lake and a small amount of natural gas has been produced from a few wells in the eastern part of the county. One well was drilled for its geothermal possibilities but the results were inconclusive. A lignite field in the northwest part of the state has only a marginal potential. Very low grade vein-type deposits of uranium and thorium have been discovered in widely separated occurrences in the county.

Petroleum Potential

by Jock A. Campbell, Ph. D
Chief, Petroleum Geology Section
Utah Geological and Mineral Survey

Introduction

As a part of the Basin and Range structural and physiographic province, Box Elder County is generally considered to have a relatively low potential for commercial reserves of petroleum (Osmond and Elias, 1971). However, there has been minor petroleum production in and near the county. Oil seeps to the surface and has been produced from Pliocene (?) rocks near Rozel Point in eastern Box Elder County. Of nearly 70 known exploratory and development wells drilled in Box Elder County since 1896, only twelve can be considered significant tests for petroleum (table 6).

Petroleum Possibilities

Throughout Paleozoic and early Mesozoic time geologic conditions in Box Elder County were generally favorable for the generation, migration, and entrapment of petroleum (Armstrong, 1968, and Hintze, 1973). Thick sequences of marine strata which include probable petroleum source beds were deposited in the Cordilleran miogeosyncline. These strata thin in an easterly direction, with the attendant potential for the development of petroleum traps related to facies changes, strata wedge-outs, and unconformities. Superimposed on these are Laramide folds and thrusts. Folds have been mapped in most areas in the county, but regionally significant thrusting may or may not occur west of the Wasatch Range. There are significant differences between Box Elder County and adjacent parts of the petroleum-rich overthrust structural province to the east: the Mesozoic petroleum source rocks (Powers, 1977) of western Wyoming and adjacent Utah and Idaho are not present in Box Elder County, and many of the petroleum traps formed by Paleozoic sedimentary and stratigraphic relations and Mesozoic structures are likely to have been broken up by Cenozoic faulting. In addition, mid-Mesozoic and early Tertiary regional metamorphism (Armstrong and Hansen, 1966; Compton and others, 1977) and Mesozoic and Tertiary silicic intrusive and extrusive activity have minimized the petroleum potential of the pre-Neogene strata of the western part of the county. In general, the uplifted blocks have the lowest petroleum potential because potential reservoir rocks have been lost through erosion and influx of meteoric waters. Stratigraphic studies such as those by Bissell (1970) and Rose (1976), who have described the facies relationships within some of the sedimentary systems present in the region, will be necessary to predict trends of possible petroleum reservoir rocks in the older strata.

Other petroleum possibilities are related to Cenozoic strata in the intermontane basins. The oldest sedimentary rocks known to occupy some of these basins are fluvial and lacustrine strata of the Salt Lake Group which are locally exposed along the basin margins (Adamson and others, 1955; Mapel and Hail, 1956, 1959; and Heylmun, 1965). Locally nearly 10,000 feet of lacustrine strata as old as Paleocene occur to the east and west of the county (Patton and Lent, 1979), and have also been identified in the Salt Lake City salient (Mann, 1974, p. 18). Dark, fetid carbonate rocks have been observed in Cache Valley (Adamson and others, 1955), but they have not yet been proven to be potential petroleum source rocks. The regional distribution of facies of the Salt Lake Group is unknown because of incomplete exposures and the paucity of exploratory drilling. The maximum age of strata assigned to the Salt Lake Group is unknown, but a tuff within the upper Salt Lake Formation (Mapel and Hail, 1959) is approximately 13 million years old (K-Ar) or late Miocene in age (Armstrong and others, 1976, p. 3).

Regional geophysical studies indicate that there are a number of fault-bounded Cenozoic basins present in the county (figure 97). The deeper parts of the basins, exceeding 5,000 feet of fill, are delineated on the basis of the geophysical studies. This is the most reasonable estimate of the depth of burial necessary for the generation and initial migration of petroleum liquids, assuming that potential source rocks exist (Cordell, 1972).

The largest and deepest of the Cenozoic basins is the Great Salt Lake basin, which also occupies parts of three other counties. Seismic reflection studies by

Table 6. Exploratory wells, Box Elder County, Utah Part 1

No.	LOCATION	AREA	OPERATOR	NAME & NO.	DATE COMMENCED	DATE COMPLETED	ELEVATION
1.	14?-6N-10W	Strongknob	Southern Pacific R. R.	Strongknob	1900?	1900	4206.5Gr.
2.	36- 7N-14W	Newfound-land	Southern Pacific R. R.	Newfound-land	1902	1902	4218.5Gr
3.	29?-7N-14W	Lemay	Southern Pacific R. R.	Lemay	1902	1904?	4217.5Gr.
4.	NENW- 4- 8N- 7W	Rozel Point	LaSalle Mineral Co.	Rozel No. 1	?	1907	4250±Gr.
5.	NWNE- 8- 8N- 7W	Rozel Point	Nebeker	Rozel No. 1	?	1907	4300±Gr.
6.	NENE- 4- 8N- 7W	Rozel Point	LaSalle Mineral Co.	Rozel No. 2	?	1908	4250±Gr.
7.	NWSW- 9- 8N- 7W	Rozel Point	A. B. Coreoy	No. 1	?	1910	4250Gr.
8.	31-10N- 2W	Bear River Valley	Corinne Oil & Gas Co.	No. 1	?	?-10-18	?
9.	NESWSW-12- 5N 9W	Lakeside	Lakeshore Oil Co.	No. 1	?	7-? - 26	4250±Gr.
10.	SWSE-31- 9N- 7W	Rozel Hills	Lakeside Oil Co.	No. 1	?	?-11-27	4250Gr.
11.	NENW-17-13N- 4 W	Whites Valley	Utah-Pennsylvanian Oil Co.	No. 2	?	1927	5160±Gr.
12.	SWSW- 9- 8N- 7W	Rozel Point	Leonora Mining & Milling Co.	No. 1 Saboda	10-10-21	?- 4-30?	4250Gr.
13.	NENW-27- 9N- 3W	Brigham City	Chesapeake Duck Club	None	Probably between and 1930	1925	4215±Gr.
14.	NWNW- 3-10N0 4W	Little Mountain	Utah-Pennsylvanian Oil Co.	No. 2 Penrose	?	?- 7-31	4300±Gr.
15.	35- 9N- 4W	Migratory Bird Refuge	U. S. Biol. Survey	No. 1	?	1931?	4206±
16.	35- 9N- 4W	Migratory Bird Refuge	U. S. Biol. Survey	No. 2	?	1936	4206±
17.	C-14- 9N- 8W	Rozel Hills	Leonora Mining & Milling Co.	No. 1 Raddatz	6-18-25	?- 6-34	4300±Gr.
18.	8?-5N?- 9W	Lakeside	Heckler	No. 1	?	Bef. 1936	?
19.	35- 9N- 4W	Migratory Bird Refuge	Duckville Gun Club	None	?	1938?	4206±Gr.
20.	NWNW-26-14N- 8W	Snowville	Utah Duchess Oil Co.	No. 1	?	?- 6-40	4819Gr.
21.	CSENE-25-13N-11W	Warm Springs	Stanford Petroleum Co.	No. 1 Fonnes-beck	?	10- 8-46	4250±Gr.
22.	NESW-17-13N- 4W	Whites Valley	Northern Oil Co.	No. 1	?	11-18-47	5140Gr.
23.	SWSE-31-12N- 8W	Hansel Valley	Mohawk Petr. Co.	No. 2	?	2-10-48	4260±Gr.
24.	CSESE- 7-13N- 4W	Whites Valley	Promontory Oil Co.	No. 1 Jensen	8- 9-49	9- 2-50 8- 1-50?	5200±Gr.
25.	SWNE-17-10N- 7W	West of Promontory	Utah Southern Oil Co.	No. 1 Bar-B	8- 5-51	9- 2-52	4253Gr.
26.	NWNW-16- 8N- 7W	Rozel Point	Liquid Asphalt Co.	No. 1	?	12- ?-52	4195±Gr.
27.	CNWNW-14- 6N-16W	Desert Range	Gulf Oil Co.	No. 1 Williams Federal	8-26-54	10-9-54	4243KB
28.	CSWNE-14-14N-10W	Curlew Valley	Utah Southern Oil Co.	No. 1 Gov't.	10-20-54	12- 1-54	4408 Gr. 4396 Gr.
29.	CNENW-21- 9N- 2W	Brigham City	Paul S. Stacey et. al.	No. 1 Nichols	4-30-55	8-15-55	4213±Gr.
30.	SESW-22-14N-10W	Curlew Valley	Utah Southern Oil Co.	No. 1 Federal	9-25-55	1-14.56	4412Gr. 4420KB
31.	CSENE- 6-14N- 9W	Curlew Valley	Utah Southern Oil Co.	No. 2 Federal	1-21-56	4-29-56	4412Gr.
32.	NWSE-27-14N-19W	Goose Creek	Eagle Oil Co.	No. 2 Carson	?	11-24-56	5400Gr.
33.	NWNW-16- 8N- 7W	Rozel Point	Ratner Oil Co.	No. 2 Stoddard	10-14-56	12-31-56	4196±Gr.
34.	NWNW-16- 8N- 7W	Rozel Point	Eller Oil Co.,	No. 1 Rozel Point	?	1956?	4196±Gr.
35.	CSWSE- 3-14N-19W	Goose Creek	Charles E. Walden	No. 1 Federal	4- 8-57	5-30-57	5100Gr.
36.	CSWNW- 2-14N-19W	Goose Creek	Eagle Oil Co.	No. 1 State	?- ?-57	7-17-57	5070Gr.
37.	CNENE-31-10N- 3W	Little Mountain	Adamantia Corp.	No. 1 Stanley	2- 8-56	9-24-57	4235±Gr.
38.	NESW-30- 9N- 2W	Brigham City	Rhine Petr. Inc.	No. 1 Knudson	12-15-57	4- 3-58	4242DF
39.	SWNW- 2-14N-19W	Goose Creek	Emil B. Kucera	No. 1 State	9-18-60	9-26-60	5450DF
40.	SESE-18-11N- 5W	Promontory Mountains	Gulf Oil Corp.	No. 1 Adams	4- 4-63	8- 7-63	4845KB
41.	SENE- 9- 8N- 7W	Rozel Point	Gulf Oil Corp	No. 1 Leonora Bullen	11-25-63	12- 8-63	4242Gr.

(continued)

Table 6. (continued)

No.	LOCATION	AREA	OPERATOR	NAME & NO.	DATE COMMENCED	DATE COMPLETED	ELEVATION
42.	NWNE-17- 8N- 7W	Rozel Point	Gulf Oil Corp.	No. 1 State-Rozel	1-9-64	2-12-64	4190Gr.
43.	SESE- 8- 8N- 7W	Rozel Point	Charles E. King	No. 1 Rozel-State	7-2-64	1-5-65	4206KB
44.	SESE-23- 8N-15W	North Beppo	Amerada-Hess Corp.	No. 1 So. Pacific	6-26-74	8-7-74	4264Gr.
45.	16-10N- 2W	Brigham City	Geothermal Kinetics Inc.	No. 1 Davis Utah Steam	2-20-74	9- ?-74	4251Gr.
46.	SWSE-23-, 7N 7 W	Great Salt Lake	Amoco Production Co.	No. 1 Indian Cove-State	6-24-78	11-4-78	4199Gr.
47.	NESE 28, 9N 7W	Rozel Flat	Kenneth D. LUff	No. 1-28 Bar-B Trust		11-22-78	4220Gr.
48.	NWSW 23, 8N 8W	Great Salt Lake	Amoco Production Co.	No. 1 State-D	11-25-78		4199Gr.

Mikulich and Smith (1974) indicate that the Tertiary fill increases southward from about 4,000 feet near Rozel Point, to 7,000 feet near the Southern Pacific Railroad causeway and finally becomes 10,000 to 12,000 feet thick near Tooele. More recent seismic data indicates a maximum of over 15,000 feet of Cenozoic basin fill (Patton and Lent, 1979). The presence of the Precambrian/Cenozoic boundary below 12,000 feet in the no. 1 Indian Cove-State well (table 6) confirms over 12,000 feet of Cenozoic fill in the basin. To date (January 1979), Cenozoic strata older than Miocene have not been identified in wells.

The other Cenozoic basins outlined on figure 97 are generally smaller in area and appear to have less structural relief than the Great Salt Lake basin.

Rozel Point Oil Field

The oil seeps at Rozel Point (Boutwell, 1904, p. 474-7; Eardley, 1963) led to early interest in the area, but much of the early record of drilling and production is lost to history. Boutwell (1904, p. 468) reports considerable drilling activity in the area. In the absence of more accurate information, the discovery date of the field is taken as 1904 (Slentz and Eardley, 1956, p. 36). Fifteen to 20 wells had been drilled at Rozel Point through 1956 and those that encountered oil did so at 125 to 300 feet below the surface (Eardley, 1963, p. 8). About 31 more wells were drilled on one acre spacing in section 8, T. 8N., R. 7W., between 1964 and 1969. They range from about 175 to 250 feet in depth and at least 9 of the wells produced oil. Production was from a fractured, vesicular basalt of probable Pliocene age. Unplugged wells are known to flow minor quantities of viscous oil in warm weather. An inability to stimulate production to a sustained commercial rate has plagued operations at Rozel Point, and most of the wells have become inundated by rising waters of the Great Salt Lake in recent years.

There is no record of production from the field prior to 1965 (table 7), but 10,000 barrels would be a conservative estimate of the production that accumulated during episodic activity in the field over the 50-year period. Rozel Point oil is unusual in its very high sulfur content, high carbon residue, and instability to fractional distillation. The nitrogen content is also anamalously high in one of the four available analyses (table 8). The high nitrogen and thermal instability suggest a submature, therefore relatively young source material. Lacustrine strata of the Salt Lake Group may represent such a source, but any proposed origin of the Rozel Point oil is speculative at this time. Heylmun (1961a) and Slentz and Eardley (1956, p. 36) speculate on the basis of a questionable carbon-14 date of 4,000 years, that the petroleum originated in Quaternary lake sediments, but present knowledge of petroleum origin and migration (Cordell, 1972) indicates that such a young and shallow origin for liquid hydrocarbons is not possible. There can be little doubt that petroleum recovered from such shallow depths has undergone bacterial degradation which has altered its physical and chemical properties.

Shallow Natural Gas

Parts of the eastern Great Basin may have additional petroleum potential in the shallow lacustrine sediments of the lake Bonneville Group. Methane-rich gasses occur in and appear to be genetically related to Pleistocene and Recent sediments (table 9). The gas probably generated through decay of the organic fraction of the young sediments (biogenic gas) and is analogous to "swamp" gas. The gas may also be genetically related to the deeper Salt Lake Group; a well drilled near Corinne (Table 6, No. 8) encountered gas at nearly 1,000 feet of depth, probably in the Salt Lake Group.

The earliest natural gas production from the Lake Bonneville Group was at the Farmington gas field in eastern Davis County (Heylmun, 1961b). It is estimated that as many as 20 wells supplied 150 million cubic feet of gas to Salt Lake City between September, 1895 and

Table 6. Exploratory wells, Box Elder County, Utah Part 2

No.	STRATIGRAPHIC SURFACE	UNIT BOTTOM	TOTAL DEPTH	REMARKS
1.	Lake Bonneville Gr.	Lake Bonneville Gr.?	781	(Abandoned (water well). Also reported in section 27?-6N-10W. T. D. 800 feet.
2.	Lake Bonneville Gr.	Lake Bonneville Gr.	293	Abandoned (water well).
3.	Lake Bonneville Gr.	Paleozoic Und.	2502	Abandoned (water well). Tertiary volcanics 1690, Und. paleozoic? 2108. Previously reported in 16?-7N-15W, T. D. 2480.
4.	Lake Bonneville Gr.	Salt Lake Gr.	1400	D & A. First drilling in Rozel Point area was circa 1896 (Boutwell, 1904, p. 475). T. D. also reported as 1610 feet.
5.	Lake Bonneville Gr.	?	300	D & A. Well may have been drilled as early as 1900-1905 (Eardley and Haas, 1936, p. 76).
6.	Lake Bonneville Gr.?	?	2012	D & A.
7.	Lake Bonneville Gr.	Salt Lake Gr.?	930	D & A.
8.	Quaternary Und.	Salt Lake Gr.?	976	D & A. 611 Btu gas sampled from 16-foot zone at 960 feet by U. S. Bureau Mines, 6-16-20.
9.	Lake Bonneville Gr.	Paleozoic?	1200	D & A. Also reported in section 17.
10.	Lake Bonneville Gr.	?	2710?	D & A. Probably the Lakeside Oil Company well of Eardley and Haas, 1936, p. 75, who report a total depth of 2850 feet. Well may have been drilled as early as 1900-1905.
11.	Oquirrh Formation?	Oquirrh Fm.?	10	D & A. Also reported as No. 1.
12.	Lake Bonneville Gr.	Paleozoic?	3600	D & A. 14 oil and/or gas shows between 170 and 1700 feet, asphalt shows especially between 1240 and 1375 feet. Possible Paleozoic strata at 1535 feet.
13.	Lake Bonneville Gr.	Lake Bonneville Gr.	502	D & A. Produced methane and salt water from 490-502 feet, 19-?-1975. (Water well).
14.	Lake Bonneville Gr.	Pennsylvanian?	4300	D & A. Good gas show at 3500 feet. (Salt Lake Gr. or Oquirrh Fm.?). Could be "Thatcher well" of Eardley & Haas, 1936, p. 76.
15.	Lake Bonneville Gr.	Lake Bonneville Gr.	?	D & A. Produced gas (Eardley & Haas, 1936). (Water well).
16.	Lake Bonneville Gr.	Lake Bonneville Gr.	1028	D & A. 6 gas zones, the shallowest of which produced for local consumption from 1931-1972 (251-265 ft.)
17.	Lake Bonneville Gr.	Salt Lake Gr.	2280	D & A. Salt Lake Group 200, 9 oil shows recorded between 197 and 2258 feet.
18.	Quaternary Und.	Mississippian	417	D & A. Drilled on northwest-trending fold.
19.	Lake Bonneville Gr.	Lake Bonneville Gr.	339	D & A. Well produced gas for local consumption from 19??-1975 (256-299 ft.). (Water well).
20.	Quaternary Und.	Lake Bonneville Gr.?	400	D & A.
21.	Lake Bonneville Gr.	Lake Bonneville Gr.?	679	D & A. Shows of gas at 640 feet. Maybe a second well in SE¼ (No. 1 Fee, T. D. 730?).
22.	Oquirrh Fm.	Madison Fm.	2013	D & A.
23.	Quaternary Und.	Lake Bonneville Gr.?	514	D & A.
24.	Quaternary Und.	Paleozoic Und.	7321	D & A. Oquirrh Fm. 50, Manning Canyon 588, Great Blue 1190, possible thrust in red beds 2700, underlain by unidentified carbonate rocks (Beus, 1963). Dead oil stain 3020-30.
25.	Lake Bonneville Gr.	Devonian	7918	D & A. Oquirrh Fm. at or near surface; Brazer 3850, Madison 6530, Devonian 7520. Minor oil shows above 2856 feet.
26.	Lake Bonneville Gr.	Salt Lake Gr.	300	D & A.
27.	Lake Bonneville Gr.	Pennsylvanian?	2894	D & A. Pennsylvanian 900 feet?
28.	Quaternary Und.	Manning Canyon Fm.	4765	D & A. Oquirrh; 3880, Manning Canyon 4382? Well is also known as No. 1 Keeler and No. 1 El Royale and located by error in 23-14N-10W.
29.	Lake Bonneville Gr.	?	1035	D & A. Gas shows in 8 zones between 240 and 792 feet.
30.	Quaternary Und.	Jefferson Fm.	6463	D & A. Oquirrh 440, Manning Canyon 3475, Chester-Meramec 4010, Madison 5012, fault block 5135-5580, Madison 5580, Jefferson? 6188.
31.	Quaternary Und.	Water Canyon Fm.	7569	D & A. Meramec 3080, Osage 3690, Madison 4295, Jefferson 5950?, Victoria 6233, Water Canyon 7365; minor gas shows at 5392 and 5528.
32.	Salt Lake Gr.	Salt Lake Gr.	265	D & A. Completed as water well. Also reported in section 34 as well No. 1; there could be two wells.
33.	Lake Bonneville Gr.	Salt Lake Gr.	293	D & A. Also known as Stoddard No. 2 Rozel Point?; oil show at 190 to 195 feet.
34.	Lake Bonneville Gr.	Salt Lake Gr.	300	Produced oil from basalt 195-210 and 251-258 feet, gas shows at 40-45 feet. Well was producing in 1956.
35.	Salt Lake Gr.	Salt Lake Gr.	900	D & A.
36.	Salt Lake Gr.	Salt Lake Gr.	808	D & A. Questionable oil show, total depth also shown as 675 feet. Location also shown as NESW.
37.	Quaternary Und.	?	110?	D & A.
38.	Lake Bonneville Gr.	?	2800	D & A. Small gas show at 370 feet. (probably Bonneville Group).
39.	Salt Lake Gr.	Salt Lake Gr.	800	D & A.
40.	Lake Bonneville Gr.	Devonian or Silurian?	8966	D & A. Salt Lake Group 120, Oquirrh Fm 790, Manning Canyon 3786, Brazer 6073, Madison 7444, Devonian; 8103, Silurian? 8440. Weak oil shows 8463 & 8485.
41.	Salt Lake Gr.	Mississippian	2442	D & A. Top Paleozoic (Mississippian?) 2014. No shows of oil or gas.
42.	Lake Bonneville Gr.	Pennsylvanian -Miss.?	3505	D & A. Salt Lake Group 80, Paleozoic (Penn. or Miss) 2350, Vertical strata in core 3237-3249 ft. Live oil saturation in fractured basalt 221-243 ft.; weak oil 310-800 ft.
43.	Lake Bonneville Gr.	Salt Lake Gr.	177	Shut-in. Top Tertiary (Salt Lake Group?) 149; completed, pumped 5 barrels oil in 2½ hours from 149-177 feet.*

(continued)

Table 6. Part 2 (continued)

NO.	STRATIGRAPHIC SURFACE	UNIT BOTTOM	TOTAL DEPTH	REMARKS
44.	Lake Bonneville Gr.	Paleozoic Und.	9077	D & A. Top Paleozoic 300; no hydrocarbon shows.
45.	Lake Bonneville Gr.	Brigham Quartzite?	11000	Suspended pending completion as water well. Salt Lake Group 580, Jefferson 4380, thrust fault, Manning Canyon 5360, Great Blue 6210, Lodgepole 7102, Swan Peak 7840, thrust fault 8300.
46.	Quaternary	Precambrian	12,470	D & A Tertiary, Farmington Canyon complex, 12,416. Minor gas shows in Miocene between 8960 and 9450.
47.	Quaternary	Paleozoic	4,550	D & A, Top Paleozoic (?) 4385. Most of section probably Salt Lake Group (Miocene-Pliocene).
48.	Quaternary			Heavy, tar-like oil shows reported at 700 feet and 2400 feet. (Drilling in progress).

D & A. Dry and abandoned. Wells are listed in approximate chronological order. The table is compiled from Anderson and Hinson, 1951; Eardley, 1963; Eardley and Haas, 1936; Granger, 1949; Hansen and Scoville, 1955; Peace, 1956; Schreiber, 1954; Slentz and Eardley, 1956; and Heylmun, 1963 and from unpublished information from the files of the Utah Geological and Mineral Survey and the Utah Division of Oil, Gas, and Mining.

*At least 31 wells have been drilled in seciton 8-8N-7W, Rozel Point field, between 1964 and 1969, which have not been listed. They are drilled on one acre spacing and are approximately 175 to 250 feet deep each. At least 11 of the wells have produced oil or have been classified by the operator as capable of production.

March, 1897 (Richardson, 1904). Assuming all 20 wells were contributing to the 17 million cubic feet of gas delivered to Salt Lake City in August, 1896 (Richardson, 1904, p. 482), the average production per well for that month was about 27,000 cubic feet of gas per day. Kirkham (1935, p. 242) reports that none of the Farmington wells produced the initial volume credited to the wells near Brigham City.

At least three wells near Brigham City are known to have produced considerable quantities of natural gas. The first of these was drilled in 1931 at the Bear River Migratory Bird Refuge (Sec. 35, T. 9N., R. 4W.) with an initial flow between 0.5 and 1.0 million cubic feet of gas per day (Kirkham, 1935, p. 240). Another well was drilled a short distance away in 1936, specifically to tap a fuel supply for newly completed facilities at the refuge. That well supplied sufficient gas to provide heat, electricity, and hot water for two residences and three other buildings until 1949, according to LaRue Allen at the refuge (oral communication, 1976). The main gas sands at the refuge evidently occur at 240-65 feet and 340-50 feet (Eardley and Haas, 1936, p. 71; Kaliser, 1976, figure 33). Another well, located about half a mile to the east at the Duckville Gun Club, blew out in November, 1975, apparently the result of casing failure. This well had provided fuel for club facilities for 37 years and was flowing at the rate of 1.5 million cubic feet per day when investigated shortly after the blow-out by the State Petroleum Engineer (P. L. Driscoll, oral communication, 1976). Gas continued to leak from the vicinity of the well at a rate of about 0.5 million cubic feet per day (Mr. Driscoll's estimate) after initial efforts were made to seal it. Leakage continued for about 85 days until February 10, 1976, when it was successfully controlled. During the effort to seal the well, constrictions in the hole were removed, and the flow of gas increased to a rate as great or greater than it had ever been. The gas was produced from sand at 256 to 299 feet below the surface. No efforts have been made to calculate the total amount of gas produced and lost from the wells, but the sustained production is noteworthy.

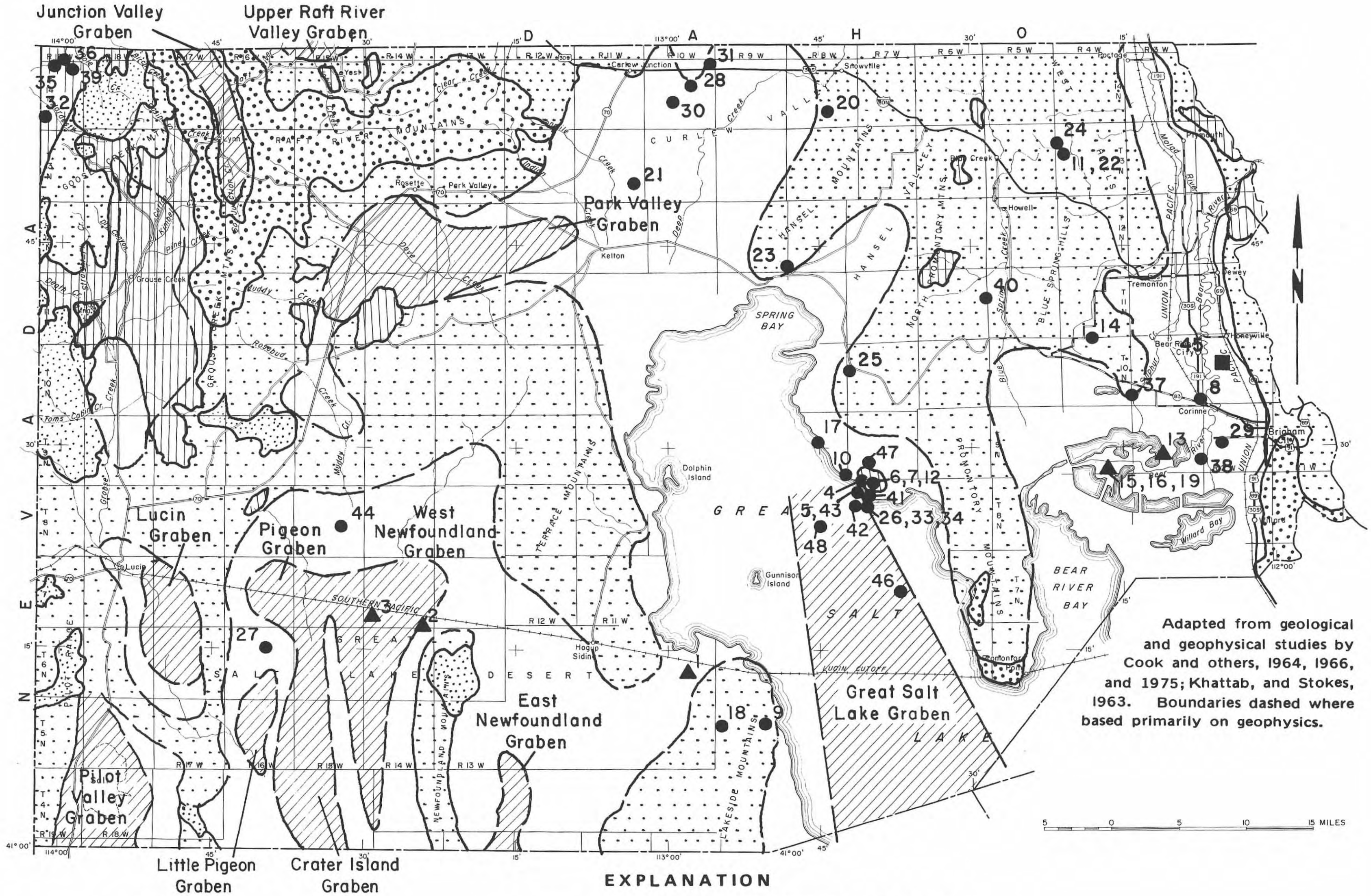
'Raja (Kaliser, 1976, plate 5) reports a concentration of natural gas occurrences in the Lake Bonneville Group between the Migratory Bird Refuge and the Wasatch Front east of Brigham City. It is also reported (oral communication cited in Kaliser, 1976, p. 57) that 20 exploratory wells were drilled for gas in the same area in the 1930's. The 200-foot depth reported for these wells is shallower than the depth from which the sustained production was obtained in the vicinity of the refuge, and it is possible that the wells did not test the potentially productive section. There is no other known record of these wells.

The existing topography and geomorphology suggests that the Bear River has been contributing sediment to the Great Salt Lake basin since at least as far back as the Pleistocene. The sands may therefore be deltaic in origin. They are lensoid and discontinuous as individual units (Kirkham, 1935, p. 241) but they may contain sufficient natural gas to constitute a developable resource. A study by Feth (1955) characterizes the surface and subsurface occurrence of lacustrine strata south of the subject area.

The sands in which the gas occurs are poorly consolidated to unconsolidated. The shallow methane occurrences are generally considered to be subcommercial (Hilpert, 1967), but the increasing demand for energy and corresponding increased prices may make this natural gas resource economically attractive, at least for local consumption.

Lignite

Lignite and carbonaceous shales are found in the Salt Lake Formation, principally in the Goose Creek and



EXPLANATION

BASIN AREAS

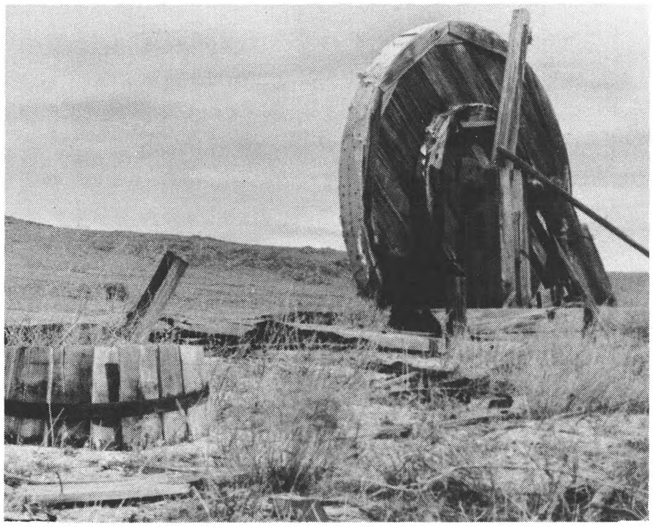
- CENOZOIC BASINS: Principally Quaternary valley-fill and Lake Bonneville Group at surface.
- DEEP CENOZOIC BASINS: Having over 5,000 feet of fill in deepest parts.
- TERTIARY SEDIMENTARY ROCKS: Principally Salt Lake Group, exposed as basin fill, at basin margins, and locally on uplifted areas.

UPLIFT AREAS

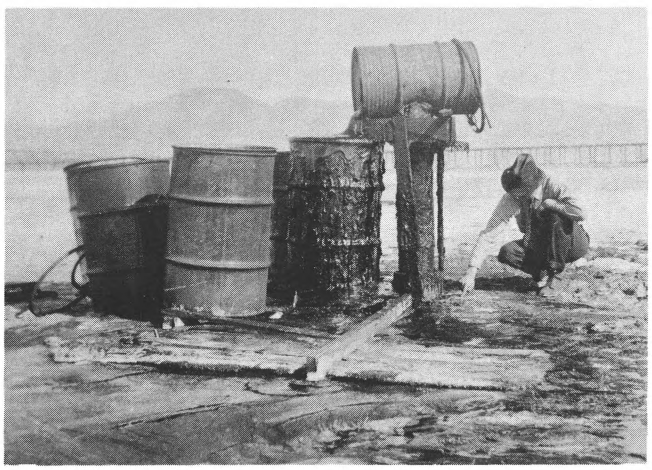
- PALEOZOIC AND YOUNGER SEDIMENTARY ROCKS: May include up to 1,000 feet of Tertiary and Quaternary cover at uplift margins.
- BASEMENT ROCKS: Metamorphic and igneous rocks of Precambrian and Paleozoic ages and sedimentary rocks of Precambrian age.
- IGNEOUS ROCKS: Intrusive rocks of Mesozoic and Tertiary ages and silicic extrusive rocks of Tertiary age.

- ● 4 Petroleum Test wells
- ■ 43 Geothermal Test well
- ▲ 1 Significant water wells

Figure 97. Generalized geologic-structural map of Box Elder County. Numbers refer to table 6.

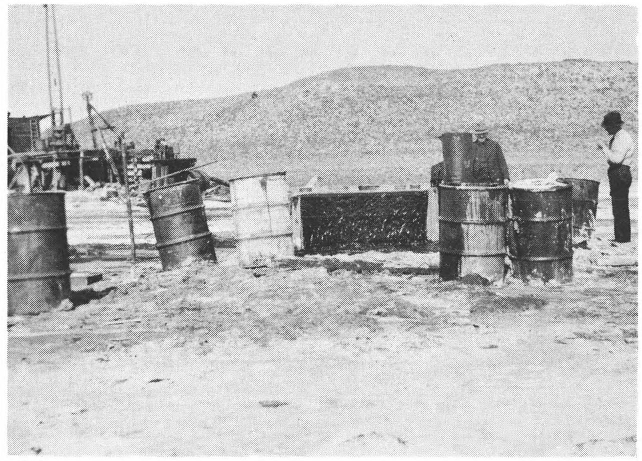


P 15. Abandoned drilling apparatus of Lakeshore Oil Co. No. 1 well along the west shore of Great Salt Lake. The well was drilled to a depth of 1200 feet (dry hole) in 1926.



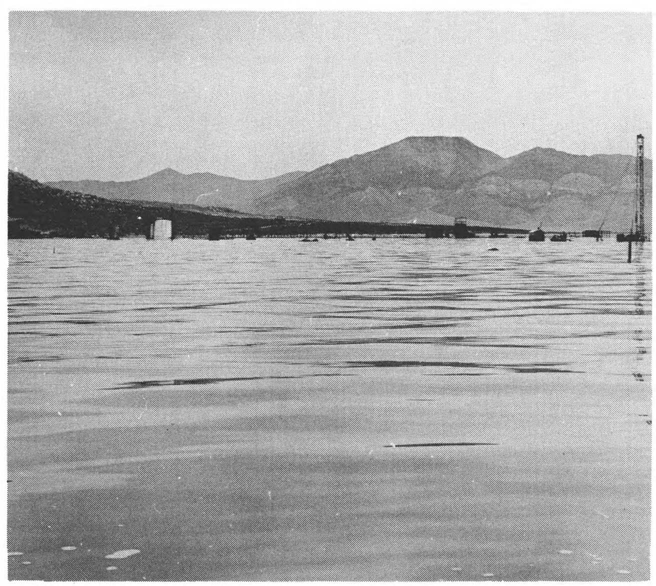
P 16. The crude oil was reportedly marketed to tire companies at \$25 a barrel for use in ". . .impregnating the cords of fabric prior to the induction of the latex."

P 17. Oil seeps at Rozel Point in foreground, photographed circa 1937.



P 18. Salt Lake Group rocks crop out in the background along with basalt flows.

P 19. Petroleum flows slowly to the surface into a low-walled bin, from a pipe driven into seepage at Rozel Point.



P 20. Eastward view of Rozel Point from Great Salt Lake in 1973. Promontory Mountains are in the background.

Pictures 16 through 19 contributed by Jack N. Conley, Petroleum Geologist.

Table 7 Petroleum production, Rozel Point oil field.[1]

Year	Oil Production	No. Producing Wells
≃1904-1952	Discontinuous; records non-existent; possibly 10,000 barrels	Unknown
1953-1955	Shut in?	Unknown
1956	Eller No. 1 Rozel Point pumping 5 to 10 barrels a day (Eardley, 1963, p.8)	1?
1957-1964	No record	No record
1965	404 barrels	Unknown
1966	439 barrels	Unknown
1967	2,053 barrels	9
1968	Shut in	None
1969	Pilot thermal stimulation (steam), no record of oil recovered	Unknown
1970-1974	Shut in	None
1975	Pilot thermal stimulation (downhole electric heaters), no record of oil recovered	Unknown
1976-1979	Shut in	None
Total recorded production:	2,896 barrels	
Estimate of total production:	≃13,000 barrels	

[1] Table modified from Stowe, 1972.

Table 8. Analyses of crude petroleum, Rozel Point, Utah.

Sample	Specific Gravity	API Gravity	Nitrogen percent	Carbon percent	Hydrogen percent	Sulfur percent	Conradson carbon residue, percent	Sample No.
[1] Seep, 1965	1.032	5.6°	0.514	---	---	12.13	8.7	PC-65-95
[2] Produced crude, 1969	1.049	3.4°	0.529	---	---	13.49	10.5	PC-70-346
[3] Produced crude, 1969	1.043	4.2°	1.3	66.00	7.8	5.47	---	---
[4] Produced crude, 1969	1.050	3.3°	0.522	---	---	12.54	9.5	69,091

[1] Analysis by DOE, Laramie Energy Technology Center, Laramie, Wyoming.

[2] Analysis by DOE, Laramie Energy Technology Center, Laramie, Wyoming. Crude oil produced prior to thermal stimulation, from about 150 feet.

[3] Analysis by Fuels Engineering Department, University of Utah, Salt Lake City, Utah. Crude oil produced by thermal (steam) stimulation, from about 200 feet.

[4] Analysis by DOE, Bartlesville Energy Technology Center, Bartlesville, Oklahoma

Table 9. Natural gas analyses, Lake Bonneville Group, Box Elder County, Utah.

	Sample A	Sample B
Methane	87.9%	98.0%
Ethane	none	<1 ppm
Nitrogen	5.5%	≃2.0%
Carbon dioxide	1.9%	
Hydrogen	3.5%	100.0%
Oxygen	0.7%	
Unsaturated hydrocarbons	0.5%	Btu: 992 (calculated)
	100.0%	

Heating value not reported.

A. U. S. Dept. Interior, Migratory Bird Refuge, NENW 35-9N-4N (Eardley and Haas, 1936, p. 71)

B. Duckville Gun Club, NWNW 36-9N-4W (UGMS files)

Grouse Creek basins in the northwestern part of the county. Preliminary studies of the Salt Lake Formation have shown that the lignite beds are thin and high in ash. Three analyses of the lignite, all taken from samples collected in Idaho's extension of the Goose Creek basin, show an average of 29.8 percent moisture, 15.6 percent volatile matter, 13.6 percent fixed carbon, and 40.9 percent ash with about 3,600 Btu/lb heat value. Only one prospect is known in Utah; it is located along Kimbell Creek, 9-12N-17W, in the Grouse Creek basin.

Lignite mined from either basin would require underground methods and mining cost would be comparable to that in areas of more desirable fuel. The cost per unit of energy becomes prohibitively high considering the high ash and low heat content. Some lignite might be used to supply local needs during times of emergency, although the fuel is very difficult to ignite.

Uranium and Thorium

Enrichment of uranium and thorium above background percentages has been intimated in pegmatites near the Century mine, Park Valley mining district; biotite-rich and cyrtolite-containing pegmatitic pods in gneiss in the Precambrian Farmington Canyon Complex in the Northern Wasatch Range; areas in which the Salt Lake Group lignites and carbonaceous shales are exposed, and areas where the Meade Peak Formation phosphatic beds crop out. Recently U. S. Geological Survey geologists measured the radium content of water from Crystal Springs north of Honeyville in the eastern part of the county and indicated the source to be uranium-bearing rocks at depth (Felmlee and Cadigan, *Salt Lake Tribune*, April 28, 1977). Based on the present radium concentration in the water Felmlee and Cadigan conclude there must be at least 6,000 tons of uranium present. However, this uranium may be scattered over a wide subsurface area. The source rocks may be part of the thick Salt Lake Group sediments known to be present under the area.

Mapel and Hail (1959) studied the Goose Creek basin lignites on behalf of the U. S. Atomic Energy Commission. Several holes were drilled; most of the samples ranged between 0.002 and 0.1 percent U_3O_8, the average about 0.01 percent. No holes were drilled in the Utah portion of the basin, but since most of the testing was done within three miles of the Utah border, it is thought that comparable results would have been obtained in western Box Elder County. Two outcrop samples taken in Utah yielded 0.005 and 0.006 percent. There have been no tests of carbonaceous beds in the Grouse Creek basin.

Monazite, along with arsenopyrite, galena, gold and pyrite, is found in the quartz veins at the Century mine, in the Park Valley mining district (Adams, 1964, p. 118). No quantitative analytical work has been done. Since quartz veins are common in the Raft River Mountains, other areas containing monazite are to be expected. Most monazite, a phosphate of the cerium metals, contains thoria (ThO_2), and suggestions are that thorium silicate is present in solid solution with the cerium phosphate. Monazite is also an accessory mineral in many granites, pegmatites, and gneisses, and concentrations of monazite may build up in weathered accumulations.

Cyrtolite, present in Precambrian pegmatite rocks in the Willard district in the eastern part of the county, is a variety of zircon which contains appreciable amounts of thorium, uranium, yttrium and other rare elements (rare earths). A small amount of uranium ore was produced from gneisses in the Precambrian Farmington Canyon Complex (Hilpert and Dasch, 1964, p. 131). Apparently disseminated uraninite occurs in associated pegmatites and within the layers of gneiss.

Hilpert and Dasch (1964, p. 131) have also intimated a correlation between phosphatic content and uranium content in the Meade Peak Formation of the Park City Group. When the Meade Peak contains 18, 24, and 31 percent P_2O_5, uranium correspondingly is present as 0.005, 0.007 and 0.01 percent. Very few analyses of the phosphate in the county are available; the highest shows 15.2 percent P_2O_5, indicating a low uranium potential. The Meade Peak is known to crop out in the Terrace and Goose Creek Mountains.

The best uranium potential for Box Elder County is in the Salt Lake Group, which underlies much of the county and crops out at the distal edges of the Bonneville basin along the margins of most mountain ranges. Very little exploratory work has been done and preliminary work has been discouraging. The pegmatites and gneisses deserve additional attention, but, like the phosphatic sources, they are expected to contain very low percentages of uranium and thorium.

Geothermal Energy

Geothermal energy development has become popular because of the search for new sources of energy and for pollution-free fuels. Geothermal energy is obtained by utilizing such sources as hot springs, geysers, steam vents and volcanic activity. In Box Elder County, one well to find steam was drilled in 1974 in 16-10N-2W (No. 45, table 6) to a depth of 11,000 feet. The attendant engineers pronounced the prospect subcommercial.

Box Elder County is a part of the Wasatch Geothermal area (figure 98), which extends north-south along its eastern boundary. Five springs in Box Elder County issue water with temperatures over 100 degrees Fahrenheit; four are within the geothermal area. Heylmun (1966) and Mundorff (1970) have reported on the more important features of these hot springs (table 10). Several warm springs (water temperatures 50-100 degrees F.) are also found in the geothermal area. Common features of these springs include a high radioactive count and a high concentration of chloride. Most are multiple springs and all issue from fault zones. The radioactivity is probably due to anomalous uranium concentrations in the Tertiary Salt Lake Group and the

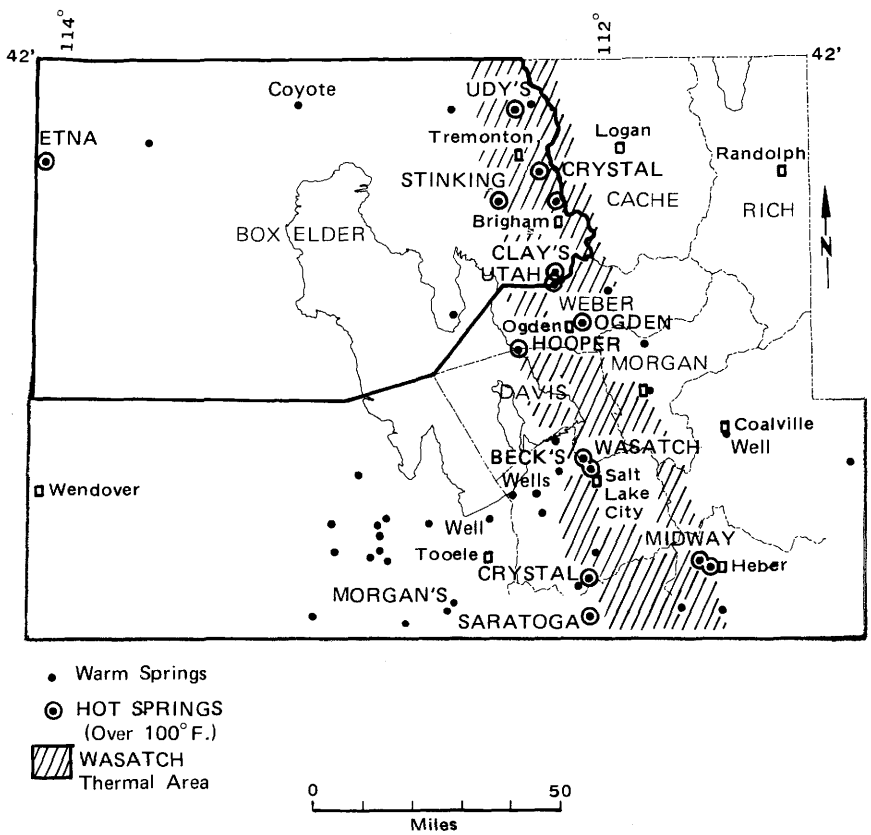


Figure 98. Principal warm and hot springs in northwestern Utah, and Wasatch geothermal area

salinity to saline deposits in the Quaternary Lake Bonneville Group sediments.

Only three springs with higher than normal temperatures are found outside of the Wasatch geothermal area. Warm Spring is located in 19-12N-15W at the base of a small knoll (Dennis Hill) on the east side of the Dove Creek Mountains. The waters (450-900 gpm) probably issue from a fault that has shattered the quartzite bed rock. The total dissolved solids content amounts to only 214 ppm (calcium bicarbonate) and the temperature is about 80 degrees F. The second thermal spring is located about 2 miles northwest of Etna (Etna hot spring); it also has a low dissolved solids content (248 ppm), produces about 75-100 gpm, and has a temperature of 107 degrees F. The third is Coyote Spring north of the Wildcat Hills (SWNW 33 - 14N-10 W). The temperature of the latter spring has not yet been officially reported.

INDUSTRIAL MINERALS

Industrial minerals include all materials not processed for their metal content or used as mineral fuels. Excluded from this listing are the raw construction materials. Industrial minerals usually require some beneficiation before they can be used for the intended purposes and stringent requirements are placed on their chemical composition or physical characteristics. Many varieties of industrial minerals have been found in Box Elder County, but only two or three have been significant in terms of value. Reported varieties include barite,

Table 10. Characteristics of Box Elder County hot springs relating to geothermal potential

Name	Location	Max. Temp.	Chloride (ppm)	T. D. S.[6] (ppm)	Water Type
1. Clay-Utah Hot Springs[1]	14-7N-2W	142° F. (135-142)	13,330	22,700	Sodium chloride
2. Crystal Hot Springs[2]	14-11N-2W	134° F. (124-134)	24,540	38,500	Sodium chloride
3. Etna Hot Springs[3]	11-11N-19W	107° F. (?)	?	248	Calcium bicarbonate
4. Stinking Hot Springs[4]	30-10N-3W	124° F. (113-124)	20,240	29,900	Sodium chloride
5. Udy Hot Springs[5]	23-13N-3W	110° F. (90-110)	4,470	7,850	Sodium chloride

[1] Manganese and germanium concentrations fairly high, deeply circulating meteoric waters along fault zone.
[2] Also known as Madsens Hot Springs, deeply circulating meteoric waters along the Wasatch fault zone, waters rise along 30 or more springs, area highly radioactive.
[3] Large areas of late Tertiary volcanics nearby.
[4] Springs issue from concealed faults; lithium, bromide, iodide concentrations fairly high, area of high radioactivity.
[5] Springs discharge from concealed faulting.
[6] Total dissolved solids

clay, diatomaceous earth, evaporites and brines, feldspar, fertilizers and soil conditioners, gem materials, kyanite, lime and magnesia, mica, oolitic sands, silica, and "supposed graphite".The approximate locations where these commodities have been found are shown on figure 99. The three leading commodities are lime, salt, and clay, providing a value through 1974 of about $4.2 million. Most of the lime has been produced by the Utah-Idaho Sugar Company near Garland, Utah; most of the salt has been produced by the Lake Crystal Salt Co. at Saline on the southern tip of the Promontory peninsula, and the clays have mostly been produced near Brigham City and Mantua.

Great Salt Lake brines are pumped from the north arm of the lake, all of which is in Box Elder County, to Weber County where potassium salts, magnesium chloride, and sodium sulfate are extracted. The U. S. Bureau of Mines Minerals Yearbooks credits this production to Weber County; through 1974 about $21.5 million worth was harvested. Other Box Elder County-produced industrial minerals have an aggregate value that does not exceed $500,000.

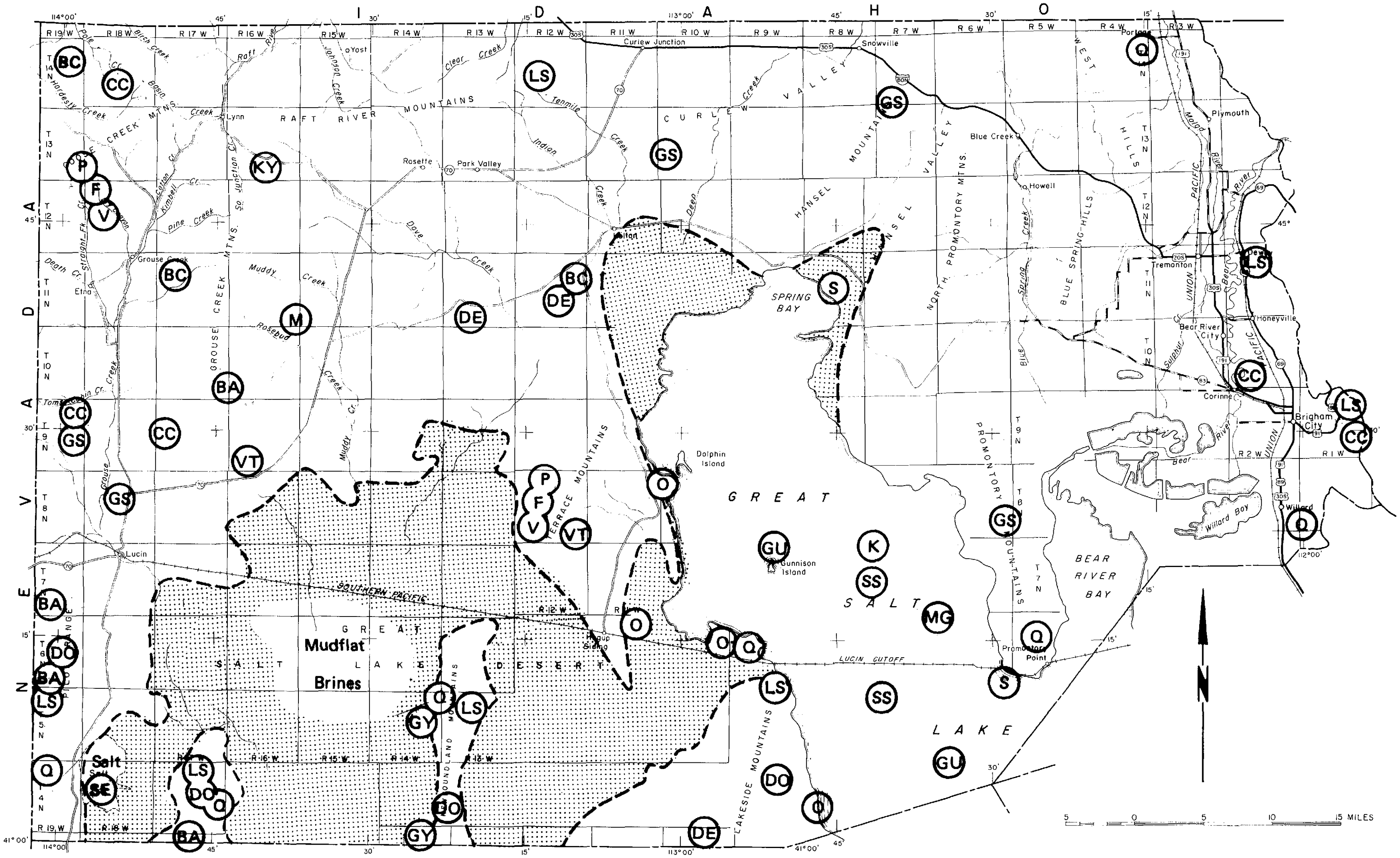
Barite

Barite is present in Box Elder County in small potential deposits and as a minor gangue mineral constituent in several of the mining districts of the county. The latter occurrences could not be considered sources of potential ore. Barite veins and irregular replacements are known in the Silver Island Mountains, in the Pilot Range, and unconfirmed reports note its presence in the Guilmette Formation in the southern Grouse Creek Mountains near Rocky Pass. In the years 1970 to 1974 the price of barite ranged from $14 to $16 a ton.

In the Tooele County portion of the Silver Island Mountains barite is intermittently mined in small tonnages (1975). Thin barite veins are present at the very northern tip of Silver Island on the Tooele-Box Elder line and in the Devonian Guilmette Formation outcrops on Crater Island. The Guilmette hosts barite veins in the Lucin mining district in the Pilot Range. In the largest noted deposit the barite is present in irregular bodies in the lower member near its contact with the quartzite member in 33-7N-19W (UTM 4574100 m.N., 749400 m.E.). At this location the barite is a breccia filling and present in several thin veins. In SESE 3-6N-19W barite is found in a 10-foot wide shear zone in the Guilmette Limestone. The zone strikes NNW and dips 15 degrees E. Irregular bodies of barite were noted at Mine No. 4 in the Mineral Mountain area on the south side of Regulator Canyon. Careful prospecting should discover additional occurrences of barite in the Guilmette Formation of the Pilot Range.

Diatomaceous Earth

Diatoms were abundant in Lake Bonneville and accumulated as diatomaceous earth in protected places throughout the basin. White deposits of diatomaceous earth are found in Box Elder County in the Hogup, Grassy, and Matlin Mountain areas. Only in the Hogup Mountains have attempts been made to produce the material commercially. Two or possibly three pits have



EXPLANATION

BA	Barite	DO	Dolomite	GS	Gem Stone	LS	Limestone
BC	Bentonite	F	Fluorine	GU	Guano	M	Mica
KY	Kyanite	GY	Gypsum dunes	O	Oolite dunes	DE	Diatomaceous Earth
Q	Quartzite	P	Phosphate	V	Vanadium	SE	Salt Encrustation
K	Potash	VT	Vitric Tuff	SS	Sodium Sulfate	CC	Common Clay
Mg	Magnesium						

Figure 99. Industrial minerals of Box Elder County.

been opened in the Hogup Mountain area. One approximately 400 feet in diameter (SW 26-11N-12W) contains small workings consisting of diggings up to 8 feet in depth. The maximum thickness is 15 to 16 feet, which can be divided into layers of varying purity. The average carbonate content is 37 percent.

An abandoned loading platform adjacent to some shallow diggings is present in NW 2-10N-12W; there is no data concerning the period of operation. There is a bulldozer cut 100 feet long north of the diggings. A maximum of five feet of diatomaceous earth relatively free of clastics is observable, with an additional foot or two beneath containing grit and pebble contaminants. The material was tested and contains 50 to 75 percent diatoms, 3 to 7 percent quartz, 2 to 8 percent clay and 10 to 40 percent carbonate. Spindle-shaped diatoms are dominant and at least 50 percent are intact.

Evaporites, Salines and Brines

The Great Salt Lake is a briny body of water containing roughly 25 percent salt. Most of this is sodium chloride, but there are considerable amounts of potash and magnesium salts. Commercial extraction companies have operations scattered around the shores of the lake, but only one is in Box Elder County; another pumps its brines out of the county into another for processing. The brine is pumped into ponds to be evaporated and later harvested. The muds of the Great Salt Lake Desert are also highly saliniferous. Interbedded with the muds are more porous and permeable layers saturated with salty water.

The final evaporative stages of a western arm of the Great Salt Lake occurred in relatively recent geologic time and left surface encrustations of salt. The most famous of these is the Bonneville salt flat, near Wendover in Tooele County, used today as a speedway. Smaller such areas of surface salt have been reported in Box Elder County. Sodium sulfate beds are known to be present under the Great Salt Lake east of Lakeside. Areas in which most of the springs are salty are known in the eastern part of the county. Most of these occurrences provide or have a good potential of providing valuable quantities of industrial minerals.

Mineral Industry Potential of Great Salt Lake in Box Elder County

by J. Wallace Gwynn, Ph. D
Chief, Research Geology Section
Utah Geological and Mineral Survey

One of Utah's most popular and longstanding scenic attractions is the Great Salt Lake. Because the lake has no outflow, it is a giant potential economic asset; its heavy concentrated brines are a veritable storehouse of mineral wealth. Box Elder County contains more than half of the area of the lake within its perimeter; the remainder of the lake is contained within Weber, Davis, Salt Lake, and Tooele Counties.

The Great Salt Lake is 75 miles long and 30 miles wide at a surface elevation of 4,200 feet. Its maximum depth is about 35 feet and the total surface area approaches 1,700 square miles. In 1959 the Southern Pacific Railroad completed a nearly impermeable earth-and-rock fill causeway across the lake from Promontory Point on the east to Lakeside on the west. The construction of this relatively impermeable structure virtually cut the lake into two parts, now known as the north and south arms, which with the passage of time have become both physically and chemically dissimilar. The south arm receives the major part of the fresh water inflow to the lake and is less dense or saline than the north arm. The north arm, receiving little fresh water inflow, acts like a large evaporation pond and has become more saline. In addition to the difference in density, a difference in surface elevation has developed. Presently (1978) the water surface in the south arm is almost one and one half feet higher than that in the north arm. In addition, the south arm of the lake is density-stratified while the north arm is not. The upper 23 to 24 feet of the south arm have a density of about 1.090 grams per liter and are relatively clean and odor-free. Below a remarkably sharp halocline the brines are clouded by dark particulate matter, possess a strong hydrogen sulfide odor, and have a density ranging from 1.178 near the interface to 1.182 at the bottom of the lake. The rate and degree of mixing between the two brines is not known. The north arm, though not stratified, does possess a slight density gradient which increases from 1.216 at the top to 1.224 at the bottom. Generally the north arm brine is free from dark clouding particulate matter, and has not had a hydrogen sulfide odor until the past few months.

The Southern Pacific Railroad causeway does permit some interchange of brine. South arm brines permeate through the upper portions of the causeway to the north arm and flow freely through two 15-foot wide culverts (20 feet deep) into the north arm. When the culverts are sufficiently free of debris, the heavy north arm brines flow to the south under the north-flowing south arm brines. It is suspected that there may also be north to south flow of dense brines through the causeway fill.

The Great Salt Lake receives fresh water inflow from precipitation, inflowing rivers and streams, and groundwater. The three principal inflowing rivers are the Jordan, Weber, and Bear Rivers; the latter contributes over half of their combined flow. Evaporation is the main mechanism by which water is removed from the lake, and amounts to an average of 48 inches annually. A minor amount of water is lost by plant evapotranspiration.

Because the Great Salt Lake is contained within a closed basin, its surface elevation is controlled entirely by the balance between fresh water inflow and its removal by evaporation. When inflow exceeds total evaporation the lake level rises, and when the opposite is true, the elevation drops. Water elevation records for the lake, which have been kept since 1850, show that its level has fluctuated widely. The historic high level was recorded in 1873 at an elevation of 4211.6 feet and the historic low was recorded in 1963 at an elevation of 4191.3 feet. Between these two extremes there have been several upward and downward trends in the level of the lake, each lasting over a period of years. At present (1979) the elevation of the lake's surface stands at 4,200 feet; the lake is in a downward trend that started in 1977. It is felt that the fluctuations in the lake's elevation are related to changing weather or climatic conditions.

In addition to the long term elevation changes, the surface of the lake has a seasonal fluctuation. The low point of the seasonal change in the lake level occurs between September and October as the high summer evaporation season comes to a close. The high point is reached in May or June after the winter storms and spring run-offs have ended. The seasonal changes in the lake level are expected and are of such a magnitude as to be accepted by those who work with the lake, but long-term, larger magnitude increases or decreases cause concern.

When the elevation of the lake becomes too low or too high, recreation, mineral industry, and other uses of the lake are affected. During periods of low-water levels, the waters recede from industrial pumping stations. If the lake level becomes too low, the brine becomes saturated and begins to precipitate sodium chloride, changing the brine chemistry. During the 1963 historic low, it is estimated that more than one billion tons of sodium chloride were deposited as a salt crust on the floor of the north arm. Since then the lake level has risen and the salt crust has been dissolved. At high levels facilities, beaches and access roads are flooded and evaporation pond dikes are subjected to erosion. In addition the brine chemistry is changed by dilution.

At present mineral values are being extracted from the lake within Box Elder County at the Lake Crystal Salt Company plant at Saline (southern tip of promontory peninsula) and from the north arm by Great Salt Lake Minerals and Chemicals Corporation which has part of its ponding complex in the county. Solar evaporation is an integral part of processing the minerals. The construction and operation of large evaporation pond complexes require large, relatively flat contiguous areas of land with tight soil to prevent the loss of brine through leakage. Existing lake industries are producing sodium chloride, potassium sulfate, sodium sulfate, chlorine, magnesium metal and magnesium chloride brine. Minor elements from the lake (boron, lithium, and bromine) will probably be produced as byproducts from the processing of potassium and magnesium minerals.

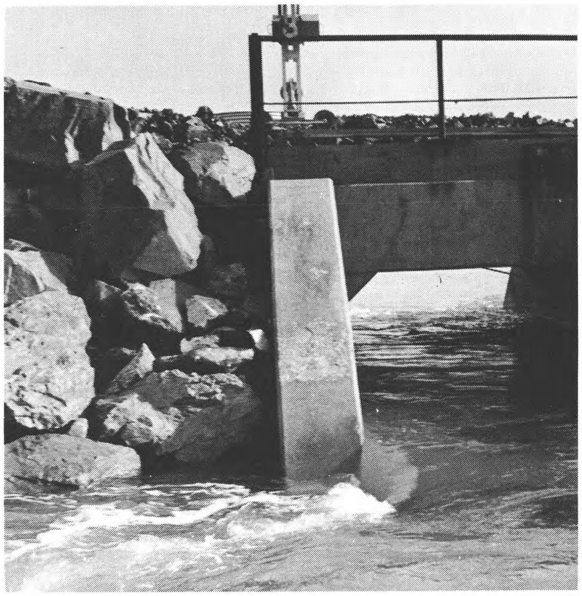
The present (1976) chemical compositions of the three brine types (North Arm, South Arm upper and lower brines) in grams per liter and weight percent of dried solids, are given in tables 11 and 12. The north arm brine contains a slight enrichment of sodium and chloride compared to the shallow south arm brine. The relative proportions of magnesium, calcium, potassium, and sulfate in the north arm brine are also slightly greater. The composition of the Great Salt Lake brine is very similar to that of sea water except its concentration.

Mirabilite

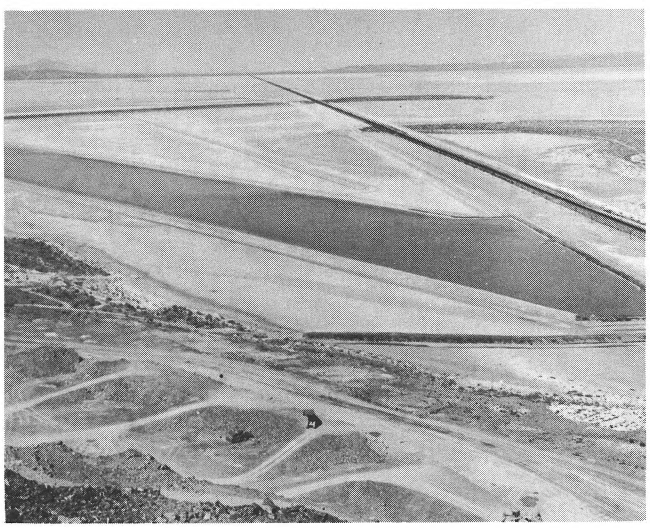
Mirabilite is $Na_2SO_4 \cdot 10H_2O$, commercially known as Glauber's salt. It precipitates from cold saturated brine and must be harvested in the spring before the brines warm appreciably and the mirabilite again goes into solution. A bed of this material with a maximum thickness of 32 feet has been discovered 15 to 25 feet below the bottom of Great Salt Lake. About 20 percent of this is impurity. It is a wedge-shaped body, thickest about 3 miles west of Promontory Point and thins gradually westward. It was discovered during construction of the railroad trestle in the early 1900s. Its north and south extension is unknown.

Surface Encrustations of Salt

A 25 square-mile area has been reported as the



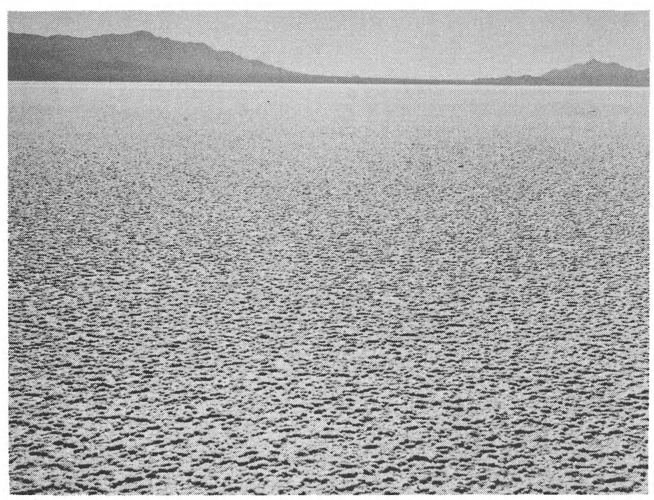
P 21. Culvert along the Southern Pacific Railroad causeway in the middle of Great Salt Lake. The causeway has divided the lake into two bodies of water, each with its own characteristics. Water rushes through the culvert from south to north inasmuch as the water level in the south arm is more than a foot higher. Evaporation from each body of water is probably the same, but most of the fresh water reaching the lake enters the south arm.



P 22. View westward from the hills above Lakeside across a rock quarry, evaporation pond and mudflat.

P 23. View eastward from hills above Lakeside. The Southern Pacific Railroad causeway constructed in 1958 divides Great Salt Lake into a north and south arm. Lavender algae in the north arm give it a darker cast than the south arm (green or blue-green algae) in the photo.

P 24. Lake Crystal Salt Co. plant at Saline, southern tip of the Promontory peninsula. This is the only salt processing plant presently operating in Box Elder County (1978), other companies have evaporating ponds in the couty, however.



P 25. Pilot Valley salt pan between Pilot Range and Crater Island in Box Elder County.

Table 11. Chemical composition of the Great Salt Lake in grams per liter, assuming the north arm and below interface south arm to contain 37.3 percent and above interface south arm to contain 54.6 percent of the total volume of the lake.

Species	South Arm Above Interface	South Arm Below Interface	Total North Arm	Weighted Average
Cl	60.42	132.53	181.41	112.20
Mg	3.83	7.66	10.38	6.63
Ca	0.19	0.41	0.43	0.30
Na	34.29	75.97	106.12	64.91
K	2.89	6.27	8.45	5.27
SO_4	8.08	17.69	22.10	14.19
Br	0.046	0.097	0.116	0.076
Li	0.018	0.039	0.051	0.032
B	0.014	0.029	0.041	0.025
Sp. Gravity	1.084	1.164	1.205	1.135

Table 12. Chemical composition of the Great Salt Lake expressed as weight percent of dried solids.

Species	South Arm Above Interface	South Arm Below Interface	Total North Arm	Weighted Average
Cl	55.08	55.09	55.15	55.13
Mg	3.49	3.18	3.15	3.25
Ca	0.17	0.17	0.13	0.14
Na	31.25	31.58	32.26	31.89
K	2.63	2.60	2.56	2.58
SO_4	7.36	7.35	6.71	6.97

Pilot Valley salt pan and is located in parts of T. 4 and 5 N., R. 18 W. between the Pilot Range and Crater Island. Except for one sample there has been no reported chemical examination of this deposit. The composition of this single sample is compared with an analysis of the Bonneville salt flats material reported by Gale (1916, p. 780) in table 13. These compositions may be compared with the chemical composition of the dried solids harvested from the Great Salt Lake (table 12).

The Pilot Valley salt pan area is often a lake, especially in winter and spring, or after a heavy rainfall. Often it appears as if there is no salt, only mudflat, and this may indeed be fact. It suggests that the salt may be precipitated and replenished by rising nearly-saturated ground water. High winds may deflate the salt and remove it from the pan as a normal erosional process. The description of the Pilot Valley salt by Stansbury, who crossed in the fall of 1849, is as follows (1853, p. 109):

> The first part of the plain consisted simply of dried mud, with small crystals of salt scattered thickly over the surface. Crossing this, we came upon another portion of it, three miles in width, where the ground was entirely covered with a thin layer of salt in a state of deliquescence, and of so soft a consistence that the feet of our mules sank at every step into the mud beneath. But we soon came upon a portion of the plain where the salt lay in a solid state, in one unbroken sheet, extending apparently to its western border. So firm and strong was this unique and snowy floor, that it sustained the weight of our entire train, without in the least giving away or cracking beneath the pressure. Our mules walked upon it as upon a sheet of solid ice.

The salt is extremely porous and coarsely crystalline; at the edges the salt is very thin and it thickens toward the center. The writer ventured 2½ miles onto the salt, but found no place where the salt crust thickness exceeded 6 inches. A large area remains unexplored. Eardley and others (1957, p. 1146) have computed the tonnage of salt in Pilot Valley on the basis of 21 square miles and an average salt thickness of 1.75 feet and a specific gravity of 1.87. The calculated tonnage is about 23,000,000 tons.

Mudflat Brines

The muds and sediments of the Great Salt Lake Desert and mudflat areas surrounding parts of the Great Salt Lake are saturated with saline water. Tremendous tonnages of salt should be present considering the huge area involved. Generally the brines along the mountainous edges of the mudflat sub-basins are more dilute because of the greater precipitation in high areas. There is dilution where streams regularly discharge onto the mud. The brine is not uniformly distributed in the sediment and varies greatly in composition from one part of the desert to another. Thin sandy horizons interbedded with clay contain most of the water. It is

Table 13. Analyses of salt encrustations in Box Elder and Tooele Counties.

Species	Bonneville Salt Flat[1]	Pilot Salt Flat[2]
K	0.07%	0.11%
Na	36.85	36.76
Ca	1.20	---
Mg	0.10	0.25
SO_4	2.88	0.56
Cl	58.98	57.49
CO_3	none	---
Total soluble salts	96.20%	not calculated

[1] Gale, 1916, p. 780.
[2] Analysis by Great Salt Lake Minerals & Chemical Corp., 1977.

Table 14. Depth versus salt content in Sink Valley well, 25-4N-10W.

Depth Interval	Total Dissolved Solids in produced water	Chloride mg/liter
225-275 ft.	3,550	1,600
305-353	6,630	3,250
399-400	14,000	5,880
505-515	18,000	9,940
588-600	29,900	17,000
675-685	48,100	27,800
739 (total depth)	---	---

not known how deep the brines extend; briny horizons have been tested to depths of several tens of feet and the concentration of sodium chloride increases downward. In a Sink Valley well, Section 25, T. 4 N, R. 10 W, the concentration of salt increases with depth (Price and Bolke, 1970); see table 14.

Nolan (1927, p. 39) took 126 brine samples from shallow drill-holes from various places (figure 100) in the Great Salt Lake Desert; a composite analysis is given in table 15. Eardley and others (1957, p. 1, 146) calculated the salt content of a 5-foot depth interval in the mudflat area assuming a brine-containing inner core area of 1,400 square miles containing 27 percent water, 3 percent salt and 70 percent clay by weight and an outer edge of 800 square miles containing only 1.8 percent salt. If these assumptions and parameters are correct, 246,000,000 tons of salt are present in 5 feet of the clay in the Great Salt Lake Desert. Roughly 112,000,000 tons of this salt would be present in western Box Elder County. Brines are known to be present in other mudflat areas around the Great Salt Lake in the eastern part of the county. Bonneville Ltd. plant of Kaiser Aluminum & Chemical Corporation near Wendover, in Tooele County, has been utilizing salt flat brines for years and the potential for a similar industry in Box Elder County should be great.

Soil Conditioners and Fertilizers

Soil is a mixture of clay, silt, sand, grit, pebbles, and decaying organic material. It supplies the environment in which plants live and grow; it is the environment in which much of man's food is produced. If the soil constituents are balanced so as to achieve the ideal porosity and permeability for meteoric water to be introduced and held, and if there is enough clay and decaying organic material to store plant nutrients, the vegetative growth should be healthy and prolific. Decaying rock minerals also supply nutrients. Soil conditioners and fertilizers supply nutrient deficiencies, provide a better texture, and neutralize acid or alkaline conditions. Potash (potassium salts) is one of the principal nutrients required by plants and is present in Box Elder County in the brines of the Great Salt Lake and Great Salt Lake Desert (see evaporites, salines and brines). Box Elder has deposits of phosphate, guano, gypsite and vitric and bentonitic tuff which have also been suggested for use as fertilizer and soil conditioners.

Phosphate

Phosphate is another of the basic plant nutrients. The Meade Peak Formation of the Park City Group contains phosphatic shales throughout northern Utah and in parts of Wyoming and Idaho (Phosphoria Formation). Exposures in the county are found in the Goose Creek Mountains northwest of Grouse Creek village and on the west side of the Terrace Mountains. The Goose Creek Mountain exposures are 10-15 miles long; those in the Terrace Mountains are comparable. The outcrops are usually heavily covered with soil, making sampling very difficult. Neither area has been exploited; there are no mines or prospects. The Terrace Mountain locality, however, has been tested and several long trenches were cut to obtain fresh samples. The analytical data was recorded by J. S. Williams in a December, 1959 report to the Utah State Land Board and is shown in table 16.

The results show very low grade material (2 to 15 percent): (31 percent contained P_2O_5 or better is considered high grade, 24-31 percent is medium grade, and 18-24 percent is low grade: Gere, 1964, p. 201). Stifel (1964, p. 160) questions the results and indicates that further investigation and sampling are necessary. In 1972 the trenches dug for J. S. Williams no longer exposed fresh phosphatic material for analysis and funds were not available for the digging of new trenches. Stifel, more optimistic of the phosphate potential of the Terrace Mountains, offers the following:

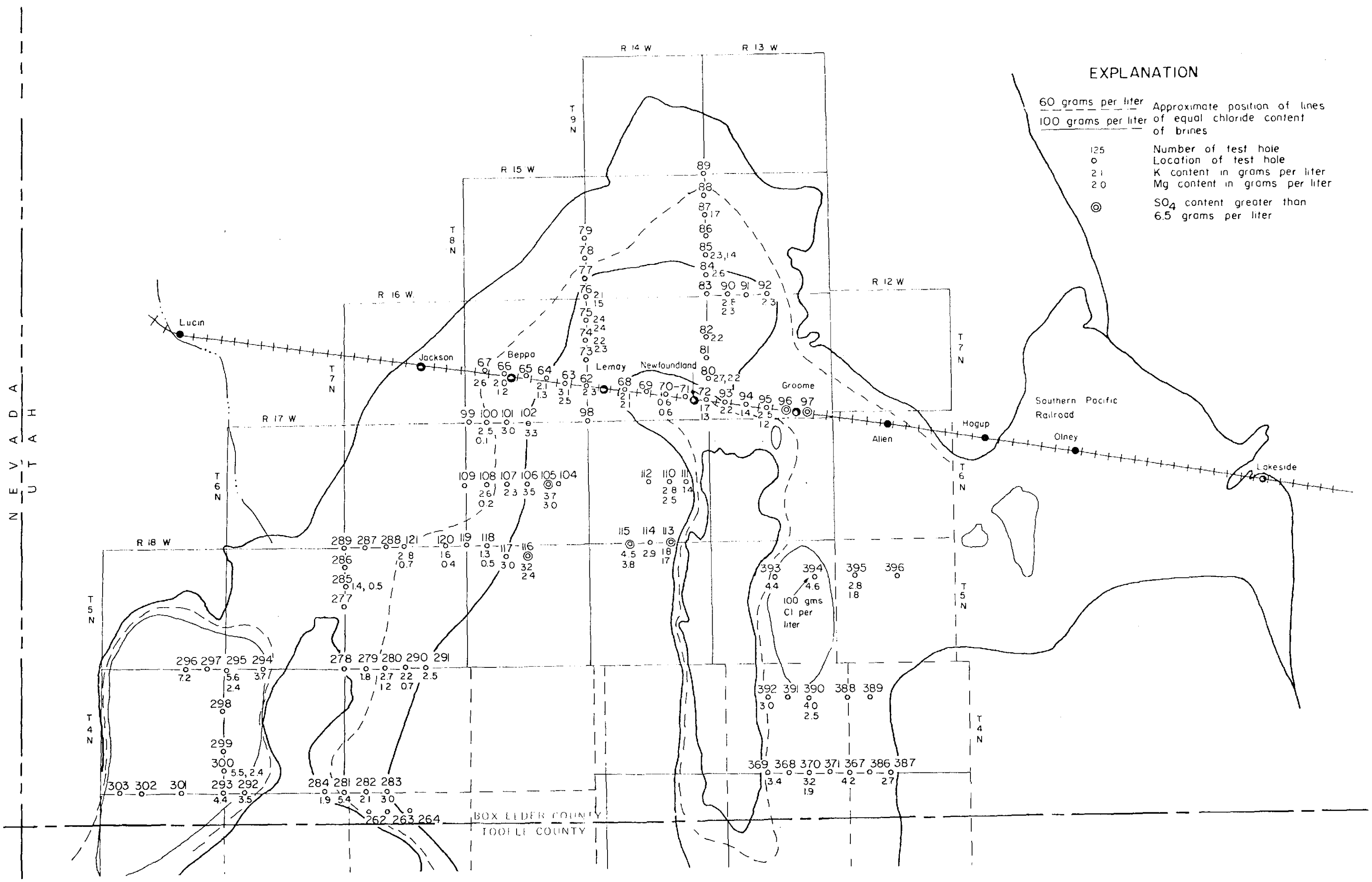


Figure 100. Salinity of brines underlying the Great Salt Lake Desert. (after Nolan, 1927).

Table 15. Composite analysis of 126 samples of brine taken from shallow wells, Great Salt Lake Desert (Nolan, 1927, p. 39), in grams per liter.

Cl	96.15	Na	57.30
Br	.00	K	2.94
I	.00	Li	.002
SO_4	4.08	Ca	1.51
CO_3	.00	Sr	.00
BO_3	.00	Mg	1.91
Specific gravity (25° C.)	1.11		

As Dr. Williams mentions, open pit mining sites do not appear to exist in the region he investigated. It is suggested, however, that occurrences in secs. 4, 9, and 16, T. 7 N., R. 12 W., because of their low dips and large area of exposure, might be exploitable by open pit methods if the P_2O_5 content is high enough here. The presence of the Southern Pacific Railroad only four miles to the south may also be a considerable factor.

Phosphate is mostly used as a fertilizer, but a small amount is converted to phosphorous and phosphoric acids for final use in a myriad of industrial and chemical products.

Guano

Guano is the decomposed excrement of bats or waterfowl. It has a brown, earthy texture, and contains easily soluble phosphate, nitrogen, and other plant nutrients. It makes excellent fertilizer material. Small quantities are found in the small caves and crevices cut in the carbonate rocks by Lake Bonneville in the low mountain ranges of western Box Elder County, but the small quantities normally found in such places have discouraged serious and extensive exploitation.

There are two small islands in the western part of the Great Salt Lake which are nesting places for migratory birds. These are Bird and Gunnison Islands, and both are in Box Elder County. The birds are well protected during the nesting season because of their inaccessibility to predators-- not only to animal predators, but to man as well. The nesting areas are broad oval to round patches, barren of vegetation, with diameters up to 100 feet. These patches are underlain with guano, but the thicknesses of these accumulations have not been measured. In some places up to 8 feet are possible.

There has been small production from these islands, but the amount and value is unknown. A small cabin remains on Gunnison Island to attest to the activity. The material was dug and sacked on the island

Table 16. Phosphate content of the Meade Peak Formation in the Terrace Mountains as sampled in December, 1959, by J. S. Williams for the Utah State Land Board.

1. Long trench in CE½NE 3-8N-12W

		Approx. thickness in feet	Sample position	Analysis %P_2O_5
Rex Chert				
Meade Peak	E. Shale	40	plus 2 feet	2.23
	D. Limestone	40		
	C. Shale	40	plus 40 feet	3.19
			plus 37 feet	6.38
			plus 17 feet	6.38
	B. Limestone	100		
	A. Shale	15	plus 13 feet	6.38
			plus 8 feet	15.19
Grandeur Formation				

2. Trench in CE½NW 3-8N-12W. Two samples were taken along 15-foot faces by selectively collecting "black spots". All samples yielded exactly 3.19 percent P_2O_5.

3. Trench at location 2, but across wash to south–"best looking material." Sample yielded 6.38 percent P_2O_5.

4. Trench in swale just above the Grandeur Formation contact in SWSW 2-8N-12W.

Shale at 12 feet above foot-wall	2.23 percent P_2O_5
Shale at 8 feet above foot-wall	4.79
Shale at foot of section	7.97

5. Trench short distance west of the No. 4 trench of hanging wall shale (at Rex Chert contact?).

Top of 10-foot exposed thickness	15.95 percent P_2O_5
Bottom of 10-foot thickness	1.59

and then shipped by boat across the Great Salt Lake. *The Salt Lake Mining Review* of October 30, 1900 states that Richter and Young shipped guano from Bird Island in the Great Salt Lake to the eastern market and in the December 30, 1900 issue it notes that 1,000 tons of guano from Gunnison Island was ready to be shipped by flatboat across the Great Salt Lake as soon as the water level rose somewhat. The properties are still actively held for the purposes of producing fertilizer.

Gypsum Dunes

Gypsum sand dunes occur in voluminous amounts along the east side of the Great Salt Lake Desert. In western Box Elder County they occur on the west side of the Newfoundland Mountains. About five such dunes exist, each of which averages 15 feet in height, 50 feet in width, and with a north-south length of about a mile. The reserves should be at least 1,000,000 tons. The composition of the sand consists of 60 percent gypsum, 35 percent calcareous material, and the remainder quartz and other impurities. There has been some development of the Newfoundland gypsum (gypsite) dunes. The use of the material is to condition soils deficient in sulfur, to correct soil alkalinity, and to granulate heavy clay soils.

Vitric and Bentonitic Tuff

Tuff is a very fine pyroclastic material emitted from volcanoes during explosive eruptions and then deposited by sedimentary processes. The particles are usually splinters of volcanic glass. The tuffs in the county are in the Tertiary Salt Lake Group sediments and are stratified lacustrine deposits. The beds are generally light colored; light gray, white, grayish orange, light green, and show various degrees of welding and alteration to bentonite. A few beds contain small fragments of spongy white pumice along with the glass shards.

At least two attempts have been made to commercialize the purer of these deposits. At milepost 17 on Utah Highway 70, near the southern tip of the Grouse Creek Mountains (12-8N-18W) is a white tuffaceous deposit that is partly bentonitic. The beds are several feet thick, 10 to 15 feet wide and dip gently to the south. A quarry has been opened in the deposit and is being worked (1972) by the Desert King Mining Company. About 300 tons have been produced since 1965 and are valued at about $6,000. The material has been used as a binder in livestock pellet feeds and as a soil conditioner. A card obtained from the owner lists the product as a "water retention soil conditioner and bentonite." It was tried as a "kitty" litter in a chinchilla farm, but the material swelled and adhered to the fur of the animals. Another suggested use for this material is as a siliceous abrasive.

A small prospect in vitric tuffs of the Salt Lake Group is found behind an old abandoned dwelling in SE 33-9N-12W along a road on the west side of the Terrace Mountains. The outcrop is found in a gully and consists of white gray, fine-grained homogeneous tuff. The exposure of the "whitest" material is about 20 feet wide. The entire Salt Lake Group tuff exposure is about 500 feet long in the east-west direction and 200 feet wide in the north-south direction. About 25 percent of this material might be considered top quality. Stifel reports (1964, p. 157):

> A claim was established in 1954 on a deposit of lacustrine vitric tuff of the Salt Lake Group in the SE ¼ sec. 33, T. 9 N., R. 12 W. by the Nadir Mining Company of Sandy, Utah. Approximately $900.00 was spent in development at the site, but the project was abandoned after 1955. Intention was apparently to cut the material into small blocks to be sold in kits for figure carving.

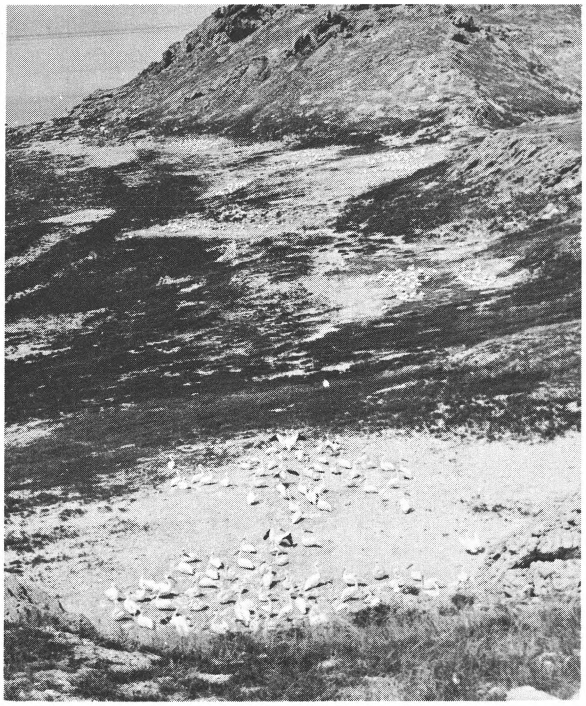
Fluorine, Vanadium and Uranium

Above background quantities of fluorine, vanadium, and uranium occur in the phosphatic shales of the Meade Peak Formation. Phosphate rock mined in Idaho and Wyoming contains 0.2 to 0.3 percent V_2O_5 (vanadium pentoxide) and 2 to 3.5 percent fluorine in the form of fluorapatite. Because of the low probability of mining the very low grade phosphate rock of western Box Elder County, the prospect of producing fluorine, vanadium or uranium is poor.

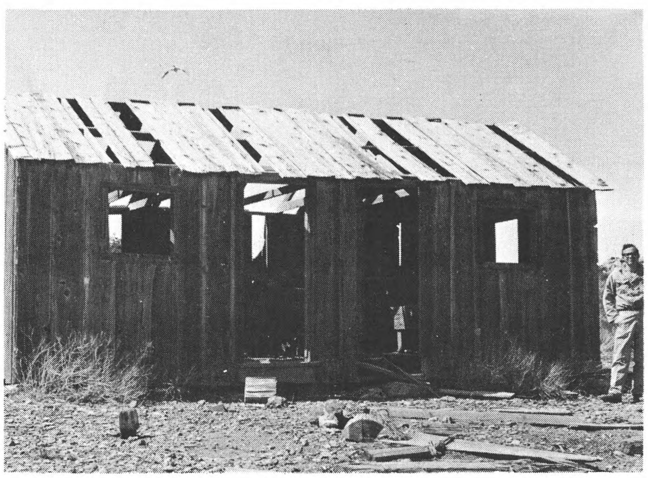
"Supposed Graphite"

In 1909 the *Salt Lake Mining Review* (September 30, 1909, p. 24 and 33) reported the discovery of graphite in the northern Wasatch Range in Box Elder County. The report claimed the deposit assayed 97 percent pure and was 16 feet wide. In addition, there were 12 inches of flake graphite described as "almost the pure quill."

The deposit was visited by Hoyt S. Gale in 1909 (1910, p. 639 and 640) and his report was published by the U. S. Geological Survey and repeated in the *Salt Lake Mining Review* on August 15, 1910 (p. 32). Gale's report showed that the material was not graphite and the excitement passed.

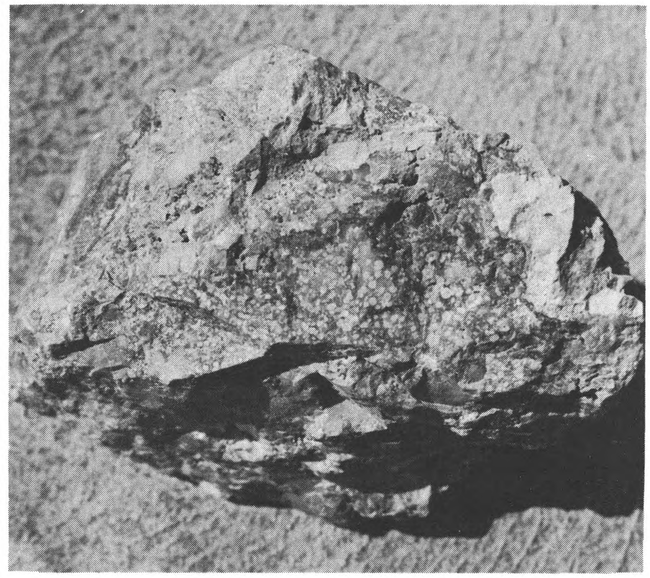


P 26. Pelicans nesting on Gunnison Island. The Island provides a sanctuary from egg-eating predators. The light-colored areas (nesting areas) are devoid of vegetation and represent prime guano areas. These broad oval to round patches often have diameters of 100 feet and accumulations are at least 8 feet thick.



P 27. The only building on Gunnison Island. It was used as a bunk house and headquarters for sacking guano. The Salt Lake Mining Review in 1900 announced that 1,000 tons of the fertilizer material was ready to be shipped from Gunnison Island.

P 28. Variscite pit on Utahlite Hill.



P 29. Specimen of variscite bearing rock about 6 inches long. The Lucin variscite comes in various shades of green and in this cobweb pattern. Although not as valuable or hard as turquoise, it is prized for use in rings, belt buckles, pendants and bolo ties.

P 30. Depression structures. These are located in Sec. 29, T. 10 N., R. 8 W., about 9 miles NNW of Rozel Point. The rims contain abundant gypsum crystals. They range from 3 to 10 feet in diameter and average about 7 feet.

The deposits are in metamorphosed sediments of Precambrian age (formation of Perry Canyon) consisting of slates, schists, graywackes, conglomerates and quartzites. Some are carbonaceous schists, which in the workings are 15 to 20 feet thick. The beds dip 20 to 40 degrees northwesterly and crop out 1½ miles into Perry Canyon (Threemile Creek). The mouth of Perry Canyon is a half-mile south of the Perry settlement along U. S. Highway 89 and 91 (SWSESW 6-8N-1W).

In 1973 the author collected a sample from the workings and submitted it to a laboratory specializing in coal analyses; Gale had found the material to be more an impure coal than graphite. The three samples collected by Gale were tested by heating them to drive off moisture and volatile matter and then placing them in the flame of a Bunsen burner to remove the fixed carbon. Each sample was weighed between each step. In the coal laboratory all the carbonaceous material was driven off in the standard test for volatile matter in coal. The "supposed graphite" had a heat value of 105 Btu/lb. and contained 1.15 percent sulfur. The results of the analyses are listed in table 17.

Part of Gale's description is pertinent and repeated here:

> . . . The carbonaceous schist shows a black lustrous polish resembling that of graphite, especially in joints or on the foliation of the rock. When pulverized, however, the substance lacks the smooth, greasy feeling of pure graphite, but much of the material selected as most promising for commercial use appears to be free from coarse sand or grit . . .
>
> . . . In all these tests the carbon burned off in the flame of an ordinary Bunsen lamp without the use of the blast, apparently indicating that the substance is more of the nature of an impure coal than of graphite. The ash derived from the combustion of these samples is essentially clay of a light-gray color, showing it to be free from whatever carbon it originally held.
>
> Material resembling the deposits near Brigham in appearance is used in the manufacture of paint and also for foundry facings. This usually contains, however, over 20 percent of carbon in the form of true graphite. The Brigham material, although containing little or no graphite, may possibly prove to be of value as a paint pigment. Its value for fire-resisting purposes is questionable.

The workings consist of three adits (figure 92) which are located one above the other. The upper working reflects the discovery and the lower two were driven to intercept mineralization. The total length of workings amounts to about 850 feet. Copper, lead, and zinc mineralization as well as the "supposed graphite" is present in the workings. Minerals identified within the workings include galena, malachite, pyrite, "supposed graphite", limonite, sulfate, and an unidentified reddish mineral. Analyses of two lead and zinc samples are also given in table 17. The country rock is principally a dark gray carbonaceous schist, with subordinate quartzite and quartz lenses and veinlets. The presence of carbonaceous material in Precambrian rock is interesting; the material appears to have been deposited with the original sediment and appears to be of organic origin.

Gem Stones and Collection Materials

Box Elder County has several variscite (also called utahlite, lucinite) deposits, the most important of which is located about four miles north of Lucin in 21 and 22-8N-18W. Variscite ($AlPO_4 \cdot 2H_2O$) is a semi-precious mineral that is often confused with turquoise, to which it is inferior in wearability and hardness. Turquoise is sky-blue to greenish-blue in color; variscite occurs in various shades of green; turquoise has a hardness of 5 to 6; variscite has a hardness of 4 on the Mohs scale; turquoise is a hydrous phosphate of aluminum and copper, but variscite contains no copper.

Table 17. Analyses of "supposed graphite" from Perry Canyon.

	Sample No. 1	No. 2	No. 3	No. 4
Moisture	---	1.24	---	0.17
Moisture and volatile matter	3.34	---	5.03	---
Volatile matter	---	9.97	---	17.45
Fixed carbon (by difference)	3.48	5.48	5.59	0.00
Ash	93.18	83.31	89.38	82.38
Btu/lb.	---	---	---	105
Sulfur	---	---	---	1.15

Samples 1, 2, and 3 collected and analyzed by Gale (1910, p. 640). Sample No. 1 is an average representing 7 ft. 4 in. of the beds in the main prospect. No. 2 is random and collected 3/4 mile farther up the canyon in a foliated and schistose bed associated with a large vein of quartz. No. 3 is a select piece of the richest looking material. No. 4 was collected in 1973 and analyzed by Commercial Testing & Engineering Company, Denver, Colorado; about 1 foot of material is represented from the upper working.

(continued)

Table 17 (continued)
Analyses of vein material in "supposed graphite" mine in Perry Canyon.

SAMPLE	SILVER Ounces/ton	LEAD Percent	ZINC Percent	COPPER
11-8-1	0.08	None	0.05	not tested
11-8-2	0.92	0.80	1.80	not tested

See figure 91 for sample locations.

The Lucin variscite deposit occurs on the crest of a hill southwest of the Grouse Creek road-Utah Highway 70 junction. The hill rises 350 feet above the desert floor and has been called Utahlite Hill. The host rock is the Permian Rex Chert; the major lithology is red to brown-stained gray chert. Thin limestone or dolomite beds are present as well. The mineralized zone extends for about 1,000 feet in a north-south direction and is about 50 feet wide. A smaller area of variscite mineralization is found on the west side of the hill. The source of the phosphate is presumed to be the Meade Peak Formation which lies below the Rex Chert. The chert is highly fractured and the variscite occurs as breccia fillings and replacements of chert nodules. The replacements are generally eyeshaped and generally have a darker green color than the breccia or fracture fillings. The general color of the Lucin variscite may be described as apple or grass green. The chalcedonic material that is found associated with the variscite occurs in shades of gray and white and may be harder or softer than the variscite. Associated minerals are few; metavariscite, chalcedony, limonite, and perhaps a little wardite. The Lucin deposit differs markedly in this respect from the other Utah deposits.

The rock is difficult to mine and shatters easily. As a result, most recovered pieces are small. Some of the Lucin variscite is translucent, however, and the matrix often presents many odd patterns and pleasing color of its own. These color patterns are known to the trade as "cobweb" or "turtleback" matrix.

The variscite deposit was first opened in 1902 when a shaft 22 feet deep was dug for gold. In 1905 the area was relocated for variscite, but there was no production until 1909. It is not known how much variscite has been produced since then, but apparently there was a "boom" from 1909 to 1912. Since that time production has been intermittent and the deposit is still periodically worked. It is estimated that the total production is in the tens of thousands of pounds valued at between $50,000 and $100,000.

Two other variscite deposits have been reported in Box Elder County. One is located south of Snowville in the Hansel or Summer Ranch Mountains in SESW 32-14N-7W. A small amount of variscite may have been produced here where the Oquirrh Formation is mineralized. Bullock (1967, p. 176) reports another locality in the Promontory Mountains which has not been located for this study.

Opalized volcanic tuff is found in prospect pits in C 26-9N-19W in the southern Goose Creek Mountains. Most of the material is ornamental stone, but some of the tuffs are opalized. The color of the opal ranges in shades of lavender and makes interesting polishing material. The opal is crudely bedded and generally less than 6 inches thick. It is quite brittle and limited to small pieces.

Chrysocolla and smithsonite of great beauty is found in very limited quantities in the abandoned mines of the Lucin district. The workability of these minerals has not been tested. Large gypsum (selenite) crystals form in the upper layers of mud on the Great Salt Lake Desert and around Great Salt Lake as brines are drawn to the surface and evaporated. These crystals have been found to 10 inches in length and are beautifully formed. Some have been collected in small quantities and sold as specimens or tourist curiosities.

Fossil collectors should have little difficulty in obtaining specimens of trilobites in Cambrian shale or carbonate units, horn corals in the Mississippian Great Blue Limestone, or brachiopods, fusulines, bryozoa, and crinoid stems in the Pennsylvanian and Permian carbonates. Other units may contain good fossils as well. In the Raft River and Grouse Creek Mountains, regional metamorphism has obliterated much of the fossils record in these units

Limestone and Dolomite

Paleozoic limestones and dolomites are abundant in Box Elder County. These rocks have principally been used as construction materials in the county, but their potential for industrial uses is good. The source formations include the Fish Haven, Laketown and Water Canyon Dolomites and the Great Blue and Brazer

Formations.

The abundance of limestone and dolomite makes location near transportation facilities and markets, as well as quality, the important factors in their commercial development. At present the only market is for high purity limestone at the Utah-Idaho Sugar Company plant at Garland. The value of the limestone, which is quarried in neighboring Cache County and calcined at Garland, is credited to Box Elder County by the U. S. Bureau of Mines.

Industrial limestone and dolomite must be relatively free of impurities. High calcium limestone is composed of more than 95 percent $CaCO_3$ and ultra-high calcium limestone is defined to contain more than 97 percent $CaCO_3$. For use in sugar refining the high calcium limestones must also contain less than 2 percent $MgCO_3$ and less than 3 percent combined Al_2O_3, SiO_2 and other insolubles. Limestone for flux in smelting must contain less than 10 percent $MgCO_3$, less than 1.5 percent SiO_2 and no more than 0.5 percent sulfur and 0.1 percent phosphorous. High purity dolomite contains more than 42 percent $MgCO_3$ and has a combined carbonate content of 95 percent or more. High purity dolomite is used as a refractory lining and in rock wool, among other uses.

There has been little testing and there is little information available concerning the quality of limestone and dolomite in the county. Production to the present is presumed to have been minor. From a pit near Deweyville, 9-11N-2W, the Brazer Limestone (Great Blue equivalent) was once used for the sugar refining process, but may not have been consistent in quality. The quarry is located near the mouth of Flat Canyon. Minobras (1974, p. 83) reports that the Southern Pacific quarry at Lakeside, 22-6N-9W, produced limestone not only to provide construction materials, but also for lime, coal dust control, and agricultural uses.

Oolite

Oolite dunes are found in several places around Great Salt Lake. These have been analyzed and contain 90.7 percent $CaCO_3$ and 3.2 percent $MgCO_3$ in average tests. Such dunes have been mined by Kennecott Copper Corporation at Garfield, Salt Lake County, for use as smelter flux. In Box Elder County several square miles of oolite dunes are to be found, some very close to the Southern Pacific Railroad tracks at Lakeside. The reserves of oolite sand are considered large.

Mica

A small amount of mica has been produced in Box Elder County. In 1958 the U. S. Bureau of Mines Minerals Yearbook commented that a small quantity of hand-cobbed mica valued at several hundred dollars was shipped to the Government purchase depot at Custer, South Dakota. Although mica is a constituent of the Precambrian rocks of the county, the more valuable varieties of muscovite and vermiculite are more common in outcrops of the Raft River and Grouse Creek Mountains. The Elba Quartzite and the other similar quartzitic units have the greatest potential. Generally, the western Box Elder County deposits have little potential to produce sheet mica, but there is a fair potential for the production of ground mica. Ground mica is used to manufacture roofing materials, wall board cement, rubber products, and as a paint pigment extender. The 1975 value varied from $40 to $100 per ton, dependent upon quality. Vermiculite is useful as an insulating material, soil conditioner, and sometimes in producing light-weight aggregate. There is one vermiculite prospect (small quarry) in NWSW 1 and 11-10N-16W on the east side of the Grouse Creek Mountains, and a small amount of dimension stone was produced from it as well. White quartzite beds 1 to 2 inches thick contain white mica foliations, but further investigation is necessary to determine the mica-quartz ratio and its economic feasibility.

Quartzite (Silica)

Quartzite sufficiently pure for industrial purposes has not been quarried in Box Elder County, but there is good potential. Quartzite and siliceous sands are the sources of silica which has use in the glass, chemical, and metallurgical industries and can be used as a refractory, filter, and abrasive. Its useful properties include chemical stability and hardness. For silica production the raw material must be extremely pure, and dependent upon use, must be completely free of certain deleterious elements.

Box Elder County's potential for silica lies in the quartzite formations, principally in the Prospect Mountain, Swan Peak, and Eureka quartzite found in the Lakeside, Newfoundland, Silver Island, Pilot, and Grouse Creek Mountains. Two quarries may contain material of suitable quality. One is in 11-10N-16W (mica quarry) in the Elba Quartzite; the rock is described as a white, micaceous quartzite. The second is in the Tintic Quartzite (Prospect Mountain equivalent) in NW 24-8N-2W along the Wasatch Range near Willard. Ketner (1964, p.

221) has tested the Swan Peak and Elba quartzites throughout Utah for deleterious elements (table 18), but much work remains to provide the chemical and geological data of specific sites.

Table 18. Deleterious elements present in quartzitic units with potential for silica production.

	Swan Peak Quartzite (10 samples)	Prospect Mountain Quartzite (7 samples)
	--- approximate spectrographic data ---	
Al	0.15 - 0.7 percent	0 - 3.0 percent
Fe	0.15 - 0.7	0.07 - 0.5
Mg	0.015 - 0.7	0.02 - 0.1
Ca	0.02 - 0.2	0.015 - 0.07
Na	0	0 - 0.07
K	0	0 - 1.5
Ti	0.005 - 0.02	0.015 - 0.1
Mn	0.003 - 0.02	0.001 - 0.007

Kyanite

Kyanite is a triclinic, usually light blue mineral, usually found in long and rarely terminated bladed crystals in regionally metamorphosed rocks. The hardness is 5 along one (parallel) crystal axis and 7+ on another. The chemical composition is $Al_2O_3 \cdot SiO_2$ and it belongs to the sillimanite group of high alumina refractories. Kyanite melts at 3290° F. and yields mullite used to produce the tough porcelains used in spark plugs, electrical insulators, and in laboratories. In addition, it is used as a refractory in the smelting and processing of metals, in glassmaking, and in boiler furnaces. The domestic price for kyanite concentrate has recently ranged from $63 to $118 per ton (1974).

Kyanite occurs in small radiating masses in micaceous, schisty interlayers in quartzites and has been noted in the schists of Precambrian and Lower Paleozoic age in the Grouse Creek and Raft River ranges. The mineral is not common and is spotty in occurrence. The percentage of the mineral in the rock is very small even in the most prolific areas. The probability of economically producing kyanite appears remote although no intensive prospecting has yet been done. The mineral must therefore be regarded as a curiosity rather than a potential economic mineral commodity. Todd (1973, p. 171) also reports the presence of sillimanite, andalusite, and staurolite in the schists north of Ingham Peak in the highest parts of the Grouse Creek Mountains in a roof pendant in Precambrian adamellite gneiss.

Clay

Clay is the name given to a common group of minerals composed of very fine particles of hydrous aluminum silicates. It has many industrial uses; the specific type of clay, purity, and lack of certain contaminants all dictate the use to which the material may be put and consequently its value. Low value common clays are mined if near market areas or points of consumption, but would have little value in the western part of the county. Clay pits have been opened in the more populous areas of the eastern part of the county, especially around Brigham City, Mantua, and Willard. Most are presently inactive and are used when the clay is needed to seal small agricultural reservoirs. Local brick from common clay was undoubtedly produced in pioneer days. Recently clay deposits have been prospected and developed in Salt Lake Group sediments in the southern Grouse Creek and Goose Creek Mountains.

An interesting pit is found in altered shales or schists (Ophir Shale?) in the Pole Patch (NE 13-7N-2W) above Utah Hot Springs. Altered reddish clay is interbedded with hard siliceous units. The coarser siliceous material is separated from the clay for use as gravel or borrow material. In 1913, Eckel (p. 348-49) reported that the Ogden Portland Cement Company had built a plant at Bakers Spur, 5½ miles northwest of Brigham City, designed to use marl and clay lying at the bottom of an abandoned lake bed. The ruins of the plant and old cement ponds are located in 33 and 34-10N-2W, just north of the Brigham City airport. A part of Eckel's report follows:

> . . . an interesting material has newly been discovered to be of value in the manufacture of Portland cement. It occurs in the form of marl underlain by clay. This deposit lies in the abandoned bed of the northern portion of the old Salt Lake basin. It is a homogeneous, unstratified, grayish, fine-grained soft marl. At the surface the material is, in midsummer, fairly dry to the depth of 1 foot or more, but becomes damp below, and at the base salty water seeps in and fills holes where the underlying clay is excavated. The clay underlying the loam ranges from light gray through yellow to bluish in color, and is also fine-grained . . . . . . The marl is 4 to 10 feet deep, and the clay has been tested to a depth of 18 feet. The marl runs generally between 1 and 3 percent magnesium oxide, between 40 and 46 percent of calcium oxide, between 7 and 12 percent of silica, and between 1 and 3.5 percent of alumina plus iron oxide. There has been found as high as 4.5 percent of sodium chloride (common salt) in the marl, and the wet material carries as high as 32.29 percent moisture. The clay carries about 48 to 50 percent silica, 16.5 to 18.6 percent of alumina plus iron oxide, about 7.6 percent of lime oxide, 2.5 to 2.8 percent of magnesium oxide, 2.7 to 2.9 percent of potassium oxide, 1.3 to 5 percent of sodium oxide, and about 2.25 percent of sodium chloride. In a wet condition the clay contains as much as 40 percent of moisture.

The only special clay noted in the region is bentonite. It has been reported from only two locations, but other areas can probably be found with intensive prospecting. Volcanics are common in the Tertiary Salt Lake Formation and the decomposition of these rocks by weathering processes converts them to bentonite. Mapel and Hail (1959) report its presence in the Goose Creek Basin; it is possible that bentonitic beds are present in the Grouse Creek Basin as well. There are no known prospects for bentonite in these areas, however. The only bentonite deposit that has been worked is in the E½ 12-11N-12W in the Hogup Mountains. This working is a series of pits and cuts in a shallow wash near the contact of Oquirrh Formation and quartz rhyolite. The rhyolite is greenish-gray in color, somewhat porphyritic, and easily weathered. Alternating ribs and furrows of unaltered and bentonitic rhyolite are found along the wash. No check was made as to grade, purity, or suitability for specialized use. The pits are abandoned, one stockpile remains, and the amount of production is unknown.

Bentonite is used for drilling mud, lining of stock reservoirs and irrigation canals, and in purer grades for sophisticated medicinal, cosmetic, and pharmaceutical preparations. Box Elder County bentonite deposits will find occasional use for lining and sealing reservoirs and canals in the future, but it is not expected to be used for the other purposes inasmuch as the grade of the material appears not to be first class.

Tuffaceous beds (Salt Lake Group) altered to white and pink clay were being mined from several quarries or pits in the southern Grouse Creek Mountains (Intermountain Brick) in 1978. These are located in sections 7 and 18, 9N-17W, and in section 12, 9N 18W. The principal quarry is in section 7, 9N 17 W.; the deposit is exposed in an area at least 500 by 800 feet with a high quality thickness of about 80 feet. Interpace Brick drilled a clay deposit at least 80 feet thick in section 26, 9N - 19 W. in similar material in the southern Goose Creek Mountains in 1978. The deposit covers an area of at least 25 acres. Smaller areas of white Salt Lake Group clays are present in the northern Grouse Creek Mountains as well.

Feldspar

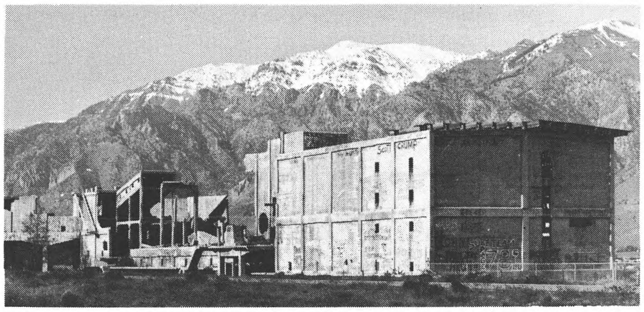
Feldspar is an important constituent in the pegmatite dikes in many of the Precambrian igneous units in the Wasatch and Raft River Mountains, but the pegmatites are small in volume and widely scattered. Crude feldspar is ground for use in industry and is principally used by the ceramics and glass producers. Here it is used primarily as a flux and also to produce fine glazes on ceramic ware. Some feldspar is used as an ingredient in scouring soaps, abrasives, and roofing materials.

CONSTRUCTION MATERIALS

Construction materials include crushed stone aggregate, sand and gravel, dimension stone, and ornamental stone. In the years 1951 to 1974 approximately \$58 million in stone and \$22 million in sand and gravel were produced. Prior to 1951 records for these products are hard to find, but it is assumed that substantial quantities were used.

In 1869 the first transcontinental railroad across the United States was completed at Promontory, Utah. It crossed Box Elder County from Brigham City through Corinne, Promontory and Kelton, across the Hogup and Matlin Mountains to the southern end of the Grouse Creek Mountains to Lucin. From there it followed the present-day Southern Pacific Railroad route into Nevada. Local gravel, borrow, and crushed stone were used to construct the original railroad bed which today is used as a road or as a stock trail. This was the first large scale use of construction materials in the region. The tonnages and values are unknown, but are suspected to have been considerable. The next big construction job, the Lucin cutoff of the Southern Pacific Railroad, lasted two years and was completed on November 13, 1903. The project cost \$8,500,000 and included 30 miles of trestles and rock fills across Great Salt Lake and 50 miles of railroad ballast across the mudflats. The distance from Ogden to Lucin was shortened by 43.8 miles. At this time the quarries at Lakeside and Lucin were opened. In June of 1955, the third great project for the area commenced with construction of Southern Pacific's rock-fill causeway across Great Salt Lake. Completed in July, 1959, the rebuilding included 43,750,000 cubic yards of rock fill valued at \$49,000,000. Most of the rock came from quarries near Promontory Point, but considerable came from the Lakeside area. The quarries at Lakeside remain active to the present, supplying ballast to maintain the rock fill. In the last 20 years, operations of the railroad quarries at Lucin and Lakeside have produced an average of 350,000 tons of broken rock annually. The production has been irregular, dependent upon need.

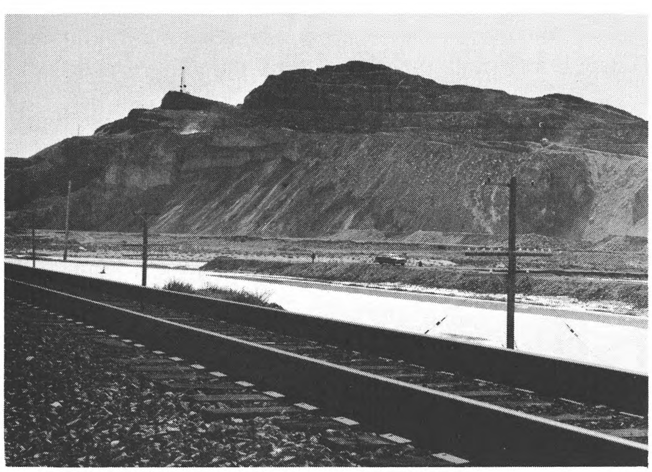
Road construction has been the major user of sand and gravel in the county. In the western part use of the material has been nearly exclusive for this purpose. The main highway, Utah 30, was originally constructed



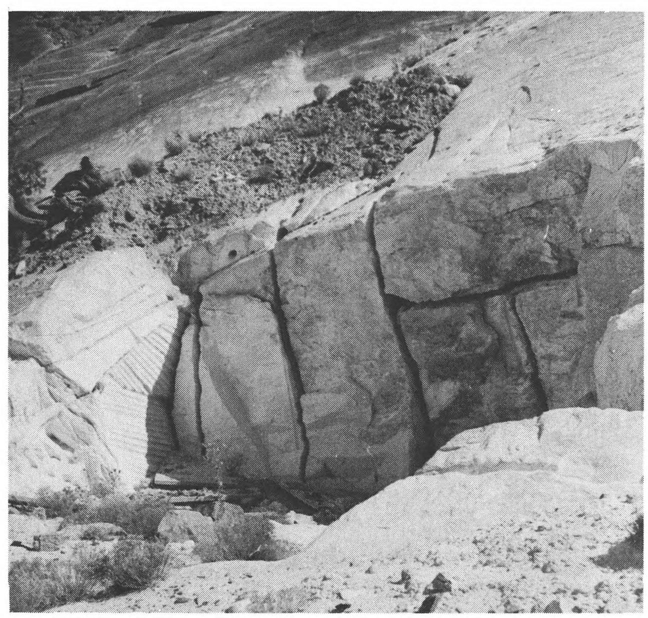
P 31. Ogden Portland Cement Co. plant at Bakers Spur, 5½ miles north of Brigham City (now along Interstate Highway 15). The plant was designed to use marl and clay lying at the bottom of an abandoned lake bed to produce portland cement.

P 32. Clay pit in the southern Grouse Creek Mountains. The white clay is used to make bricks for use in the Wasatch Front area. The host is the Late Tertiary Salt Lake Group.

P 33. Pallets of flagstone, dimension stone quarried in the Vipont Mountains. The source rock is the Quartzite of Clarks Basin.



P 34. Lakeside No. 2 quarry of the Southern Pacific Railroad. This quarry is used as riprap and railroad ballast.



P 35. Pure white marble quarried by closely spaced drilling. Only small tonnages of this rock have been produced in the Newfoundland Mountains.

in 1933-34 as a 14-foot and 18-foot crushed gravel highway. In 1946 it was widened to 20 feet and paving with asphalt road mix began in 1953. Improvements and extensions occurred in 1961, 1962, and 1966. In the late 1960s and throughout the 1970s large quantities of road bed gravel were used in the construction of the various freeway routes in the eastern and northern part of the county. Most of the important quarrying of dimension and ornamental stone has occurred in the years since 1950.

Broken or Crushed General Purpose Stone

Broken or crushed general purpose stone is produced for construction projects and chosen for its cheapness, convenience, and durability rather than its decorative or ornamental quality. Limestone, dolomite, and quartzite, most often used,are plentiful in Box Elder County. Most of the broken and crushed stone produced has been for railroad ballast and riprap. Railroad ballast should be sound, durable, and relatively free of soft and friable particles. It is subjected to normal weathering processes and to mechanical forces imparted by heavily loaded railroad cars, engines, and tamping tools.

Riprap is large angular fragments of rock placed around the bases of piers, abutments, causeways, and other construction subject to attack by water (waves). This attack may be chemical or mechanical. To determine the suitability of a rock for riprap it is subjected to 50 cycles of freezing and thawing and run through 5 cycles of a sodium sulfate bath. If the stone loses more than 25 percent of its initial volume it is unsuitable.

Crushed stone, used as a road metal and cement aggregate, is more desirable than gravel because the angular pieces create a stronger concrete or pavement. There are certain compositional requirements for rock used for these purposes (also for the gravel) so that weakness does not result from chemical reaction between the cement and the rock. Gravel, although less desirable, has been the favored material in the county for road construction because of its ready availability.

Quarries to produce crushed or broken stone have been opened in several places, mostly for riprap and/or railroad ballast. The four most important quarry areas are all convenient to the Southern Pacific Railroad tracks. Several quarries were cut in massive quartzites of younger Precambrian age at the southwestern end of the Promontory peninsula by the Morrison-Knudsen Company, Inc., for the Southern Pacific Railraod causeway project. Most of the rock for the 1955-1959 project came from this location; pits are found in NE 14-6N-6W and in SE 23-6N-6W. These quarries are presently (1975) abandoned. Quarries at Lakeside are cut in the Great Blue Limestone and are operated by the Southern Pacific Railroad, principally for railroad ballast. The broken rock is loaded on railroad cars, carried out on the causeway and dumped over the side to shore-up those parts of the fill being attacked by storm waves of the Great Salt Lake. Some has been used to produce lime, rock dust for coal mines, and as a soil conditioner in agricultural use. The quarries are located in 22-6N-9W and in NESW 21-6N-9W. The limestone at Lakeside is a cherty, thick-bedded to massive, dark gray hard rock. The chert is sparse and scattered as large nodules in the lower 218 feet of the formation. Key horizons may be chert free and usable for industrial purposes. A large quarry in the Grandeur Limestone in 33-8N-18W and 3, 4-7N-18W is located 3/4 mile north of the railroad tracks at Lucin. The rock is mostly cherty dolomitic limestone in massive beds and was used to provide and maintain the railroad bed across the Great Salt Lake Desert.

The Grandeur, Oquirrh, Great Blue Deseret, Madison, Guilmette, Simonson, Laketown, Fish Haven, Garden City, Upper Cambrian and Prospect Mountain formations provide suitable crushed or broken rock for construction. A list of rock quarries in Box Elder County is given in table 19; their locations are shown in figure 101. Stone production statistics for Box Elder County for recent years is given in table 20.

Dimension Stone

Dimension stone is any kind of rock, rough or worked, that provides width and length in structural, decorative, or monumental construction. The more desirable material has qualities of durability, beauty, color, hardness, strength and texture. Box Elder County has produced quartzite and marble dimension stone and has a potential in granite, basalt, rhyolite, sandstone, and tuff sources. The value of produced dimension stone amounts to a few percent of the total stone production; most dimension stone has been produced since World War II.

Quartzite is the leading dimension stone in the region. Most of the quarries are in the Grouse Creek and Raft River mountains where the rocks are regionally metamorphosed. The Precambrian Elba Quartzite and a few of the other quartzitic units of Cambrian and Ordovician age contain the best material. The thin-bedded rock breaks out in flat plates 1/2 to 2 inches in

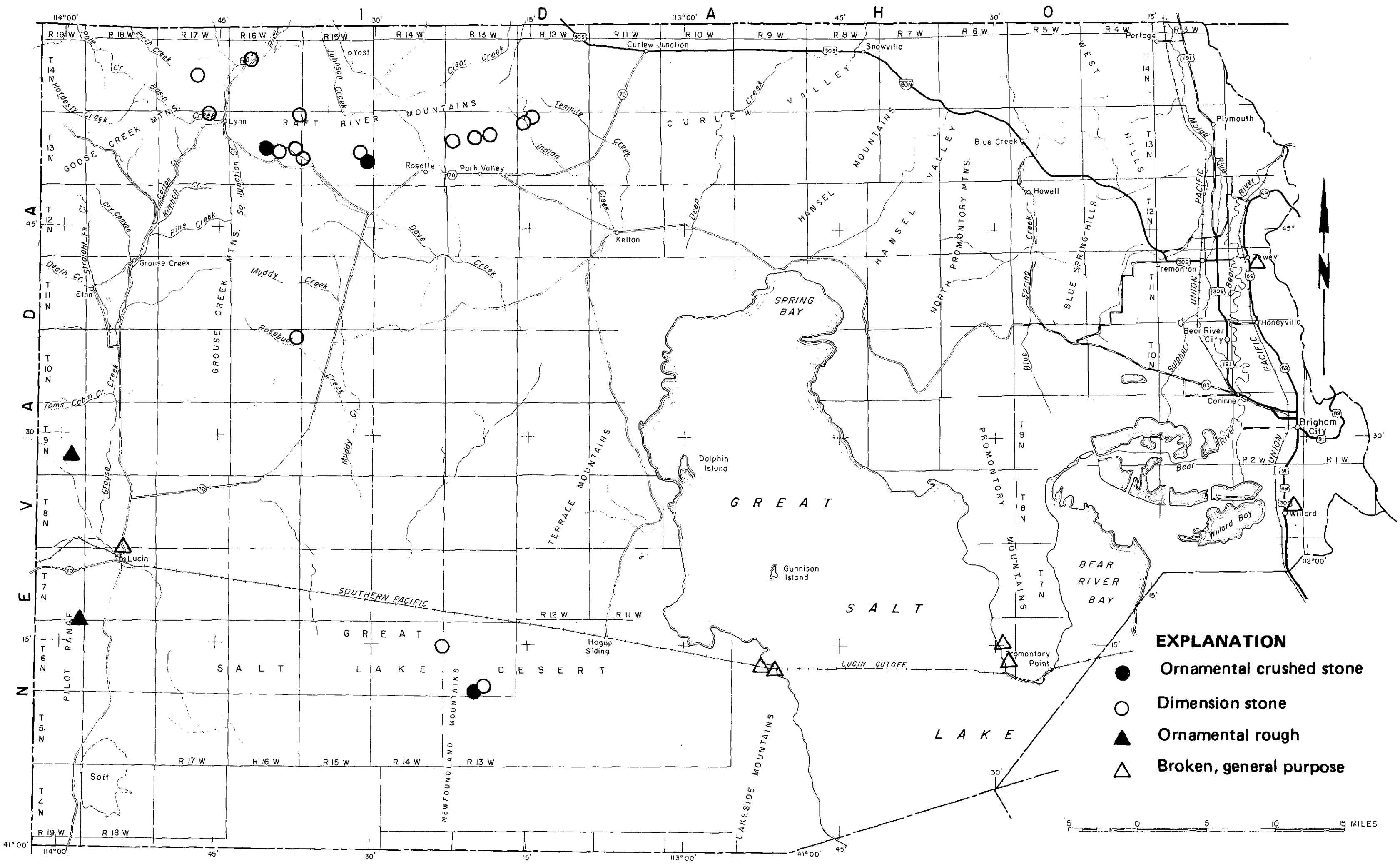


Figure 101. Stone in Box Elder County.

Table 19. Selected stone quarries of Box Elder County, Utah

Name	Location	Class	Description
Promontory (Railroad quarry)	NESE 23- 6N- 6W	BS	Gray and brown massive quartzite (Precambrian Z), breaks into angular blocks of various sizes, used for railroad ballast and riprap.
Little Valley (Railroad Q.)	NWSE 14- 6N- 6W	BS	White, green, and violet quartzite (Precambrian Z), massive, breaks into large angular blocks, used for railroad ballast and riprap.
Lakeside No. 1	SENW 21- 6N- 9W	BS	Dark gray massive limestone (Mississippian Great Blue), breaks into angular blocks of various sizes for use as railroad ballast.
Lakeside No. 2	NWSE 22- 6N- 9W	BS	Dark gray and blue massive limestone (Mississippian Great Blue), is broken into angular blocks and gravel for railroad ballast and riprap.
E. Newfoundland No. 1	NE 33- 6N- 13W	CS	Pure white marble (metamorphosed and bleached Upper Cambrian limestone and dolomite), crushed into chips for garden and roofing stone.
E. Newfoundland No. 2	33- 6N- 13W	DS	Pure white marble (metamorphosed and bleached Upper Cambrian limestone and dolomite), massive material cut into slabs for sculpture work.
NW Newfoundland	SW 7- 6N- 13W NE 13- 6N- 14W	DS	Pure white quartzitic dolomite (Ordovician Garden City Formation, bleached) undeveloped deposit.
East Pilot	SE 1- 6N- 19W	OS	Quartzitic sandstone with Liesegang banding and interesting color patterns (Tertiary Salt Lake Group), can be shaped into blocks, ornamental rough.
Lucin (Railroad quarry)	3, 4- 7N- 18W 33- 8N- 18W	BS	Cherty limestone (Permian Grandeur), used for railroad ballast.
S. Goose Creek Mountains	C26- 8N- 19W	OS	Opaline and banded welded tuff (Tertiary Salt Lake Group) ornamental rough stone, undeveloped deposit.
Rosebud Creek	11- 10N- 16W	DS	Gray micaceous and flaggy quartzite (Precambrian Elba Quartzite).
Deweyville	SESW 9- 11N- 2W	BS	Gray massive limestone (Mississippian Brazer Formation), has been used in sugar refining process, road metal, crushed gravel.
Park Valley area quarries	S½SW 5- 13N- 12W SWSW 5- 13N- 12W W½SE 8- 13N- 13W S½NW 8- 13N- 13W	DS	Green, white and tan, micaceous quartzitic flagstone (Precambrian Elba Quartzite), makes excellent wall facings, fireplaces, etc.
Park Valley area quarries (continued)	SWSE 10- 13N- 13W NE 16- 13N- 13W SWNE 18- 13N- 13W	DS	
Rock Canyon	NW 18- 13N- 13W	DS	Bright green micaceous quartzitic flagstone (Precambrian Elba Quartzite), makes excellent wall facings, fireplaces, etc.
Black Hills Cr. Nos. 1, 2	NE 23- 13N- 15W	DS	Brown, tan patterned quartzitic flagstone (Cam-

BS = ballast, riprap CS = crushed stone DS = flagstone OS = ornamental stone

(continued)

Table 19. Selected stone quarries of Box Elder County, Utah (continued)

Name	Location	Class	Description
	NW 23- 13N- 15W		brian? Quartzite of Clarks Basin), wall facings, patio stones, fireplaces, etc.
Black Hills Cr. No. 3	NE 26- 13N- 15W	CS	Thinbedded pure-white quartzite (Ordovician? Eureka Quartzite) crushed for garden or roofing stone.
Clarks Basin (at least 4 quarries)	14, 23, 24- 13N- 16W	DS	Tan, brown, gray-green, red micaceous quartzitic flagstone (Cambrian? Quartzite of Clarks Basin).
Dove Creek Pass No. 1	SE 21- 13N- 16W	CS	Thinbedded pure-white quartzite (Ordovician? Eureka Quartzite) crushed and sized for garden or roofing stone.
Dove Creek Pass No. 2	SW 22- 13N- 16W	DS	Tan, brown, and gray micaceous quartzitic flagstone (Cambrian? Quartzite of Clarks Basin), patio stones, fireplaces, etc.
Yost Stone (Pine Spring) (at least 4 quarries)	1, 2 -13N- 16W	DS	Tan, white, brown, gray micaceous quartzitic flagstone (Cambrian? Quartzite of Clarks Basin) ornamental wall facings, fireplaces, etc.
Lynn Pass	SE 3- 13N- 17W	DS	Tan, brown, micaceous quartzitic flagstone (Cambrian? Quartzite of Clarks Basin)
Upper Narrows	SE 8- 14N- 16W	DS	Light micaceous quartzitic flagstone (Precambrian Elba Quartzite), fireplaces, etc.
Star Stone (Vipont Mountains)	NW 21- 14N- 17W	DS	Tan, brown, gray patterned micaceous quartzitic flagstone (Cambrian? Quartzite of Clarks Basin), wall facings, fireplaces, etc.

thickness. The plates are usually pried out with hand tools and stacked on pallets. Individual pieces have lengths to 5 feet and widths to three feet. The pure quartzite is generally blue-gray with a silvery micaceous coating on the bedding surfaces. In addition some desirable stone has irregular or banded ferruginous staining in fantastic patterns. Thicker-bedded material, 2 to 4 inches thick and averaging 6 inches in width and 1 to 3 feet in length, is stacked as irregular shaped "bricks." The general color is a shade of gray, tan, or brown, but at the Rock Canyon quarry, north of Park Valley, it is bright green. The rock is ideally suited for decorative facings on all types of buildings, for fireplaces, patios, walks and wall trim. The thinner stone plates break under weight and require some support. The surface can effectively withstand all weathering without damage. The prime material sells for $70 to $100 per ton.

In the Newfoundland Mountains an Upper Cambrian pure white marble has been cut into slabs by closely spaced drilling. The rock is massive and can be cut into large (up to 3 feet) blocks as desired. The carbonate rocks have been selectively bleached and marbleized near a monzonite intrusive contact. The bleaching and marbleization extend to 1000 feet along the strike of the relict bedding and may be found to 100 feet in thickness. The Ordovician Swan Peak Quartzite has been modified by the intrusive activity as well,and in the northwest corner of the mountain range is described as a durable, well-bedded, white, medium-grained quartzitic dolomite, 6 to 30 inches thick. This area is undeveloped.

Some of the limestone and dolomite beds might be worked into hard and durable building blocks, but prospects for development are small. Outcrops of granitic rock, often used as a building stone, are found in the Raft River, Grouse Creek, Pilot, Silver Island, and Newfoundland ranges. These need to be tested to determine compressive strength, and durability under stress and weathering. In some areas the granitic rocks are subject to general granulation and rapid exfoliation. In other areas the granitic rocks appear durable and are

Table 20. Stone production statistics as recorded by the U. S. Bureau of Mines Mineral Yearbooks for Box Elder County.

Stone	Tonnage	Value	Comments
Pre-1957	Not recorded		
1957	5,983,800	$5,983,800	
1958	W	W	Substantial
1959	2,024,000	2,024,500	
1960	No production		
1961	60	75	
1962	W	W	
1963	594,197	300,745	
1964	364,064	938,845	
1965	2,463	99,195	
1966	149,697	299,077	
1967	3,357	115,655	
1968	3,544	92,000	
1969	1,460,368	1,563,000	
1970-1973	W	W	Substantial
1974	751,000	W	
Inc. totals	11,336,550	$11,416,892	

W = information withheld

potentially exploitable. Some of the latter occurs in the Raft River Mountains.

In a study of eastern Cassia County, Idaho, Anderson (1931, p. 142) notes that tuffaceous beds in the Tertiary were extensively used in the buildings of that area. Tuff is found in the Salt Lake Formation of Box Elder County.

Basalt and rhyolite are also found in the western Box Elder region, but no efforts have been made to verify the suitability of this material.

Crushed Ornamental Stone

Pure white rock has been crushed and sized from small pebbles to 1 inch gravel at two quarries. One is located at Dove Creek Pass, on the road from Rosette to Lynn, the source material being a fine-grained thin-bedded quartzite (Eureka Quartzite?). The other is on the east side of the Newfoundland Mountains in the bleached and marbleized Upper Cambrian limestones and dolomites. There are large reserves at each locality and much gravel has been stockpiled. The material is suitable for roofing gravel, patio and garden aggregate, for flower pots and fish bowls. The chips may be cemented together to produce interesting and decorative rubble walls, terrazzo, or walkways.

Some of the marble of the Newfoundland area is tremolitized. Tremolite, calcium-magnesium amphibole, is an industrial mineral sometimes used as asbestos. Tremolite is the least valuable of the asbestos minerals, and the small quantity of this material in the Newfoundland Mountains seems to eliminate it from economic consideration.

Ornamental Rough Stone

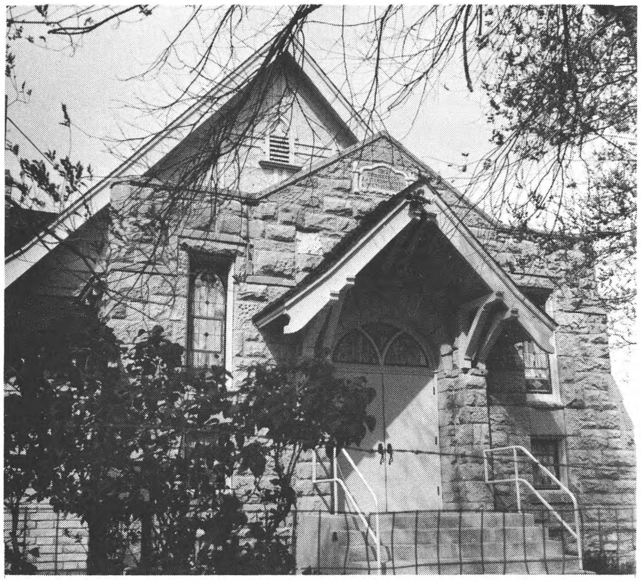
Ornamental rough stone has been quarried in two places in the county. The first is in the Salt Lake Formation near the south end of the Goose Creek Mountains. The rock is a vitreous welded tuff of an unusual salmon pink color. Much of it is banded in shades of purple and the material is partly opalized. The banding and intricate patterns of the rock are in some cases exceptionally attractive. At least four shallow pits and cuts have been made below the rhyolite and vitrophyre cliffs. The material can easily be hewn into rough blocks, to create fireplaces, garden walls, fountains, and other decorative paraphernalia. If the rock is of the type designated by Anderson (1931, p. 142) it might be quite durable, but no tests have been made to prove the strength.

The second quarry is found on the east side of the Pilot Range and is also cut in the Salt Lake Formation. The rock type is a sandstone that is normally, yellow, tan, or light brown in color, decorated with a ferruginous banding. The sandstone is medium grained, quite friable, and easily broken; all the pieces inspected showed signs of deterioration by weathering and its use may be limited to interior stone work. The largest pieces are rarely greater than 1 foot in diameter, although careful quarrying may be rewarded with larger ones. Both the Pilot Range and Goose Creek deposits contain considerable reserve.

Basalt, rhyolite, granite, and tufa found in the region have potential as ornamental rough stone. The rock occurs in interestingly irregular shapes and forms, especially suitable for landscape use.

Sand, Gravel, and Borrow

Sand and gravel is present in profuse quantity throughout Box Elder County. Numerous sand, gravel, and borrow pits have been opened along the highways and roadways, railroads and near towns by the Utah State Department of Transportation, by the railroad companies, and by private construction firms. The chief sources are in Quaternary, and to a lesser extent in Tertiary unconsolidated rocks, especially in the Lake Bonneville deposits. Test data have been recorded as part of a county by county materials inventory examination developed by the Utah Department of Transportation;



P 36. Meetinghouse of the Church of Jesus Christ of Latter Day Saints in Grouse Creek. This chapel, constructed in 1912 out of tuffaceous sandstone of the Salt Lake Group, was quarried nearby.

P 37. Close-up of Eureka Quartzite? in quarry in the Dove Creek Mountains.

P 38. Quarry in the Eureka Quartzite? in the Dove Creek Mountains. The rock is crushed and sized for use as white garden stone.

P 39. Cross-section through a gravel embankment at the Bonneville level Grassy Mountains. Gravel is an important mineral deposit in Box Elder County.

one for Box Elder County was completed in 1964. A representative part of that data is given in table 21. The Department of Transportation divided the alluvial deposits into three divisions; (1) flowing stream deposits, (2) sandy and silty soils, and (3) gravelly and stony soils. The first can be considered a good potential for gravel deposits, the other two rarely provide good gravel, but may make excellent borrow material.

The Lake Bonneville deposits have also been subdivided into three groups; (1) clayey soils, (2) sandy and silty soils, and (3) gravelly and stony soils. The first group contains 30 to 100 percent clay-sized particles, 0 to 55 percent silt and 0 to 55 percent sand and is usually saturated with saline water (mud-flats). The use of this material is not recommended for any construction work. No. 2 contains 20 to 100 percent sand, 0 to 100 percent silt and less than 30 percent clay and can be used for borrow if better alluvial material is not near at hand. The last (No. 3) consists of well-rounded resistant pebbles to cobbles deposited along the terraces and ancient shorelines of Lake Bonneville and forms the best sand and gravel deposits of the region. Landslide materials contain too much clay, making them unsuitable for general construction work. Some of the Tertiary units contain conglomeratic and sandy rock which can be used for gravel, sand, and borrow if better alluvial or lacustrine material of Quaternary age is not available. Production statistics for sand and gravel from 1962 are given in table 22.

GROUND WATER RESOURCES

The general nature and problems of water in the Box Elder County region are adequately discussed in several *Technical Publications* of the Utah Department of Natural Resources, Division of Water Rights, which are listed with the references. To summarize, water falling on the land in the form of precipitation is evaporated, transpired, converted to runoff or is taken into the rock to reemerge in the form of springs. The amount of precipitation received in a normal year ranges from less than 5 inches in the Great Salt Lake Desert to more than 40 inches in the Raft River and Wasatch Mountains. The source of all fresh water in the county is runoff or groundwater adjacent to the high mountains, except for that entering the area in the Bear River and Malad River system in the eastern part. Table 23 lists the various subbasins in the county, the estimated precipitation in acre-feet, and the amount of water available for recharge. The dry climate is responsible for the large losses.

Little water sinks into the ground water reservoirs below 6,000 feet and this occurs only during severe cold winters when a deep snow accumulates below that level. Grouse Creek Valley and Park Valley are adjacent to high mountains from which a few small but permanent streams originate. About 5 percent of the precipitation enters the ground water reservoir. At Sink Valley, surrounded by mountains less than 7,000 feet in altitude, less than 1 percent contributes to the ground water. On this basis it is assumed that the Lakeside, Hogup, Terrace, Grassy, Matlin, Newfoundland and Silver Island Mountains, which have no permanent streams and only a few small-flow springs, contribute very little water. The higher Raft River and Wasatch Mountains contribute most to the ground water reservoirs.

Movement of Water

Excepting the through-going streams, surface and underground water moves from the mountains basinward. The major discharge basin in western Box Elder County is the Great Salt Lake Desert; that for eastern Box Elder County is the Great Salt Lake. The movement of ground water in the east is generally east or west down the slopes of the various north-south trending mountain ranges, and then southerly under the valleys to the Great Salt Lake. From Curlew Valley and eastward of the Hogup, Terrace, and Lakeside Mountains the flow is toward Great Salt Lake. Part of the Pilot Range waters flows westward and then southward into southern basins, part flows westward and northward to enter the main basin of the Great Salt Lake Desert via the pass used by Thousand Springs Creek. Water from the Goose Creek Mountains supplies three areas; the first northward into the Goose Creek Basin, the second westward into the Granite and Crittenden Creek drainages of Nevada, the third into the Grouse Creek drainage. The flow into the latter two drainage systems eventually reaches the Great Salt Lake Desert. The Goose Creek drainage flows into Idaho and eventually reaches the Snake River. A goodly amount of water enters the Great Salt Lake Desert basin through the Thousand Springs drainage that originates in Nevada. Water from the northern half of the Grouse Creek and Raft River Mountains supplies the Raft River drainage system, tributary to the Snake River in Idaho. The northwestern corner of the county marks the divide between Great Basin and Columbia River drainage systems.

Aquifers

The rocks of the region vary greatly with respect

Table 21. Representative sand and gravel test pits, 1964, Utah Department of Transportation for Box Elder County.

Location	Owner	Use of Material	Type of deposit	Thickness of Material
1. NESW 19- 9N- 1W	Fife Sand & Gravel	Base, surface gravel	Lake terrace	---
2. SWSE 19- 9N- 1W	Utah Fish & Game	Base, surface gravel, borrow	Lake terrace	50ft.
3. SENE 21- 9N- 1W	V. S. Jeppsen et al	Borrow	Alluvial fan	5
4. SWNW 27- 9N- 1W	Box Elder County	Base, surface gravel	Lake terrace	10
5. NESE 11- 7N- 2W	W. R. White	Base, surface gravel	Lake terrace	60
6. NENE 14- 7N- 2W	Parcell & Cragun	Base, surface gravel, borrow	Lake terrace	65
7. SENE 2- 8N- 2W	Young & Nielson	Base, surface gravel, borrow	Lake terrace	75
8. NENE 10- 8N- 2W	J. A. Ward	Base, surface gravel	Lake spit	20
9. NWSE 23- 8N- 2W	Box Elder Co.& Perry	Base, surface gravel	Stream channel	10
10. SWNE 26- 8N- 2W	Nicholas & Woodyatt	Base, surface gravel	Alluvial fan	15
11. NESE 35- 8N- 2W	P. Marsh	Base gravel, borrow	Alluvial fan	10
12. SESE 3-10N- 2W	B. Hunsaker	Riprap	Bedrock	---
13. SENE 4-10N- 2W	B. Hunsaker	Base, surface gravel	Lake terrace	50
14. NESW 10-10N- 2W	Hunsaker, Yates & W.	Base, surface gravel, borrow	Lake terrace	60
15. SWNE 23-10N- 2W	S. Jensen	Riprap	Talus	---
16. N½NW 30-11N- 2W	J. Thompson	Borrow, base gravel	Lake bar, fl. plain	8
17. N½NW 31-11N- 2W	P. M. Jensen	Borrow	Flood plain	15
18. NESW 7-12N- 2W	W. Hansen	Borrow	Flood plain	100
19. SWNE 29-12N- 2W	Utah Dept. of Transp.	Base, surface gravel	Lake terrace	50
20. NENW 32-12N- 2W	Utah Dept. of Transp.	Base, surface gravel	Lake bar	20
21. NENE 19-10N- 3W	Wm. Nicholas	Base, surface gravel, borrow	Lake terrace	20
22. NENE 3-12N- 3W	A. A. Capener	Base, surface gravel	Lake bar	10
23. SWSW 25-12N- 3W	P. S. Larsen	Borrow	River bank	30
24. NWNE 4-14N- 3W	R. Nelson	Base, surface gravel	Alluvial fan	10
25. NWSW 35-14N- 3W	Nish & Allen	Base, surface gravel	Lake terrace	50
26. SESW 24-10N- 4W	V. M. Ferry	Base, surface gravel, borrow	Lake terrace	40
27. SWSE 30-11N- 4W	M. Christensen	Base, surface gravel, borrow	Lake terrace	10
28. N½SW 25-12N- 4W	R. Holdaway	Base, surface gravel	Lake terrace	40
29. SWNE 34- 7N- 5W	H. S. Arthur	Base, surface gravel	Lake terrace	20
30. NESE 29- 8N- 5W	N. S. Flint	Base, surface gravel	Lake terrace	25
31. NWSE 20-11N- 5W	Thiokol	Base, surface gravel	Lake terrace	30
32. NENW 29-13N- 5W	S. F. DeJarnatt	Borrow	Lake terrace	12
33. S½SE 7-14N- 5W	Church	Base, surface gravel	Lake terrace	---
34. NENW 12- 9N- 6W	Cedar Ridge Ranch	Base, surface gravel	Lake terrace	50
35. SESE 11-10N- 6W	Larsen & Larsen	Borrow	Lake terrace	20
36. SESE 35-11N- 6W	O. P. Nelson	Base, surface gravel	Lake terrace	40
37. NESE 2-13N- 6W	P. Bradshaw	Borrow	Lake terrace	7
38. NWNW 4-13N- 6W	B. L. M.	Base gravel	Lake terrace	10
39. NENE 7-11N- 7W	Connor Cattle Co.	Base, surface gravel, borrow	Lake terrace	5
40. NENE 27-14N- 7W	R. Ward	Borrow, base gravel	Lake terrace	6
41. NWSE 31-12N- 8W	B. L. M.	Base, surface gravel, borrow	Lake terrace	10
42. NESW 32-12N- 8W	State Land Board	Borrow	Lake terrace	6
43. SWSE 2-14N-10W	W. L. Stokes	Borrow	Lake floor	10
44. SESE 4-14N-11W	G. Beukenhorst	Base, surface gravel	Lake terrace	10
45. SWSE 28-14N-11W	G. Beukenhorst	Base, surface gravel	Lake terrace	7
46. NWNE 33-13N-13W	H. A. Carter	Base, surface gravel, borrow	Alluvial plain	6+
47. NENW 36-13N-13W	G. Rose	Borrow	Alluvial plain	9
48. SENE 5-12N-14W	Central Pacific RR	Base, surface gravel, borrow	Alluvial plain	15
49. SESW 18- 9N-15W	B. L. M.	Base, surface gravel	Lake terrace	15
50. SENE 29-10N-15W	Nick Chournas	Borrow	Lake floor	7
51. NWNW 32-10N-15W	State Land Board	Base, surface gravel	Lake terrace	8
52. SESW 4-14N-15W	M. Gill	Base, surface gravel	River terrace	20
53. NESW 5- 8N-16W	Nick Chournas	Base, surface gravel, borrow	Lake terrace	20
54. SWNW 15-13N-17W	---	Borrow, base gravel	River terrace	20
55. NWSW 16- 8N-18W	State Land Board	Riprap	Bedrock	25

(continued)

Table 21. Representative sand and gravel test pits, 1964, Utah Department of Transportation for Box Elder County. (continued)

	Depth of overburden	Type of Sample	Depth of Sample	Date Sampled	Sieve analysis Before Crushing > 3"	> 1"	Percent passing after Crushing to 1 inch maximum size 1"	½"	#4	#10*	#40*	#200
1.	0-2ft.	Crusher	---	1953	---	---	100	---	57.9	43.5	25.2	7.0
2.	1	Cutbank	0-70ft.	1962	0.0	13.1	86.9	---	54.2	40.5	19.9	4.7
3.	½	---	---	1952	---	---	100	---	38.2	---	---	7.7
4.	1	---	0-10	1952	5.3	20.2	100	---	47.6	36.1	18.7	6.9
5.	0-5	Cutbank	---	1963	22.4	39.8	100	72.2	42.6	29.3	16.1	2.1
6.	1-2	Cutbank	22-55	1964	4.9	24.3	100	85.0	53.5	39.0	14.5	7.0
7.	1-2	Test hole	0-14	1946	0.0	25.5	100	82.3	58.1	40.6	23.1	3.5
8.	1	Cutbank	0-20	1964	5.1	20.5	100	80.1	44.4	31.3	15.9	4.0
9.	---	Cutbank	---	1946	---	34.7	100	64.2	33.0	23.1	11.1	3.9
10.	0-1	---	---	---	---	---	---	---	---	---	---	---
11.	0	---	---	1941	---	44.0	100	77.2	47.6	40.3	17.9	3.3
12.	---	---	---	1957	---	---	---	---	---	---	---	---
13.	1	Cutbank	0-7	1957	0.0	10.9	100	---	53.8	30.6	17.6	6.9
14.	1	Cutbank	0-8	1957	3.8	30.8	100	---	25.7	20.3	15.0	4.0
15.	---	---	---	1959	---	---	---	---	---	---	---	---
16.	---	Test hole	0-9	---	0.0	4.5	100	---	62.0	48.1	31.3	9.8
17.	---	Cutbank	0-15	1958	0.0	0.0	100	100	100	99.9	99.2	61.5
18.	---	---	---	---	---	---	---	---	---	---	---	---
19.	1-3	Cutbank	---	1964*	0.0	19.9	100	73.7	46.6	32.7	9.9	5.1
20.	1	Cutbank	---	1964*	0.0	21.2	100	76.8	45.3	29.6	10.2	3.3
21.	1	Test hole	1-7.5	1946	---	10.6	100	48.4	31.7	22.8	11.5	9.2
22.	1	Cutbank	---	1964*	0.0	12.9	100	85.0	53.5	39.0	14.5	7.0
23.	---	---	---	1946	0.0	0.0	100	100	100	99.6	98.5	94.5
24.	1-2	---	---	1952	1.5	11.7	100	---	39.0	30.0	22.0	8.2
25.	1-2	---	---	1953	0.0	13.9	100	---	32.9	17.5	12.5	3.5
26.	0-11	Cutbank	0-15	1959	0.0	92.0	100	---	54.2	29.3	14.9	3.9
27.	0-1	---	---	1953	3.9	9.6	100	---	47.0	28.2	18.1	9.4
28.	1	Cutbank	---	1964*	1.6	16.5	100	71.0	36.7	25.1	9.8	6.3
29.	---	Cutbank	0-20	1964*	5.4	12.0	100	85.7	56.7	44.8	14.1	6.0
30.	1	---	---	1956	13.6	28.5	100	---	28.0	14.8	7.3	1.9
31.	1	Test hole	---	1960	0.0	30.6	100	---	33.6	17.8	9.2	4.7
32.	0	Test hole	0-12	1957	7.7	---	86.1	---	70.2	61.6	51.0	38.2
33.	---	---	---	1950	0.0	14.1	100	---	51.4	37.4	26.3	7.8
34.	1-4	---	---	1956	5.9	19.0	100	---	45.3	30.5	15.5	8.5
35.	0	Test hole	6-10	1956	0.0	28.2	71.8	---	25.2	15.5	11.1	9.0
36.	1	Cutbank	0-50	1960	15.8	44.0	100	65.0	22.4	14.8	8.9	3.7
37.	0	Test hole	0-7	1957	15.1	---	84.7	---	78.9	77.0	65.6	55.2
38.	0	Cutbank	---	1964*	0.0	16.9	100	68.5	33.0	24.4	19.4	15.7
39.	0	Cutbank	0-5	1964*	2.3	13.4	100	69.5	38.2	28.9	9.2	6.1
40.	0	Test hole	0-6	1957	0.0	4.6	95.9	---	83.1	68.5	58.8	22.6
41.	0	Cutbank	0-10	1964*	0.0	17.5	100	74.5	50.5	42.5	28.4	25.3
42.	0	Cutbank	0-6	1964*	0.0	15.7	100	60.4	32.3	28.1	21.7	14.0
43.	0	Test hole	0-5	1958	0.0	0.0	100	100	100	99.9	99.7	98.4
44.	0	Cutbank	---	1964*	0.0	19.0	100	70.0	37.4	27.6	14.1	8.1
45.	1-2	Test hole	---	1955	13.6	43.0	100	---	49.0	35.0	18.6	6.9
46.	0-1	Test hole	0-6	1952	28.2	53.5	100	---	38.0	26.7	13.5	7.9
47.	0	Test hole	0-9	1952	0.0	12.2	87.7	---	56.6	46.0	31.3	16.3
48.	0-1	Cutbank	0-20	1964*	8.6	41.9	100	68.7	42.4	34.4	20.3	12.2
49.	0	---	---	1961	16.0	36.8	100	74.2	49.6	39.4	19.7	7.8
50.	0	Test hole	0-6	1961	0.0	4.7	95.3	---	87.4	76.2	47.9	26.2
51.	2	Test hole	2.5-8	1961	3.5	24.2	100	82.5	56.5	35.5	17.3	9.2
52.	1	Cutbank	---	1964*	2.3	18.6	100	75.2	49.2	39.4	22.5	9.8
53.	1	Test hole	0-12	1960	0.0	6.2	100	---	49.5	39.0	29.1	20.8
54.	0	Cutbank	0-20	1964*	0.0	7.1	100	70.0	38.5	29.6	19.4	13.1
55.	0	---	---	1962	5.9	21.4	100	80.3	43.6	26.0	4.8	1.3

(continued)

Table 21. Representative sand and gravel test pits, 1964, Utah Department of Transportation for Box Elder County. (continued)

	Liquid Limit	Plasticity Index	Swell	Immersion compression Average P. S. I. Lime Without	With	Abrasion 500 Revolutions	Sodium Sulfate +4	loss -4
1.	19.5	NP	0.01	---	---	19.5	---	---
2.	16.2	NP	0.0	---	---	---	---	---
3.	14.9	NP	---	---	---	---	---	---
4.	17.5	NP	0.005	---	---	25.1	---	---
5.	20.0	NP	0.003	91	36	20.2	1.8	8.2
6.	17.0	NP	0.002	131	235	20.5	2.0	4.8
7.	19.6	NP	0.015	---	---	20.9	2.5	---
8.	20.0	NP	0.004	157	234	26.7	1.8	7.7
9.	17.2	NP	0.032	---	---	29.4	---	---
10.	---	---	---	---	---	---	---	---
11.	---	---	0.015	---	---	39.0	---	---
12.	---	---	---	---	---	25.3	1.32	---
13.	15.5	NP	0.005	---	---	22.8	---	---
14.	16.4	NP	0.001	---	---	23.9	---	---
15.	---	---	---	---	---	20.4	0.0	---
16.	16.6	NP	0.020	---	---	24.5	---	---
17.	19.8	NP	0.67	---	---	---	---	---
18.	---	---	---	---	---	---	---	---
19.	16.0	NP	0.003	93	219	16.98	0.27	2.05
20.	18.0	NP	0.004	166	225	20.0	0.93	3.20
21.	14.8	1.1	0.016	---	---	16.4	---	---
22.	21.0	NP	0.002	67	169	16.0	0.95	3.46
23.	43.6	20.6	2.5	---	---	---	---	---
24.	20.8	NP	0.021	---	---	23.8	---	---
25.	24.8	NP	0.009	244	313	18.0	0.89	5.38
26.	20.1	NP	0.006	---	---	16.0	---	---
27.	19.7	NP	0.014	---	---	20.0	---	---
28.	19.0	NP	0.004	52	268	19.9	1.82	7.29
29.	17.0	NP	0.000	---	---	20.8	0.45	2.30
30.	18.9	NP	0.007	---	---	17.3	---	---
31.	18.5	NP	0.008	---	---	21.3	---	---
32.	22.2	NP	0.35	---	---	---	---	---
33.	25.9	NP	0.021	---	---	22.6	---	---
34.	18.2	NP	0.007	---	---	14.9	---	---
35.	30.5	10.8	---	---	---	---	---	---
36.	20.0	NP	0.008	---	---	18.0	---	---
37.	38.5	8.4	1.74	---	---	---	---	---
38.	34.0	3.0	0.007	183	261	13.8	9.25	11.58
39.	20.0	NP	0.001	---	---	20.4	1.55	13.05
40.	32.7	NP	0.73	---	---	---	---	---
41.	17.0	NP	0.008	---	---	24.3	3.62	5.46
42.	35.0	10.0	0.014	---	---	16.6	1.24	14.57
43.	36.0	10.4	---	---	---	---	---	---
44.	19.0	NP	0.003	131	209	21.7	1.50	6.29
45.	19.7	NP	0.010	---	---	23.7	---	---
46.	22.0	NP	0.018	---	---	23.7	---	---
47.	26.2	NP	---	---	---	---	---	---
48.	30.0	9.0	0.035	0	0	24.4	3.54	6.07
49.	20.8	NP	0.013	---	---	24.6	---	---
50	18.1	NP	0.2	---	---	---	---	---
51.	21.7	NP	0.027	---	---	28.2	---	---
52.	19.0	NP	0.003	---	---	23.4	---	---
53.	17.8	NP	0.020	---	---	20.2	---	---
54.	34.0	12.0	0.004	---	---	32.3	16.74	16.74
55.	21.9	NP	0.013	---	---	22.0	---	---

Table 22. Sand and gravel production statistics as recorded by the U. S. Bureau of Mines Mineral Yearbooks for Box Elder County

Sand and Gravel		
Pre-1962	Not recorded	
1962	940,000	$680,000
1963	763,000	612,000
1964	669,000	757,000
1965	807,000	708,000
1966	572,000	589,000
1967	642,000	612,000
1968	873,000	842,000
1969	819,000	801,000
1970	547,000	343,000
1971	635,000	445,000
1972	637,000	472,000
1973	321,000	W
1974	Not listed	
Inc. totals	8,225,000	$6,861,000

W = withheld

to their porosity and permeability, but the units can be divided into classes, here arranged according to their water transmitting capability:

I Unconsolidated and semiconsolidated coarse clastics.
II Consolidated competent formations
III Consolidated incompetent formations
IV Unconsolidated and semiconsolidated fine clastics and clays.

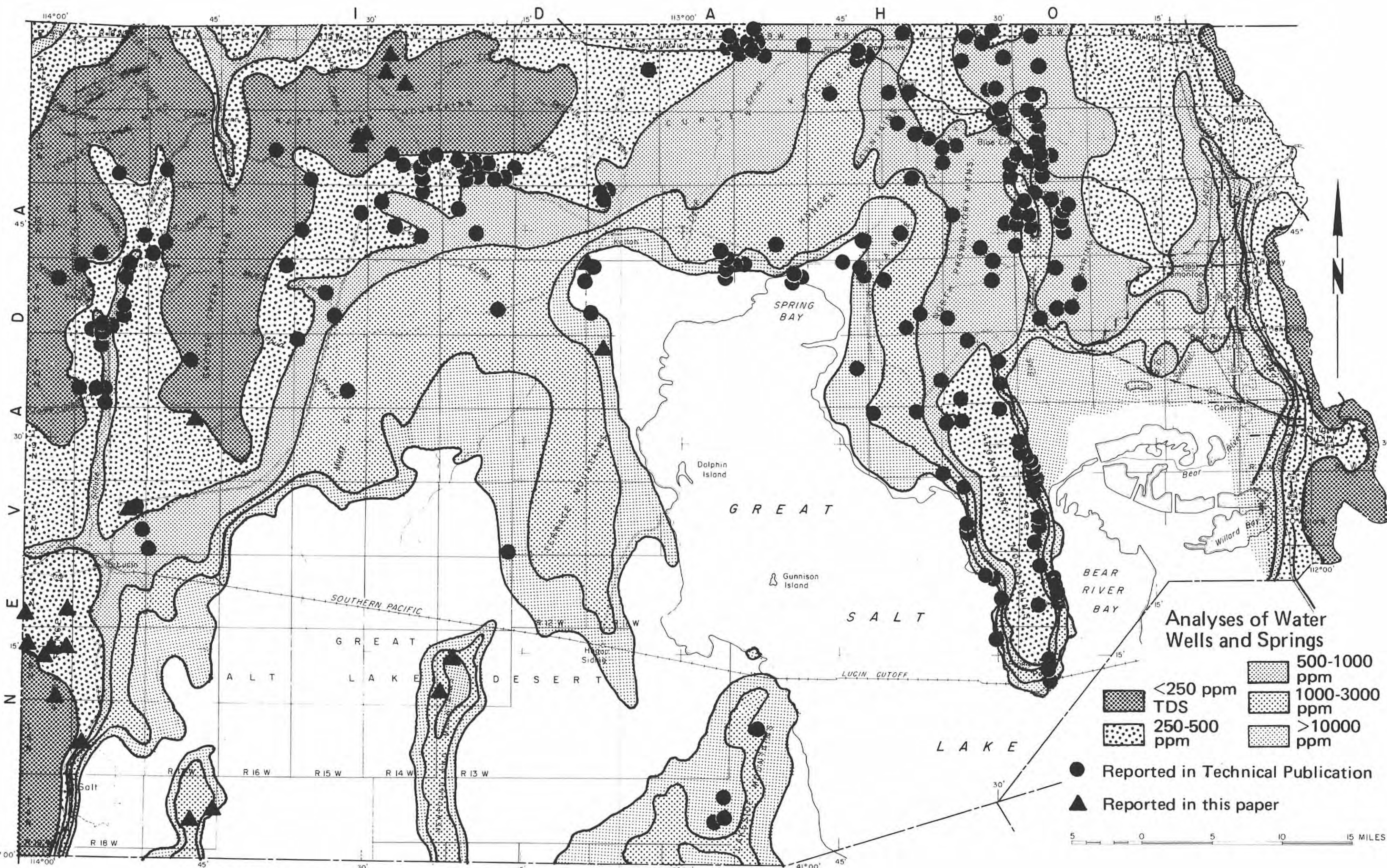
The geologic materials of Class I and IV fill the valleys and basins of the region. The other two dominate in the mountain ranges and rocky knolls. Class I affords the best and most reliable aquifers. The unconsolidated nature of the rock provides for good porosity and permeability. Basically these include many of the Quaternary and Tertiary units. They are interbedded with units of Class IV which act as aquicludes. The percentage of Class I beds is greatest near the high mountains and gradually diminishes basinward. Class II includes most Paleozoic formations and some Precambrian units. Typical rock types are limestone, dolomite, quartzite, conglomerate, and perhaps sandstone. Basically the units are tight, some having been subjected to great regional metamorphism, and even the conglomerates and sandstones are well cemented. They transmit water along bedding planes and fractures, and through solution cavities. The competent units break when subjected to mountain-building forces and these breaks take much time to heal. In geologic history the area has been subjected to many such upheavals. Class III rocks are the schists, shales, siltstones and similarly composed rocks of Precambrian, Paleozoic, and Mesozoic age, that transmit very little water and that react to tectonism by folding rather than breaking and fracturing. Fractures are therefore few, more widely spaced, and some are subject to rapid healing. Granites react somewhere between Class II and III, but most extrusive rocks are Class II. Some of the tuffs in the Tertiary Salt Lake Formation may be excellent aquifers, but if they are decomposed to bentonite they become aquicludes.

The nature of the different classes of aquifers becomes apparent if one traces the movement of the water from mountain to basin, as from the Raft River Mountains southward to the Great Salt Lake Desert. First it seeps slowly through thin soil, from its originating snow bank, into a highly fractured and thin-bedded quartzite. It passes quickly through the fractures and bedding planes to the schist contact and then moves laterally in the quartzite, southward and downward along the dip of the contact. Near the base of the mountain it may emerge from a spring at the rate of a few gallons per minute and flow onto a loamy or clayey alluvial soil. Farther downhill it reaches a gravel and again becomes subterranean. The gravel dips under the valley sediments, confined between two clayey units, and thins basinward, grading into sand, silt, and clay with a resultant loss of porosity and permeability. The movement of the water is slowed and tremendous amounts are evaporated from the surface of the Great Salt Lake Desert. The muds and clays beneath the surface layer of the desert are always saturated and the water is drawn to the surface by capillary action through the drying mud. Shrinkage cracks in the upper surface accelerate the evaporation. Salts from chemical deposits interlayered with the silts and clays of the basin render the water highly saline. The dissolving and reprecipitation of these salts may permit movement of water to the surface through the confining muds.

The best targets for ground water production are the gravelly beds of the valley fill.

Water Quality

Except for the sodium chloride content of the water in the basin fill (salinity increases basinward) the water quality characteristics are similar to those in any other area of Utah. In the higher mountains most water has less than 250 ppm total dissolved solids. Basinward the dissolved material increases gradually and at the edge of the Great Salt Lake or Great Salt Lake Desert, where all vegetation disappers, the dissolved solids content of ground waters reaches 10,000 ppm. The map, figure 102, is developed to be a guide in predicting surface water quality.



NOTE: Wells and springs in Bear River Valley too numerous to show.

Figure 102. Total dissolved solids content in surface and ground waters, Box Elder County.

Table 23. Analyses of spring water, west Box Elder County

No.	Location	Name	Date of Sampling	Flow	Source
1.	SESWSE 8-14N-14W	Wrights Corral Spring	Oct. 17, 1972	several gpm	Limestone in Oquirrh Formation
2.	SESE 17-14N-14W	Spring	Oct. 17, 1972	2 gpm	Alluvium atop Precambrian quartzite
3.	SESW 22-14N-14W	Spring	Oct. 17, 1972	1/2 to 1 gpm	Precambrian quartzite
4.	SESWNW 13-13N-15W	Susannah mine water	Oct. 17, 1972	1 gpm	Prec. schists and quartzites
5.	NENENW 13-13N-15W	Century mine water	Oct. 17, 1972	1 gpm	Prec. schists and quartzites
6.	NWNWNW 24-13N-15W	Spring near Corner Cr.	Oct. 17, 1972	2 gpm	Dove Creek Quartzite
7.	NWSESW 6-11N-11W	Black Butte Spring	Nov. 30, 1972	2 gpm	Lake Bonneville sediments
8.	NWNE 8-10N-11W	Duck Spring	Nov. 30, 1972	Indet.	Lake Bonneville sediments
9.	NENWNW 10-9N-17W	Mud Springs	Sept. 15, 1972	5-10 gpm	Alluvium atop Lower Paleozoic rocks
10.	NWSE 14-8N-18W	Owl Spring	Oct. 18, 1972	Indet.	Lake Bonneville sediments?
11.	NWNENW 25-7N-19W	Coal Bank Springs	Dec. 1, 1972	10 gpm	Diabase dam across Pequop Fm.
12.	NWSENE 33-7N-19W	Crystal Cave water	Aug. 31, 1972	Indet.	Guilmette Limestone
13.	NWNWSW 9-6N-19W	6-shooter Spring	Sept. 14, 1972	1/2 gpm	Alluvium on Laketown Dolomite
14.	NWSE 10-6N-19W	Governors Spring	Aug. 30, 1972	1-2 gpm	Alluvium on Guilmette Limestone
15.	SWNWNE 15-6N-19W	Spring	Sept. 6, 1972	1-2 gpm	Alluvium on monzonite
16.	NESESW 12-6N-19W	Tunnel Spring No. 1	Dec. 1, 1972	10 gpm	Alluvium on monzonite or Pequop Fm.
17.	NESE 35-6N-19W	Patterson Pass Spring	Dec. 1, 1972	5 gpm	Alluvium on Prospect Mtn. Quartzite
18.	SWSENW 17-6N-13W	Spring	Nov. 30, 1972	10 gph	Monzonite
19.	SENW 30-6N-13W	Spring	Nov. 30, 1972	2 gpm	Monzonite
20.	NESE 19-5N-18W	Spring	Dec. 1, 1972	5-10 gpm	Alluvium on Prospect Mtn. Quartzite
21.	SE 13-4N-17W	Desolation Pt. sump	Oct. 23, 1972	No flow	Mudflat
22.	SWSE 22-4N-17W	Spring	Oct. 23, 1972	800 gpd	Quartz monzonite

Table 23. Analyses of spring water, west Box Elder County (continued)

No.	$ECx10^6$ @25°C	pH a	Diss. Solids	SAR	pH c	Sat Index	Ca++	Mg++	Na+	K+	CO_3=	HCO_3-	Cl-	SO_4=
1.	709	7.7	377	1.6	7.2	0.5	3.64	1.16	2.52	0.03	none	4.37	2.29	0.53
2.	433	7.5	219	1.0	7.6	-0.1	2.28	0.81	1.29	0.06	none	2.80	1.08	0.51
3.	238	7.3	114	0.8	8.0	-0.7	1.15	0.53	0.74	0.03	none	1.76	0.35	0.27
4.	190	7.3	96	1.1	8.5	-1.2	0.74	0.28	0.75	0.03	none	0.96	0.62	0.18
5.	196	7.2	97	1.1	8.4	-1.2	0.74	0.30	0.80	0.04	none	1.01	0.65	0.27
6.	304	7.2	148	1.4	8.2	-1.0	1.12	0.44	1.24	0.04	none	1.22	1.26	0.31
7.	37700	7.7	23300	76.0	6.9	0.8	30.00	11.50	346.00	10.25	none	3.35	380.48	9.25
8.	12100	7.7	7080	34.0	7.1	0.6	8.30	9.80	101.00	2.80	none	3.53	113.54	7.00
9.	578	7.9	320	1.1	7.3	0.6	3.00	1.48	1.59	0.05	none	4.15	1.39	0.43
10.	735	7.6	451	2.2	7.4	0.2	2.96	1.04	3.08	0.40	none	4.03	2.36	1.00
11.	629	7.8	350	0.8	7.2	0.6	3.36	2.04	1.25	0.05	none	4.51	1.24	0.90
12.	555	8.0	314	0.8	7.2	0.8	2.51	2.15	1.24	0.08	none	4.21	0.95	0.54
13.	679	8.0	399	0.9	7.2	0.8	3.24	2.44	1.60	0.09	none	4.34	1.70	1.19
14.	633	7.9	372	0.4	7.0	0.9	3.08	3.28	0.70	0.04	none	5.15	0.57	1.36
15.	557	8.0	324	0.4	7.1	0.9	3.80	1.60	0.70	0.03	none	4.65	0.55	0.90
16.	665	7.9	397	0.7	7.0	0.9	3.40	2.96	1.18	0.04	none	5.48	0.87	1.09
17.	372	8.0	215	0.7	7.6	0.4	2.29	0.62	0.85	0.06	none	2.82	0.57	0.39
18.	1400	8.0	752	6.9	7.4	0.6	2.90	1.00	9.70	0.12	none	4.18	7.87	1.60
19.	2770	8.0	1500	11.0	7.1	0.9	4.50	2.10	19.50	0.20	none	5.40	19.52	2.16
20.	450	8.0	254	1.7	7.7	0.3	1.73	0.68	1.90	0.16	none	2.45	1.55	0.43
21.	23900	7.1	15100	56.0	7.6	-0.5	17.40	16.00	222.00	7.00	none	0.74	228.08	25.60
22.	3440	7.5	1950	8.0	7.1	0.4	8.24	3.68	19.40	0.41	none	3.21	26.32	2.24

Analyses by the U. S. Bureau of Reclamation Salt Lake City laboratory completed December 8, 1972. Samples were collected by the Utah Geological and Mineralogical Survey.

In a Sink Valley well in 25-4N-10W the concentration of salt increases with depth (table 14). This information may be of greater value to those who would extract the salt rather than those attempting to find water resources; for the purpose of locating stock wells, the more potable water is nearer the surface and closer to the mountains.

Water quality tables for the various springs and wells in the county are available in the various *Technical Publications* of the Utah Department of Natural Resources, Division of Water Rights. 22 samples collected by the Utah Geological and Mineral Survey in the western part of the county in 1972 were analyzed by the U. S. Bureau of Reclamation (table 23).

REFERENCES

Adams, J. W., 1964a, Thorium and the rare earths, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 115-119.

Adams, J. W., 1946b, Titanium, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 119-120.

Adams, J. W., Pegmatite minerals, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 194-195.

Adams, O. C., 1962, Geology of the Summer Ranch and North Promontory Mountains, Utah: Utah State University M. S. thesis.

Adamson, R. D., C. T. Hardy, and J. S. Williams, 1955, Tertiary rocks of Cache Valley, Utah and Idaho, in Tertiary and Quaternary geology of the eastern Bonneville Basin: Utah Geological Society Guide Book 10, p. 1-23.

Allen, LaRue, 1976, personal communication.

Anderson, A. L., 1931, Geology and mineral resources of eastern Cassia County, Idaho: Idaho Bureau of Mines and Geology Bulletin 14.

Anderson C. C. and H. H. Hinson, 1951, Helium-bearing natural gases of the United States: U. S. Bureau of Mines Bulletin 486, 141p.

Anderson, W. L., 1957, Geology of the northern Silver Island Mountains, Box Elder and Tooele Counties, Utah: University of Utah M. S. thesis.

Anonymous (compiled in cooperation with Hauptman, C. A.), 1949, Location plot of walls drilled in Utah, 1891-1948, in Oil and Gas Possibilities of Utah: Utah Geological and Mineral Survey Symposium, ch. III, pt. 1, p. 127-178.

Armstrong, R. L., 1968, The Cordilleran miogeosyncline in Nevada and Utah: Utah Geological and Mineral Survey Bulletin 78, 58p.

Armstrong, R. L. and others, 1976, K-Ar dates from Arizona, Montana, Nevada, Utah and Wyoming: Isochron-West No. 16, p. 1-6.

Baker, W. H., 1959, Geologic setting and origin of the Grouse Creek pluton, Box Elder County, Utah: University of Utah Ph.D. dissertation.

Beus, S. S., 1958, Geology of the northern part of Wellsville Mountain, northern Wasatch Range, Utah: Utah State University M. S. thesis.

Beus, S. S., 1963, Geology of the central Blue Spring Hills, Utah-Idaho: University of California – Los Angeles, Ph.D. dissertation.

Bissell, H. J., 1970, Realms of Permian tectonism and sedimentation in western Utah and eastern Nevada: American Association of Petroleum Geologists Bulletin, v. 54, p. 285-312.

Blue, D. M., 1960, Geology and ore deposits of the Lucin mining district, Box Elder County, Utah and Elko County, Nevada: University of Utah M. S. thesis.

Bolke, E. L. and Don Price, 1969, Hydrologic reconnaissance of Curlew Valley, Utah and Idaho: Utah Dept. of Natural Resources Tech. Publ. 25.

Bolke, E. L. and Don Price, 1972, Hydrologic reconnaissance of the Blue Creek Valley area, Box Elder County, Utah: Utah Dept. of Natural Resources Tech. Publ. 37.

Boutwell, J. M., 1904, Oil and asphalt prospects in Salt Lake basin, Utah, *in* Emmons, S. F. and C. W. Hayes, 1905, Contributions to Economic Geology: U. S. Geological Survey Bulletin 260, p. 468-479.

Bullock, K. C., 1967, Minerals of Utah: Utah Geological and Mineral Survey Bulletin 76.

Bullock, K. C., 1970, Iron deposits of Utah: Utah Geological and Mineral Survey Bulletin 88.

Buranek, A. M., 1942, Report on the Silver Eagle mine, Box Elder County, Utah: Utah Dept. of Public and Ind. Dev. Circ. 3.

Butler, B. S., 1920, Grouse Creek Range, *in* Ore deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 494-496.

Butler, B. S., 1920, Park Valley district, *in* Ore deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 497-499.

Butler, B. S., 1920, Pilot Range, *in* Ore deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 488-494.

Butler, B. S., 1920, Silver Islet Range, *in* Ore deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 486-488.

Clark, D. L. and others, 1977, Permian-Triassic sequence in northwest Utah: Geology, v. 5, p. 655-658.

Clay, Walter, 1968, The story of Don McGuire's aerial tram: personal report, Ogden, Utah 84404.

Compton, R. R., 1972, Geologic map of the Yost quadrangle, Box Elder County, Utah and Cassia County, Idaho: U. S. Geological Survey Miscellaneous Investigations Series, Map I-672.

Compton, R. R., 1975, Geologic map of the Park Valley quadrangle, Box Elder County, Utah, and Cassia County, Idaho: U. S. Geological Survey Miscellaneous Investigations Series, Map I-873.

Compton, R. R. and others, 1977, Oligocene and Miocene metamorphism, folding, and low-angle faulting in northwestern Utah: Geological Society America Bulletin, v. 88, p. 1237-1250.

Condie, K. C., 1969, Geologic evolution of the Precambrian rocks in northern Utah and adjacent areas *in* Guidebook of northern Utah: Utah Geological and Mineral Survey Bulletin 82, p. 71-90.

Conner, J. G., 1958, A compilation of chemical quality data for ground and surface waters in Utah: Utah State Eng. Tech. Publication 10.

Cook, K. C. and others, 1964, Regional gravity survey of the northern Great Salt Lake Desert and adjacent areas in Utah, Nevada, and Idaho: Geological Society America Bulletin, v. 75, p. 715-740.

Cook, K. L. and others, 1966, Some Cenozoic structural basins in the Great Salt Lake area, Utah, indicated by regional gravity surveys, in the Great Salt Lake: Utah Geological Society Guidebook 20, p. 57-75.

Cook. K. L. and others, 1975, Simple Bouguer gravity anomaly map of Utah: Utah Geological and Mineral Survey Map 37.

Cordell, R. J., 1972, Depths of oil origin and primary migration, a review and critique: American Association Petroleum Geologists Bulletin, v. 56, p. 2029-2067.

Crane, G. W., 1936, Report on Blue Bird Mining Co., Box Elder County, Utah: Private report.

Crawford, A. L. and others, 1948, Kyanite schists of Grouse Creek Range, Box Elder County, Utah: Utah Academy of Science Proc. 25, p. 180-181.

Crittenden, M. D., Jr., 1963, New data on the isostatic deformation of Lake Bonneville: U. S. Geological Survey Prof. Paper 454-E.

Crittenden, M. D., Jr. and others, 1971, Nomenclature and correlation of some Upper Precambrian and basal Cambrian sequences in western Utah and southeastern Idaho: Geological Society America Bulletin, v. 82, p. 581-602.

Dasch, M. D., 1964, Antimony and other minor metals, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 135-144.

Dasch, M. D., 1964, Gem materials, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 169-177.

Doelling, H. H., 1964, Geology of the northern Lakeside Mountains and the Grassy Mountains and vicinity, Tooele and Box Elder Counties, Utah: University of Utah Ph.D. dissertation.

Doelling, H. H., 1972, Goose Creek lignite field, *in* Eastern and Northern Utah Coal Fields: Utah Geological and Mineral Survey Mon. Series No. 2, p. 379-394.

Dolanski, Joseph, 1971, Letter to Utah Geological and Mineral Survey (Aug. 3).

Eardley, A. J., 1938, Sediments of Great Salt Lake: American Association of Petroleum Geologists Bulletin, v. 22, p. 1305-1411.

Eardley, A. J., 1962, Glauber's salt bed west of Promontory Point, Great Salt Lake: Utah Geological and Mineral Survey Special Studies 1.

Eardley, A. J., 1962, Gypsum dunes and evaporite history of the Great Salt Lake Desert: Utah Geological and Mineral Survey Special Studies 2.

Eardley, A. J., 1963, Oil seeps at Rozel Point: Utah Geological and Mineral Survey Special Studies 5.

Eardley, A. J. and Merrill Haas, 1936, Oil and gas possibilities in the Great Salt Lake Basin: Utah Academy Proc. 13, p. 61-80.

Eardley, A. J., Vasyl Gvosdetsky, and R. E. Marsell, 1957, Hydrology of Lake Bonneville and sediments and soils of its basin: Geological Society America Bulletin, v. 68, p. 1141-1202.

Eckel, E. C., 1913, Portland cement resources of Utah, *in* Portland cement materials and industry in the United States: U. S. Geological Survey Bulletin 522, p. 348-349.

Everett, F. D., 1961, Tungsten deposits in Utah: U. S. Bureau of Mines Inf. Circ. 8014.

Ezell, R. L., 1953, Geology of the Rendezvous Peak area, Cache and Box Elder Counties, Utah: Utah State University M. S. thesis.

Felix, Clarence, 1956, Geology of the eastern part of the Raft River Range: Utah Geological Society Guide Book 11, p. 76-97.

Felmlee, J. K. and R. A. Cadigan, 1977, Determination of uranium in source rocks by using radium in Crystal Springs, Great Salt Lake area, Utah: U. S. Geological Survey open-file report.

Feth, J. H., 1955, Sedimentary features in the Lake Bonneville Group in the east shore area near Ogden, Utah: Utah Geological Society Guide Book 10, p. 45-69.

Fouch, T. D., 1979, Character and paleogeographic distribution of Upper Cretaceous (?) and Paleogene nonmarine sedimentary rocks in east-central Nevada, *in* Armentrout, J. M., Cole, M. R., and TerBest, Harry, eds., Cenozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, 15 p., in press.

Gale, H. S., 1910, Supposed deposits of graphite near Brigham, Utah: U. S. Geological Survey Bulletin 430, p. 639-640.

Gale, H. S., 1916, Potash in Salduro salt deposits: Engineering and Mining Journ., v. 102, p. 780-782.

Gelnett, R. H., 1958, Geology of the southern part of Wellsville Mountain, Wasatch Range, Utah: Utah State University M. S. thesis.

Gere, W. C., 1964, Phosphate *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73,

p. 201.

Gilbert, G. K., 1890, Lake Bonneville: U. S. Geological Survey Monograph 1.

Granger, A. E., 1949, Basin and Range area, *in* Oil and Gas Possibilities of Utah: Utah Geological and Mineral Survey, p. 289-333.

Hansen, G. H., and H. C. Scoville, 1955, Drilling records for oil and gas in Utah: Utah Geological and Mineral Survey Bulletin 50, 116p.

Hansen, W. R., 1964, Stone, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 222-228.

Hanson, A. M., 1949, Geology of the southern Malad Range and vicinity in northern Utah: University of Wisconsin Ph. D. dissertation.

Hayes, J. J., 1944, Variscites and phosphates in Utah: Mineralogical Society News Bulletin 5, no. 1, p. 37-47.

Heikes, V. C., 1920, Newfoundland district, *in* Ore Deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 488.

Hess, F. L., 1917, Tungsten minerals and deposits: U. S. Geological Survey Bulletin 652.

Heyl, A. V., 1963, Oxidized zinc deposits of the United States, part 2, Utah: U. S. Geological Survey Bulletin 1135-B.

Heylmun, E. B., 1961a, Rozel Point oil field, *in* Oil and gas fields of Utah, a symposium: Intermountain Assoc. Petroleum Geologists.

Heylmun, E. B., 1961b, Farmington field, *in* Oil and gas fields of Utah, a symposium: Intermountain Assoc. Petroleum Geologists.

Heylmun, E. B., 1963, Oil and gas possibilities of Utah west of the Wasatch and north of Washington County, *in* Oil and Gas Possibilities of Utah, Re-evaluated: Utah Geological and Mineral Survey Bulletin 54, p. 287-301.

Heylmun, E. B., 1965, Reconnaissance of the Tertiary sedimentary rocks in western Utah: Utah Geological and Mineral Survey Bulletin 75, 38p.

Heylmun, E. B., 1966, Geothermal power potential in Utah: Utah Geological and Mineral Survey Special Studies 14, 28p.

Heylmun, E. B., R. E. Cohenour, and R. B. Kayser, 1965, Drilling records for oil and gas in Utah, 1954-1963: Utah Geological and Mineral Survey Bulletin 74, 518p.

Higgins, W. C., 1909, The Century and Susannah mines, Utah: Salt Lake Mining Review, v. 11, p. 19-22.

Hilpert, L. S., 1967, Summary report on the geology and mineral resources of the Bear River Migratory Bird Refuge, Box Elder County, Utah: U. S. Geological Survey Bulletin 1260-C, 10p.

Hilpert, L. S., and M. D. Dasch, 1964, Uranium: Utah Geological and Mineral Survey Bulletin 73, p. 124-132.

Hintze, L. F., 1973, Geologic history of Utah: Brigham Young University Geological Studies, v. 20, part 3, 181p.

Hite, R. J., 1964, Salines, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 206-215.

Hood, J. W. and Don Price, 1970, Hydrologic reconnaissance of Grouse Creek Valley, Box Elder County, Utah: Utah Dept. of Natural Resources Tech. Publ. 29.

Hood, J. W., 1971, Hydrologic reconnaissance of the Park Valley area, Box Elder County, Utah: Utah Dept. of Natural Resources Tech. Publ. 30.

Hood, J. W., 1972, Hydrologic reconnaissance of the Promontory Mountains area, Box Elder County, Utah: Utah Dept. of Natural Resources Tech. Publ. 38.

Howes, R. C., 1972, Geology of the Wildcat Hills, Utah: Utah State University M. S. thesis.

James, H. L. 1972, Subdivision of Precambrian: an interim scheme to be used by U. S. Geological Survey: American Association of Petroleum Geologists Bulletin, v. 56, p. 1128-1133.

Jessup, D. W., 1916, The Lakeview mine, Utah: Engineering & Mining Journal 102, p. 573-576.

Kaliser, B. N., 1976, Final report to the U. S. Geological Survey Earthquake Hazard Reduction Program: Utah Geological and Mineral Survey Report of Inv. 108, 231p.

Ketner, K. B., 1964, Silica, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 218-222.

Ketner, K. B., 1964, Refractory minerals, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 205-206.

Khattab, M. M., 1969, Gravity and magnetic surveys of the Grouse Creek Mountains and the Raft River Mountains area and vicinity, Utah and Idaho: University of Utah Ph.D. dissertation, 195p.

Kiilsgaard, T. H. and A. V. Heyl, 1964, Lead, zinc, and silver, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 96-103.

Kirkham, V. R., 1935, Gas in Washington, Idaho, Oregon, and Utah, *in* Geology of natural gas, a symposium: American Association of Petroleum Geologists, p. 221-243.

Lee, R. L., Elvon Bay, and Paul Holbrook, 1963, Developing a state water plan, Utah's water resources – problems and needs, a challenge: Utah Water and Power Board–Utah State University.

Lemmon, D. M., 1964, Tungsten, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 121-124.

Loughlin, G. F., 1920, Region north of Ogden, Wasatch Range, *in* Ore Deposits of Utah: U. S. Geological Survey Prof. Paper 111, p. 221-225.

MacFarren, H. W., 1909, The Park Valley mining district of Utah: Salt Lake Mining Review, v. 11, p. 17-18.

Mann, D. C., 1974, Clastic Laramide sediments of the Wasatch hinterland, northeastern Utah: M. S. thesis, University of Utah, 112p.

Mapel, W. J. and W. J. Hail, Jr., 1956, Tertiary stratigraphy of the Goose Creek district, Cassia County, Idaho, and adjacent parts of Utah and Nevada: Utah Geological Society Guide Book 11, p. 1-16.

Mapel, W. J. and W. J. Hail, Jr., 1959, Tertiary geology of the Goose Creek district, Cassia County, Idaho, Box Elder County, Utah and Elko County, Nevada: U. S. Geological Survey Bulletin 1055-H, p. 217-254.

McDonald, R. E., 1976, Tertiary tectonics and sedimentary rocks along the transition: Basin Range Province to Plateau and Thrust Belt Province, Utah: Rocky Mtn. Assoc. of Geologists Symposium on Geology of Cordilleran Hingeline, p. 281-317.

Mikulich, M. J. and R. B. Smith, 1974, Seismic reflection and aeromagnetic surveys of the Great Salt Lake, Utah: Geological Society of America Bulletin, v. 85, p. 991-1002.

Minobras, 1974, Colorado and Utah Industrial Minerals: Minobras, Colorado.

Moore, W. J., 1975, Personal communication from Menlo Park (U. S. Geological Survey) on dating of the Crater Island pluton.

Morris, H. T., 1964, Limestone and dolomite, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 188-194.

Mundorff, J. C., 1970, Major thermal springs of Utah: Utah Geological and Mineral Survey Water-Resources Bulletin 13.

Murray, D. K. and L. C. Brotz, 1967, Eagle Springs oil field, Railroad Valley, Nye County, Nevada: American Association of Petroleum Geologists Bulletin, v. 51, p. 2133-2145.

Nolan, T. B., 1927, Potash brines in the Great Salt Lake Desert, Utah: U. S. Geological Survey Bulletin 795, p. 25-44.

Olson, R. H. 1960, Geology of the Promontory Range, Box Elder County, Utah: University of Utah Ph. D. dissertation.

O'Neill, J. M., 1968, Geology of the southern Pilot Range, Elko, County, Nevada, and Box Elder and Tooele Counties, Utah: University of New Mexico M. S. thesis.

Osmond, J. C., and Elias, David W., 1971, Possible future petroleum resources of the Great Basin -- Nevada and western Utah, *in* Cram, Ira H., Editor, Future petroleum provinces of the Unites States, v. 1, p. 413-430: American Association of Petroleum Geologists Memoir 15.

Paddock, R. E., 1956, Geology of the Newfoundland Mountains, Box Elder Couty, Utah: University of Utah M. S. thesis.

Patton, T. L., and Lent, R. L., 1979, *in* Great Salt Lake update, Utah Geological and Mineral Survey Bulletin in press.

Peace, F. S., 1956, History of exploration for oil and gas in Box Elder County, Utah, and vicinity: Utah Geological Society Guide Book 11, p. 17-31.

Pepperberg, L. J., 1911, Variscite near Lucin, Utah: Mineral and Science Press 103, p. 233-234.

Peterson, D. L., 1974, Bouguer gravity map of part of the northern Lake Bonneville Basin, Utah and Idaho: U. S. Geological Survey Miscellaneous Field Studies Map, MF-627.

Peterson, V. E., 1942, Geology and ore deposits of the Ashbrook mining district: Economic Geology, v. 37, p. 466-502.

Piper, A. M., 1923, Geology and water resources of the Goose Creek basin, Cassia County, Idaho: Idaho Bureau of Mines and Geology, Bulletin 6, p. 1-78.

Powers, R. B., 1977, Assessment of oil and gas resources in the Idaho-Wyoming thrust belt, *in* Rocky Mountain thrust belt geology and resources, p. 629-637: Wyoming Geological Association, 29th Annual Field Conference (in conjunction with Montana Geological Society and Utah Geological Association.

Price, Don and E. L. Bolke, 1970, Hydrologic reconnaissance of the Sink Valley area, Tooele and Box Elder Counties, Utah: Utah Dept. of Natural Resources Tech. Publ. 26.

Reeves, R. G., Iron, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, 89-96.

Richardson, G. B., 1904, Natural gas near Salt Lake City, Utah, *in* Contributions to Economic Geology, 1905: U. S. Geological Survey Bulletin 260, p. 480-483.

Rigo, R. J., 1968, Middle and Upper Cambrian stratigraphy in the autochthon and allochthon of northern Utah: Brigham Young University Geology Studies, v. 15, part 1, p. 31-66.

Roberts, R. J., 1964, Copper, *in* Mineral and Water Resources of Utah: Utah Geological and Mineral Survey Bulletin 73, p. 75-83.

Robison, R. A. and A. R. Palmer, 1968, Revision of Cambrian stratigraphy, Silver Island Mountains, Utah: American Association of Petroleum Geologists Bulletin, v. 52, p. 167-171.

Rose, P. R., 1976, Mississippian carbonate shelf margins, western United States: Journal of Research, U. S. Geological Survey, v. 4, p. 449-466.

Salt Lake Mining Review, 1899-1928, Many articles and paragraphs concerning mining activity in Box Elder County. An index is given by Warren, C. W., 1971, Index to the Salt Lake Mining Review, 1899-1928: Utah Geological and Mineral Survey Bulletin 91.

Schaeffer, F. E. and W. L. Anderson, 1960, Geology of the Silver Island Mountains, Box Elder and Tooele Counties, Utah, and Elko County, Nevada: Utah Geological Society Guide Book 15.

Schaller, W. T., 1912, Crystallized variscite from Utah: U. S. Geological Survey Bulletin 509, p. 48-65.

Schaller, W. T., 1916, Lucinite, a new mineral; a dimorphous form of variscite: U. S. Geological Survey Bulletin 610, p. 56-68.

Schreiber, J. F. Jr., 1954, Tertiary well logs in the Salt Lake Desert: Utah Geological and Mineral Survey Reprint 39, 16p.

Siegfus, S. S., 1924, A reconnaissance of the Promontory Point mining district, Utah: University of Utah M. S. thesis.

Slentz, L. W. and A. J. Eardley, 1956, Geology of the Rozel Hills: Utah Geological Society Guide Book 11, p. 32-40.

Smith, R. B., M. J. Mikulich, and R. J. Wold, 1970, Great Salt Lake seismic reflection survey – preliminary results: Eos (Am. Geophys. Union Trans.) v. 51, p. 355.

Sorensen, M. L. and M. D. Crittenden, Jr., 1972, Preliminary geologic map of part of the Wasatch Range near North Ogden, Utah: U. S. Geological Survey Miscellaneous Field Studies, Map MF- 428.

Sorensen, M. L. and M. D. Crittenden, Jr., 1976, Preliminary geologic map of the Mantua quadrangle and part of the Willard quadrangle, Box Elder, Weber, and Cache Counties, Utah: U. S. Geological Survey Miscellaneous Field Studies, Map MF-720.

Southern Pacific Railroad Co., 1964, Minerals for industry – northern Nevada and northwestern Utah, Vol. 1: published by the Land Dept., Geological Survey of the Southern Pacific Railroad.

Stanford field classes (R. R. Compton), various years through 1976.

Stansbury, Howard, 1953, Exploration and survey of the valley of the Great Salt Lake of Utah: Corps of U. S. Army Eng., Washington, p. 108-113.

Stephens, J. C. and J. W. Hood, 1973, Hydrologic reconnaissance of Pilot Valley, Utah and Nevada: Utah Dept. of Natural Resources Tech. Publ. 41.

Stephens, J. C., 1974, Hydrologic reconnaissance of the northern Great Salt Lake Desert and summary hydrologic reconnaissance of northwestern Utah: Utah Dept. of Natural Resources Tech. Publ. 42.

Sterret, D. B., 1911, Variscite near Lucin, Utah: U. S. Geological Survey, Mineral Resources 1910, part 2, p. 894.

Stifel, P. B., 1964, Geology of the Terrace and Hogup Mountains, Box Elder County, Utah: University of Utah Ph. D. dissertation.

Stokes, W. L., 1963, Geologic map of northwestern Utah: Utah State Land Board.

Stowe, C. H., 1972, Oil and gas production in Utah to 1970: Utah Geological and Mineral Survey Bulletin 94, 179p.

Stowe, C. H., 1975, Utah mineral industry statistics through 1973: Utah Geological and Mineral Survey Bulletin 106, 121p.

Stringham, B. F., 1961, Geologic map of the Grouse Creek Mountains and vicinity, Box Elder County, Utah: Utah State Mapping Project.

Thorp, E. M., 1953, Groundwater reconnaissance, Park Valley-Kelton areas, Utah: U. S. Soil Conservation Service, unpublished report.

Todd, V. C. 1978, Geology of parts of Matlin, Prohibition Spring, Red Dome, Runswick Wash, Russian Knoll, Warm Spring Hills quadrangles: preliminary unpublished maps.

Todd, V. R., 1973, Structure and petrology of metamorphosed rocks in central Grouse Creek Mountains, Box Elder County, Utah: Stanford University Ph. D. dissertation.

U. S. Bureau of Mines, 1905-1974, Minerals Yearbooks.

U. S. Bureau of Reclamation, 1973, West Box Elder County, Utah, appraisal report: June, 1973, revised December 1973, Salt Lake City, Utah.

U. S. Geological Survey, 1976, Index of topographic maps of Utah, Dec. 1976.

Utah Dept. of Transportation, 1964, Box Elder County, materials inventory.

White, M. R., 1975, personal communication.

Williams, J. S., 1958, Geologic Atlas of Utah, Cache County, Utah: Utah Geological and Mineral Survey Bulletin 64, 104p.

Williams, J. S., 1959, Phosphate content of the Meade Peak Formation in the Terrace Mountains: Special report for Utah State Land Board.

Young, A. R., 1979, Geology of Goose Creek Mountains and vicinity, Box Elder County, Utah and Elko County, Nevada: University of Utah Ph. D. mapping and dissertation in progress.

Archives Approval No. 8000141
Appropriations No. 01-61-03

UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108

THE UTAH GEOLOGICAL AND MINERAL SURVEY is a Division of the Utah Department of Natural Resources and operates under the guidance of a Governing Board appointed by the Governor from industry and the public-at-large. The Survey is instructed by law to collect and distribute reliable information concerning the mineral resources, topography, and geology of the state, to investigate areas of geologic and topographic hazards that could affect the citizens of Utah, and to support the development of natural resources within the state. The *Utah Code Annotated, 1953 Replacement Volume 5, Chapter 36, 53-36-1 through 12,* describes the Survey and its functions.

The Survey publishes bulletins, maps, a quarterly newsletter, and a biannual journal that describe the geology of the state. Write for the latest list of publications available.

The Survey also sells the colored geologic map of Utah (Army Map Service base, 1:250,000, in four quarters), a project of the College of Mines and Mineral Industries of the University of Utah from 1961 through 1964. It acts as sales agent for publications of the Utah Geological Association and its predecessor organizations, the Utah Geological Society, the Intermountain Association of Geologists, and the Intermountain Association of Petroleum Geologists.

THE SAMPLE LIBRARY is maintained to preserve well cuttings, drill cores, stratigraphic sections, and other geological samples. Files of lithologic, electrical, and mechanical logs of oil and gas wells drilled in the state are also maintained. The library's collections have been obtained by voluntary donation and are open to public use, free of charge.

THE UTAH GEOLOGICAL AND MINERAL SURVEY adopts as its official policy the standard proclaimed in the Governor's Code of Fair Practices that it shall not, in recruitment, appointment, assignment, promotion, and discharge of personnel, discriminate against any individual on account of race, color, religious creed, ancestry, national origin, or sex. It expects its employees to have no interest, financial or otherwise, that is in conflict with the goals and objectives of the Survey and to obtain no personal benefit from information gained through their work as employees of the Survey. For permanent employees this restriction is lifted after a two-year absence, and for consultants the same restriction applies until publication of the data they have acquired.

Plates 1, 2, and 3

Hellmut H. Doelling -- Geology and Mineral Resources of Box Elder County, Utah

B-115

Geology and Mineral Resources

of

Box Elder County, Utah

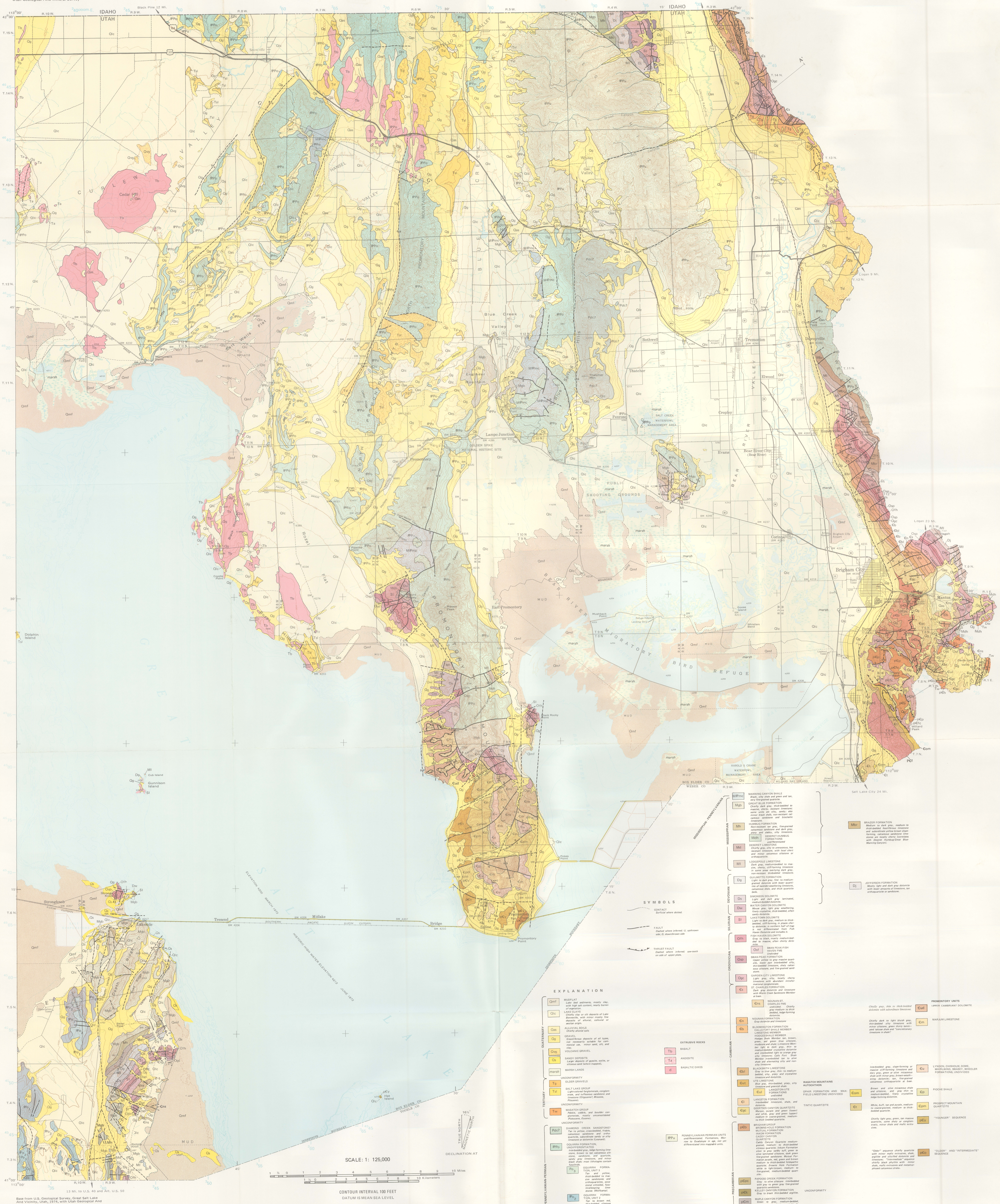
by Hellmut H. Doelling

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of the
UTAH DEPARTMENT OF NATURAL RESOURCES

BULLETIN 115, 1980

STATE OF UTAH
Department Of Natural Resources
Utah Geological And Mineral Survey

Hellmut H. Doelling, Geology and Mineral Resources of Box Elder County, Utah



Base from U.S. Geological Survey, Great Salt Lake And Vicinity, Utah, 1974, with Utah Geological And Mineral Survey additions.

Appropriations Number 016103
Approval Number 7900288

See page 81 and figure 41 on page 82 for authors of source work.

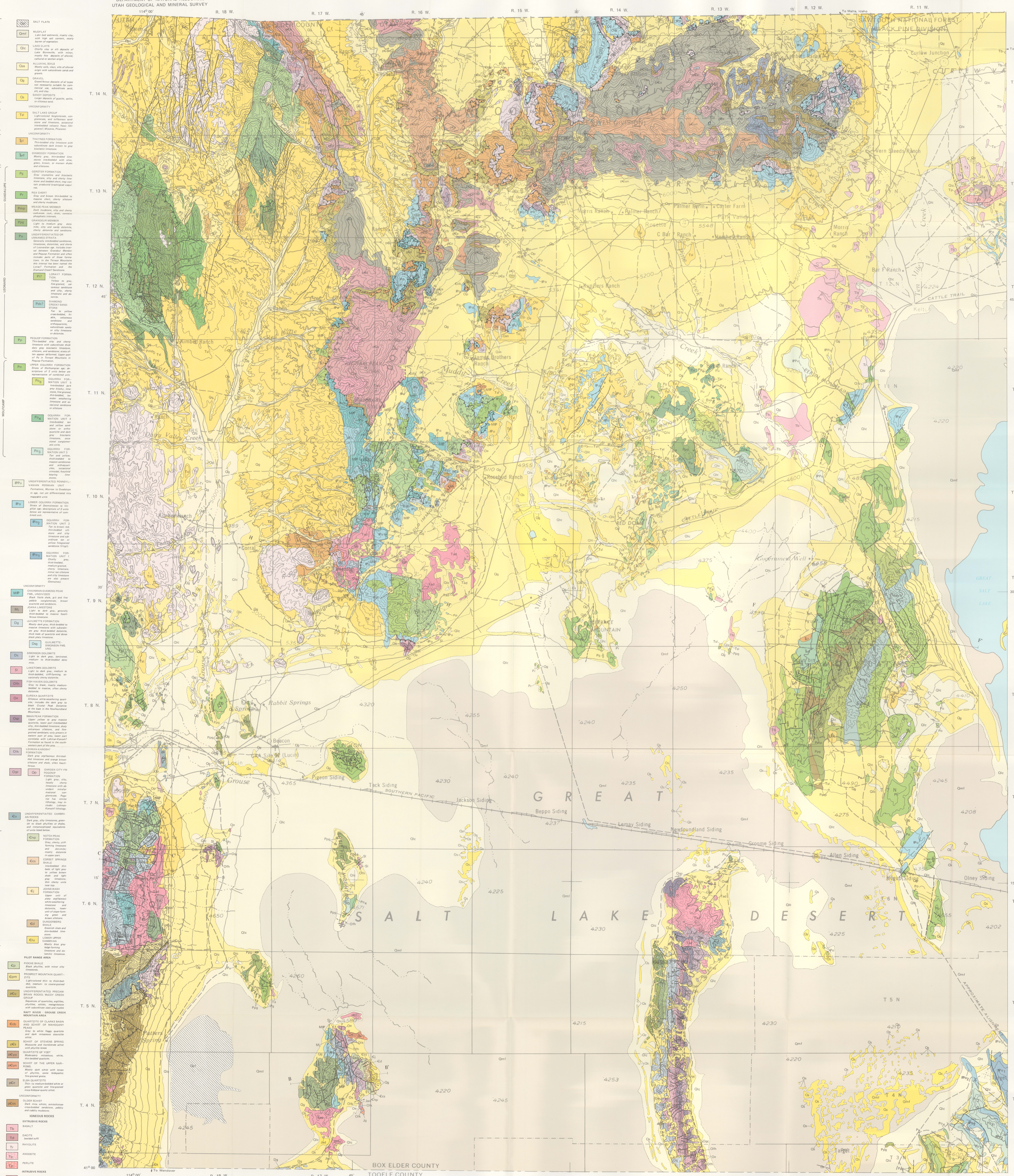
GEOLOGY OF BOX ELDER COUNTY, UTAH
EAST HALF

compiled by Hellmut H. Doelling

1980

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES
UTAH GEOLOGICAL AND MINERAL SURVEY

PLATE 2
Bulletin 115,
Hellmut H. Doelling, Geology and Mineral
Resources of Box Elder County, Utah



Base from U.S. Army topographic maps, Brigham City, Utah; Idaho, 1:250,000, and Tooele, Utah, 1:250,000.

SYMBOLS

CONTACT
Surficial where dotted

FAULT
Dashed where inferred; U, upthrown side; D, downthrown side

THRUST FAULT
Dashed where inferred, saw-teeth on side of upper plate

TRUE NORTH
MAGNETIC NORTH
17°
DECLINATION AT CENTER OF SHEET

SCALE 1:125,000

1 ½ 0 1 2 3 4 5 6 7 8 9 10 MILES

1 ½ 0 1 2 3 4 5 6 7 8 9 10 KILOMETERS

CONTOUR INTERVAL 200 FEET

DATUM IS MEAN SEA LEVEL

GEOLOGY OF BOX ELDER COUNTY, UTAH
WEST HALF

compiled by Hellmut H. Doelling

1980

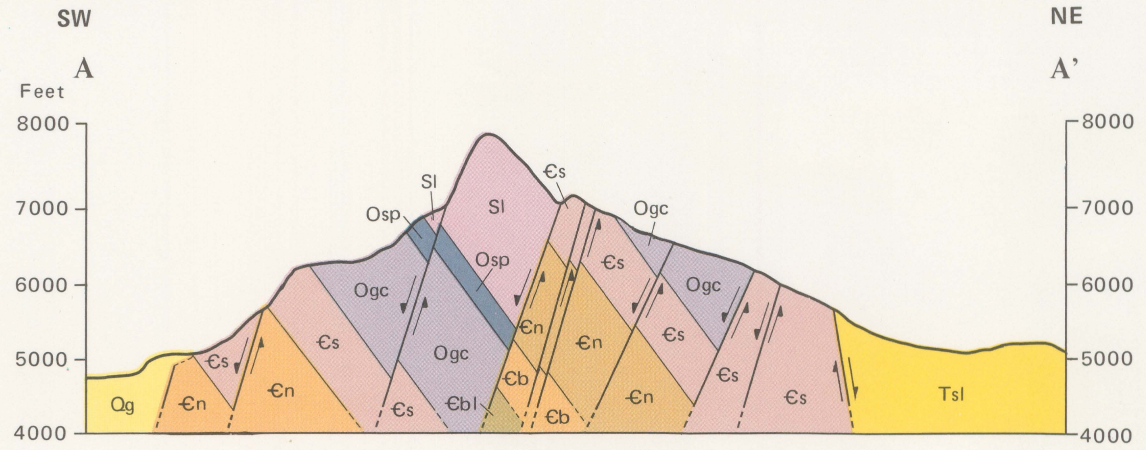
Appropriations Number: 016103
Approval Number: 7900288

Drafted by: B. Jones, S. Stewart & D. Powers

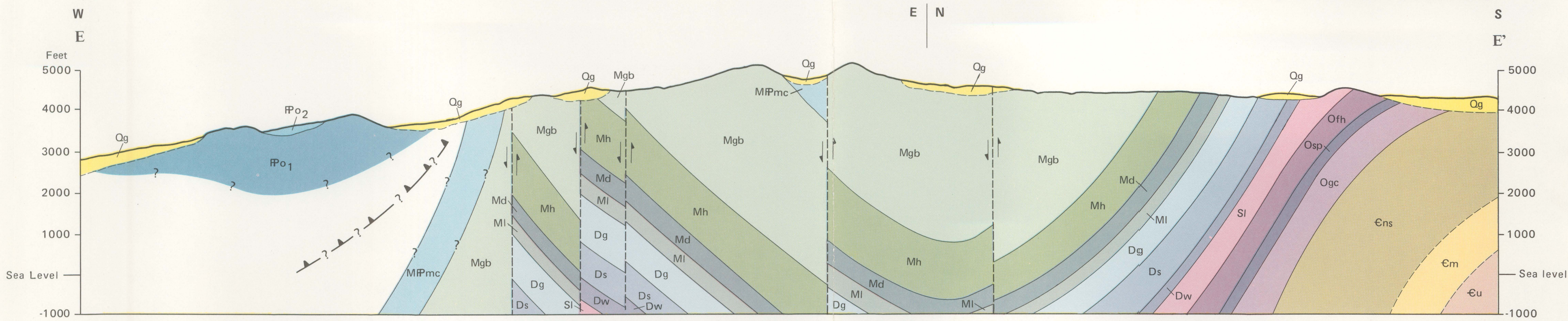
See Plate 3 for cross sections

STATE OF UTAH
Department Of Natural Resources
Utah Geological And Mineral Survey

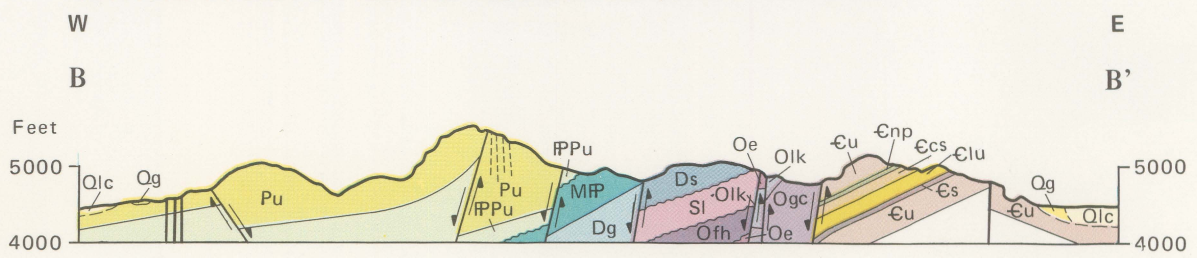
CLARKSTON MOUNTAIN



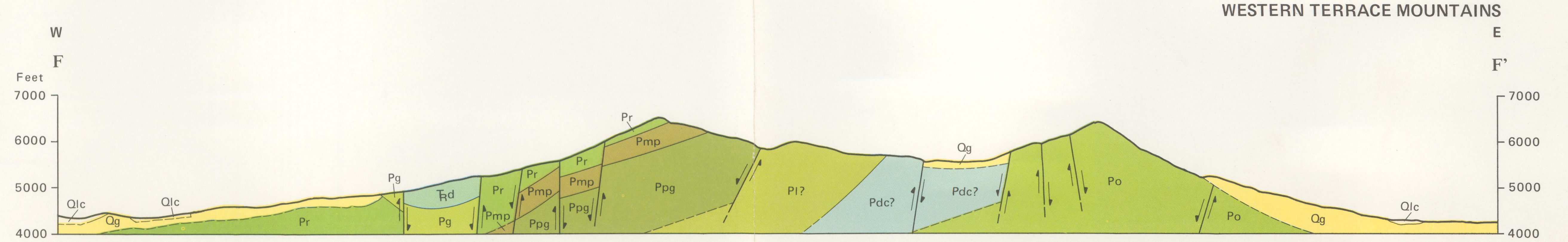
GRASSY MOUNTAINS AND LAKESIDE MOUNTAINS



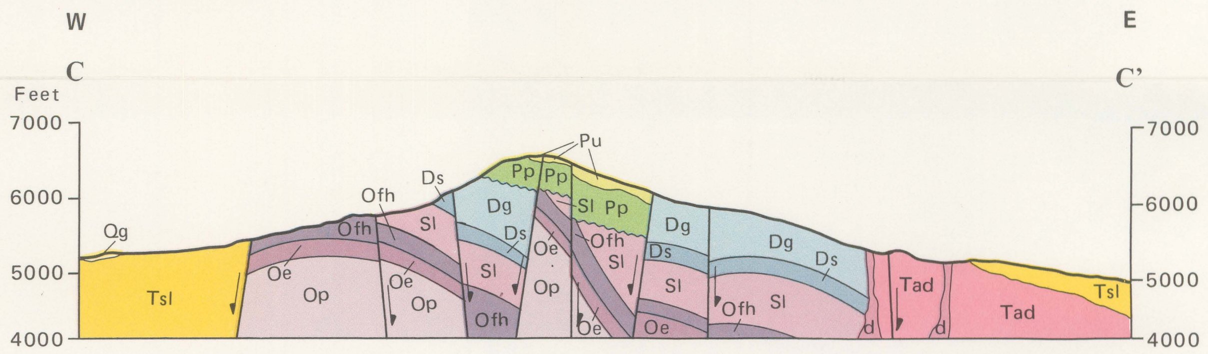
NORTHERN SILVER ISLAND MOUNTAINS (CRATER ISLAND)



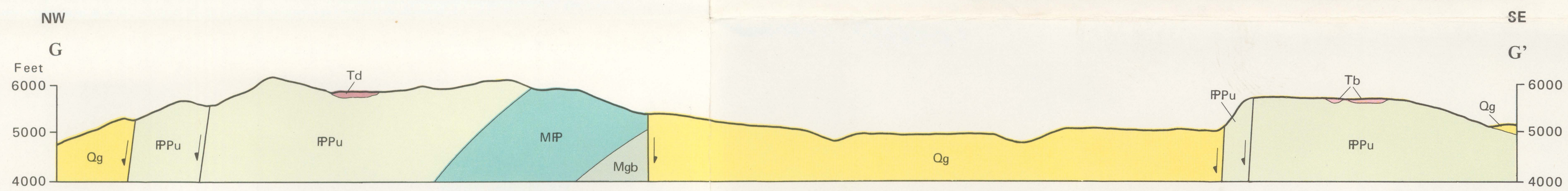
WESTERN TERRACE MOUNTAINS



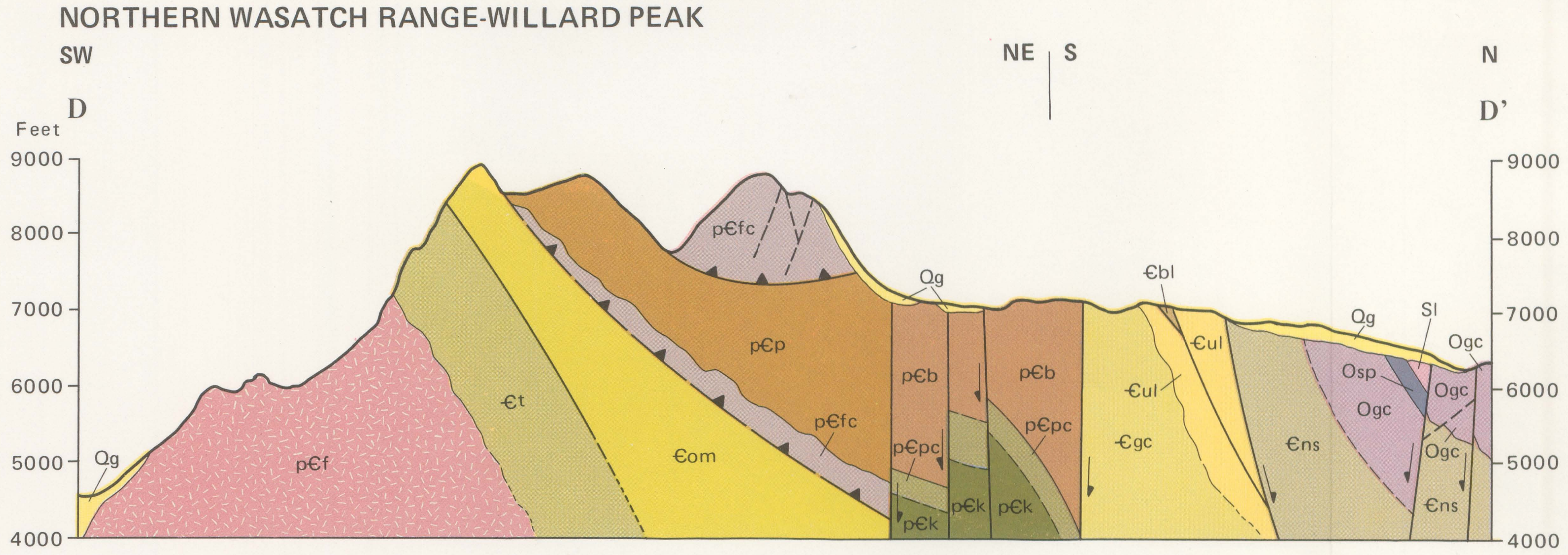
PILOT RANGE



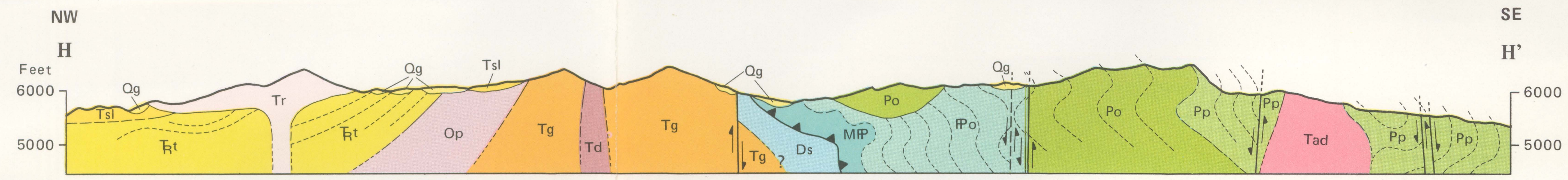
SUMMER RANCH AND NORTHERN PROMONTORY MOUNTAINS



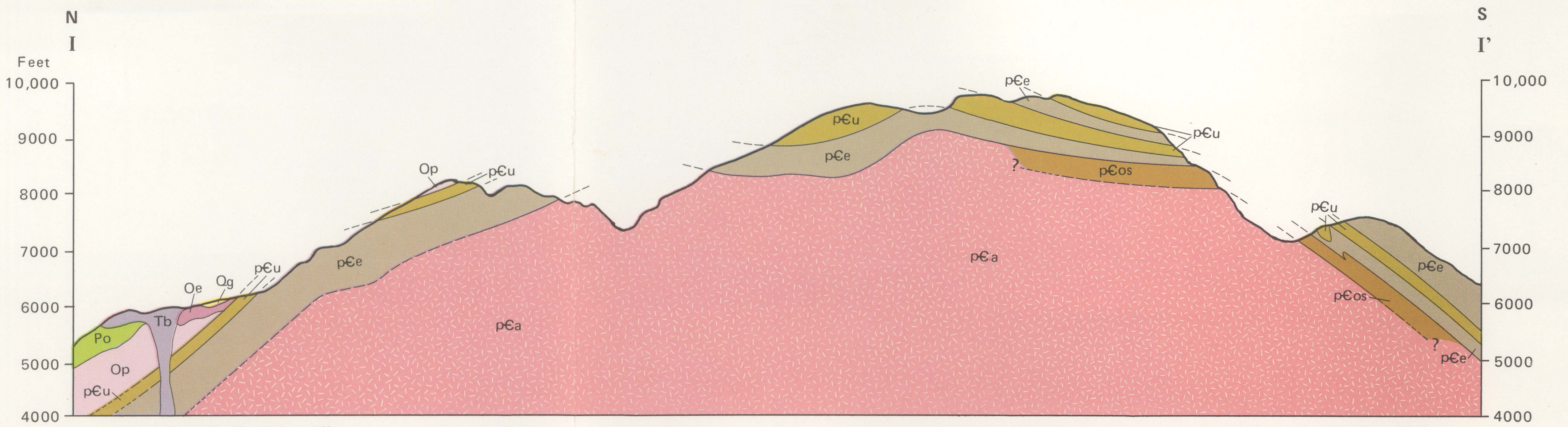
NORTHERN WASATCH RANGE-WILLARD PEAK



SOUTHERN GROUSE CREEK MOUNTAINS



EASTERN RAFT RIVER MOUNTAINS



1 0 1 2 Miles

1 0 1 2 Kilometers

2X VERTICAL EXAGGERATION

CROSS-SECTIONS OF SELECTED MOUNTAIN RANGES, BOX ELDER COUNTY, UTAH

See page 81 and Figure 41 on page 82 for authors of source work.

Drafted by: B. Jones, G. McLaughlin,
S. Stewart and D. Powers

Appropriations Number 016103
Archives Approval Number 7900288