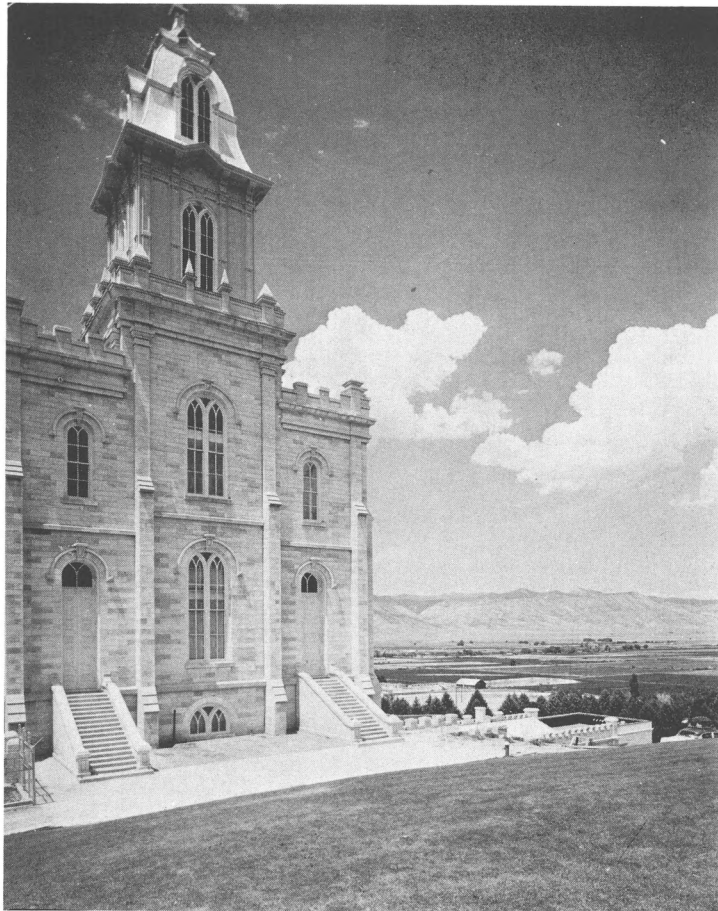


LAND AND MINERAL RESOURCES OF SANPETE COUNTY, UTAH

by Alan R. Pratt and Eugene Callaghan



The Manti Temple is made of local limestone known as Sanpete White, Manti Stone or Sanpete Sandstone.

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
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FOREWORD

Preparation of this bulletin commenced in January 1964, with library research. It was followed by two summers of detailed field investigation in which an effort was made to visit every known prospect pit, and during which time exploration companies contributed generously from their fund of subsurface data. The authors have been through the throes of writing and rewriting, or reinterpreting structural pictures, and the vicissitudes of editing.

Without the patience and understanding of the authors, this bulletin would not have been possible. If, in its final form, it is not precisely what the authors had in mind, I, the UGMS Director, in the interest of having it published without further delay, assume full responsibility.

To all who have contributed to it, the authors, outside contributors, and particularly to the UGMS editorial staff—editors, illustrators, and design assistants, I express my thanks, and in their behalf I express the hope of the Utah Geological and Mineralogical Survey that this Bulletin No. 85, *Land and Mineral Resources of Sanpete County, Utah*, will be of benefit to the residents of Sanpete County.

William P. Hewitt
Director

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LAND AND MINERAL RESOURCES OF SANPETE COUNTY, UTAH

by Alan R. Pratt¹ and Eugene Callaghan²

ABSTRACT

Sanpete County has extensive mineral resources for use as dimension stone, road construction materials and chemical minerals. Further investigation of fossil fuels should be encouraged; evidence of gas has been found, and coal mining was a pioneer industry. Deep oil testing preceded by an understanding of the complex geologic structures should be undertaken. Arable land and groundwater, properly managed, could be put to better use. The human resources of the county could be developed with introduction of new industries and better management of the old ones. The spectacular scenic values and possibilities for recreational development should be explored.

SUMMARY AND RECOMMENDATIONS

It will be obvious to the reader that this investigation is in the nature of a reconnaissance, and, in fact, the principal recommendation is that all facets brought out in this investigation be subjected to much more intensive study and analysis.

Factors worthy of further study in Sanpete County are environmental conditions as they would affect new people and new agricultural and industrial ventures. Facts about the soil and the geologic and scenic features are known. Facts about the climate, warm and dry in the summer and briefly cold and crisp in the winter, are on record even though no particular effort has been made to exploit them. The availability of water, variable in quality and quantity as it is, and the regulation of its use, are factors of prime importance. Industrial minerals, heretofore used in many enterprises ranging from construction of streets, roads and buildings to a frontier coal mining industry to the feeding of poultry, warrant extensive study. Minerals useful in chemical industries in particular should be investigated in connection with potential industries which may be introduced to the county. Locations of specimen minerals of interest to collectors should be made note of by those thinking of developing the recreational potential. Information about all of these features and more has been assembled and presented in the following pages in the

1. Former field chief, Utah Geological and Mineralogical Survey; presently medical intern at Sacred Heart Hospital, Spokane, Washington.

2. Associate director, Utah Geological and Mineralogical Survey.

hope that it will be useful to government agencies, planners and potential investors of money and manpower in Sanpete County.

In spite of the preoccupation with the physical features of Sanpete County, the most important resource of this area is its people.

If it is important that a community prosper, it is important to provide reasons for people to live and work in the community. To make this community a pleasant place to be, recreation must be taken into account. Residents aside, recreation as an industry is worth considering. Sanpete County lies in a strategic location, between the national parks of southern Utah and Salt Lake City. Recreational activities that make people stop—skiing, rock-hunting, camping, hunting, fishing, photography — are all potentially profitable for the county and could be made more so. An extension of this concept is the development of the area as a desirable place to retire to. For many reasons—the dry, warm climate, the clean air, wide open spaces with no bumper-to-bumper traffic, the rural atmosphere—many people of retirement age like to live in such an environment. Whatever their income or requirements, whether a condominium apartment facility, a closely knit community with golf course, shuffleboard and a swimming pool, or an acreage, they would spend money in the county, money that did not cost the county anything. Other states in the Southwest with less to offer have been eminently successful in this area.

In making best use of the resources of Sanpete County with the minimum of damage to and waste of these resources, the importance of cooperation among public and private groups cannot be overemphasized. Experience elsewhere has shown that neither government alone nor private organizations alone can do an adequate job. A workable balance seems to be one where government agencies (U. S. Forest Service, Bureau of Land Management, Soil Conservation Service, Water Pollution Commission, State Highway Department, State water resource and flood control agencies, county road and industrial control agencies, planners and all the others) provide information, advice, a long-range point of view and regulatory control (occasionally in the form of money), and private and citizens' organizations (chambers of commerce, conservation groups, private industry, subdividers, investors, and just people) provide the ideas, the initi-

ative, the drive, and the money for planning and execution of community and private projects.

The tried-and-true and the traditional all have been tried in Sanpete County, often successfully, but human resources diminish and times change, and what worked well when the pioneer farmers and coal miners entered the valleys in the mid-nineteenth century is losing out to changes in our society. Loss of population and income in the county are messages written on the wall in letters too large to be ignored.

BACKGROUND INFORMATION ON SANPETE COUNTY

Vital Statistics

In this section of the report, salient statistics, taken in part from an unpublished profile of Sanpete County by the Bureau of Business and Economic Research, University of Utah, are presented to show the present status of the human response to the geologic environment. This is followed by summary statements of findings with respect to each of the categories of resources with recommendations for their further investigation and development.

The people of Sanpete County have followed the national tendency of rural to urban shift, largely by migration of younger people, so that whereas in 1940, 23.5 percent of the population was 45 years of age or more, in 1960, 35.7 percent was in this age group. Agricultural employment dropped between 1950 and 1964 and nonagricultural employment increased. In the 1960 census, the male labor force is given as 2,693 and the female labor force as 936. The enrollment in county schools fell from 4,230 in 1940 to 3,084 in 1964, but expenditure per student increased from \$75.26 to \$401.08. In 1960, 74 percent of the population had more than a ninth grade education.

Total assessed valuation of property increased from \$11,286,004 in 1950 to \$12,721,378 in 1964. In 1962, personal income sources were labor 49 percent, proprietorship 16 percent, property 18 percent, and transfer payments (pensions, welfare, etc.) 17 percent. Of total wages, government employment accounted for 35.4 percent, trade 10.7 percent, farms 13.8 percent, manufacturing 19.4 percent, and other, 20.8 percent. In spite of the population drop, retail sales increased from \$8,260,000 in 1954 to \$9,694,000 in 1962.

Power facilities in Sanpete County are provided by municipal plants in Fairview, Mount Pleasant, Spring City, Ephraim and Manti. Utah Power and Light Company maintains a 138-KV transmission line across the southwest edge of the county and a 46-KV distribution system in Sanpete and central Sevier valleys with connections to the municipal plants (figure 1).

Maps

Most of the county will be covered by a series of maps in preparation by the U. S. Geological Survey. These maps, drawn to a scale of 1:24,000, will be immensely valuable in the study of geologic formations, engineering structures, plant sites, drainage, water supply and property lines. Already available are planimetric maps published by the U. S. Forest Service, Soil Conservation Service and Bureau of Land Management, and the Utah State Highway Department, and topographic maps on a 1:250,000 scale by the U. S. Geological Survey.

The distribution of geologic formations in Sanpete County is shown on the Geologic Map of Utah (Stokes and others, 1963). Figure 2 is an index map and a map showing areas owned by the state. Detailed maps of small areas appear in several publications cited at the end of this report.

History Since 1849

The colonists were first attracted by the water and the land of Sanpete Valley, well suited to livestock and grain crops. The discovery of coal west of Wales in 1859 brought the Sanpete Valley railroad from Nephi in the early 1870's; it reached Manti in 1893 and the Morrison coal mine near Sterling in 1894. The Union Pacific and Central Pacific railroads were joined in 1869, and the Denver and Rio Grande Western reached Salt Lake City in 1883. The Sevier Valley branch of the Rio Grande was started at Thistle in 1890, reached Manti in 1891, and continued on through the county, reaching the vicinity of Marysvale in Piute County in 1896.

Manti, the county seat, was incorporated in 1851, and Sanpete County was organized in 1852. By 1853 the white population was 765 and by 1895 it was 15,538. Exact population figures are given in table 1. In 1898 there were 1,540 farms; in 1959 there were 999. Improved land totalled 60,000 acres in 1898 of which 35,000 acres were cultivated and 25,000 in meadow. Most of this land was irrigated by 31 canal and ditch companies. In 1959, 57,030

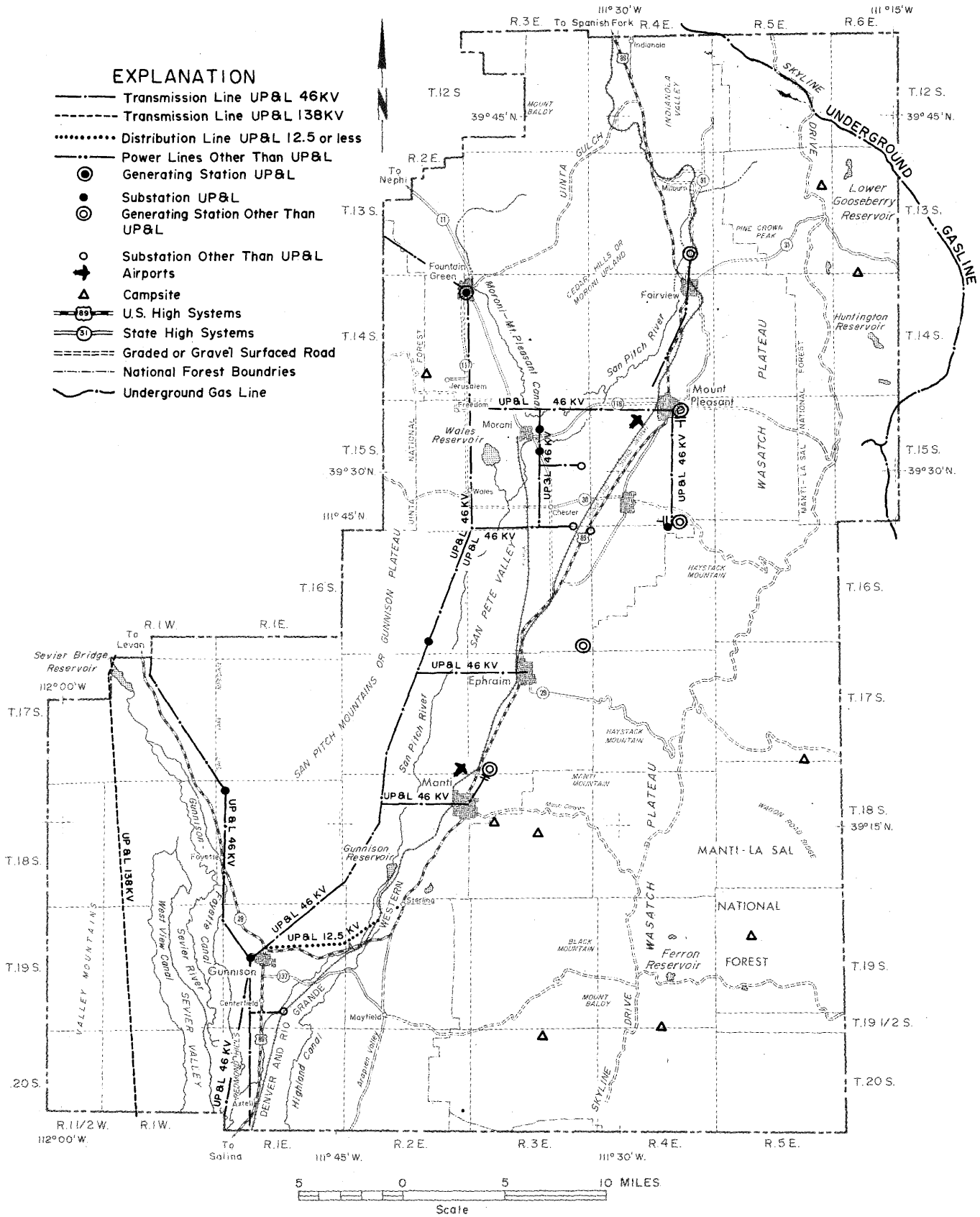


Figure 1. Recreation, transportation, power and pipeline facilities in Sanpete County.

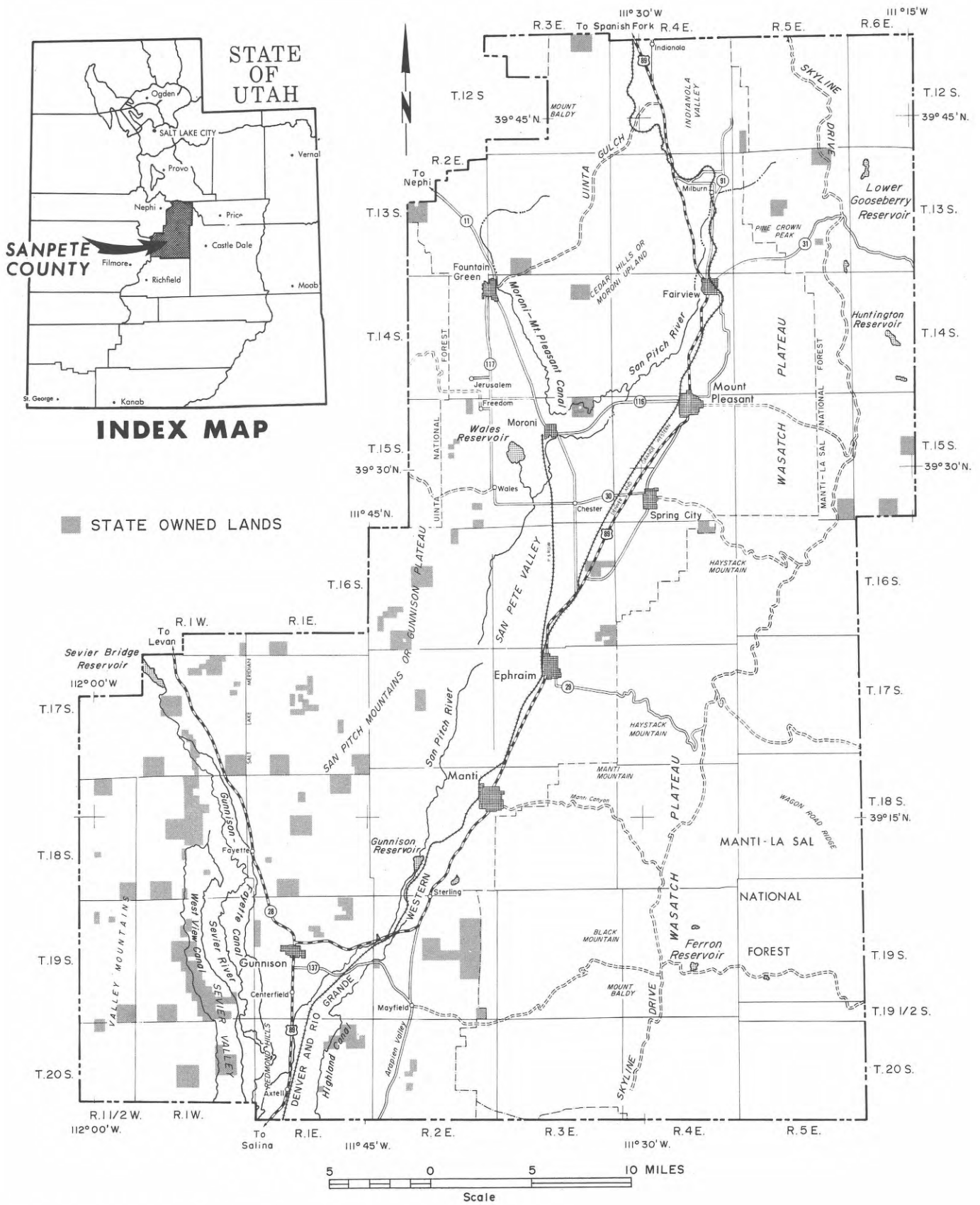


Figure 2. Index map of Sanpete County showing state-owned lands.

Table 1. Population of Sanpete County, 1900-1965

Year	Population
1900	16,313
1910	16,704
1920	17,505
1930	16,022
1940	16,063
1950	13,891
1960	11,053
1965	11,100 (est.)

Town	Population
Ephraim	1,801
Manti (county seat)	1,739
Mount Pleasant	1,572
Gunnison	1,059
Moroni	879
Fairview	655
Fountain Green	544
Centerfield	475
Spring City	463
Mayfield	329
Fayette	161
Sterling	137
Wales	130
Persons per sq. mi.	6.9

acres were reported as cropland harvested. The wool clip was 3 million pounds compared with 1.3 million pounds in 1959.

Lever (1898, p. 35) states that exploitation of coal deposits was an important factor in the growth and development of the county. In 1894 five active coal mines supplied the Salt Lake area. Stone quarrying was begun for construction of the Manti Temple and continued intermittently.

The history of the county since the turn of the century to the twenties was marked by stability, and by population decline since. These changes reflect changes in the pattern of agriculture. Sugar beets were introduced and a sugar factory built in 1917 in Moroni and dismantled in 1937. The sugar factory at Gunnison was opened in 1919; it closed in January of 1961. In spite of high sugar content of the beets, the short growing season limited production to the point that operation of the sugar plants was unprofitable. Livestock continue to be the main money crop.

Sheep have declined and cattle increased. Turkeys are the main source of agricultural income now (table 2).

ROCK UNITS AND GROUPS

The purpose of this discussion is to provide a geologic background and environmental concept of land and mineral resources as an aid in understanding the economic characteristics of the resources and the landscape. The reader should consult the cited references for detailed descriptions and interpretations, particularly Spieker (1946, 1949), Dutton (1880) and Keroher (1966). The results of all available work have been compiled in the four sheets of the Geologic Map of Utah (Stokes and others, 1963). Figure 3 shows the generalized regional correlations through Sanpete County and figure 4, the Cretaceous-Tertiary stratigraphy through the Green River Formation of the region north and east of Sanpete County. Figure 5 gives four structural cross sections through Sanpete County.

Jurassic

Two formations contain Jurassic rocks, mostly of sedimentary origin. The Arapien Shale, which correlates with the Carmel of the standard Colorado Plateau section and the Twin Creek of the Wasatch front, is divided into two members, the lower Twelve Mile Canyon, and the upper Twist Gulch (figure 4). The second formation, the Morrison, forms a ridge west of Sterling.

These rocks of Jurassic age are important economically in Sanpete County as the source of salt in the Redmond Hills and as a possible source of gypsum and shale which in the future may be used commercially. The salts contaminate groundwater, and water in contact with or derived from Jurassic rocks may be unfit for some uses.

Stratigraphic units older than the Arapien Shale have been penetrated by petroleum test wells in the neighboring counties to the east, south and west. It can be assumed with considerable assurance that the Navajo or Nugget Sandstone, the formation immediately beneath the Arapien Shale, underlies the entire county, and that the older Mesozoic formations, many units of Paleozoic age and the Precambrian basement extend throughout the county at great depth.

Cretaceous

In the Cretaceous rocks, the striking feature is a stratigraphic and structural transition (Spieker,

1946, 1949) between the west and the east parts of the county roughly along the central Sevier and Sanpete valleys (figure 4). Coarse clastics (conglomerate and sandstone) dominate the Indianola Group, equivalent in age to sandstone and shale which are in part of marine deposition, in the Wasatch Plateau. Various units in the Indianola are separated by angular unconformities and are sliced by thrust faults. The variations in structure and stratigraphy are interpreted to mean that the region west of Sanpete County was tectonically active in Cretaceous time and supplied clastic sediments rapidly to a subsiding basin of deposition. Irregularities in the rates of relative uplift and subsidence provided breaks in the pattern of deposition of sediments, and unequal pressures on blocks of sediments provided the conditions for thrust faulting. Thrusts of deep-seated origin affected the older rocks and the newly formed sediments (Roberts and others, 1965, p. 1926-1956).

Armstrong (1968, p. 429-458) designated this early Cretaceous structural disturbance the Sevier Orogeny, and included the westernmost part of Sanpete County in the Sevier orogenic belt. Movements on the thrusts for the most part were completed by Upper Cretaceous time.

Rocks of Cretaceous age are important economically in Sanpete County for large coal deposits and for potential petroleum and natural gas. In the Joes Valley gas field, natural gas has been obtained from the Ferron Sandstone Member of the Mancos Shale and from the Dakota Sandstone. The North Horn Formation near Wales and the Six Mile Canyon Formation near Sterling yielded coal. Coal occurs in limited outcrops of the Blackhawk in the southeastern corner of the county and in the Blackhawk Formation east of Mount Pleasant.

Tertiary

Deposition was continuous in the North Horn Formation from Upper Cretaceous into Paleocene time. In Upper Paleocene (Flagstaff) and Eocene (Green River) time the region which had been so active in Cretaceous time became sufficiently quiet to permit lake basins to occupy all of Sanpete County. Variable tectonic activity continued in the Upper Tertiary, and smaller basins formed and received sediments. Near the end of the Tertiary or in the beginning of the Quaternary, Basin and Range-type faulting broke the area into longitudinal blocks which were variably uplifted and depressed, leading to the configuration of the landscape we now see. These movements are continuing as shown by Recent fault scarps along the west side of the Gunnison Plateau in

Table 2. Status and categories of the land and means of livelihood in Sanpete County.

Area: 1,022,000 acres or 1,597 sq. mi. (U.S. Census)

	sq. mi. ^a	percent
Federal land		
Bureau of Land Management	260	16.3
National forests	648	40.6
Coal land withdrawals	36	2.3
State land		
Surface and mineral rights	49	3.0
Mineral rights only	35	2.2
Private land	569	<u>35.6</u>
		100.0
Agricultural land		
Area of alluvial cover		
Central Sevier Valley	100	
Sanpete Valley	225	

	1959		1954	
	acres	percent	acres	percent
Land in farms	654,132		667,457	
Total area in farms		64.0		65.3
Cropland harvested	57,030		66,365	
Cropland harvested to total farmland		8.7		9.9
Cropland pastured	19,189		14,972	
Cropland not pastured or harvested	18,832		16,698	
Total cropland	95,051		98,035	
Irrigated land	59,519		72,301	

	1959	1954
Value of Agricultural Products Sold		
All crops	\$ 736,368	\$ 800,746
All livestock and livestock products	<u>10,879,666</u>	<u>8,810,632</u>
All farm products	\$11,616,034	\$9,611,378

	1959
Percent of Agricultural Income	
Turkeys	34.4
Beets	21.4
Sheep and wool	18.8
Dairy	14.4
Crops	4.0

	1963
Manufacturing	
Establishments	
(3 with more than 20 employees)	17
Number of employees	214
Value added	\$1,631,000

^a Approximations arrived at by the use of a Compensating Polar Planimeter.

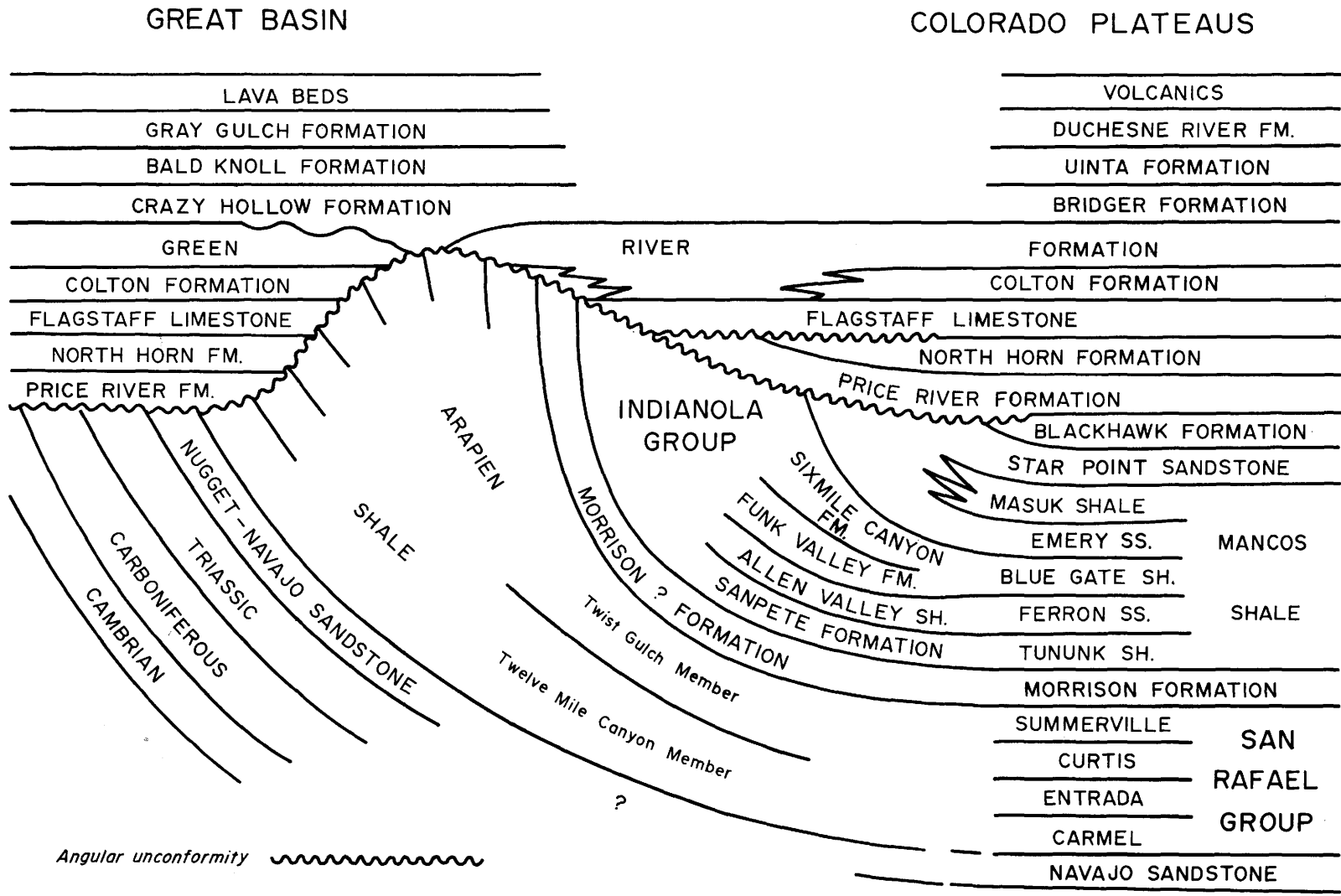
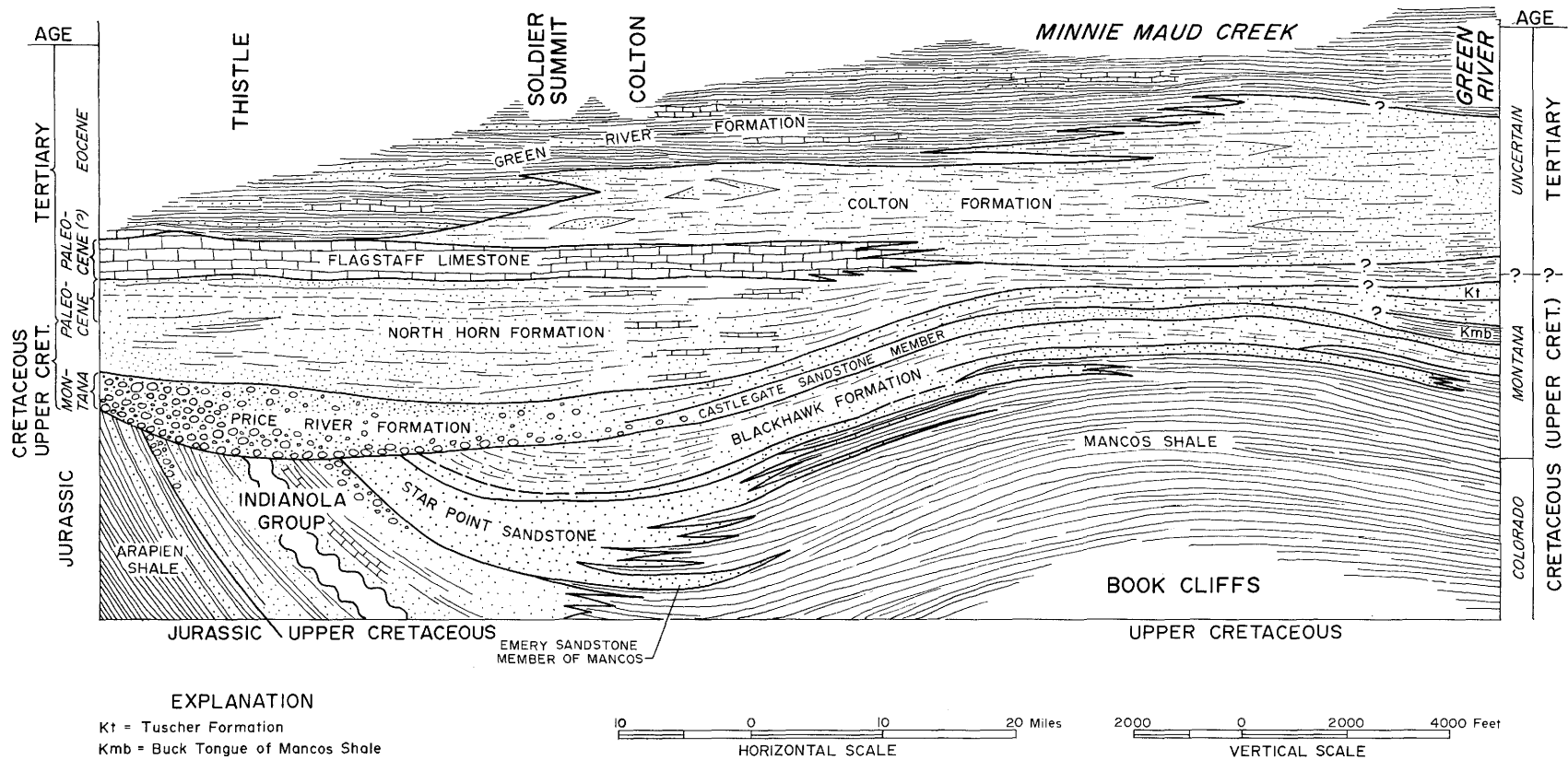


Figure 3. Stratigraphic diagram from Great Basin to Colorado plateaus through Sanpete County showing generalized regional correlations (after Spieker, 1949, figure 2).



EXPLANATION
 Kt = Tuscher Formation
 Kmb = Buck Tongue of Mancos Shale

Figure 4. Stratigraphic diagram of post-Jurassic rocks through area north and east of Sanpete County (after Spieker, 1946, figure 18).

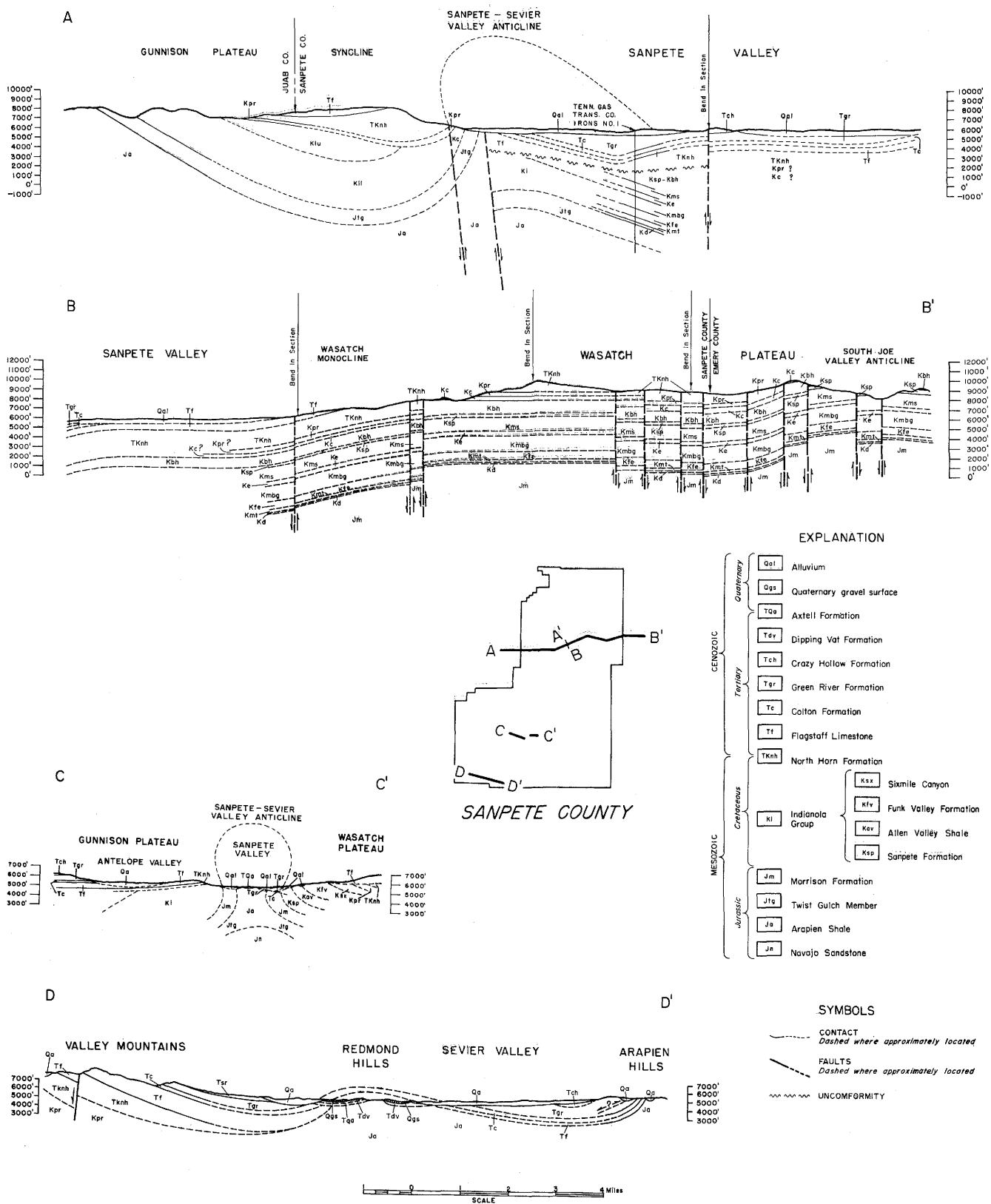


Figure 5. Structural cross sections through northern and southwestern Sanpete County.

Juab County and at the north end of the Pavant Range in Millard County and by recorded, though infrequent, earthquakes (figure 6).

Quaternary

The unconsolidated or partly consolidated Quaternary sediments that fill central Sevier and Sanpete valleys and the smaller basins are valuable as reservoirs for groundwater and as sources of sand, gravel and borrow material for construction purposes. The soil cover on these sediments provides the base for all agricultural activities except grazing and forest crops.

The main valleys owe their configuration to tectonic activity; they probably are still depressed relative to the adjoining highlands and provide receptacles for the debris eroded from the highlands. The process, started during Pleistocene time prior to the highest stage of Lake Bonneville, is still in progress as shown by the many floods recorded in the past 100 years. In Sanpete Valley and the smaller basins, floods deposit boulders and coarse sediment in alluvial fans at the point where the stream reaches the valley and carry the finer materials into the further reaches.

Much of the crest of the Wasatch Plateau has an elevation of 10,000 feet or more and was extensively glaciated in Pleistocene time. The heads of the canyons were rounded out into horseshoe-shaped basins, some of which contain ponds and morainal debris on broad, sloping floors.

STRUCTURAL ARRANGEMENTS AND MODIFICATIONS

Explanatory Statement

The brief description of the complex structures given here includes interpretation and is limited to generalizations which will be modified or changed as knowledge becomes more precise (table 3 and figure 7).

Tertiary and Quaternary Structures

The high plateaus, Wasatch, Gunnison and Valley Mountains, mainly Paleozoic, and the central Sevier and Sanpete valleys comprise the most obvious features of Sanpete County. The Cedar Hills (Moroni Upland) emerge from the Sanpete Valley and rise toward the adjoining Wasatch Range. Tertiary rocks and Quaternary sediments have collected in the San-

pete and central Sevier valleys after having for the most part been stripped by erosion from the uplifted areas.

The central Sevier Valley is an elongate structural depression. Tertiary formations dip toward the valley on both sides and disappear beneath the Quaternary valley fill which is as much as 600 feet deep. Young and Carpenter (1965, plates 1 and 3) state that the portion of the valley in Sevier County is bounded by faults on both sides as the amount of downwarp exceeded the amount of depression that could be accommodated by bending of the strata. In Sanpete County, faults may continue along the face of the Valley Mountains but possibly not along the opposite side of the valley. The strip of Jurassic rocks of the Redmond Hills is interpreted by Young and Carpenter (1965, plate 1) as a narrow wedge thrust upward through the Tertiary section.

Sanpete Valley is an elongate depressed trough filled with Quaternary sediments to a depth of more than 500 feet in the Ephraim—Manti area with bedrock exposed at both ends of the valley west of Sterling and north of Fountain Green (figure 8). An arm of the valley containing the towns of Mount Pleasant and Fairview branches to the north and terminates against a ridge of bedrock separating it from the Indianola Valley at the north end of the county. The valley fill in this arm is shallow and hills of bedrock project through it. It appears that the westward dip of the Wasatch Monocline at the east side of the valley continues beneath it and into the Cedar Mountains on the west side.

The main portion of Sanpete Valley follows the arcuate escarpment of the Gunnison Plateau. On the east side, Tertiary formations dip west into the valley and disappear beneath the Quaternary valley fill. This situation provides optimum conditions for artesian groundwater storage beneath the valley. On the west side of the valley conditions are strikingly different. The North Horn Formation dips west in the lower part of the escarpment, but at the margin of the valley the Price River Formation is turned up vertically in places (figure 4). Outcrops of beds of the Indianola Group accompany the Price River, and outcrops of the Arapien Shale and Twist Gulch Formation appear intermittently. These outcrops of Jurassic rock appear to be continuous with the belt of Arapien Shale that appears at Gunnison Reservoir and continues south into Sevier County. Gilliland (1963, p. 115-124) has interpreted this structure to be a highly compressed anticline. The writers suggest an alternative interpretation of a thrust fault zone to account for the marked facies change between the

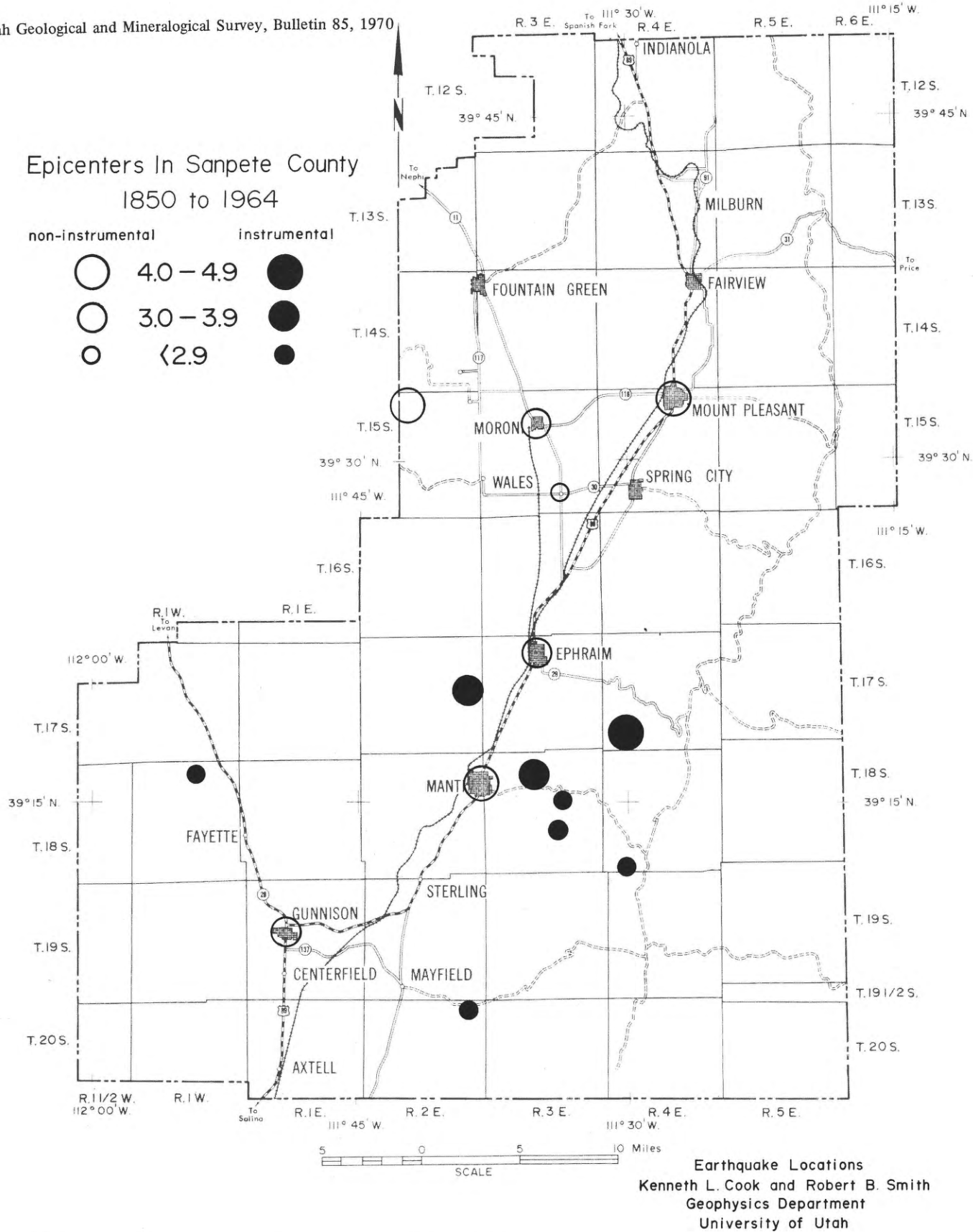


Figure 6. Earthquake epicenters in Sanpete County, 1850-1964.

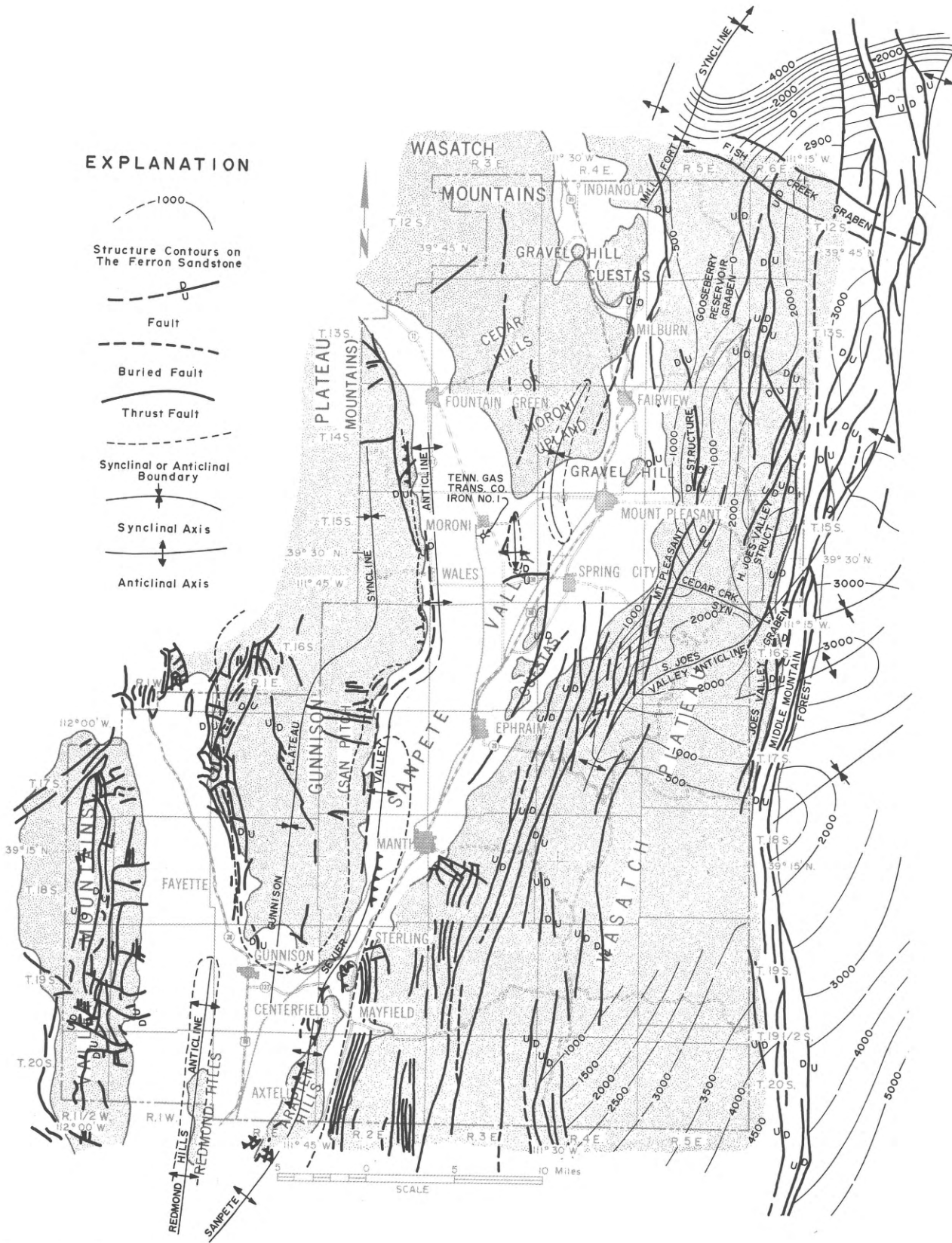


Figure 7. Geologic structure.

Table 3. Stratigraphic column, Sanpete County.

AGE	ROCK UNIT	SYMBOL	GROSS LITHOLOGY	THICKNESS (feet)				
Upper Tertiary	Axtell (Sevier River)	TQa (Tsr)	Poorly indurated conglomerate of pebbles, cobbles, and boulders derived from all.	0-200				
Middle to Upper Tertiary	(Moroni)	T ₁ ap	Complex of poorly indurated sediments consisting of volcanic clastics and quartzite ranging from pebble to large boulder in size. Rare volcanic bedrock outcrops occur.	2,050				
Upper Eocene	Dipping Vat (Gray Gulch)	Tav (Tgg)	Complex of pyroclastics, sandstone, limestone, bentonites, agglomerate	200				
Upper Eocene	Crazy Hollow	Tch	Sandstone, siltstone, shale, local conglomerate sandstone orange to red and salt and pepper.	600-1,000				
Eocene	Goldens Ranch	Tvg	Volcanic conglomerate, welded tuff, minor flows and limestone.	625-725 (?)				
Lower to Middle Eocene	Green River	Tgr	Cream to tan limestone, some oolitic; blue grey to light blue shale; some siltstone and sandstone.	100-4,250 (?)				
Paleocene (?)	Colton	Tc	Sandstone and shales in shades of reds, browns, lavender and bluish grey.	300-1,000 1,600 maximum				
Paleocene	Flagstaff	Tf	Freshwater limestone, dark grey to cream and light tan unfossiliferous, some lithographic; some dark grey, fossiliferous. Minor gypsum, volcanic ash, oil shale, and conglomerate.	300-1,500				
Paleocene - Upper Cretaceous	North Horn	TKnh	Buff sandstones: red, grey, green shales; calcareous siltstone, limestone; coal; minor oil shale and conglomerate.	400-3,000 9,000 maximum				
Upper Cretaceous	Price River	Mesaverde Group	Kpr	Grey, buff, and red conglomerate, sandstone, minor shale.	600-1,300			
	Castlegate					Kc	Light colored sandstone (considered to be basal Price River).	200-350
	Black Hawk					Kbh	Sandstone, shale, coal.	900-2,100
	Star Point					Ksp	Buff to grey massive sandstone and minor black shale.	250-1,100
	South Flat					Ksf	Upper member contains sandstone, limestone, coal. Lower two members contain conglomerate and sandstone.	2,854
	Masuk	Mancos Shale (Reached only in deep wells in Sanpete County)	Kms	Blue black to grey sandy shale with thin sandstone beds.	0-1,300			
	Emery					Ke	Buff massive to thin bedded sandstone.	250-1,600
	Bluegate					Kmbg	Pale blue-green shale with thin sandstone.	0-1,800
	Ferron					Kfe	Buff to white sandstone with grey sandy shale; local lenticular coal.	100-1,000
	Tununk					Kmt	Blue grey to black shale with many sandstone layers.	0-600
	Dakota	Kd	Brownish grey, conglomeritic sandstone.	0-400				
	Six-mile	Indianola Group (Equivalent to Twist Gulch and Arapien -- not exposed in Sanpete County)	Ksx	Buff to grey sandstone and conglomerate local coal.	2,700+			
	Punk Valley					Kfv	Buff to brown limestone; grey shale; local conglomerate.	2,250
	Allen Valley					Kav	Grey marine shale.	620
	Sanpete					Kspt	Buff to grey sandstone; conglomerate; minor shale.	1,350
Morrison	Jm					Varicolored shale, sandstone and conglomerate; white freshwater limestone.	1,800	
Upper Jurassic	Summerville	San Rafael Group (Equivalent to Twist Gulch and Arapien -- not exposed in Sanpete County)	Jsu	Chocolate to reddish-brown sandstone and shale. Some gypsum and minor limestone.	125-331			
	Curtis					Jcu	Grey green conglomerate and shale and grey sandstone.	76-253
	Entrada					Je	Red shale and sandstone; massive red-brown sandstone.	265-844
	Twist Gulch					Jtg	Siltstone, dark red; sandstone, white to grey.	3,000
Jurassic	Arapien	Ja	Red to grey shale, siltstone, sandstone and limestone; local rock salt and gypsum.	<3,000 [±]				
Jurassic - Late Triassic	Navajo	Jna	Red, massive, cross bedded sandstone	400-1,000				

Adapted from: Gilliland (1963), Keroher (1966), Spieker (1949), Utah Geological and Mineralogical Survey, Geologic Map of Utah (Stokes, 1963), Vogel (1957), and Walton (1954).

Mancos section found in the petroleum test well at Moroni (see petroleum section of this report) and the undifferentiated Indianola Group in the Gunnison Plateau only four miles away. It is further suggested that a concealed normal fault terminates the west-dipping Tertiary formations near the west side of the valley, providing a western limit to the artesian groundwater reservoir beneath the valley.

Pre-Tertiary Structures

Formations older than the Tertiary are exposed only in limited outcrops and have been penetrated by a few test wells. Structural arrangements and modifications in Sanpete County can be interpreted from the characteristics of sediments, exposed discontinuities and well records. Observations made outside of the county are useful, supplying explanations of conditions in concealed areas. For a general review of structural history in this area, the reader is referred to Stokes and Heylman (1958, p. 1-37) and Eardley (1963, p. 19-29). The accounts of Spieker (1946, p. 142-160; 1949, p. 39-81; 1954, p. 9-13) apply more specifically to Sanpete County; the cited references describe local structural situations. Roberts and others (1965, p. 1926-1956) have drawn particular attention to prevalence of thrust faults in the Great Basin and its marginal areas.

WATER RESOURCES

Introductory Statement

Water is in good supply in Sanpete County. All available supplies are covered by water rights, and those contemplating agricultural or industrial development should take into account purchase of suitable water rights. Supplies in the portion of central Sevier Valley in Sanpete County may be regarded as limited, but according to Marsell (1958, p. 32), "Because of the great size of the groundwater reservoir in Sanpete Valley, both the alluvial source, already partly developed, and the relatively new source of artesian water from the underlying bedrock, present production can be more than doubled without endangering whatsoever the potential groundwater supply." With careful management, the supply of water could accommodate industrial expansion.

The entire drainage area of the San Pitch River, a major tributary of the Sevier River, and a portion of the Sevier River are included in the county. Numerous permanent and intermittent streams descend into the central Sevier and Sanpete valleys from the

Wasatch Plateau, and intermittent stream courses enter the valleys from the Moroni Upland (Cedar Hills), Gunnison Plateau and Valley Mountains. In recent years the San Pitch River has been dry below Gunnison Reservoir.

The Wasatch Plateau annually intercepts as much as 40 inches of precipitation, much of which is stored as snow for a considerable part of the year (Normal annual precipitation map, 1931-1960, Utah State Engineer and Utah Water and Power Board). Average precipitation on the Gunnison Plateau is 25 inches; in the valley bottoms it averages 12 inches or less. The frequent summer thunder showers add little to the total water supply. As shown on the mean annual runoff map by Bagley (1964, p. 55), 40 inches of precipitation provide an average of 20 inches of runoff, and 25 inches, 8 inches of runoff. Annual precipitation of 12 inches or less yields essentially no runoff. The rise in groundwater level in Sanpete Valley in the last few years (Robinson, 1965, p. 65) is attributed to increase in annual precipitation. Annual losses from evapotranspiration are estimated at 21,000 acre-feet for the Redmond-Gunnison basin, 30,000 acre-feet for the Gunnison-Sevier Bridge Reservoir basin (Young and Carpenter, 1965, p. 49) and 80,000 acre-feet for Sanpete Valley (Marsell, 1958, p. 32).

The earliest comprehensive report on underground water supplies in Sanpete County including central Sevier and Sanpete valleys is that by Richardson (1907) who described the possibilities of artesian supplies in the bedrock. The groundwater conditions in the central Sevier Valley are covered by Young and Carpenter (1965). Sanpete Valley is not included in these recent reports but brief reviews on Sanpete Valley by G. B. Robinson appear in Cooperative Investigations, Report No. 2 (1964) and No. 3 (1965) published by Utah Water and Power Board. A brief but informative account by R. E. Marsell appears in the 6th Biennial Report of Utah Water and Power Board (1958, p. 28-36). Sanpete Valley is currently the subject of intensive groundwater investigations by G. B. Robinson. During the summer of 1964 the senior author examined many of the springs described by Richardson (1907), additional springs located by the U. S. Forest Service and the U. S. Geological Survey, and many others not previously mapped or described. Locations of these springs are listed in table 4. Temperature and discharge data on the springs are taken from the cited references, from Stearns and others (1937, p. 182) and the writer's observations.

Table 4. Springs in Sanpete County.

Location				Discharge		Source
1/4	Sec.	Township	Range	Gal/Min	Sec/Ft	
SW	6	12S	3E			U. S. F. S.
SE	10	12S	3E	Trickle		U. S. G. S.
SE	10	12S	3E	Trickle		U. S. G. S.
NE	22	12S	3E			U. S. F. S.
NW	27	12S	3E			U. S. G. S.
SW	32	12S	3E			U. S. F. S.
NE	34	12S	3E			U. S. F. S.
NE	7	12S	4E			U. S. F. S.
NW	8	12S	4E			U. S. G. S.
SW	8	12S	4E			U. S. F. S.
SW	8	12S	4E			U. S. F. S.
SW	5	12S	5E			U. S. G. S.
SE	4	12S	6E			U. S. F. S.
NW	1	13S	2E			U. S. F. S.
SW	1	13S	2E			U. S. G. S.
SW	1	13S	2E			U. S. G. S.
NE	14	13S	2E			Disc. in field
NW	4	13S	3E			U. S. G. S.
NW	6	13S	3E			U. S. F. S.
NW	13	13S	3E	Dry 9/13/64		U. S. G. S.
SE	18	13S	3E			Disc. in field
NE	22	13S	3E			U. S. F. S.
NE	25	13S	3E			U. S. F. S.
SW	27	13S	3E			U. S. G. S.
SE	2	13S	4E		0.6	Richardson (1907)
NE	11	13S	4E		12.1	Richardson (1907)
SE	11	13S	4E	20 [±]		Richardson (1907)
NW	12	13S	4E		12.1	Richardson (1907)
NW	17	13S	4E			U. S. G. S.
SW	29	13S	4E	3 [±]		Disc. in field
SW	3	13S	5E			U. S. F. S.
SE	4	13S	5E			U. S. F. S.
SW	7	13S	5E			Disc. in field
NE	10	13S	5E			U. S. F. S.
SW	11	13S	5E			U. S. F. S.
NE	11	13S	5E			U. S. F. S.
SW	14	13S	5E			U. S. F. S.
NW	16	13S	5E			U. S. F. S.
NE	17	13S	5E			U. S. F. S.
NW	17	13S	5E			U. S. F. S.
NE	19	13S	5E			U. S. F. S.
SW	20	13S	5E			U. S. F. S.
NW	21	13S	5E			U. S. R. S.
NE	32	13S	5E	Trickle		Disc. in field
NW	2	14S	2E		12.37	Richardson (1907); U. S. G. S.
NW	9	14S	2E			U. S. G. S.
SE	11	14S	2E			U. S. G. S.
NE	21	14S	2E			U. S. F. S.
NW	21	14S	2E			U. S. F. S.
SE	21	14S	2E			U. S. F. S.
SW	21	14S	2E			U. S. G. S.
NE	23	14S	2E		1.53	Richardson (1907)

Location				Discharge		Source
1/4	Sec.	Township	Range	Gal/Min	Sec/Ft	
SE	26	14S	2E		0.15	Richardson (1907)
NW	27	14S	2E			U. S. G. S.
SW	27	14S	2E			U. S. F. S.
SE	27	14S	2E			U. S. F. S.
NE	34	14S	2E			U. S. F. S.
SW	34	14S	2E			U. S. G. S.
NE	12	14S	3E			U. S. G. S.
SW	14	14S	3E			U. S. F. S.
NE	23	14S	3E	12		Richardson (1907); U. S. G. S.
SW	11	14S	4E		0.25 [±]	Richardson (1907)
SE	22	14S	4E		0.15 [±]	Richardson (1907)
NW	27	14S	4E		0.2	Richardson (1907)
NW	27	14S	4E		0.27	Richardson (1907)
NW	27	14S	4E	1.5		Richardson (1907)
SW	28	14S	4E		0.61	Richardson (1907)
NE	2	15S	2E			Richardson (1907)
SW	9	15S	2E			U. S. F. S.
NW	13 ^a	15S	2E		0.35	Richardson (1907); Stearns et al. (1937); U.S.G.S.
SW	13 ^a	15S	2E		0.08	Richardson (1907); Stearns et al. (1937)
NW?	24 ^a	15S	2E		0.45	Richardson (1907); Stearns et al. (1937); U.S.G.S.
SE	26	15S	2E	5 [±]		Disc. in field
NE	27	15S	2E	3 [±]		Disc. in field
NE	27	15S	2E	10 [±]		Disc. in field
SW	4	15S	3E		2.4	Richardson (1907); U. S. F. S.
NE	5	15S	3E		0.6	Richardson (1907)
SW	25	15S	3E			U. S. G. S.
NW	3	15S	4E		0.21	Richardson (1907)
SE	5	15S	4E	20 [±]		Richardson (1907)
SE	5	15S	4E	270 [±]		Richardson (1907)
SW	7	15S	4E		3.8	Richardson (1907)
NE	8	15S	4E		0.9	Richardson (1907)
NW	11	15S	4E	20 [±]		Richardson (1907)
SE	12	15S	4E		2.3?	Richardson (1907)
SE	18	15S	4E			U. S. G. S.
SW	29	15S	4E	4 [±]		Richardson (1907)
SW	29	15S	4E	16		Richardson (1907)
SW	29	15S	4E	27		Richardson (1907)
SE	30	15S	4E	4 [±]		Richardson (1907)
SE	31	15S	4E	44		Richardson (1907)
NW	32	15S	4E	30		Richardson (1907)
SW	32	15S	4E	20 [±]		Richardson (1907)
NW	36	15S	4E	20		Richardson (1907)
SW	6	15S	5E	40		Richardson (1907)
SE	30	15S	5E	1/2 [±]		Richardson (1907)
NE	5	16S	2E	25 [±]		Disc. in field
NW	5	16S	2E	25 [±]		Disc. in field

Table 4. continued

Location				Discharge		Source
1/4	Sec.	Township	Range	Gal/Min	Sec/Ft	
SE	35	18S	2E	Seep		Disc. in field
NE	7	18S	3E	60 ⁺		Richardson (1907)
NW	17 ^a	18S	3E	8		Richardson (1907)
NW	17 ^a	18S	3E	20		Richardson (1907)
NW	17 ^a	18S	3E	12		Richardson (1907)
NE	20	18S	3E	5-10		Disc. in field
SW	21	18S	3E	2-3		Disc. in field
NW	29	18S	3E			Disc. in field
SW	34 ^a	18S	3E			Disc. in field
SE	18 ^a	19S	1E	8		Richardson (1907); Stearns et al. (1937)
NE	23	19S	1E	60		Richardson (1907)
NW	1	19S	2E	25		Disc. in field
NW	1	19S	2E	25		Disc. in field
SE	4 ^a	19S	2E	(900) ^b		Richardson (1907); Stearns et al. (1937) U.S.G.S.
NW	5	19S	2E	(3 ⁺)	0.2	Richardson (1907)
SE	5	19S	2E		0.25 [±]	Richardson (1907)
NW	9	19S	2E		2.2	Richardson (1907)
SW	18	19S	2E	180		Richardson (1907)
SW	18	19S	2E		0.15 [±]	Richardson (1907)
SW	18	19S	2E		0.5 [±]	Richardson (1907)
SE	20	19S	2E			Young and Carpenter (1965)
SW	20	19S	2E	Dry		Richardson (1907); U. S. G. S.
NE	29	19S	2E			Richardson (1907)
SE	33	19S	2E		0.14 [±]	Richardson (1907)
SW	36	19S	2E	10 [±]		Disc. in field
SE	28	19S	3E			U. S. F. S.
SW	32	19S	3E			U. S. G. S.
SE	21	19S	4E			U. S. F. S.
NE	25	20S	1E			Young and Carpenter (1965)
NE	4	20S	5E	10 [±]		U. S. F. S.
NE	11	20S	5E	10 ⁻		Disc. in field

Location				Discharge		Source
1/4	Sec.	Township	Range	Gal/Min	Sec/Ft	
NW	5	16S	2E	25 ⁺		Disc. in field
NE	12	16S	2E	6 (5 ⁻)		Richardson (1907)
NE	12	16S	2E	6 (Trickle)		Richardson (1907)
NE	12	16S	2E	6 (5 [±])		Richardson (1907)
SW	18	16S	2E	10 ⁺		Disc. in field
NE	19	16S	2E	10 ⁺		U. S. G. S.
NW	19	16S	2E			Disc. in field
SW	19	16S	2E			Disc. in field
NW	30	16S	2E	10 ⁺		U. S. G. S.
SE	32	16S	2E	5 ⁺		Disc. in field
SE	2	16S	4E			U. S. F. S.
NE	14	16S	4E			U. S. F. S.
SE	10	17S	1E	10 [±]		Disc. in field
SW	11	17S	1E	10 [±]		Disc. in field
NW	14	17S	1E	5 ⁻		Disc. in field
NE	18	17S	3E	Dry		Richardson (1907)
SE	7	17S	4E			U. S. F. S.
SE	8	17S	4E			U. S. F. S.
SW	26	17S	4E			U. S. F. S.
SE	19 ^a	17S	1E			Young & Carpenter (1965)
SW	13 ^a	18S	2E		0.61	Richardson (1907); Stearns et al. (1937)
SW	13 ^a	18S	2E	10 [±]		Richardson (1907); Stearns et al. (1937)
SW	22	18S	2E	10 [±]	1.25 [±]	Richardson (1907)
NE	23 ^a	18S	2E	20		Richardson (1907); Stearns et al. (1937)
SE	23 ^a	18S	2E	20		Richardson (1907); Stearns et al. (1937)
NE	26	18S	2E	7		Richardson (1907)
SW	33	18S	2E		1 [±]	Richardson (1907)
SE	34 ^a	18S	2E		1.2	Richardson (1907)
SE	35 ^a	18S	2E	(2500) ^b	5.64	Richardson (1907); Stearns et al. (1937)

a. Thermal spring

b. Interpolated Richardson (1907)

Surface Water

The average annual flow of the Sevier River near Gunnison is 157,800 acre-feet (1917-1959) and below Sevier Bridge Reservoir is 173,000 (1911-1959; Young and Carpenter, 1965, p. 25). Except for 1958, there has been no outflow of the San Pitch River in recent years, although some contribution is made through returned irrigation diversions.

Water is diverted from San Pitch drainage for irrigation purposes by the Moroni and Mount Pleasant Canal; storage reservoirs are the Wales Reservoir, Gunnison Reservoir northwest of Sterling, Gunnison Highland Reservoir southeast of Sterling, and Funks Lake northeast of Sterling.

Downstream and northward from the mouth of the San Pitch River near Gunnison, the Sevier River flows approximately seven miles northwest to the Sevier Bridge Reservoir. This reservoir is approximately 17 miles long and $\frac{1}{4}$ to $2\frac{1}{2}$ miles wide. When full its area is 10,120 acres and at an 80-foot depth contains 235,962 acre-feet (Woolley, 1947). The greater part of the Sevier Bridge Reservoir lies in Juab County, behind Yuba Dam.

Along its course in Sevier Valley in southwest Sanpete County above the mouth of the San Pitch River, the Sevier River receives only intermittent tributary flow from the Valley mountains and the Gunnison Plateau. A complex of canals, particularly Piute, Westview, and Gunnison-Fayette, directs much of the Sevier basin drainage in this area for irrigation.

Groundwater

The portion of the central Sevier Valley in Sanpete County is divided into two groundwater basins, the Redmond-Gunnison and the Gunnison-Sevier Bridge Reservoir. Sanpete Valley is a single enclosed groundwater basin (figure 8).

Redmond-Gunnison Basin

Young and Carpenter (1965, p. 17-18) describe the Redmond-Gunnison basin, which includes the uppermost two miles of the central Sevier Valley in Sevier County:

The Redmond-Gunnison basin is a Y-shaped depression; its northwest leg extends down the Sevier Valley to about three miles northwest from Gunnison, and its northeast leg extends about seven miles up the San Pitch River northeastward from Gunnison to the Gunnison Reservoir. The basin is 12 miles long and ranges in width from 3 to 8 miles. The downstream boundaries are marked by the northernmost outcrops of the Arapien Shale in the project area.

Their geologic sections show the basin as underlain by the Sevier River or Axtell Formation (figure 5).

Groundwater under artesian conditions occurs almost everywhere in the alluvium and in the Sevier River Formation (Axtell) on the west side of the valley. From west of Axtell north, the artesian area increases in width as the confining silty clay cover extends from the river to the east and the west. About 150,000 acre-feet of groundwater is in storage in the sand and gravel deposits of the Redmond-Gunnison basin, but the amount of water that could be developed annually during a long period of time would probably be less than 1,000 acre-feet (Young and Carpenter, 1965, p. 70-72). Distance to the water table ranges from 10 to 160 feet.

Gunnison-Sevier Bridge Reservoir Basin

This groundwater basin is described by Young and Carpenter (1965, p. 18) as extending from three miles northwest of Gunnison to the Yuba Dam (Sec. 1, T. 17 S., R. 2 W.) about 18 miles and consisting of two smaller basins. The upper basin lies in Sanpete County. The alluvium ranges to 500 feet in thickness near Fayette and consists of fine-grained material deposited in a lake retained by a bedrock constriction across the valley as the Sevier Bridge Reservoir narrows.

Artesian groundwater in the Gunnison-Sevier Bridge Reservoir basin occurs in large quantities in the alluvium in the center of the valley floor and in lesser amounts under water table conditions in the alluvium and in the Sevier River Formation (Axtell) at the sides of the valley floor. The observed water table ranges from 30 to 90 feet below the surface. The confining material in the artesian area is a silty clay ranging in thickness from about 20 to 80 feet, a continuation of the material overlying the artesian area in the Redmond-Gunnison basin. About 300,000 acre-feet of groundwater are stored in sand and gravel deposits in the Gunnison-Sevier Bridge Reservoir

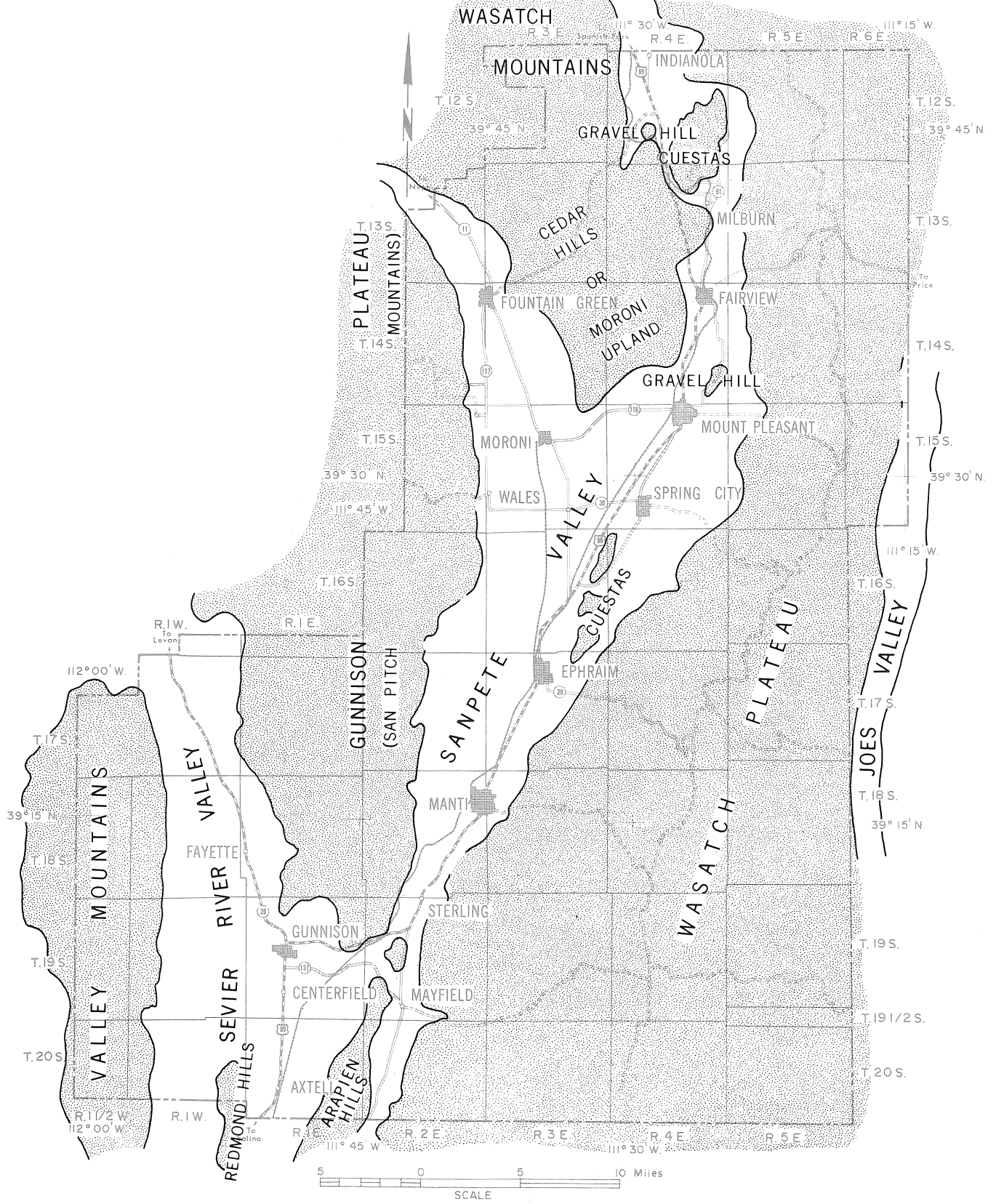


Figure 8. Geomorphic regions.

basin. The best aquifers are the beds of sand and gravel between 40 and 425 feet below the surface. About 15,000 acre-feet of water could be removed annually without greatly affecting the flow of the Sevier River (Young and Carpenter, 1964, p. 72-73).

Sanpete Valley

By definition (Robinson, 1965, p. 61), Sanpete Valley includes the area north of Nine Mile Reservoir near Sterling and the Arapien Valley in which Mayfield is situated. The valley bifurcates north of Ephraim; the northeasterly arm which includes Mount Pleasant is nearly separated from the main valley by breached westward-dipping ridges of the Green River Formation. The widest part (eight miles) of the alluvial valley is at Ephraim. Ridges of bedrock separate Sanpete Valley from central Sevier Valley. The westward dip of sedimentary beds into and beneath both portions of the valley provide optimum conditions for artesian water storage in porous layers of the Green River and Flagstaff formations, particularly as the continuous supply of runoff from the high Wasatch Plateau passes over the exposed edges of these layers. Faults and associated structures along the west side of the valley provide a dam against further westward migration of artesian water, and escape into central Sevier Valley is blocked by bedrock exposures of Green River Formation and Arapien Shale in the vicinity of Sterling. Alluvial fill is more than 500 feet deep in the Ephraim-Manti area (Robinson, personal communication) and provides an easily tapped reservoir of groundwater which is recharged from the drainage along the Wasatch Plateau front on the east and from the Moroni Upland and Gunnison Plateau on the west. At the time of Richardson's investigation in 1906, the water level in the valley floor was mostly 0-10 feet and there was considerable marshland. The water-level contour map by Robinson (1965, p. 63) shows the water in the valley fill still close to the surface in the low parts of the valley.

Robinson reports that in 1964, 1,500 wells in the valley had an average discharge of 2 gallons per minute. Total production in 1964 was about 16,000 acre-feet distributed as shown below. Well discharge in 1965 was reduced to 12,000 acre-feet owing to above-normal precipitation.

The 16,000 acre-feet in 1964 were used as shown below:

Water use	Acre-feet
Irrigation	11,600
Public supply (pumped wells)	500
Industry (pumped wells)	400
Domestic, stock and some irrigation (flowing wells and wells with small pumps)	3,500
Total	16,000

Groundwater levels in wells in alluvium are responsive to seasonal changes and to changes in precipitation. At times of high precipitation, surface waters are used instead of underground water, and recharging increases concurrently because of the greater supply.

Artesian conditions prevail in many of the wells in valley fill and in wells drilled in bedrock. The westward dip of formations exposed in the Wasatch Monocline on the east side of the valley has provided unusually favorable conditions for artesian accumulation in the porous layers of several formations. Favorable beds in the North Horn, Flagstaff, Colton, Green River and Crazy Hollow formations may be water bearing. Marsell (1958) mentions three successful wells: one in sandstone of the North Horn Formation, another in sandstone of the Crazy Hollow Formation and a third in the porous oolitic dolomite of the Green River Formation. Springs emerge from some of these geologic units and there is probably leakage into the valley fill. The possibilities for expanding water supplies, based on geologic and hydrologic conditions, appear to be good.

Springs

Springs in the alluvium occur at the intersection of the surface and water table and are especially responsive in their discharge to fluctuations in water level. Richardson (1907, p. 25) described fault springs originating in bedrock and so classified 30 of the 88 springs he lists for the entire central Sevier-Sanpete Valley area, and states that discharge of fault springs tends to be constant because they tap the deep circulation. Discharge data are given in table 4. Young and Carpenter (1965, p. 48) estimated annual discharge from springs in Redmond-Gunnison basin to be 4,000 acre-feet and for those in Gunnison-Sevier

Bridge Reservoir basin, 12,000 acre-feet. They also estimated groundwater storage conditions in sand and gravel in the basins within Sanpete County in table 5 below:

Table 5. Goundwater storage conditions in sand and gravel in the Redmond-Gunnison and Gunnison-Sevier Bridge Reservoir basins (Young and Carpenter, 1965, p. 39).

Basin	Thickness of saturated aquifer (feet)	Area underlain by aquifer (acres)	Estimated recoverable storage (acre-feet)
Redmond-Gunnison	50	20,000	150,000
Gunnison-Sevier Bridge Reservoir	200	11,500	300,000

These data represent about half of the total groundwater stored in the alluvium; the other half occurs in more or less impermeable silt and clay.

Estimated annual groundwater discharge from wells, springs, drains is presented in tables 4 and 6.

Thermal Springs

The temperature of the springs mapped by Richardson (1907) ranged from 43°-73° F. Stearns and others (1937, p. 182) classified 11 of these springs as "thermal springs," with a range in temperature from 57°-73° F. Data are given in table 7 (adapted from Stearns and others, 1937, p. 182, and Young and Carpenter, 1965, p. 18, 77).

Table 7. Thermal springs in Sanpete County.

Location				Discharge Gal/Min	Temper- ature (°F)
1/4	Sec.	Township	Range		
NW	13	15S	2E	400	57-62
SW	13	15S	2E	400	57-62
NW	24	15S	2E	400	57-62
SE	19	18S	1E	1900	64
NE	23	18S	2E	40	59, 62
SE	23	18S	2E	40	59, 62
SW	13	18S	2E	285	62, 73
SW	13	18S	2E	285	62, 73
NW	17	18S	3E	30	59, 65
SE	35	18S	2E	2500	61
SE	18	19S	1E	8	61
SE	4	19S	2E	900	64, 72

Quality of the Water in Sanpete County

Irrigation

Characteristics of water applicable to irrigation depend upon (1) total concentration of soluble salts, (2) relative proportion of sodium to other concentrations, (3) concentrations of boron or other toxic elements and (4) bicarbonate concentration relative to those of calcium and magnesium. Content of total dissolved solids is classified below:

Class	Dissolved solids (ppm)
Fresh	0 to 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	35,000+

Fresh water is suitable for irrigation, and if the land is well drained, slightly to moderately saline water can be used. Less than 0.33 ppm of boron is not harmful to any plant but a concentration of 1 ppm is harmful to fruit trees. Concentrations of 3.9 ppm is toxic to all plants.

Domestic and Public Supply

The recommended maximum concentrations of common chemical substances in water for human consumption are:

Substance	Parts per million
Chloride	250
Fluoride	1.2
Iron	.3
Manganese	.05
Nitrate	45
Sulfate	250
Dissolved solids	500

Hardness, largely related to content of calcium and magnesium, is a factor in domestic and industrial use. Carbonate hardness is expressed in terms of parts per million of CaCO₃. Water with less than 60 ppm is soft, with 61-120 ppm is moderately hard, with 121-180 ppm is hard and with more than 181 ppm is very hard.

Table 6. Estimated annual discharge of groundwater from wells in the Redmond-Gunnison and Gunnison-Sevier Bridge Reservoir basins (Young and Carpenter, 1965, p. 50), and discharge in 1963 and 1964 from wells in Sanpete Valley north of Nine Mile Reservoir (Robinson, 1964, p. 64; 1965, p. 61).

Basin	Mainly for irrigation					For stock, domestic, municipal and industrial use					Total estimated discharge
	No. of wells		Estimated discharge (acre-feet)			No. of wells		Estimated discharge (acre-feet)			
	Pumped	Flowing	Pumped	Flowing	Total	Pumped	Flowing	Pumped	Flowing	Total	
Redmond-Gunnison	3	200	700	3500	4200	153	0	300	0	300	4500
Gunnison-Sevier Bridge Reservoir	0	205	0	3500	3500	18	24	negligible	400	400	3900
Sanpete Valley (1963)	56 ^a	750 ^b	8300	3600	11900	5 ^c	--	1300 ^d	-	1300	13200
Sanpete Valley (1964)			8000	3600	11600						4400 ^e

^a Concentrated near Manti, near Ephraim, south of Moroni, south of Fountain Green, and between Spring City and Mount Pleasant.

^b Estimated.

^c Public and industrial supply only; number for stock and domestic purposes unknown.

^d Includes 400 acre-feet used for stock and domestic purposes.

^e Includes some pumped and flowing irrigation wells.

Livestock Supply

Livestock can tolerate considerable concentrations of total dissolved solids but the following may be regarded a maximum for each livestock group.

Class	Total dissolved solids (ppm)
Poultry	2,860
Swine	4,290
Horses	6,440
Cattle, dairy	7,150
Cattle, beef	10,000
Sheep, adult, dry	12,900

In general, water with 3,500 to 4,500 ppm of dissolved solids is regarded as poor and with more than 4,500 ppm as unfit for livestock.

Industrial Supply

Requirements for industrial use vary with the industry. Carbonates and silica are deposited as scale or coatings in pipes and other surfaces. Fresh water is desirable for processing and steam generation and saline water may be used for cooling. Silica forms a hard, adherent scale in boilers, and maximum concentrations for various operating pressures are: less than 150 psi (pounds per square inch), 40 ppm; 150-250 psi, 20 ppm; 250-400 psi, 5 ppm; and more than 400 psi, 1 ppm.

Groundwater

Young and Carpenter (1965, p. 87) summarize the quality of groundwater in the central Sevier Valley:

In the Redmond-Gunnison basin, water in the alluvium near Axtell and in the northwestern part of the basin is generally of acceptable quality for most uses. In most of the remainder of the basin, however, the water is not suitable for public supply or for domestic use because of excessive concentration of mineral constituents dissolved from the Arapien Shale. This slightly to moderately saline water can nevertheless be used on well-drained land. An unidentified sandstone underlying the Sevier River Formation in the center of the valley also contains water of poor quality.

The groundwater in the alluvium in the Gunnison-Sevier Bridge Reservoir basin is generally of suitable chemical quality for irrigation and other uses. The water from deep wells is of better chemical quality than is water from shallow wells.

Robinson (personal communication) states that the quality of water in Sanpete Valley, except that affected by proximity to the Arapien Shale, is good and tends to become better with depth in the alluvial fill. Water from the Green River Formation may be very hard.

Chemical, biochemical, bacteriological and radiological analyses of surface water in the Sanpete County portion of the Sevier Lake basin as performed by Hahl and Cabell (1965) are given in table 8.

Surface Water

Analyses of surface water samples collected at various places in Sanpete County are given in tables 9, 10 and 11. Where cold well water is available, large quantities may be used for cooling towers and air conditioning. Table 12 presents a range of water requirements for industrial use.

Table 12. Industrial water requirements by units of product (adapted from Illinois Tech Adv. Comm. on Water Res., 1967, p. 97).

Industrial Product	Gallons of water (per unit)
1 gal gasoline	7-10
1 case canning vegetables, No. 2 cans	25-35
1 kw electricity	80
1 beef animal	2,200
1 ton coke	3,600
1 ton paper	50,000
1 ton finished steel	65,000
1 ton rayon yarn	200,000
1 ton synthetic rubber	600,000

Industrial water requirements in Utah for selected industries, published by the State Engineer

Table 9. Suspended-sediment analyses for surface water in the Sanpete County portion of the Sevier Lake basin, 1964 (modified from Hahl and Cabell, 1965, p. 21-22).

Location	Date of Collection	Time (24 Hrs.)	Water Temp. (F)	Discharge (cfs)	Sediment Concentration (ppm)	Sediment Discharge (tons per day)
<i>Sevier River near Gunnison</i>						
SE¼ Sec. 14, T. 19 S., R. 1 W.	March 10	1115	34	150	678	275
	May 19	1200	63	212	619	354
	July 28	1010	66	44	68	8.1
	September 22	0945	50	78	114	24
<i>San Pitch River at Fairview</i>						
SW¼ Sec. 35, T. 13 S., R. 4 E.	March 8	1800	32	4.4	23	0.3
	May 21	1200	47	58	149	23
	July 30	0830	54	4.6	24	.3
	September 23	1645	53	1.1	24	.1
<i>Pleasant Creek near Mt. Pleasant</i>						
NW¼ Sec. 5, T. 15 S., R. 5 E.	March 11	1100	45	—	40	—
	May 21	1030	47	48	1,200	156
	July 30	0730	53	12	13	.4
	September 23	1615	54	9.1	4	.1
NW¼ Sec. 19, T. 18 S., R. 3 E.	May 21	0730	39	86	617	143
	July 29	1915	64	22	22	1.3
	September 23	1430	54	9.1	26	.6
<i>Sevier River near Fayette</i>						
SE¼ Sec. 25, T. 18 S., R. 1 W.	March 10	1525	38	169	1,240	566
	May 18	1550	66	232	726	455
	July 28	1405	79	60	143	23
	September 22	1330	60	88	172	41

*Methods of Analysis

B: bottom withdrawal tube S: sieve
 C: chemically dispersed V: visual accumulation tube
 P: pipet W: in distilled water

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Suspended sediment, percent finer than size mm.										Methods of Analysis*
0.002	0.004	0.008	0.016	0.031	0.062	0.125	0.250	0.500	1.000	
<i>Sevier River near Gunnison</i>										
—	—	—	—	—	—	—	—	—	—	—
18	23	—	31	—	75	97	100	—	—	VPWC
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
<i>San Pitch River at Fairview</i>										
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	87	94	97	100	—	V
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
<i>Pleasant Creek near Mt. Pleasant</i>										
—	—	—	—	—	—	—	—	—	—	—
18	25	34	44	51	66	80	92	100	—	VBWC
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
28	38	—	58	—	87	96	100	—	—	VPWC
—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—
<i>Sevier River near Fayette</i>										
—	—	—	—	—	—	—	—	—	—	—
18	25	—	33	—	67	95	100	—	—	VBWC
30	41	56	72	86	100	—	—	—	—	SBWC
—	—	—	—	—	—	—	—	—	—	—

Table 10. Trace element analyses of surface water in the Sanpete County portion of the Sevier Lake basin, 1964.

Location	Date	Time (24 hours)	Discharge (cfs)	Temperature (°F)	Aluminum (Al)	Beryllium (Be)	Bismuth (Bi)	Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Gallium (Ga)	Germanium (Ge)	Iron (Fe)	Lead (Pb)	Manganese (Mn)	Molybdenum (Mo)	Nickel (Ni)	Titanium (Ti)	Vanadium (V)	Zinc (Zn)
San Pitch River at Fairview, Sanpete County																					
SW $\frac{1}{4}$ Sec. 25, T 18 S, R 1 W	Mar. 8	1800	4.4	32	1.2	0.50	0.25	1.2	1.2	1.2	1.2	5.0	0.25	7.0	1.2	1.2	2.8	0.35	0.50	0.45	5.0
	July 30	0830	4.6	54	14	.51	.26	1.3	1.3	1.3	1.3	5.1	.26	6.9	1.3	1.3	2.8	.59	.51	.51	5.1
Sevier River near Fayette, Sanpete County																					
SE $\frac{1}{4}$ Sec. 25, T 18 S, R 1 W	Mar. 10	1525	169	38	1.2	0.50	0.25	1.2	1.2	1.2	1.2	5.0	0.25	2.8	1.2	1.2	1.8	0.85	0.50	3.8	5.0
	July 28	1405	60	79	7.9	.51	.26	1.3	1.3	1.6	3.8	5.1	.26	4.4	3.3	1.3	4.4	.90	.51	3.8	5.1

Table 11. Chemical analyses of water from selected wells, test holes and springs in parts of Sanpete County (all analyses by U. S. Geol. Survey; modified from Young and Carpenter, 1965, p. 77).

Well or spring location	Date of Collection	Geologic Source	Parts per million																		pH	
			Temperature (°F)	Silica (SiO ₂)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Na + K		Lithium (Li)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Dissolved Solids	Hardness as CaCO ₃	Noncarbonate hardness as CaCO ₃	Sodium-adsorption-ratio (SAR)		Specific conductance (microhos per cm. at 25° C)
SW $\frac{1}{4}$ Sec 34, T 17 S, R 1 W	9- 3-57	Qal	54	34	0.46	0.00	51	44	143	8.7	0.6	227	48	282	0.5	2.5	731	308	122	3.6	1,440	8.1
NE $\frac{1}{4}$ Sec 12, T 18 S, R 1 W	8-27-57	Qal	55	17	.09	.00	38	39	59	2.3	.2	245	25	114	.2	1.4	417	256	54	1.6	775	7.8
SE $\frac{1}{4}$ Sec 25, T 18 S, R 1 W	10-21-59	Qal	54	17	--	--	78	72	198		--	260	95	432	--	1.8	1,020	492	279	3.9	1,580	7.4
NW $\frac{1}{4}$ Sec 11, T 19 S, R 1 W	10- 8-56	Qal	51	22	.25	--	214	173	748	5.4	--	442	833	1,160	.1	89	3,460	1,240	883	9.2	5,440	7.2
SW $\frac{1}{4}$ Sec 23, T 19 S, R 1 W	8-27-57 9- 3-57	Qal Qal	50 53	25 34	.23 .11	.00 .00	225 116	153 101	765 438	17 6.2	-- 1.6	476 605	822 518	1,130 399	.1 .5	64 93	3,370 2,010	1,190 705	800 209	9.7 7.2	5,360 3,280	7.4 7.6
SW $\frac{1}{4}$ Sec 25, T 19 S, R 1 W	7- 2-58	Qal	52	34	.04	--	202	174	391		--	514	996	402	--	57	2,510	1,220	799	4.9	3,500	7.4
SE $\frac{1}{4}$ Sec 25, T 19 S, R 1 W	11- 5-59	TKs ¹	--	15	--	--	359	60	1,700		--	20	705	2,860	--	57	5,770	1,140	1,120	22	9,230	7.9
SE $\frac{1}{4}$ Sec 19, T 18 S, R 1 E (spring)	8-27-57	Tf	64	13	.00	.00	49	43	99	1.9	.3	305	43	152	.3	1.2	553	300	50	2.5	1,020	7.6
SE $\frac{1}{4}$ Sec 4, T 19 S, R 2 E (spring)	--do--	Fz ² / Tgr	67	13	.05	.02	38	19	94	3.8	.4	310	71	34	1.1	.1	429	173	0	3.0	711	8.3
SE $\frac{1}{4}$ Sec 20, T 19 S, R 2 E (spring)	8-28-57	Tgr	55	19	.09	.00	74	66	49	1.7	.2	450	107	37	.3	23	598	456	87	1.0	978	7.5
NE $\frac{1}{4}$ Sec 4, T 20 S, R 1 E	9- 3-57	Qal	54	22	1.0	.03	192	143	271	9.5	1.5	458	902	228	.6	48	2,040	1,067	692	3.6	2,960	7.5
NE $\frac{1}{4}$ Sec 25, T 20 S, R 1 E (spring)	12- 8-59	Qal	53	25	--	--	45	45	118		--	396	65	108	--	11	612	298	0	3.0	1,030	7.7

1. Undifferentiated Tertiary or Cretaceous Sedimentary rocks.
2. Fault Zone.

(Criddle and others, 1962, p. 47); (table 13) includes the following items.

Table 13. Industrial water requirements.

Industrial Product	Water Requirement (in gallons)
1 ton ammoniated superphosphate	30
1 bbl beer or ale	300- 2,500
1 ton refined beet sugar	2,000- 34,000
1 ton Portland cement	750
1 ton copper	28,000
1 ton coke	1,400- 2,800
1 ton magnesium carbonate (from dolomite, coke)	400
1 ton live hogs	6,000
1 gal oil produced from shale	10-30
1 gal milk	5
1 ton phosphoric acid	7,500-75,000
1 ton potash (from sylvinite)	4,000
1 ton soda ash (from salt, limestone)	15,000- 18,000
1 ton sulphuric acid (from sulphur)	2,500- 4,000
1 ton soap	500- 4,500
1000 kw of power steam generated	52,000-170,000

Mineral industries such as preparation of coal for market or washing of sand and gravel require large supplies of water but most of it is recirculated.

Harline (1966, table 3, op. p. 33f) has calculated withdrawal of water for municipal and industrial use in Sanpete County as 5,257 acre-feet in 1960. His projection for 1980 is 6,514 acre-feet and for the year 2020, 10,150 acre-feet, an increase of 93.1 percent over 1960. A major change in industrial and population development would alter this projection materially.

Agricultural use will continue to account for most of the water requirements of the county. Live-stock require water ranging from 0.6 gallons per day for poultry to 35 gallons per day for large animals (Illinois Tech. Adv. Comm. on Water Res., 1967, p. 97). For much of the year the cattle and sheep populations are dispersed in the ranges but at other times are concentrated in valley pastures and feed lots. In Utah, the State Engineer (Criddle and others, 1962, p. 23) estimates 650 gallons per day for each farm family, 25 gallons for a cow or horse, 5 gallons for a sheep or hog and 0.75 gallons for a chicken or turkey. The amount of water required to mature various crops ranges widely depending on plant variety,

weather pattern, length of growing season, latitude, altitude, soil type, depth to water table and many other factors, including, of course, efficiency in water management.

The basic data for calculation of consumptive use of water for crops and for municipal and industrial requirements for Utah are given in Technical Publication No. 8 (revised) of the State Engineer's Office. Paul D. Christensen, extension soil specialist of Utah State University, has provided (personal communication) a table of consumptive water use in Utah which includes a calculation for Manti in Sanpete County. Table 14 below is prepared from these sources.

Table 14. Consumptive use of water for crops in Sanpete Valley based on weather data for Manti (Utah State University, extension soil specialist).

Crop Plants	Consumptive Use (inches)
Alfalfa	26
Corn	25
Small grain (fall)	25
Small grain (spring)	20
Pasture	25
Peas	16
Potatoes	21
Small truck crops (1 crop)	13
Sugar beets	22
Tomatoes	22

Climatic factors governing plant growth

Mean monthly temperature	°F
June	62.5
July	69.8
August	68.4
September	60.9
Altitude	5,585 feet
Latitude	39.250°
Average freeze dates	May 7-Nov. 12
Average growing season	158 days
Average annual precipitation	12.06 inches

A table supplied by the U. S. U. extension agent for Salt Lake County, Joseph F. Parrish, taking into account the effective rainfall and an efficiency of 50 percent on the part of the farmer, arrives at a

total water requirement 50 to 60 percent more than the figure cited for consumptive use. Based on the manner in which water is commonly applied in irrigation, the State Engineer's report (Criddle and others, 1962, p. 21) shows requirements for Utah in table 15 below:

Table 15. Water requirements for crops in Utah (Criddle and others, 1962, p. 21).

Crop Plants	Water Requirement (inches)
Potatoes	31
Tomatoes	36
Peas	20
Spring grain	24
Sugar beets	36
Sorghums	27
Alfalfa (2 crops in 160 days)	36

The area of land irrigated each year in Sanpete County is about 57,000 acres, and the U.S.U. extension agent, Mr. Dell Purnell, states (personal communication) that there is commonly a water deficit of 24,000 to 27,000 acre-feet. The lack of correlation in the figures cited above underline the need for accurate information on total water supply and the reorganization of water management so that all water in the county may be used efficiently.

Water-related recreation in Sanpete County consists of fishing in the streams, ponds and reservoirs and of boating and swimming in the reservoirs. A number of natural ponds a few acres in extent occur in the Manti-LaSal National Forest in the summit area of the Wasatch Plateau. Small reservoirs in this area include Ferron (90 acres), Gooseberry Lake (52 acres) and Huntington (118 acres) (figure 1). In the lowlands the reservoirs are larger but subject to marked fluctuation of level and area. Wales (130 acres), Gunnison (395 acres), and Nine Mile Reservoir (100 acres), and Funks Lake (78 acres) in Palisades State Park (figure 1) are the principal reservoirs. A small part of Sevier Bridge Reservoir is in Sanpete County.

Most of the towns in Sanpete County are subjected to cloudburst floods during the months of July and August. The settlements are located on the banks of streams and on alluvial fans. Records show that Manti has been flooded at least nine times.

Earlier studies on flood control should be supplemented by plans for maximum control of flood

water and the necessary funding secured and construction undertaken. Following enactment of the Federal Flood Control Act of 1936, it has been possible to include flood control in general programs of water resource development. Federal agencies directly concerned with flood control are the U. S. Army Corps of Engineers and the Soil Conservation Service; the latter is currently engaged in a flood control project in the county.

INDUSTRIAL MINERALS AND ROCKS

Construction materials, especially carbonate rocks (limestone, dolomite, and dolomitic limestone) and sand and gravel are abundant in Sanpete County. The Sevier Valley in the southern part of the county contains salt deposits. A welded tuff of volcanic origin is being processed as a product called Azomite and used in the poultry industry. Bentonite, argonite, tufa and quartz occur in the valley at the south end of the county. Reported occurrences of fuller's earth have not been confirmed in this study. Shale of possible use in cement manufacture, sandstone and quartzite conglomerate, though little used now, are available for commercial use.

Carbonate Rocks

Limestone, dolomite, and dolomitic limestone are widely distributed (figure 3) in two geologic formations, the Flagstaff Limestone and the Green River Formation. The Flagstaff Limestone, of non-marine origin, caps much of the surface of the Wasatch Plateau, where it is 300 to 800 feet thick and contains beds of sandstone, shale, conglomerate and gypsum. It also occupies large areas in the Valley Mountains and Gunnison Plateau, where the proportion of carbonate to clastic rocks is much smaller. Most of these areas are relatively inaccessible, but Flagstaff Limestone occurs in the Wasatch Monocline along the east side of the central Sevier and Sanpete valleys, where it may be reached in the tributary canyons. Carbonate rock in the Green River Formation occurs in the margins of the valleys and is readily available for quarrying. Carbonate rocks of the Flagstaff Limestone are used now only for road metal. Limestone has been used locally for lime and until 1960 was quarried for use in sugar refining at Centerfield. Carbonate rock of the Green River Formation has some use as road metal or borrow material and is intermittently quarried for dimension stone. Localities of interest for carbonate rocks are shown on the map (figure 9) and listed in table 16.

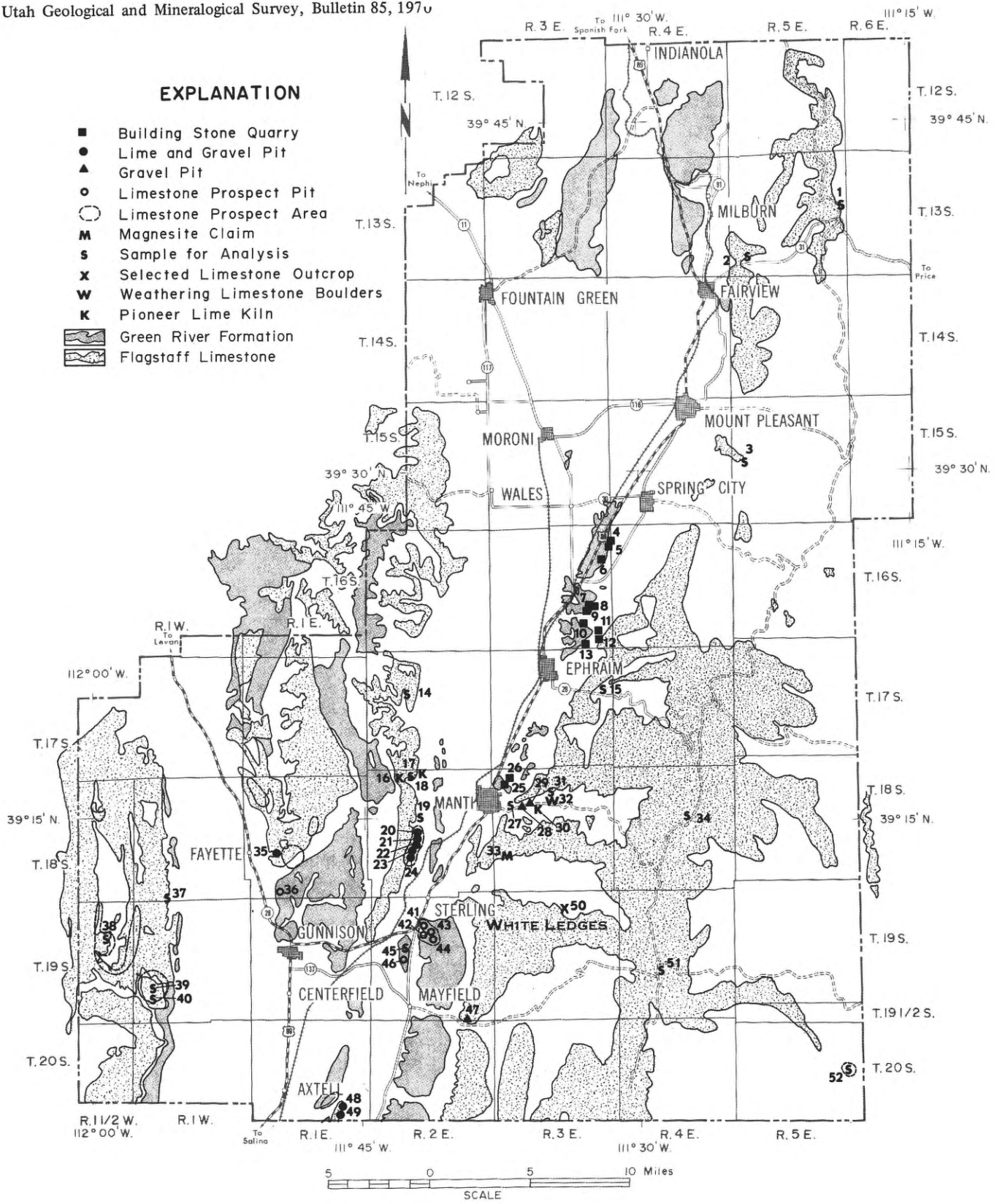


Figure 9. Carbonate rock localities, Sanpete County.

Table 16. Analyses of carbonate rocks from the Green River Formation and the Flagstaff Limestone.

Locality No. ^a	percent						A = selected analyses ^b
	CaO	MgO	Insoluble	SiO ₂	Fe ₂ O ₃ and Al ₂ O ₃	Ignition loss	
Green River Formation							
5	37.5	11.2	11.2	10.0	1.2	40.0	A
6	44.0	8.2	5.2	4.2	1.0	42.6	A
7	39.0	10.0	7.6	6.0	1.6	42.5	A
8	38.0	8.3	13.5	12.0	1.5	39.0	
9	44.0	7.9	5.2	4.0	1.2	42.0	
10	31.8	14.7	13.5	9.3	4.2	40.0	
13	39.8	8.6	9.5	8.4	1.1	41.0	A
25	43.5	6.2	7.0	6.0	1.0	42.0	A
36	27.0	15.5	16.3	14.0	2.3	39.8	A
42	32.5	14.4	11.0	10.0	1.0	40.5	A
45	21.2	9.8	41.8	40.0	1.8	27.0	
46	32.7	18.8	5.2	2.4	2.8	43.3	A
Flagstaff Limestone							
1	52.9	17.9	3.4			41.8	A
2	31.0	1.8	9.6			41.4	A
3	32.8	18.6	5.6			42.9	A
14	33.6	16.8	7.4	3.7	3.7	42.2	A
15	31.5	20.2	4.0	3.0	1.0	44.3	A
17	29.9	15.8	14.5	11.0	3.5	39.8	
19	34.8	18.6	2.0	2.0	.0	44.6	A
20	54.5	0.8	1.0	1.0	.0	43.7	
21	54.4	0.8	1.0	1.0	.0	43.8	A
22	54.5	0.8	1.0	1.0	.0	43.7	
23	54.5	0.8	1.0	1.0	.0	43.7	
24	54.0	1.2	1.0	1.0	.0	43.8	
27	32.9	14.4	13.4	10.5	2.9	39.3	A
27	37.1	16.5	2.0	2.0	.0	44.4	A
31	31.0	16.5	12.0	10.0	2.0	40.5	A
31	28.8	15.8	18.0	13.0	5.0	37.4	A
34	31.6	22.2	1.6			44.4	A
37	31.2	17.4	9.8	6.0	3.8	41.6	A
38	54.2	0.8	1.0	1.0	.0	44.4	A
39	54.0	0.8	2.0	1.0	1.0	43.2	A
40	48.7	3.5	6.3	3.0	3.3	41.5	A
48	51.1	3.1	2.0	1.0	1.0	43.8	
49	54.5	0.8	1.0	1.0	.0	43.7	A
51	29.5	19.8	8.5			42.0	A
51	29.5	23.5	1.6			45.2	A
52	53.3	2.2	1.6			42.6	A
52	53.0	2.1	2.2			42.5	
Theoretical limestone							
	56.0					44.0	
Theoretical dolomite							
	30.4	21.7				47.9	

^a Used to obtain an average Sanpete County Green River and Flagstaff limestone analyses.

Carbonate Rock in Flagstaff Limestone

Analyses of 29 samples of carbonate rock from localities in the Flagstaff Limestone listed in table 16

show the wide range in composition compared with theoretically pure limestone and dolomite.

Twenty of the analyses, indicated in the right-hand column of table 16, show the average, high, and low percentages of major constituents as follows:

	Average	High	Low
Soluble carbonates	94.4	99.0	82.0
Insoluble residue	5.8	18.0	1.0
CaO	39.4	54.5	28.8
MgO	12.4	23.5	0.8

Average, high and low percentages of SiO₂ and Fe₂O₃ - Al₂O₃ of 13 of the 20 samples are:

	Average	High	Low
SiO ₂	4.4	13.0	1.0
Fe ₂ O ₃ - Al ₂ O ₃	1.7	5.0	0.0

According to Pettijohn's (1949, p. 313) classification, the average carbonate of the 20 samples included above would be classified as calcitic dolomite. Individually, they would be classified as follows:

Limestone	4 samples
Magnesian limestone	1 sample
Dolomitic limestone	2 samples
Calcitic dolomite	9 samples
Dolomite	4 samples

On the basis of petrographic examination, Fagadeau (1949, p. 89-90) described the limestone of the Manti-Willow Creek area as ranging from less than 0.5 to greater than 40 percent of insoluble material consisting of quartz, clay, chert, hematite and carbonaceous material. Gill (1950, p. 125-126) found the average percentages of content of 120 samples from the Manti-Spring City area to be:

Soluble carbonates	96.5
Argillaceous residues	2.8
Coarse residues	0.7

The coarse residues consisted of transparent and milky quartz, spongy and botryoidal silica and flakes of red opaque hematite.

The qualifying terms, magnesian, dolomitic and calcitic refer to proportions of calcite and dolomite as mechanical mixtures, since the crystal structure of these minerals permits very limited inclusion of the magnesium atom in calcite or any appreciable variation of the ratio of calcium to magnesium in dolomite.

The Flagstaff Limestone is well exposed in cliffs in the deep canyons of the Wasatch Monocline on the east side of the Sevier and Sanpete valleys. A typical exposure forms the high north rim of Manti Canyon east of Manti. For the most part, the outcrop consists of massive beds one to six feet thick of light to medium-gray, medium-grained to lithographic limestone, some of which is fossiliferous. A bed one foot thick and very dark gray is particularly fossiliferous. Some limestone beds are separated by beds of structureless mudstone one foot thick. Talus cones of limestone blocks at the base of these high cliffs are convenient sources of stone for local use.

High calcium limestone from localities 48 and 49 (figure 9, table 16) was quarried by Poulson Brothers of Redmond and used in sugar refining at Centerfield. Flagstaff Limestone in outcrops west of Gunnison Reservoir, localities 20 to 24 is particularly pure, containing less than 1.3 percent of MgO. It has been investigated as a source of flux in making steel. Limestone from these pits was probably used locally for road metal. Dense limestone that appears to be satisfactory for dimension stone occurs in several localities; one recommended by Wilson (1949, p. 103) and known locally as the White Ledges, is in Six Mile Canyon in Sec. 3, T. 19 S., R. 3 E. The stone is in vertical cliffs, 200 feet high, extending for 6,000 feet. Wilson (1949, p. 103) says talus blocks at the base of the cliff could be used for building stone. The deposit could be reached by construction of one-half mile of road from the Six Mile Canyon road. Talus in Manti Canyon (figure 1) 1 to 1.5 miles east of Manti and in Twelve Mile Canyon 2.5 miles east of Mayfield is used for road metal.

Carbonate Rock in Green River Formation

Analyses of 12 samples of carbonate rocks from localities in the Green River Formation shown on the map (figure 9) are listed in table 16. All these

samples show a high content of MgO and insoluble material. Typical samples were selected to show average composition and range:

	Percent		
	Average	High	Low
Soluble carbonates	90.1	94.8	83.7
CaO	37.0	44.0	27.0
MgO	11.6	18.8	6.2
Insoluble residue	9.1	16.3	5.2
SiO ₂	7.6	14.0	2.4
Fe ₂ O ₃ - Al ₂ O ₃	1.5	2.8	1.0

Of the 12 samples, 7 are classified dolomitic limestone and 5 calcitic dolomite.

A sample of siliceous oolite from locality 45, 2.5 miles north of Mayfield, analyzed by Black and Deason, assayers and chemists, show the following percentages:

CaO	21.2
MgO	9.8
SiO ₂	40.0
Fe ₂ O ₃ - Al ₂ O ₃	1.8

The carbonate oolites, 1.5–2 mm in diameter, are either hollow or partly filled with granular material and are cemented by medium-gray silica. The oolites surround ostracod valves and occur in a bed 6 inches thick.

Descriptions of the carbonate rock of the Green River Formation are given in the section on dimension stone. Typically, the carbonate rock occurs in tan-colored beds in the upper part of the formation. The beds average three feet in thickness, with beds to eight feet thick. They are commonly separated by layers of thin platy limestone or calcareous shale. Some of the material contains abundant chert and the analyses indicate the widespread occurrence of silica. The amount of argillaceous material in the carbonate rock is small.

The carbonate rock in the Green River Formation has been used for road metal and borrow material. Material in a small pit two miles north of Manti east of U. S. 89 consists of angular, platy sandstone and shale fragments in the form of 20 percent easily reduced boulders, 50 percent gravel and 30 percent fines. Another pit on U. S. 89 one mile north of Sterling is 1,000 feet long and 15 feet high

Table 17. Sample localities for carbonate rocks in Sanpete County.

Locality No.	Location				Formation	Commercial Commodity	A=samples analyzed
	1/4	Sec.	Township	Range			
1	CN $\frac{1}{2}$	13	13S	5E	Flagstaff		A
2	NE	31	13S	5E	Flagstaff		A
3	CS $\frac{1}{2}$	18	15S	5E	Flagstaff		A
4	SW	1	16S	3E	Green River	Building stone	
5	SW	1	16S	3E	Green River	Building stone	A
6	SW	12	16S	3E	Green River	Building stone	A
7	SE	23	16S	3E	Green River	Building stone	A
	(2 quarries)						
8	SW	24	16S	3E	Green River	Building stone	A
9	NE	26	16S	3E	Green River	Building stone	A
10	CS $\frac{1}{2}$	26	16S	3E	Green River	Building stone	A
11	SE	26	16S	3E	Green River	Building stone	
12	NE	35	16S	3E	Green River	Building stone	
13	SE	35	16S	3E	Green River	Building stone	A
14	SE	17	17S	2E	Flagstaff		A
15	CN $\frac{1}{2}$	13	17S	3E	Flagstaff		A
16	NE	5	18S	2E		(lime kiln)	
17	NE	5	18S	2E	Flagstaff		A
18	NW	4	18S	2E		(lime kiln)	
19	NW	16	18S	2E	Flagstaff		A
20	NW	21	18S	2E	Flagstaff	Lime and gravel	A
21	CW $\frac{1}{2}$	21	18S	2E	Flagstaff	Lime and gravel	A
22	SW	21	18S	2E	Flagstaff	Lime and gravel	A
23	NE	29	18S	2E	Flagstaff	Lime and gravel	A
24	CE $\frac{1}{2}$	29	18S	2E	Flagstaff	Lime and gravel	A
25	SW	6	18S	3E	Green River	Building stone	A
	(2 quarries)						
26	SW	6	18S	3E	Green River	Building stone	
	(5 quarries)						
27	SE	7	18S	3E	Flagstaff		A
28	SW	8	18S	3E	Flagstaff	Talus gravel	
29	SE	8	18S	3E	Flagstaff	Talus gravel	
30	SE	8	18S	3E		(lime kiln)	
31	NE	9	18S	3E	Flagstaff		A
32			18S	3E	Flagstaff	(weathered boulders)	
33	NE	30	18S	3E	North Horn (?)	Magnesite claim	
34	NE	15	18S	4E	Flagstaff		A
35	SW	20	18S	1E	Flagstaff	Lime and gravel	
36	SW	32	18S	1E	Green River		
37	CS $\frac{1}{2}$	32	18S	1W	Flagstaff		A
38	CS $\frac{1}{2}$	11	19S	1 $\frac{1}{2}$ W	Flagstaff		A
39	SE	30	19S	1W	Flagstaff		A
40	NE	31	19S	1W	Flagstaff		A
41	SW	9	19S	2E	Green River		
42	SW	9	19S	2E	Green River		A
43	CS $\frac{1}{2}$	9	19S	2E	Green River		
44	NE	16	19S	2E	Green River		
45	SE	17	19S	2E	Green River		A
46	SE	17	19S	2E	Green River		A
47	NW	2	20S	2E	Flagstaff	Talus gravel	
48	NW	26	20S	1E	Flagstaff	Lime and gravel	A
49	SW	26	20S	1E	Flagstaff	Lime and gravel	A
50	SW	3	19S	3E	Flagstaff	White Ledges	
51	CW $\frac{1}{2}$	21	19S	4E	Flagstaff		A
52	CW $\frac{1}{2}$	13	20S	5E	Flagstaff		A

and exposes broken bedrock consisting of limestone and 5 percent chert; the material yields 8 percent boulders, 30 percent gravel and 62 percent fines.

Uses of Carbonate Rocks

Uses of the carbonate rocks of Sanpete County for building or dimension stone and for aggregate or borrow material are discussed in the appropriate sections of this report. For most chemical uses, the stone is calcined or burned with elimination of the CO₂; the relative amount of impurities in the original rock is thereby doubled in the calcined product. Typical analyses of commercial quicklimes are given below (Boynton and Gutschick, 1960, p. 498).

Component	High calcium quicklimes, (range percent)	Dolomitic quicklimes, (range percent)
CaO	93.25-98.00	55.50-57.50
MgO	.30- 2.50	37.60-40.80
SiO ₂	.20- 1.50	.10- 1.50
Fe ₂ O ₃	.10- .40	.05- .40
Al ₂ O ₃	.10- .50	.05- .50
H ₂ O	.10- .90	.10- .90
CO ₂	.40- 1.50	.40- 1.50

The Flagstaff Limestone from localities 20-24 and 49 might qualify for high calcium quicklimes. Dolomite or limestone used for flux in the steel industry must contain less than 1 percent SiO₂. High calcium limestone for use in sugar manufacture and other chemical uses should have at least 97 percent calcium carbonate. Cement is prepared from a mixture of limestone, shale, and sand with some minor constituents. However, the amount of MgO in the finished product must not exceed 5 percent (Clausen, 1960, p. 210) in all types of cement, and the alkalis (K₂O, Na₂O) must not exceed 0.6 percent.

Magnesite in North Horn Formation

The occurrence of magnesite boulders in Six Mile Canyon (Locality 33) is discussed in the section of this report on miscellaneous industrial minerals and rocks.

Dimension Stone

After rock salt, the best known mineral product of Sanpete County is dimension stone, chiefly limestone (calcitic dolomite) from the Green River Formation, and to a lesser extent, sandstone from the Crazy Hollow Formation. The temple at Manti (see frontispiece) is probably the best known building made of the local limestone known as Sanpete White, Manti Stone or Sanpete Sandstone. The limestone was used in the Sanpete County courthouse, the Park Building at the University of Utah, and in the interiors of the Utah and California state capitol build-

Table 18. Dimension stone quarries in Sanpete County.

Locality No.	Location				Formation	Rock type
	1/4	Sec.	Township	Range		
1	NW	11	13S	4E	Crazy Hollow	Sandstone
2	SE	3	14S	4E	Crazy Hollow	Sandstone
3	NE	15	14S	4E	Crazy Hollow	Sandstone
4	SW	1	16S	3E	Green River	Limestone
5	SW	1	16S	3E	Green River	Limestone
6	SW	12	16S	3E	Green River	Limestone
7	SE	23	16S	3E	Green River	Limestone
(2 quarries)						
8	SW	24	16S	3E	Green River	Limestone
9	NW	26	16S	3E	Green River	Limestone
10	CS	26	16S	3E	Green River	Limestone
11	SE	26	16S	3E	Green River	Limestone
12	NE	35	16S	3E	Green River	Limestone
13	SE	35	16S	3E	Green River	Limestone
14	SW	6	18S	3E	Green River	Limestone
(5 quarries)						
15	SW	6	18S	3E	Green River	Limestone
(2 quarries)						
16	NW	28	19S	2E	Crazy Hollow	Sandstone
17	SW		19S	3E	Flagstaff	Limestone
18	NE	9	15S	3E	Moroni	Sandstone
19	SW	3	15S	3E	Moroni	Welded Tuff

ings (Hansen, 1964, p. 226). The sandstone was used chiefly in buildings at Fairview, notably in the North Ward chapel of the Church of Jesus Christ of Latter Day Saints. Locations of dimension stone quarries are shown on the map (figure 10 and table 18).

Limestone

Limestone is quarried from thick (up to eight feet) massive beds of uniform texture. Unweathered stone is light gray or nearly white in color, turning to a light tan color on exposure. The stone is a fairly porous aggregate of oolitic grains mostly less than 1 mm in diameter. Bedding lamination is not obvious, although there are fine-grained calcite partings and thin black laminae of ferromagnesian minerals in some of the material. The uniform structure is favorable for decorative carving as seen on the facade of the Sanpete County Courthouse in Manti (figure 11). The stone dresses to a smooth slightly grainy surface.

The stone performs satisfactorily if protected from excessive moisture or if not subjected to air containing SO₃. The exterior stone in the Park Building at the University of Utah has scaled badly, and an unpublished study made in the College of Mines and Mineral Industries shows that the scaling was caused by the growth of gypsum crystals formed by reaction of the calcium carbonate with sulfuric acid created by the combination of water with SO₃ from the polluted air. No satisfactory way has been found to prevent this deterioration. The stone also deteriorates in courses close to the ground where moisture in the rock is subjected to freezing and thawing.

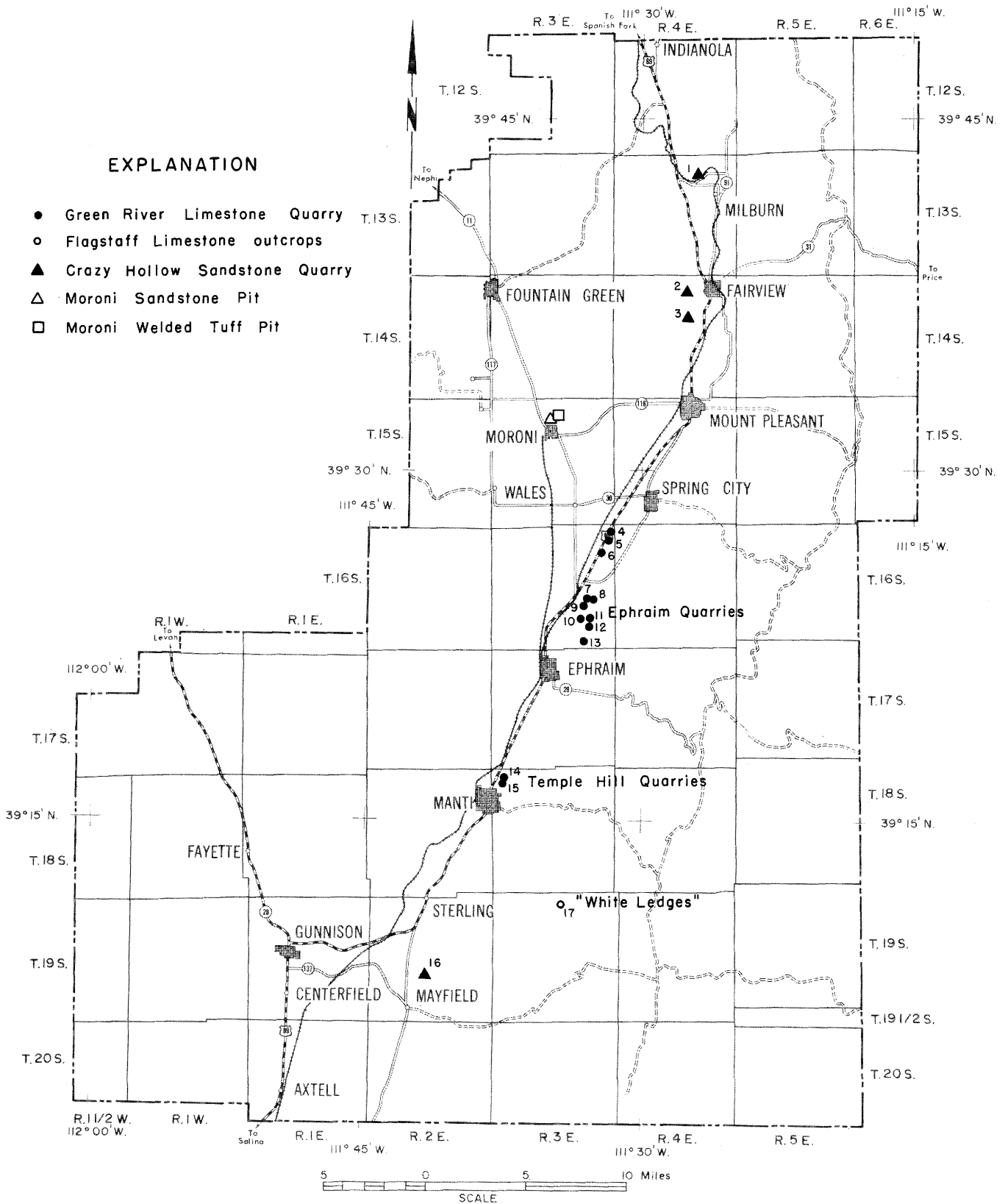


Figure 10. Location of dimension stone quarries.

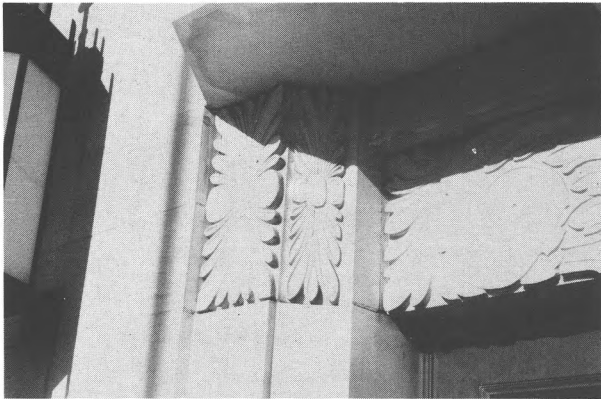


Figure 11. Decorative use of Green River limestone in the facade of the Sanpete County Courthouse, Manti, Utah.

Of the 12 quarries in the Green River Formation shown on the map (figure 9), the three largest are the quarry two miles northeast of Ephraim (locality 10) and the Manti quarries (localities 14 and 15) at the north side of Manti on the north and south central parts of Temple Hill. The Ephraim quarry face is 50 to 75 feet high and about 2,400 feet long. The upper part is waste rock consisting of calcareous shale and thin-bedded limestone. The lower portion consists of massive limestone beds four to six feet thick separated by thin shale partings. The massive stone is grayish white, fine-grained, finely oolitic and somewhat chalky. At Manti, the quarry most recently worked (locality 14, figure 9) lies on both sides of a north-flowing gully and forms a discontinuous chain for a composite length of 2,380 feet. The latest quarrying was done on the east side where an oolitic bed eight feet thick is overlain by 22 feet of waste rock consisting of limestone and slightly calcareous platy shale, shown in figure 12. At locality 15, east of the temple, the quarry face, unworked for many years, is 10 to 15 feet high and 1,650 feet long. The usable stone is in the base of the cut in a bed three to five feet thick.

A small quarry (locality 9) 2 1/2 miles northeast of Ephraim is operated from time to time by the American Stone Company of Salt Lake City. The quarry face is 12 to 15 feet high. The relatively thin waste rock overlies a massive bed of oolitic limestone eight feet thick.

Sandstone

Sandstone in outcrops of the Crazy Hollow Sandstone has been quarried on a small scale for local use, particularly from the hills west of Milburn and Fairview in the northern part of the county (localities 1-3). The largest quarry (locality 3) exposes



Figure 12. Green River Limestone quarry on Temple Hill near Manti. The 8-foot oolite bed at base of quarry is used for building stone.

a face 17 feet high and 125 feet long. The sandstone is medium-grained, calcareous, and yellowish brown to salt-and-pepper gray in color. The thick beds are friable and not sufficiently indurated for permanence, but thinner beds, about 15 inches thick, are well indurated and lend themselves to the rough- or ashlar-type construction shown in figure 13. A small quarry (locality 15) in Crazy Hollow Sandstone is 1.5 miles northeast of Mayfield.

Sandstone from the Moroni Formation has been quarried north of Moroni (locality 18) and used for local construction in Moroni. The sandstone is very coarse-grained, consisting of poorly sorted angular quartz grains and small shattered pebbles.

Welded Tuff

Welded tuff from the Moroni Formation has been quarried north of Moroni (locality 19) and used for local construction in Moroni. The rock is pink to very light gray and consists of angular quartz and ferromagnesian, cemented in a finely granular vitreous matrix.

Sand, Gravel, Aggregate and Borrow Material

The Utah State Department of Highways, as the principal user of sand, gravel, stone and borrow material is, through its Materials and Research Division, conducting a materials inventory survey of the entire state "designed to collect, organize, and tabulate all useful information related to materials available or potentially available for highway construction." The results of the survey are released in county atlases which show all sample locations plotted on colored geologic maps, taken mainly from the Geologic Map

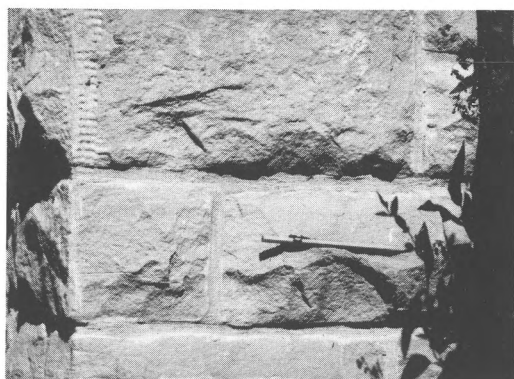


Figure 13. Roughly finished Crazy Hollow Sandstone in North Ward LDS Church, Fairview, Utah.

of Utah and published at a scale of 1/4 inch to 1 mile. The potential usefulness of each geologic unit is evaluated. The field and laboratory data are presented in tabular form in the atlases. The atlas for Sanpete County has not yet (1966) been released but those for the adjoining counties of Juab, Carbon and Emery are available. Data on Sanpete County were made available to the writers and have been added to those already obtained by the senior author in his own investigations. The U. S. Forest Service has information on open file concerning tested materials and sites throughout the national forests in Utah.

As to general evaluation, it was shown earlier in this report that Sanpete County is underlain by sedimentary rocks of Tertiary and Cretaceous age in the higher portions and by alluvium and Jurassic Arapien Shale in the major valleys. Tertiary volcanic tuffs and welded tuffs may be too soft, but dense hard-flow rocks make excellent aggregate. Alluvial deposits, composed of fragments from local bedrock, will have the general characteristics of the bedrock formations from which they are derived. Those derived from conglomerate beds may consist mainly of quartzite, a very hard sandstone.

Local materials are used in Sanpete County as shown by the pit location map (figure 14) and by the list in table 19. The various types of material are described briefly under the headings outlined below. The chief producers have been the Utah State Department of Highways, the Sanpete County Road Department, the Johnson Company of Ephraim, Hales and Gravel Company of Redmond, and Cox Brothers of Manti.

Quaternary Alluvium

Most of the stream channel deposits of sand and gravel occur near the mouths of canyons in the Wasatch Plateau and Monocline where they enter San-

pete Valley. A deposit of this type occurs near Ephraim, where a boulder-filled channel extends from the mouth of Ephraim Canyon three miles west to the south edge of Ephraim. A large pit (locality 56) operated by the Johnson Company has been opened in the channel near Ephraim, where the gravel consists of 80 percent limestone and 20 percent sandstone, 35 percent occurring as boulders and cobbles, 50 percent as gravel, and 15 percent as fine material. Other important stream channel pits are one mile south of Milburn, one-fourth mile northeast of Fairview, near the mouth of Wales Canyon, west of Wales, near the mouth of Maple Canyon 5.5 miles northwest of Manti, and one mile northwest of Mayfield. Most of these stream channel deposits are easily accessible on gravel or asphalt roads. Their relief is low and the material is easily removed. Abundant boulders, cobbles, and coarse gravel make crushing the material a necessity.

Alluvial fans contain some fairly satisfactory material, but the quality is not equal to that of stream channel deposits. One large sprawling pit occurs in Sec. 36, T. 14 S., R. 2 E. (figure 14, locality 24). The material is 94 percent quartzite, 4 percent sandstone and 2 percent basalt, occurring as 7 percent boulders, 53 percent gravel, and 40 percent fine material. The gravels are poorly cemented by calcium carbonate and contain pockets of silt.

An unworked deposit of gravel occurs as a large terrace in Secs. 35 and 36, T. 19 S., R. 1 W., and Secs. 1 and 2, T. 20 S., R. 1 W. (locality 107). The terrace is about 50 feet high, its area is one-half square mile, and it stands out sharply as a bluff overlooking the west bank of the Sevier River. The terrace material is composed of about 80 percent limestone, 10 percent sandstone and 10 percent chert, occurring as subangular to rounded small boulders and cobbles (10 percent) and 70 percent gravel in 20 percent fine material. The gravel is readily accessible, is in part on state-owned land, and should be of commercial value.

Several commercially important gravel deposits are not readily identifiable. They are mostly in valley flatland, some at least five miles from the nearest significant highland. They contain abundant rounded coarse detrital boulders and scattered sand or silt lenses (locality 35) but their exact mode of deposition is in question. They may be the result of a combination of processes, most likely stream channel, alluvial fan, and perhaps mud flowage, but isolated by subsequent drainage changes. Some may be mid-valley river terraces.

A pit in such a deposit in NE $\frac{1}{4}$ Sec. 24, T.15 S., R. 3 E. (locality 39) four miles southeast of

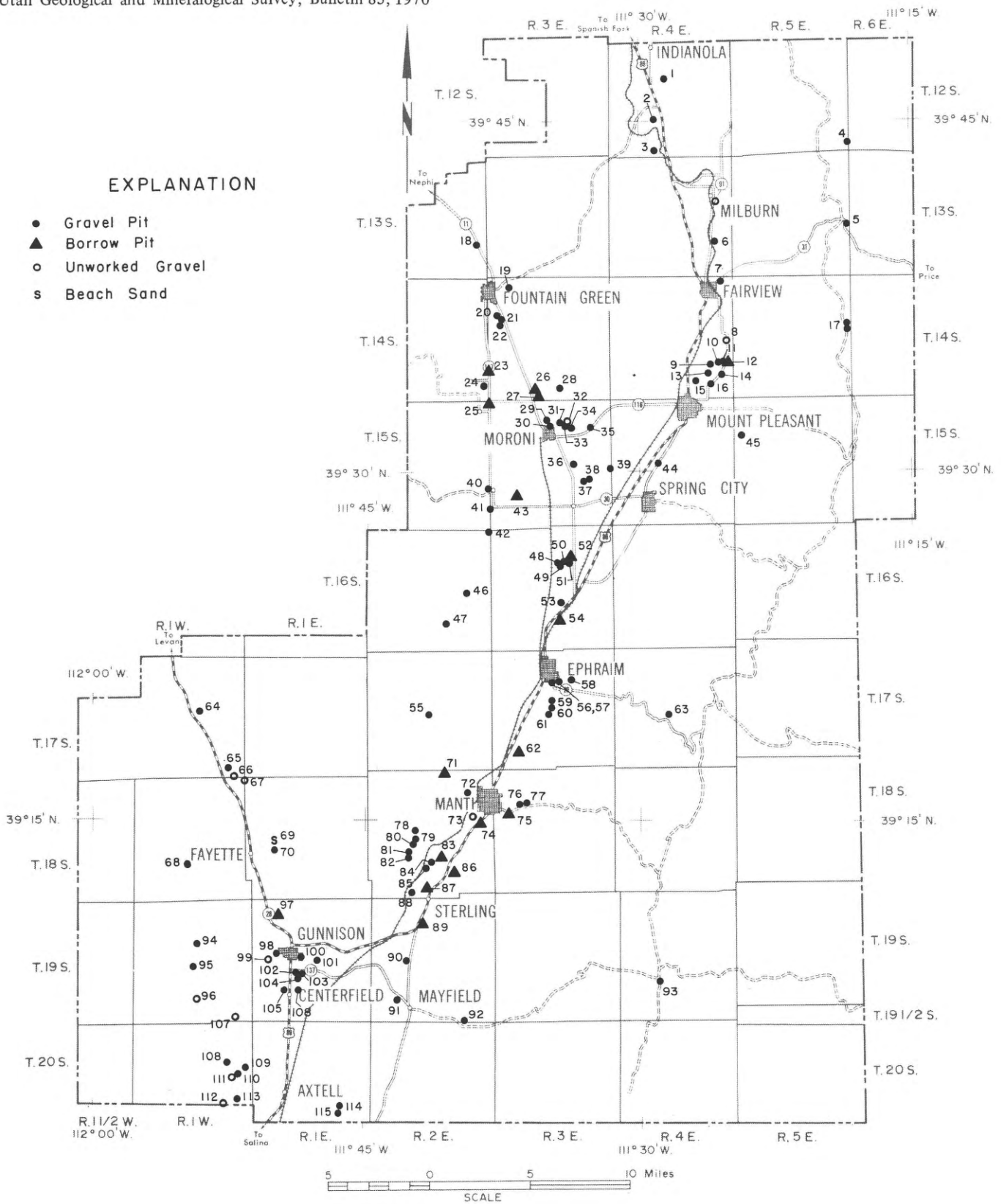


Figure 14. Location of gravel and borrow pits, Sanpete County, Utah.

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Table 19. Gravel and borrow pits in Sanpete County.

Locality No.	Location				Formation	Type of deposit	Locality No.	Location				Formation	Type of deposit
	1/4	Section	Township	Range				1/4	Section	Township	Range		
1	SW	9	12S	4E	Qal	Stream channel	45	NW	7	15S	5E	Flagstaff (?)	Bedrock (?)
2	SE	20	12S	4E	Qao	Alluvial terrace	46	NE	23	16S	2E	Qal	Alluvium
3	SW	33	12S	4E	Qao	Alluvial terrace	47	SE	27	16S	2E	Qal	Alluvium
4	NE	36	12S	5E	Flagstaff	Bedrock (?)	48	SW	10	16S	3E	Qal	River terrace (?)
5	NE	24	13S	5E	Flagstaff	Limestone	49	SW	10	16S	3E	Qal	River terrace (?)
6	NE	26	13S	4E	Qal	Stream channel	50	SE	10	16S	3E	Qal	River terrace (?)
7	NW	1	14S	4E	Qal	Stream channel	51	SE	10	16S	3E	Qal	River terrace (?)
8	SE	13	14S	4E	Qal	Terrace gravel	52	SE	10	16S	3E	Qal	River terrace (?)
9	NE	26	14S	4E	Qal	Volcanic rock fragments in sediments	53	SE	22	16S	3E	Green River	Talus
10	NW	25	14S	4E	T ₁ ap	Pyroclastics	54	SW	27	16S	3E	Qal	Alluvium
11	CN $\frac{1}{2}$	25	14S	4E	T ₁ ap	Pyroclastics	55	NE	21	17S	2E	Qal	Stream channel
12	CN $\frac{1}{2}$	25	14S	4E	Colton	Shale and limestone	56	SE	9	17S	3E	Qal	Stream channel
13	SE	26	14S	4E	T ₁ ap	Pyroclastics	57	SW	10	17S	3E	Qal	Stream channel
14	SW	25	14S	4E	Qal	Volcanic rock fragments in sediments	58	SE	10	17S	3E	Qal	Stream channel
15	SE	27	14S	4E	Qal	Alluvium	59	SE	16	17S	3E	Qal	Alluvium
16	NE	35	14S	4E	T ₁ ap	Pyroclastics	60	NE	21	17S	3E	Qal	Stream channel
17	NE	13	14S	5E	North Horn	Sandstone	61	NE	21	17S	3E	Qal	Stream channel
(2 pits)							62	NW	31	17S	3E	Green River	Shale and sandstone
18	NW	25	13S	2E	Qal	Alluvial fan	63	NE	21	17S	4E	North Horn	Bedrock (?)
19	SE	6	14S	3E	T ₁ ap	Pyroclastics	64	SE	15	17S	1W	Tertiary breccia	Sandstone and limestone
20	SE	7	14S	3E	Qal	Stream channel	65	SE	35	17S	1W	Qal	Terrace
21	SE	7	14S	3E	Qal	Stream channel	66	NW	1	18S	1W	Qag, Qao	Terrace
22	NE	18	14S	3E	Qal	Stream channel	67	NE	1	18S	1W	Qag	Terrace
23	SE	25	14S	2E	Qal	Pediment	68	NE	28	18S	1W	Axtell	Conglomerate
24	NE	36	14S	2E	Qal	Alluvial fan	69	SW	20	18S	1E	Qlts	Sand
25	NE	1	15S	2E	Qal	Alluvium	70	SW	20	18S	1E	Flagstaff	Limestone
26	SW	33	14S	3E	Qal	Alluvium	71	NE	3	18S	2E	Green River	Shale and limestone
27	SW	33	14S	3E	Qal	Alluvium	72	NE	11	18S	2E	Qal	Stream channel
28	NW	34	14S	3E	T ₁ ap	Pyroclastics	73	NE	14	18S	2E	Qal	Stream channel
29	SE	4	15S	3E	Qal	Volcanic rock fragments in sediments	74	SW	13	18S	2E	Qal	Alluvium
30	NE	9	15S	3E	Qal	Volcanic rock fragments in sediments	75	NE	18	18S	3E	Qao	Alluvial terrace
31	SW	3	15S	3E	Qal	Volcanic rock fragments in sediments	76	SW	8	18S	3E	Flagstaff	Limestone talus
32	SE	3	15S	3E	Qal	Volcanic rock fragments in sediments	(2 pits)						
33	CN	10	15S	3E	Qal	Volcanic rock fragments in sediments	77	SE	8	18S	3E	Flagstaff	Limestone talus
34	NE	10	15S	3E	Qal	Volcanic rock fragments in sediments	78	NW	21	18S	2E	Flagstaff	Limestone
35	NE	11	15S	3E	Qal	Alluvium	79	CW $\frac{1}{2}$	21	18S	2E	Flagstaff	Limestone
36	NE	22	15S	3E	Green River	Shale and limestone	80	SW	21	18S	2E	Flagstaff	Limestone
37	CN	23	15S	3E	Qal	River terrace (?)	81	NE	29	18S	2E	Flagstaff	Limestone
38	SE	23	15S	3E	Qal	River terrace (?)	82	NE	29	18S	2E	Flagstaff	Limestone
39	NE	24	15S	3E	Qal	River terrace (?)	83	Center	27	18S	2E	Green River	Limey shale
40	Center	25	15S	2E	Qal	Stream channel	84	SE	28	18S	2E	T ₁ ap	Pyroclastic gravel
41	NE	36	15S	2E	Qal	Alluvial fan	85	NE	33	18S	2E	Axtell	Conglomerate
42	NE	1	16S	2E	Qal	Stream channel	86	NW	34	18S	2E	Green River	Shale and limestone
43	SW	29	15S	3E	Qal	Alluvium	87	SE	33	18S	2E	Qal	River terrace
44	SE	17	15S	4E	Qal	Alluvium	88	NE	5	19S	2E	Qal	River terrace (?)
							89	NW	9	19S	2E	Qal	Alluvium
							90	NE	20	19S	2E	Qal	Talus
							91	NW	32	19S	2E	Qal	Stream channel
							92	NW	2	20S	2E	Flagstaff	Limestone talus
							93	NW	28	19S	4E	Tf	Bedrock
							94	NW	15	19S	1W	Qal	Alluvial fan

Moroni is large, sprawling and irregular and has been exposed by surficial scraping. Shallow pits with a maximum depth of 15 feet have been opened in pockets in this material which contains subrounded boulders (5 percent), gravel (65 percent) and 30 percent fine material. The material is 82 percent limestone and 18 percent sandstone. Some sand and silt layers are present. The whole is poorly cemented by calcite.

Another large pit in material of uncertain origin is in SE $\frac{1}{4}$ Sec. 20, T. 19 S., R. 1 E. (locality 102), one mile south of Gunnison and is being operated by Hales Sand and Gravel Company of Redmond. The material is 99 percent limestone and 1 percent sandstone, occurring as 5 percent cobbles and 75 percent gravel in 20 percent sand and silt. The gravel ranges from subangular to rounded and is small. The deposit contains scattered sand beds, but its generally unsorted nature suggests a mudflow origin.

A deposit, shown on the Geologic Map of Utah as "Qao" (relatively older alluvial deposits; on terraces above active streams), has supplied a small amount of gravel in north Sanpete County, in Secs. 20 and 33, T. 12 S., R. 4 E., three to five miles south of Indianola (localities 2 and 3). The material in these deposits varies according to geographic location, but in localities south of Indianola it is 70-80 percent quartzite, with associated sandstone, limestone and basalt occurring as 60 percent boulders, cobbles and gravel, and 40 percent fine material. Unworked deposits of this group north of Fayette in T. 12 S., R. 1 W. contain more sandstone and less quartzite.

A small concentration of gravel terraces occurs two to three miles west of Axtell (localities 111, 112, and 113), designated on the Geologic Map of Utah as "Qgs" (gravel surfaces; mainly terraces and pediments undergoing erosion). These terraces are adjacent to outcrops of Arapien Shale and the Dipping Vat Formation. The terrace tops are 50 to 75 feet above the surrounding alluvium and are composed mainly of gravel-sized detritus composed of limestone, sandstone, volcanics, quartzite and chert. A small amount of gravel produced from these deposits appears to have good commercial possibilities.

An alluvial fan type deposit designated on the Geologic Map of Utah as "Qag" (colluvium and alluvium; mostly stony and unfit for agricultural crops) occurs at the west base of the Gunnison Plateau, two or three miles due north of Fayette. This deposit is composed of 50 percent silty soil and 50 percent gravel occurring as sandstone, limestone and quartzite. A few boulders up to three feet in diameter are present. The material would make a fair fill material.

A small deposit of fine medium-brown sand, one mile east of Fayette (locality 69), has been described by Gilliland (1951, p. 54-56) as consisting of 50 percent subrounded quartz and 50 percent altered feldspar grains. The material is unstratified, occupies an area of about one-fourth square mile, lies 250 feet above the floodplain and 150 feet above the adjacent washes. Although Gilliland concedes the deposit could be of aeolian origin, he regards it more probably as a beach sand associated with a short-lived inundation of Sevier Valley by ancient Lake Bonneville. He says the deposit has been used commercially as a sand source in manufacturing cement blocks and concrete.

Tertiary-Quaternary Axtell Formation

The Axtell or Sevier River Formation is a conglomeratic deposit which in Sanpete County most commonly occurs as a dissected alluvial fan rimming the western margin of the Sevier River Valley at the foot of the Valley Mountains. A small amount also occurs in the foothills below the Wasatch Monocline southeast of Gunnison, and caps a small hill east of the Gunnison Reservoir. Gilliland (1951, p. 51) describes the formation as a conglomerate composed of boulders (many two feet in diameter), cobbles and pebbles derived from local bedrock. The formation ranges in color from gray to buff to orange-brown. It is poorly sorted and lightly indurated in a silt and clay matrix. It also contains thin sandstone beds. At the localities examined by the senior author, limestone was the most abundant rock type making up the fragments. The Axtell Formation would make good fill material and a fair road gravel. A large gravel pit may be in this formation five miles southwest of Manti (locality 85). The pit is 1,600 feet long and 360 feet wide, and the exposed material consists of 100 percent limestone occurring as 5 percent boulders and 75 percent gravel in 20 percent finer material. The material is poorly cemented by calcium carbonate.

Moroni Formation

A sedimentary formation containing detritus of volcanic rocks, boulders of quartzite, sandstone, chert and metaconglomerate occurs in the Cedar Hills (Moroni Upland) along the northwest fork of Sanpete Valley northwest of Moroni. It is included in the designation "early Tertiary andesite, trachyte, latite pyroclastics" on the Geologic Map of Utah. It was designated by Schoff (1951, p. 634-636) as pyroclastic rocks. Some 50 feet of tuff and breccia and 60 feet of white tuff occur at the top of the formation. The remaining 1,450 feet consist of conglomerate, boulders, pebbles of volcanic rock, and rocks

and sands from sedimentary formations. The lower part is mainly sandstone. Bedrock outcrops of the conglomerate are rare and the surface of the formation is a blanket of poorly sorted rock fragments ranging from gravel to large boulders in the matrix of silt and sand. No lava flows occur in the sequence, but small sills of igneous rock are found.

The surface debris derived from the conglomerate member of the Moroni Formation is mainly quartzite and volcanic rocks, with some sandstone, chert and metaconglomerate fragments. Rocks range from subangular to well-rounded boulders measuring to four feet. For the most part these rocks occur on the higher elevations and stream divides in the Cedar Hills. Some reach the valley floor from Moroni northward to the county line and in an isolated area in the valley near Mount Pleasant (figure 15) where they are used as a source of gravel (localities 10, 11, 13, 16 in table 19).

Tertiary Bedrock

The broad extent of the Flagstaff Limestone in Sanpete County is shown in figure 5. The hardest of the limestone beds in the Flagstaff provides good fill and satisfactory aggregate for surfacing. It is produced from talus derived from high cliffs above canyons incised in the Wasatch Monocline and possibly from surficial bedrock outcrops. The largest talus deposit occurs in Manti Canyon one to one and one-half miles east of Manti, where two large pits (figure 9, localities 75 and 76) extending 250 feet above the valley floor (figure 16) have been excavated. In one place, the pits extend for 1,400 feet along the north side of the canyon. The material in the talus is 100 percent angular limestone fragments occurring as 80 to 90 percent gravel-sized fragments and the re-

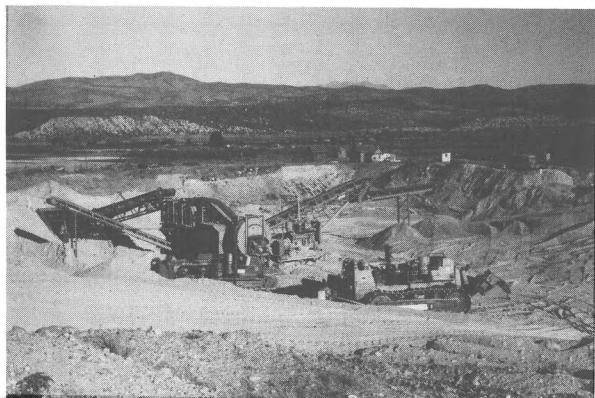


Figure 15. Gravel pit in the Moroni Formation, three miles northeast of Mount Pleasant.

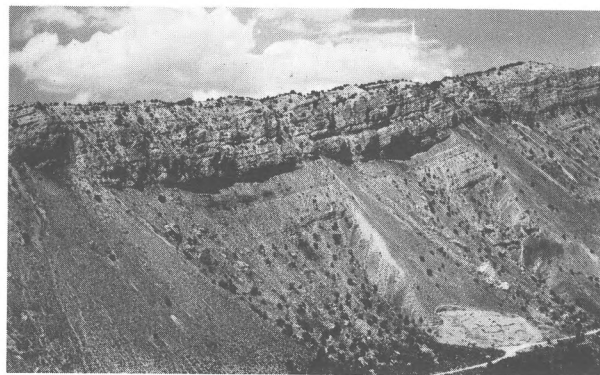


Figure 16. Flagstaff Limestone overlying North Horn Formation, Manti Canyon, Sec. 8, T. 18 S., R. 3 E. Gravel pit in talus at base of slope.

mainder as boulders, sand and silt. The material is poorly stratified and poorly cemented with CaCO_3 . These deposits are reached on a gravel-surface road and the material is easily removed. Another pit in Flagstaff talus is in Twelve Mile Canyon, two and one-half miles east of Mayfield (locality 92). Here the material contains a greater percentage of fines than do the Manti Canyon deposits.

Two large hillside pits on the east scarp face of a westward-dipping cuesta have been blasted out of the Flagstaff Formation in both the NW $\frac{1}{4}$ and SW $\frac{1}{4}$ Sec. 26, T. 20 S., R. 1 E. (localities 114 and 115). The material has been used in sugar refining in the past, and it would also provide satisfactory aggregate. West of the Gunnison Reservoir, in Secs. 21 and 29, T. 18 S., R. 2 E. (localities 78-82), a series of pits was dug in outcrops of the Flagstaff to prospect for limestone for use as flux in steelmaking.

The Green River Formation, consisting chiefly of interbedded shale, calcitic dolomite and oolite (Spieker, 1949), has been used chiefly as borrow material, in the form of small, thin, platy and easily broken fragments of limestone, calcareous siltstone, limy shale and sandstone. The major borrow pits are along U. S. Highway 89 in Secs. 27 and 34, T. 18 S., R. 2 E., north of Sterling (localities 83 and 86). Smaller pits occur two miles north of Manti (locality 62) and two miles northwest of Manti (locality 71). A large pit in broken rock derived from the Green River Formation is near Utah Highway 11, one and one-half miles south of Moroni (locality 36). The material here consists of 50 percent gravel-sized, thin, platy and angular limestone, calcareous shale fragments and 50 percent fines.

Borrow material has been removed from a cut N½ Sec. 25, T. 14 S., R. 4 E. (locality 12), which is on the east side of the bedrock hill and immediately west of the blacktop road. It is 800 feet long and 75 feet high. The upper 25-foot section is composed of interbedded sand, volcanic gravel and ash, and probably belongs to the Moroni Formation; the lower 50-foot section is a mixture of light greenish-gray, medium-grained, calcareous sandstone and white, very fine-grained, thin-bedded limestone and probably belongs to the Colton Formation. The limestone breaks into thin slabby pieces yielding a material consisting of 65 percent fine gravel, and 20 percent coarse gravel and 15 percent boulders and fines.

A Tertiary breccia occurs in the Goldens Ranch Formation, (Tvs) on the geologic map of Sanpete County. Vogel (1957) describes this formation as tawny colored limestone, sandstone, shale, siltstone and conglomerate, derived from nearby "Tawny beds" (probably the Green River Formation) and deposited as alluvial fan, stream channel and slump debris. A large sprawling pit in this breccia occurs just east of Utah Highway 28, three miles south of the Juab-Sanpete County line (locality 64). The material in the pit consists of 50 percent limestone and 50 percent sandstone, occurring as 5 percent subangular to subrounded boulders and cobbles, 75 percent gravel and 20 percent fines.

Salt

The earliest settlers quarried salt in the Redmond Hills, a low ridge in the middle of Sevier Valley at the south end of Sanpete County and the adjoining part of Sevier County. Approximately 10,000 tons per year from both counties are removed and sold in rough blocks as quarried for cattle and crushed for sheep. Crushed salt is used on roads and highways in the winter. No attempt is made to refine the salt for human consumption or industrial use. Brief descriptions are given by Pratt, Heylman and Cohenour (1966, p. 48-58), Hite (1964, p. 210-211) and Hardy (1952, p. 62).

Most of the salt is coarse-grained with a brick-red color, but some discontinuous beds of white salt to two feet in thickness and scattered pockets of pure, transparent, halite crystals are found in the quarries. Owing to intense deformation and flowage, much of the salt has an oriented structure and is drawn out into parallel acicular grains. Blocks of red shale and siltstone representing former sedimentary clastic beds may occur in the salt. A chemical analysis obtained by Gilliland (1951, p. 81) from a sample taken from the Poulson Brothers pit just

south of the Sanpete County line in Sevier County gives percentages of the constituents.

NaCl	Si	SO ₄	Ca	Fe ₂ O ₃ · Al ₂ O	Mg	I
95.60	2.16	1.10	.51	.04	.04	.03
Total=99.48						

Analysis of a sample from the Albert Poulson pit in Sanpete County gives the following percentages:

Na	Cl	Ca	SO ₄
37.57	59.36	.59	2.48
Total=100.00			

Additional analyses undoubtedly would indicate considerable variation in the distribution of impurities in the salt. Gypsum is an obvious contaminant; it is evident from the analysis that only a small amount of red clay is required to provide the coloration. The indicated content of MgCl₂ is small. The indicated amount of iodine is sufficient for nutrition for cattle.

Salt occurs in discontinuous lenses and masses in the Arapien Shale described elsewhere in this report. The probable distribution of the salt horizon (unit E of Hardy, 1952, p. 22) in the Redmond Hills and the location of the pits are shown on the accompanying map (figure 17). Outcrops of the salt horizon are discontinuous owing to erosion of this relatively weak formation and to cover by much younger sediments, mainly gravels and volcanic debris of Tertiary age. The rocks associated with the salt are mainly interbedded red and gray shale, red siltstone, gray calcareous sandstone, arenaceous limestone and gypsum. The bedding is commonly nearly vertical. Because of intense deformation, the salt has flowed and has been broken and reorganized into discontinuous masses which do not necessarily reflect the original distribution or thickness as deposited. Hardy (1952, p. 62) estimates a possible thickness of 200 feet. Since the amount of salt found in the known pits is sufficient for market requirements, no effort has been made to drill through cover to determine the total amount of salt available to open pit mining.

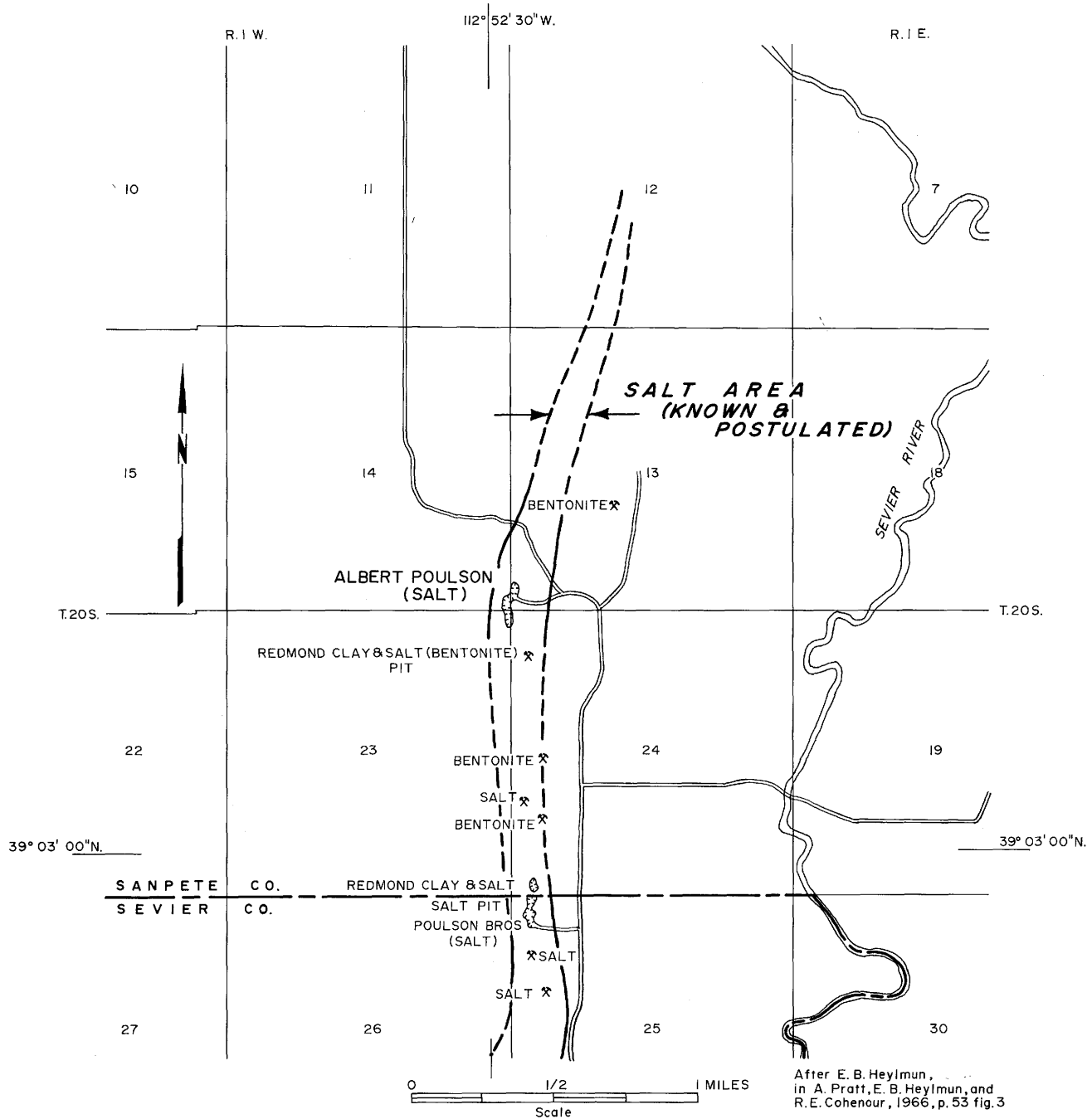


Figure 17. Evaporites and bentonites (after E. B. Heylman, 1966, in Pratt, Heylman and Cohenour, p. 53, figure 3).

The pit of Albert Poulson Salt Company, located at the common corner of Secs. 13, 14, 23, and 24, T. 20 S., R. 1 W., is 750 feet long and ranges from 50 to 150 feet in width. In 1967 the salt was being mined from a face 50 feet high overlain unconformably by 30 feet of sand and gravel at the south end of the pit (figure 18).

The pit of Redmond Clay and Salt Company is in the SW corner of Sec. 24, T. 20 S., R. 1 W., immediately north of the Poulson Brothers pit in Sevier County. In 1964, the pit was 275 feet long and 180 feet wide, and salt was being mined from a 20-foot face overlain by 20 to 30 feet of gravel and clay.

Gypsum

In Sec. 30, T. 19 S., R. 2 E., west of Mayfield, Hardy (1952, p. 89) measured three gypsum beds ranging from three to seven and one-half feet in thickness. The gypsum is dark gray to medium yellow and weathers to a dirty brownish gray color.

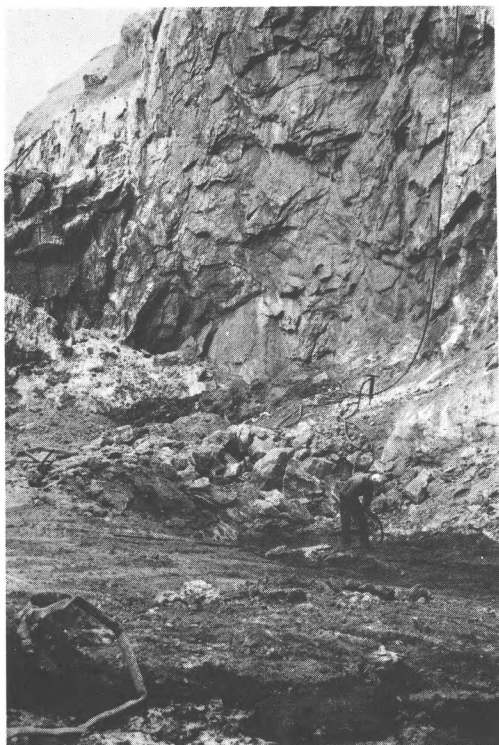


Figure 18. Massive rock salt, Albert Poulson Salt Co. pit, at common corner Secs. 13, 14, 23, 24, T. 20 S., R. 1 W.

Stone and Lupton (1920, p. 266) mention the presence of gypsum in a bed 20 to 40 feet thick exposed for four miles at the head of Manti Canyon. The senior author of this paper examined this area but found no trace of such a bed. Minor occurrences of gypsum have been mentioned by Spieker (1949, p. 31) in the Flagstaff Limestone.

Miscellaneous Industrial Minerals and Rocks

Welded tuff in the Goldens Ranch Formation (Muessig, 1951) has been quarried by the Azome Utah Mining Company in Sec. 4, T. 17 S., R. 1 W., west of State Highway 28 near the Juab County line (locality 3, figure 19) and prepared and marketed under the trade name "Azomite." The quarry is 120 feet high and cut in the face of a low rounded hill consisting entirely of the tuff. The material is crushed at the quarry and trucked to the company's plant at Sterling where it is further reduced in size and marketed as poultry grit, feed additive for domestic animals, and soil conditioner. Other prospects (localities 4 and 5) have been opened near the present quarry.

The welded tuff on the weathered surface is pitted and cavernous and has a conglomeratic appearance, incorporating pebbles, granules and crystals of various minerals. Vogel (1957, p. 144-145) described the rock as a pink to orange to tan tuff composed of a fine-grained, glassy matrix containing numerous crystallites, reddish brown pumice fragments up to 40 mm long, subhedral and rarely zoned sanidine and oligoclase, large tan and white to black glass shards, and small dark globules of volcanic glass. Accessory minerals are biotite, hornblende, sphene, magnetite and calcite. Quartzite fragments were noted. The matrix is a partly devitrified glass. The late Bronson Stringham of the University of Utah examined the rock and found it to be unaltered. Vogel (1957, p. 128-129) listed the percentages of the components as follows:

	Percent
Large red pumice fragments	20
Small glass shards	20
Sanidine	15
Oligoclase	5
Matrix of partly devitrified glass	35
Accessory materials:	
biotite, hornblende, sphene, magnetite, calcite, hematite, and quartzite	5
Total	100

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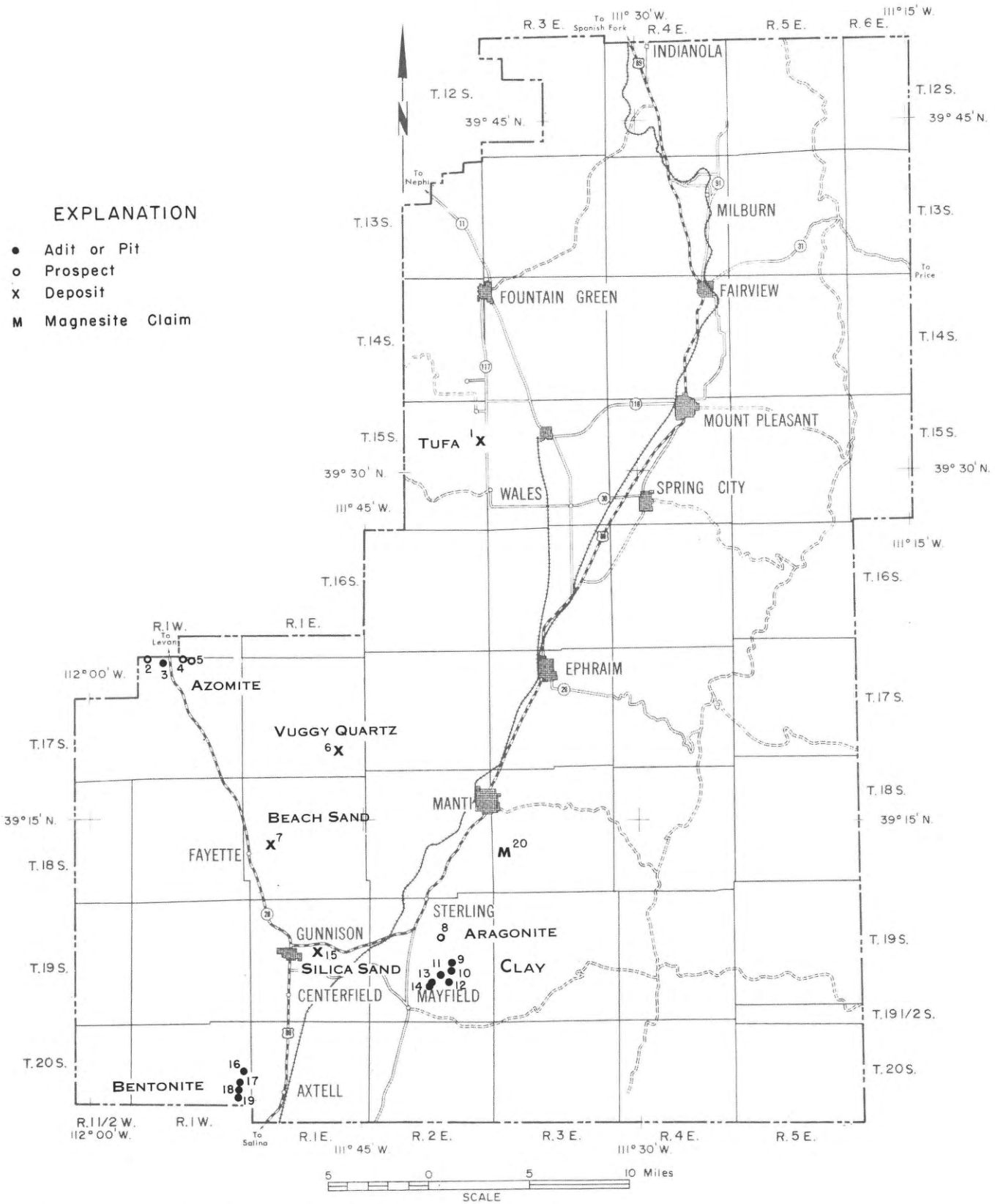


Figure 19. Location of miscellaneous rocks and minerals, Sanpete County.

A spectrographic analysis made by Harold Bradford of the University of Utah revealed the following elemental components:

	Percent
Ba, Co, Cb, Cu, Ga, Zn, Cr	less than .01
Pb, Mo, Ni, Ag, Ti, V	.01 - 0.1
Fe, Mn	0.1 - 1.0
Al, Ca, Mg, K, Na	1.0 - 10.0
Si	10.0

Figure 19 and table 20 show the distribution of miscellaneous industrial minerals and rocks in Sanpete County.

Four pits have been opened in the Redmond Hills on bentonite deposits in the Dipping Vat Formation (localities 16-19, figures 17 and 19 and table 20) near the salt deposits. The bentonite is quarried intermittently for local use as a lining for irrigation ditches and stock ponds or reservoirs to control leakage, and to cover roofs and as a filler in soap. Its value derives from its property of swelling to 3½ times its volume after grinding and addition of water.

X-ray and differential thermal analyses of the bentonite in the Redmond Hills show it to be an impure montmorillonite clay with small amounts of quartz. Quartz grains and biotite flakes are visible under the hand lens. The bentonite occurs in beds (figure 20) interlayered with pyroclastic beds or as pockets in these beds or in alluvial gravel where the Gray Gulch Formation dips eastward. One pit (locality 17) is operated intermittently by Redmond Clay and Salt Company. Local demand can be sup-

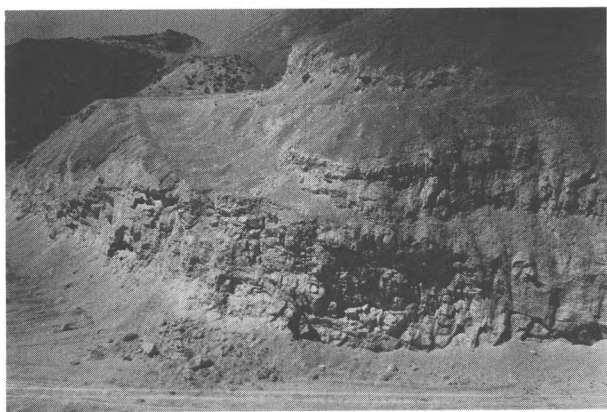


Figure 20. Bentonite bed in the Redmond Hills west of Axtell, Utah.

plied readily from the present pits and no attempt has been made to determine the extent of the bentonite.

A group of at least six adits and a number of pits near Mayfield were excavated in the Green River Formation to prospect for fuller's earth. No clearcut evidence of this clay was found.

Aragonite, a form of calcium carbonate, appears in a prospect pit on a fault zone in the Green River Formation at locality 8 (figure 19 and table 16) near Sterling, occurring in a variety of forms in the prospect, principally as a white crystalline material filling thin fractures and lining cavities, concentric bands, mammillary forms, and massive, translucent, structureless material. Its chief interest lies in its attractive forms and colors useful for a decorative material.

Large white boulders of dense magnesite or magnesium carbonate occur in a gully in the north wall of Six Mile Canyon four and one-half miles northeast of Sterling (locality 20, figure 19, and table 16) at the foot of steep red cliffs of the North Horn Formation. No magnesite was found in the bedrock. A mining claim is located here but no evidence of prospecting or development work was seen.

Tufa, a porous aggregate of calcium carbonate generally deposited in springs such as Mammoth Hot Springs in Yellowstone Park, occurs in a series of 100-foot high hills (figure 21) that continue for 1,300 feet in a northwesterly direction near the contact of valley fill with the Cretaceous Indianola Formation at the east base of Gunnison Plateau, three and one-half miles west of Moroni (locality 1, figure 19 and table 20). The surface of the tufa is rough and pockmarked by cavities up to one inch in

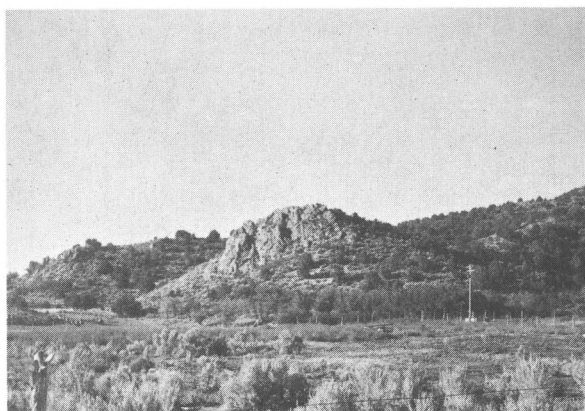


Figure 21. Hillock of tufa west of Moroni.

Table 20. Occurrences of miscellaneous industrial minerals and rocks in Sanpete County.

Locality No.	Location				Formation	Type of occurrence
	1/4	Sec.	Township	Range		
1	Center S. boundary	12	15S	2E		Tufa
2	NW	5	17S	1W	Goldens Ranch	"Azomite" prospect (?)
3	NW	4	17S	1W	Goldens Ranch	"Azomite"
4	NE	4	17S	1W	Goldens Ranch	"Azomite" prospect
	(2 pits)					
5	NW	3	17S	1W	Goldens Ranch	"Azomite" prospect
6	SW	26	17S	1E	Flagstaff	Vuggy quartz
7	SW	20	18S	1E	Qlts	Beach sand
15	SW	15	19S	1E	Crazy Hollow	Bedrock sand
8	NW	15	19S	2E	Green River	Aragonite
9	SE	22	19S	2E	Green River	Clay
10	SE	22	19S	2E	Green River	Clay
11	NW	27	19S	2E	Green River	Clay
12	SE	27	19S	2E	Green River	Clay
13	SE	28	19S	2E	Green River	Clay
14	SE	28	19S	2E	Green River	Clay
16	SW	13	20S	1W	Gray Gulch (?)	Bentonite pit
17	NW	24	20S	1W	Gray Gulch (?)	Bentonite pit
18	CW $\frac{1}{2}$	24	20S	1W	Gray Gulch (?)	Bentonite pit
19	SW	24	20S	1W	Gray Gulch (?)	Bentonite pit
20	NE	30	18S	3E	North Horn (?)	Magnesite claim

diameter. The rock is a medium pinkish-brown, weathering to chalky white or brownish gray.

Crystals of quartz up to one-fourth inch in diameter occur as vein fillings and incrustations of cavities in chert at locality 6 (figure 19 and table 20) northwest of Fayette. The material is of interest to mineral collectors.

A prospect for silica sand has been staked on a low hill one-half mile east of Gunnison (locality 15, figure 19, and table 20). The rock is a medium-grained quartzose sandstone in the Crazy Hollow Formation described elsewhere in this report. Laboratory examination shows that it consists of 96 percent subangular quartz grains, 3 percent black ferromagnesian grains, 1 percent feldspar and rare chert grains. The grains are coated with clay.

As described by Crawford and Buranek (1942, p. 6-9), magnesium sulfate occurs as efflorescences and small pockets along with sodium sulfate and gypsum, and traces of sodium chloride and alum on

the north wall of Manti Canyon, three miles east of Manti and opposite the powerhouse. These occurrences may be traced along the base of a cliff for a mile or so. The material in the cliff is a dense limestone or marlstone of the Flagstaff Limestone underlain by a bentonitic shale unit. A tunnel driven 100 feet into the shale revealed sparsely distributed small pockets of magnesium sulfate or epsomite in the shale.

METALLIC MINERAL PROSPECTS

Inasmuch as Sanpete County almost wholly embraces outcrops of sedimentary rocks, mainly of late Cretaceous and Tertiary age, with no granitoid intrusive rocks and no significant occurrences of lavas, its possibilities for workable deposits of metallic minerals are not favorable. The county has been prospected and some minor occurrences have been found. All prospects and occurrences known to the writer are shown on the map (figure 22) and listed in table 21.

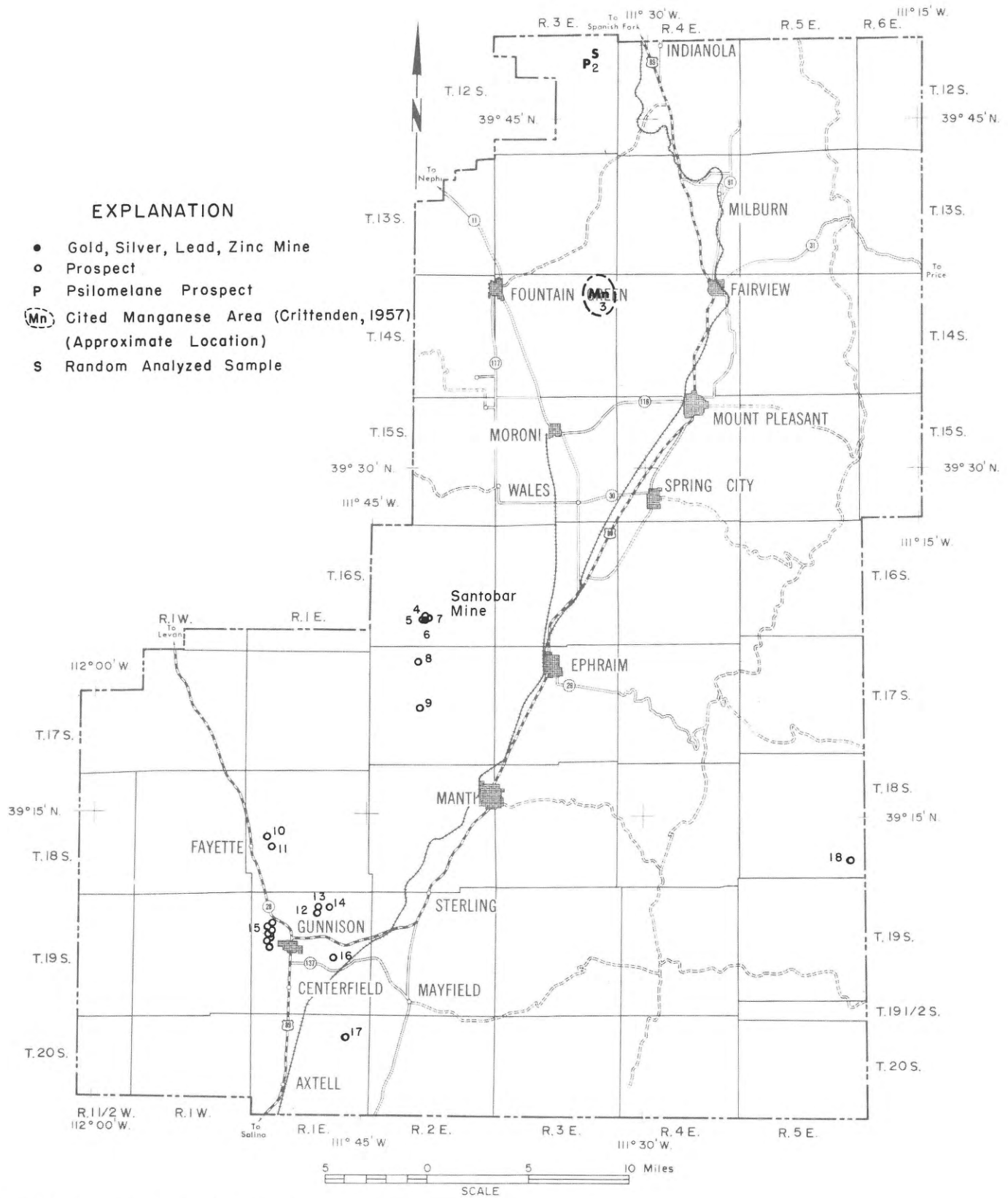


Figure 22. Location of metallic minerals.

Table 21. Locations of metallic mineral prospects and assays of sample.

Locality No.	Location				Oz/ton		Percent		
	1/4	Sec.	Township	Range	Au	Ag	Pb	Zn	Mn
1	NW	11	12S	3E					25.1
2	SE	28	16S	2E	tr	1.6	0	0	
2	SE	28	16S	2E	tr	tr	0	0	
2	SE	28	16S	2E	tr	tr	0.8	0	
3	SE	28	16S	2E	tr	1.4	0	0.5	
3	SE	28	16S	2E	tr	0.8	1.4	0.5	
3	SE	28	16S	2E	tr	0.4	0	2.5	
4	SE	28	16S	2E	0.02	3.0	15.1	1.4	
4	SE	28	16S	2E	tr	0.4	none	0.8	
5	SE	28	16S	2E	tr	tr	1.2	0.8	
6	SW	4	17S	2E	tr	tr	0.8	0	
6	SW	4	17S	2E	tr	tr	0.6	0	
6	SW	4	17S	2E	0.01	0.2	?	?	
7	NW	21	17S	2E					
8	NE	19	18S	1E	0	0			
9	SW	20	18S	1E	0	0			
10	NE	18	19S	1E	0	0			
11	SW	23	19S	1E					
12	CN $\frac{1}{2}$	36	16S	5E	tr	tr			0.08
13	SE	12	14S	3E					27.8
14	SE	2	12S	3E					

Manganese

Congo No. 1

A prospect in the Cedar Hills (locality 2, figure 22 and table 21) in an area of pyroclastic rocks reveals some blocks of black manganese oxide in residual soil. No manganese deposits were found in bedrocks. The deposit is said to have been investigated by Geneva Steel Company. A sample of dense blue-black manganese oxide assayed 25.1 percent manganese.

Losty Canyon

A sample of float on a ridge (locality 1) near the Congo No. 1 prospect assayed 27.8 percent manganese. No manganese was found in bedrock.

Prospect of Uncertain Location

Crittenden (1951, p. 35) mentions an occurrence of manganese oxide mixed with jasper assaying 38 percent manganese said to be located eight miles northwest of Mount Pleasant (locality 13, figure 22, and table 21). The senior author examined the suggested location but found no manganese deposit. A test of black andesite float in this area showed 0.08 percent manganese.

Lead-Zinc and Other

Santobar

Some lead-zinc ore was mined in 1961 (Howes, 1962, p. 1028, table 4) from an adit (locality 6, figure 22 and table 21) trending N. 50° W. for 160 feet. The portal (figure 23) is in the North Horn Formation near its contact with the overlying Flagstaff Limestone on the west side of a gully in the eastern foothills of the Gunnison Plateau. Several prospect pits are near the adit (localities 4, 5, and 7). In 1967, 21 tons of lead and zinc ore, reportedly valued at \$200/ton, were removed from the mine.

At the mine, conglomerate limestone in a faulted area contains veinlets of galena, pyrite and calcite. Three samples near the adit (locality 6) assayed as follows:

Gold	trace
Silver	0.4-1.4 oz/ton
Lead	0.0-1.4 percent
Zinc	0.5-2.5 percent

Assays of samples from a prospect pit (locality 5) above the adit assayed:

Gold	trace to 0.02 oz/ton
Silver	0.4-3.6 oz/ton
Lead	0.0-15.1 percent
Zinc	0.8-1.4 percent

Lost Josephine

At locality 8 (figure 22 and table 21) an adit was driven 175 feet S. 45° W. in calcareous dark-red

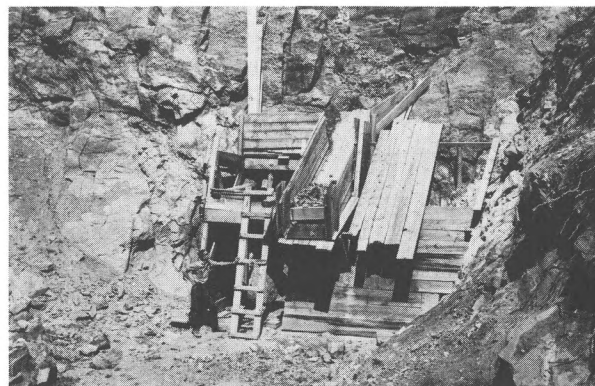


Figure 23. Portal of Santobar lead and zinc mine.

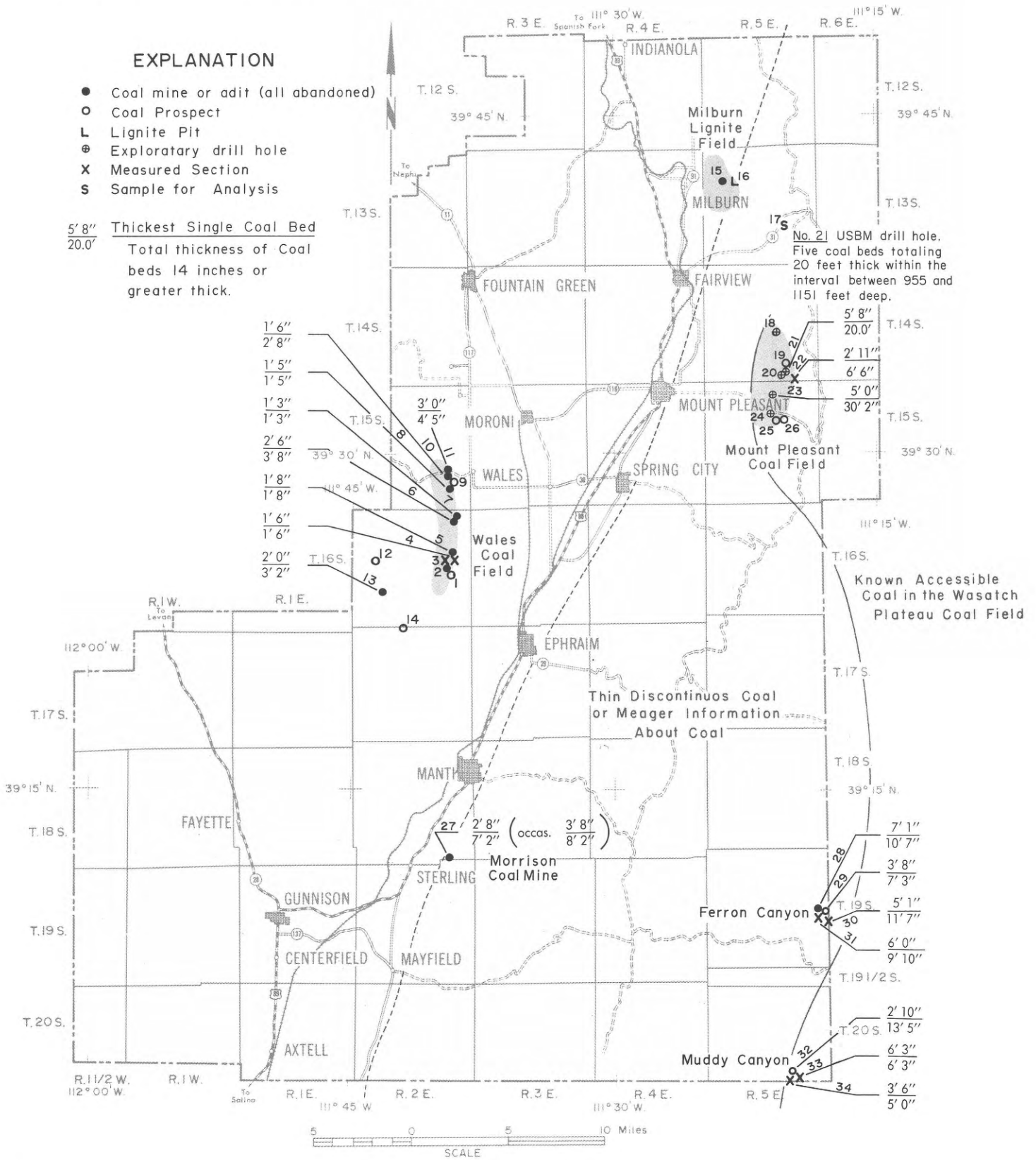


Figure 24. Localities of coal and lignite.

siltstone and grayish-white, fine-grained sandstone of the Arapien Shale near the contact with conglomerate of the Price River Formation. The adit penetrated the conglomerate, which has been shattered by faulting and contains veinlets of pyrite and calcite. In places the conglomerate is cemented by calcite, and limonite gossan occurs in the weathered surface. Three samples assayed showed gold, a trace to 0.01 oz/ton, and silver, a trace to 0.80 oz/ton. Another sample showed lead, 0.6 percent and zinc, none.

Prospects Near Gunnison

Several pits have been dug in rusty red, limonitic-yellow or hematitic-black siltstone, sandstone and calcareous shale of the Crazy Hollow Formation (locality 15). At locality 16 east of Gunnison, a short adit has been driven in shattered limestone containing stringers of chert.

Prospects Near Fayette

Two pits in shattered Tertiary sediments (localities 10 and 11) show a little calcite and limonite. Assays showed no precious metals.

Big Horn Prospect

At locality 18 in the Wasatch Plateau, some calcite veinlets occur in interbedded sandstone, limestone and shale of the North Horn Formation. Assays revealed traces of precious metals.

Lewis Claims

An outcrop of conglomerate of the North Horn Formation or Price River Formation at locality 9 shows slight radioactivity.

FOSSIL FUELS

Coal and Lignite

Coal-bearing formations of Cretaceous and Paleocene age are widespread in Sanpete County (figures

24, 25). Coal was discovered in 1859. Mines near Wales on the east side of the Gunnison Plateau were reached by railroad in 1870 and the coal was moved to the Salt Lake City market. Later coal was found in the area east of Sterling and the railroad was extended into this area. Production virtually ceased by the early 1940's. No active mines were available for inspection and the information given in this report is taken almost wholly from publications by Richardson (1905), Clark (1912), Spieker (1931) and Duncan (1944). Although beds of the great Wasatch Plateau coal field doubtless underlie the large part of the county east of the Sevier-Sanpete Valley, they are for the most part too deeply buried to be mined competitively under present conditions. They are at or near the surface in two localities on the west slope at Sterling and Mount Pleasant, and in two canyons, Ferron and Muddy creeks, on the east slope, in the southeast corner of the county. The Wales field on the west edge of the county is the only other exposure of coal of commercial interest and here the coal occurs in the North Horn Formation of Cretaceous and Paleocene age. The coal is all of bituminous rank.

Gunnison Plateau

A single bed of coal two to seven feet thick follows the east base of the Gunnison Plateau from a point 1.5 miles west of Wales southward for 6 miles. Averitt (1964, p. 46) describes the bed as "containing about equal parts of coal and shale. The bed includes benches of coal 1½–2½ ft. thick that are free of partings, but even these benches are high in ash." Though ranked as bituminous and having a fairly high ratio of fixed carbon to volatile material (fuel ratio), its value is greatly reduced by a high content of sulphur and ash. According to Burma and Hardy (1953, p. 551) the coal occurs near the middle of the middle unit of the North Horn Formation, associated with beds of shale, sandy and carbonaceous shale with limestone, and resting on a locally profound unconformity over highly deformed and thrust-faulted beds of Jurassic and Cretaceous age which crop out in a belt only a half mile wide at Wales. The coal bed for most of its course dips

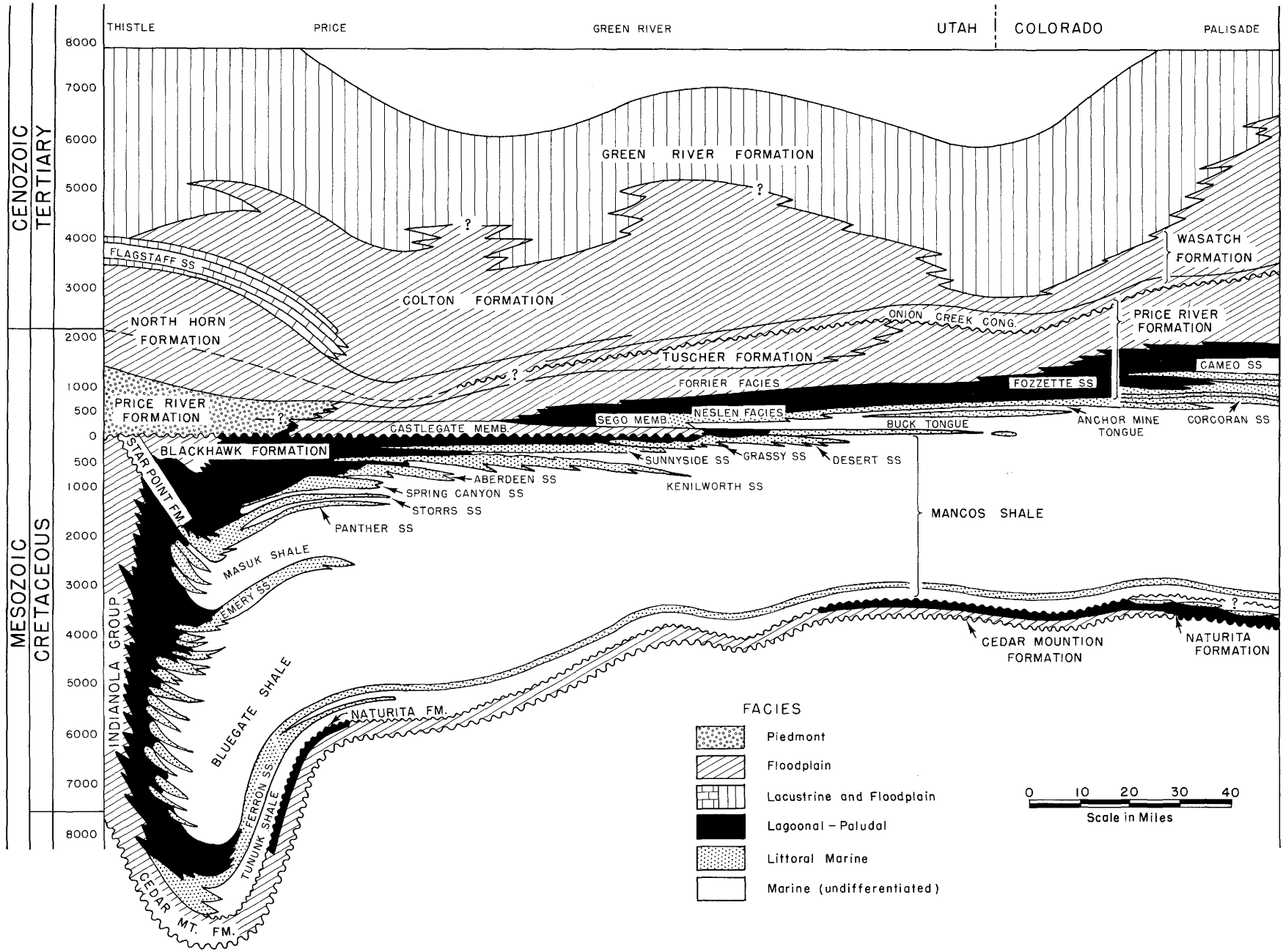


Figure 25. Stratigraphy of coal-bearing rocks of Book Cliffs, Utah-Colorado (Young, 1966, figure 2).

10°–16° W. but dips as steep as 64° W. are recorded. The coal is readily accessible in a number of canyons cut in the face of the Gunnison Plateau.

Coal was found in a small area two miles east of Sterling and mining began in 1887 (Wilson, 1949, p. 10). A railroad was built to the mine in 1894. The mine operator drove an adit 2,000 feet southward from Six Mile Canyon. Operations were hampered by a large flow of water and another adit was driven as a drainage tunnel, but the cost of handling the water forced the closing of the mine and only a small amount of coal has been removed since the early 1940's. No data on total production are available. The water rights have been a valuable property (Richardson, 1905, p. 284), and the Manti Water Board is using the drainage tunnel water to increase irrigation supplies.

The coal occurs in several seams separated by thick sandstone layers in the middle unit of the Six Mile Canyon Formation (Spieker, 1946, p. 128) of Cretaceous age. The coal-bearing unit, about 300 feet thick, is underlain by 2,000 feet of conglomeratic sandstone and overlain by 425 feet of conglomeratic sandstone. The dip in the mine area is 15°–20° E.

Milburn Lignite Field

Lignite, consisting of dark gray to brownish black, earthy, friable, poorly bedded material containing woody fragments, was prospected between 1955 and 1963, in Secs. 7 and 8, T. 13 S., R. 5 E. in Dry Creek Canyon east of Milburn (localities 15 and 16, figure 24). Some of the lignite was subsequently mined, ground, and mixed with turkey feathers to produce a soil conditioner. The bed in a prospect pit (locality 16) is 1.1 feet thick and beds as thick as 14 feet have been found. The lignite beds occur in the North Horn Formation. An adit on the north side of the canyon in Sec. 7 (locality 15) shows 1.6 feet of lignite containing clay partings and associated with limestone. At locality 17, a lignite bed one foot thick occurs in a highway cut.

PETROLEUM AND NATURAL GAS

Sanpete County is entirely underlain by sedimentary rocks and by units which elsewhere in the

state yield petroleum and natural gas. With the discovery of natural gas in Carbon and Emery counties interest was stirred by the possibilities throughout the entire Wasatch Plateau, and the Joes Valley gas field at the eastern margin of the county was discovered in 1956. The cumulative production of the two wells (localities 12 and 13, figure 26) from 1956 to January 1, 1968, was 3,418,208 MCF. Nineteen tests were made elsewhere in the county. Further details of tests are on file in the Utah Geological and Mineralogical Survey and the Utah Oil and Gas Commission. Discussions of stratigraphy and structure appear elsewhere in this report and in many of the cited references. The reader especially interested in gas and petroleum is invited to read Walton (1954) and pertinent chapters in Bulletin 54 of the Utah Geological Survey, "Oil and Gas Possibilities of Utah, Re-evaluated" (Crawford, 1963), especially those by Christiansen and Walton. Bulletin 73 of the Utah Geological and Mineralogical Survey (1964, p. 51-60) gives a brief review of the petroleum and natural gas resources of Utah.

The Dakota Sandstone in the Wasatch Plateau is commonly 25 feet or less and may be absent in some places (Katich, 1954, p. 44-45). The pebbles commonly are 70 percent quartzite and 30 percent chert, and may be as large as 2 inches in diameter. The Dakota in the subsurface at Joes Valley is hard and tight with low reservoir capacity (Walton, 1963, p. 349).

No wells in the Sanpete County portion of the Wasatch Plateau have been drilled deeper than the Morrison, the formation immediately underlying the Dakota. In the Gordon Creek gas field 10 miles east of Sanpete County a strong flow of carbon dioxide was obtained in the Sinbad Limestone in the lower part of the Triassic sequence and in the Coconino Sandstone of Permian age (Walton, 1963, p. 352). The depth of these formations below the Dakota in Sanpete County may be about 5,000 ft. The Manning Canyon Shale, about 1,000 ft. below the Coconino, also yielded gas.

Gas was found in the north Joes Valley structure (Walton, 1963, p. 345; Johnson, 1961) where it was obtained from the Ferron and Dakota formations. In the Ferron the structure, which is a truncated portion of a fold against a north-trending fault in the east side, has a closure of 1,600 ft. with a gas-water contact at 2,600 ft. above sea level. The apparent size of the field is about 1 by 2½ miles. Six holes were drilled in this field (figure 26, localities 7, 8, 12, 13, 15 and 18).

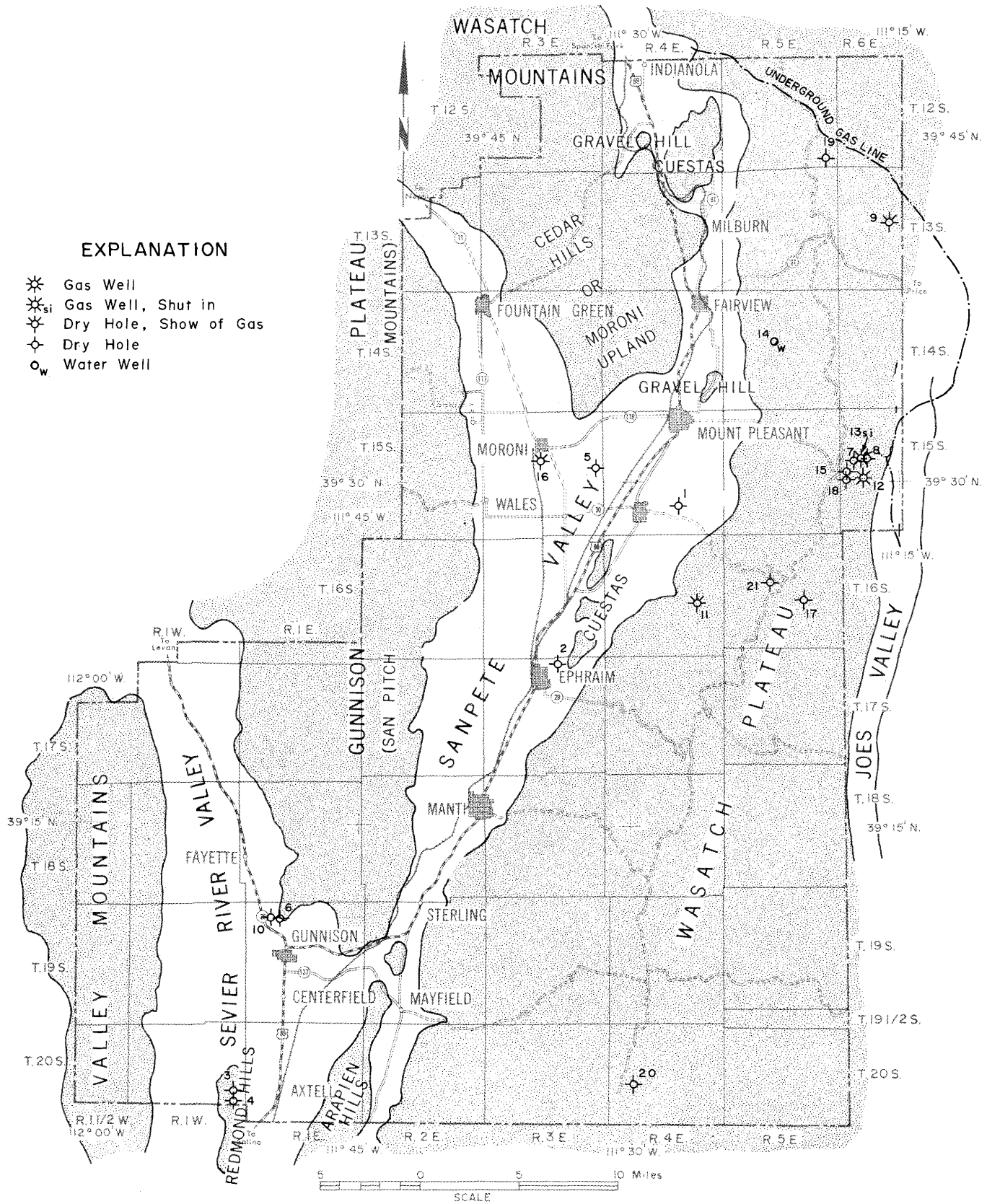


Figure 26. Drilling for oil and gas.

A broad anticline trending ENE northeast of Ephraim is truncated on the east end by faults of the Joes Valley system and on the west by a complex of faults marking the break into the Wasatch Monocline. The closure is at least 300 ft. One well drilled near the crest of the anticline (locality 17) tested both the Ferron and Dakota without finding gas. Another well (locality 11) drilled on the faulted flank of the structure yielded a show of gas in both the Ferron and the Dakota.

A curved fault trending north has dropped the beds to the west on the westward slope of the Wasatch Monocline producing a closure of about 300 feet. The structure has a length of about seven miles and a width of more than a mile. A well (locality 14) drilled through both the Ferron and Dakota into the Morrison in the north part of this structure is said to show no gas, but it yielded 14,000 bbl/day of water (Heylman, Cohenour and Kayser, 1965). Evidently the highest part of the structure has not been tested.

The structure on the west side has a closure of at least 200 ft. A well (locality 19) drilled through the Ferron into the Lower Mancos or Tununk Shale Member on the crest of this structure yielded no show of gas. The structure on the east side of the graben ends about six miles southeast of the other structure and was tested by a well (locality 9) drilled through both the Ferron and Dakota into the Morrison. A show of gas was found in the Ferron but not enough for commercial production.

An unnamed monocline in the southeast corner of the county slopes northwest away from the Joes Valley fault zone. A dry well (locality 20) was drilled through the Ferron into the Frontier in an area where this monoclinical structure is interrupted by a group of faults.

Walton (1963, p. 352) has suggested that the structures already tested should be drilled through the Cretaceous section to test lower formations that are productive east of the Plateau. Also he suggested drilling untested structures where gas may have been trapped by faulting.

Western Sanpete County

Possibilities for finding commercial quantities of petroleum and natural gas in that part of Sanpete County west of the Wasatch Plateau and the Wasatch Monocline are clouded by the complex structure discussed earlier in this report and by failure to find

significant indications of gas or oil in the tests that have been drilled. Two wells, one near Moroni (locality 16, figure 26; total depth 9,995 ft.) and one near Levan in Juab County NE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 17, T. 15 S., R. 1 E.; total depth 7,526 ft.) have been drilled deep enough to reveal significant characteristics of the subsurface formations. The test at Moroni was favorable in that it showed that the Cretaceous section found in the Wasatch Plateau, including the Ferron and Dakota, persisted this far west; there was a slight show of gas in the Ferron. The possible structure is a closure of the Ferron against a fault west of the well. The Levan test, spudded in the Jurassic Arapien Shale, went through the nose of an anticline, overturned toward the east, which includes the Jurassic Navajo Sandstone, indicating strongly that there is little chance for persistence of the favorable Cretaceous horizons, even beneath a possible thrust plate, more than three miles west of Moroni. The Levan test shows that the pre-Cretaceous formations continue through Sanpete County westward. Another deep test outside the county is the Standard Oil Company of California Sigurd unit No. 1 drilled to a depth of 9,640 ft. in NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 32, T. 22 S., R. 1 W. in Sevier County, penetrating 9,000 ft. of Arapien Shale before reaching the Navajo Sandstone. This is a probable thickening of the Arapien owing to tectonic disturbance (Gilliland, 1963, p. 122).

The recognition of the Dakota and Ferron in the test at Moroni is of special interest because it indicates that these formations may occur under the portion of Sanpete Valley east of Moroni and in the Cedar Hills (Moroni Upland) northward to the belt of transition between these formations and the unfavorable rocks of the Indianola Group. This region is covered by Tertiary formations that make location of optimum positions for drilling difficult. The probable persistence of the Dakota and Ferron under this area at depths corresponding to those in the Moroni test (8,200 for the Ferron and 9,700 for the Dakota), makes this a promising area.

In the Upper Cretaceous rocks, the characteristically marine shale of the Tununk and other members of the Mancos change to dominantly sandy and conglomeratic rocks of the Indianola Group. Since the western area was tectonically active during deposition of the marine phases of the Upper Cretaceous, there are many unconformities and thrust faults which further tend to terminate favorable horizons. Also their tectonic movements tended to elevate the weak Arapien Shale into an anticline (Gilliland, 1963, p. 115-123) or belt of thrusting which further barred the extent of marine Cretaceous

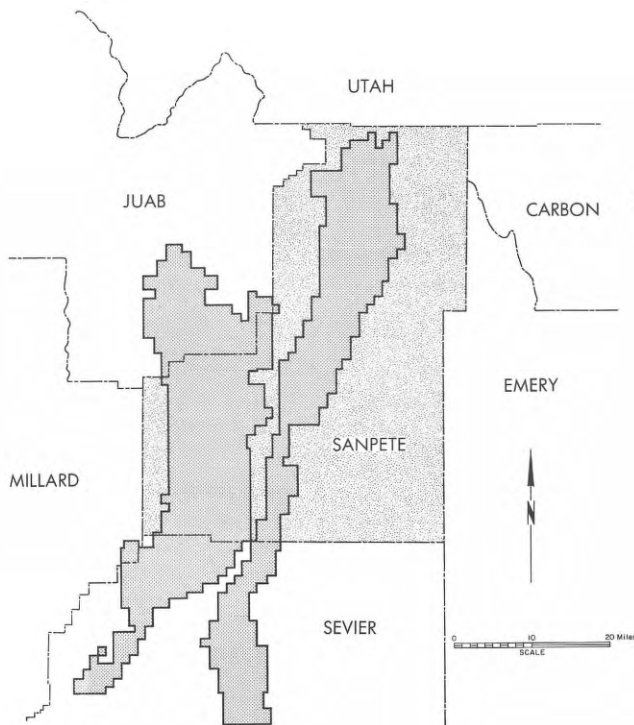


Figure 27. Outline of lands classified as oil-shale lands under executive order 5327, April 15, 1930 (after U. S. Geological Survey map issued December 1967; federal lands within outline are withdrawn from various types of lease or sale related to oil shale).

into this area. The abrupt facies change just west of the Moroni test well between the Mancos and Indiola strongly suggests thrust faulting. The change in direction of the trend of the Indianola and the Price River at Fountain Green from southwest to south also suggests that the boundary southward from Fountain Green is tectonically controlled and very possibly the locus of thrust faulting. Nearly vertical faults in the Late Tertiary also may in part coincide with this boundary, at least along the east side of the Gunnison Plateau.

The structure interpreted as a recumbent anticline broken by a thrust found in the well near Levan doubtless indicates the complexities of structure to be expected in western Sanpete County and adjacent areas to the west. Such structures are not particularly favorable to hydrocarbon accumulation and their complexity makes finding such accumulations difficult, particularly when the complexity is concealed beneath younger formations whose structures do not closely reflect conditions in the older rocks. Furthermore, there is a tendency for sandstone units to be cemented with silica, greatly reducing the reservoir pore space. This is illustrated by exposures of Navajo in Piute County and by the logs of the Levan and Sigurd wells. The expense of exploratory drilling would be increased by the probable great depth of possible productive horizons beneath thick

Cretaceous and Tertiary cover. Nevertheless, drilling alone will verify the presence or absence of hydrocarbon accumulations.

Oil Shale and Bitumens

The Green River Formation, which contains enormous resources of oil shale in the Uinta Basin, is exposed in the Sevier and Sanpete valleys and probably underlies considerable areas in the Cedar Hills (Moroni Upland), but no oil shale has been recognized in Sanpete County. Certain lands in Sanpete County (figure 27), however, are included in public oil shale lands in central Utah withdrawn from availability for production (U. S. G. S., 1967).

Dense limestones and calcareous siltstones which emit a strong petroleum odor on fresh fracture occur in the North Horn Formation above the coal zone previously described in Wales Canyon (C W line NE¼ Sec. 26, T. 15 S., R. 2 E.; H. R. Ritzma, written communication). The dark petroliferous rocks occur interbedded with black shales and mudstones, carbonaceous shales and thin coals through 18 to 20 feet of section.

Tracing these rocks along strike to north and south is difficult because of sparse outcrops and heavy vegetative cover. Small amounts of petroliferous shale were found in the same stratigraphic inter-

val two miles south in Pete's Canyon. Here the lacustrine and paludal sediments of the North Horn have changed largely to massive sandstone.

The occurrence indicates that petroleum source beds and potential reservoir sandstones exist in the North Horn Formation. In the right structural and stratigraphic situation oil and gas accumulations possibly are present.

SCENIC AND RECREATIONAL AREAS

Historical Development

The scenic and recreational areas of Sanpete County may be counted as a significant part of its resources and assets which are inexhaustable and which can be made more valuable and remunerative with development and publicity. These are almost entirely geologic features.

Sanpete County is chiefly within a subprovince of the Colorado Plateau called by Dutton (1880, prefatory note, p. xi) the High Plateaus of Utah. The west boundary follows the mountain front a short distance east of U. S. Highway 91 or Interstate 15 from Nephi to the vicinity of Cedar City. The east and south boundaries are drawn at the base of the erosional escarpments facing the lower Canyonlands. This general pattern is shown on the physiographic map of the United States, U. S. Geological Survey, 1930.

The highest and probably most scenic portion of the Wasatch Plateau is in Sanpete County. The highest points are along the divides between drainages reaching the Great Basin to the west and the Colorado River to the east. The streams on the west side of the divide have short, steep gradients; those on the east side have more gentle slopes. Much of the eastward drainage is interrupted by the structural depression or graben of Joes Valley and by the upper valley of Gooseberry Creek in the northeast corner of the county near the summit. Although this great area is called a plateau because the rock formations are nearly flat, it is thoroughly dissected by the drainage pattern. The summit area is underlain by the North Horn Formation which weathers to somewhat subdued slopes and light to medium brown colors where the rock is exposed, and by the overlying, much more spectacular Flagstaff Limestone. The white and light gray-banded cliffs of the Flagstaff contrast with the green woodland on the lower slopes and on the narrow flat summits.

The summit area ranges in altitude from 9,000 feet in the northeast part of the county to 11,300 feet 11 miles east of Ephraim. Much of the summit in the southern part of the county is between 10,000 and 11,000 feet. The summit is well watered and supports woodland and mountain pastures, lakes, ponds, permanent streams and reservoirs. It is completely blocked by snow in winter. During the Pleistocene, the heads of the stream valleys were glaciated, producing the horseshoe-shaped basins outlined by cliffs of the Flagstaff Limestone. Glaciation was most widespread on the east slope, but there were glaciers on the western slope in favorable situations. Glacial erosion is responsible for the most scenic localities and for most of the ponds and meadowlands.

The west boundary of the Wasatch Plateau is determined by the Wasatch Monocline in which the beds exposed in the summit area bend downward sharply into the Sanpete and central Sevier valleys. The monocline has been breached by many steep-walled canyons providing spectacular scenery. Alluvial fans at the mouths of canyons in Sanpete Valley and hogbacks of the Green River Formation emerge from the sediment cover or merge with the monocline south of Sterling.

The prominent escarpment of the Gunnison Plateau (San Pitch Mountains) rises abruptly 2,000 or more feet above Sanpete Valley to a dissected summit area having an altitude of 8,000 feet or more. The escarpment is breached by short, deep canyons. The summit area is capped by the Flagstaff Limestone, and evidence of the overlying Green River Formation is preserved in the trough of a syncline in the southern part of the plateau. Cretaceous rocks of the Indianola Group underlie the summit in the north part opposite Fountain Green. Older Cretaceous rocks and Jurassic rocks are sharply upturned along the base of the escarpment, but the North Horn Formation dips gently westward in the face of the escarpment.

The Moroni Upland (Cedar Hills) rises gently from both arms of Sanpete Valley to heights of 8,000 feet within Sanpete County. It is dominated by a conglomerate containing boulders of volcanic rocks and by beds of volcanic tuff.

The Valley Mountains rise from an alluvial slope at the west side of central Sevier Valley. Again the Flagstaff Limestone is the most prominent formation. Associated formations, including the Green River, dip toward the valley. Hidden in the interior



Figure 28. Aerial photo of Sanpete Valley, looking northward. The Gunnison Plateau is on the left and the Wasatch Monocline on the upper right. The town of Manti is in the upper right at the base of the Wasatch Monocline. (Photo by Stan Rasmussen, courtesy of the U. S. Bureau of Reclamation.)

of the Valley Mountains is Jap or Japanese Valley, an alluviated structural depression or graben, outlined by faults on either side.

Central Sevier Valley is a structural depression between fault zones, along which the beds of Tertiary rocks are warped downward into the trough of the valley. A particularly interesting feature is the salt-bearing Redmond Hills, in which a rib of Jurassic rocks has been thrust upward, bending the Tertiary beds that were deposited against it and even elevating terrace gravels. During the Pleistocene, the valley in Sanpete County was flooded briefly by an arm of Lake Bonneville. The Sevier River undoubtedly was much larger then and brought in sediments or eroded them out as the regimen and base level of the stream changed.

Sanpete Valley is a structural basin in which the west-dipping beds of the Wasatch Monocline continue under the valley fill and terminate against buried faults at the west side of the valley. At times in the history of the valley, erosion and removal of sediment undoubtedly were dominant, but at present, downwarping of the part of the valley along the Gunnison Plateau dominates (figure 28). Consequently, most of the material eroded from the surrounding uplands is deposited in the valley and little sediment is transported to the central Sevier Valley.

Scenic Areas

The outstanding scenic attraction of Sanpete County is the high country of the Wasatch Plateau in the Manti-LaSal National Forest, readily accessible in summer from unpaved Skyline Drive which follows the summit from Tucker on U. S. Highway 6-50 in Utah County to Ferron Reservoir, a distance of 77 miles. Skyline Drive may be reached by canyon roads from Fairview, Mount Pleasant, Spring City, Ephraim, Manti and Mayfield. Three of these roads, from Fairview (State 31), from Ephraim (State 29), and from Mayfield, cross the plateau to Castle Valley in Emery County to the east. All provide striking scenic views. From Skyline Drive, which is a mile in altitude above the valleys adjoining the plateau, the traveller has superb views across the colorful Canyonlands to the east and the desert ranges and valleys of the Great Basin to the west. From the north county line southward to a point opposite Fairview, Skyline Drive follows a narrow ridge of Flagstaff Limestone at an altitude of 9,000 feet. From this point south to a point opposite Ephraim, the drive is on the North Horn Formation and climbs to 10,000 feet. From this point southward, the drive is on the Flagstaff Lime-

stone at altitudes between 10,000 and 11,000 feet. The last is perhaps the most scenic portion. Most of the valleys have been glaciated, and are floored with mountain meadows, dotted with ponds and rimmed with cliffs of white limestone, contrasting with a forest cover of dark spruce or lighter aspen groves. Wild flowers in season cover great areas and the vast expanses of colored leaves in the early autumn are breathtaking. The small lakes and reservoirs provide opportunity for boating. Hunting for deer and elk and fishing attract local and out-of-state people. Manti-LaSal National Forest campgrounds are available in the scenic areas.

The unpaved road across the Gunnison Plateau (San Pitch Mountains) from Wales to Levan provides fine views of Sanpete Valley and the Wasatch Plateau to the east and of the desert ranges and valleys of the Great Basin to the west. The road enters the plateau west of Wales through upturned, highly colored beds of Jurassic and Cretaceous age, climbs slopes of the North Horn Formation, which contains the coal bed which was a factor in the early settlement of Sanpete County, and reaches the Flagstaff Limestone at the summit.

Of the many steep canyons which breach the eastern escarpment of the Gunnison Plateau, Maple Canyon west of Freedom is best developed as a tourist attraction, complete with campground (figure 29). The road enters the canyon through ramparts of steeply dipping and colorful Jurassic and Cretaceous rocks. At the north side is Box Canyon, a narrow chasm 500 to 700 feet deep, cut in conglomerate of the Price River Formation.

The agricultural valleys of Sanpete and central Sevier are pleasant and interesting. Palisade State Park at Funks Lake a mile east of Sterling has been developed as a tourist area. The canyon east of the park is of interest to geologists who find here distinct formations of the Cretaceous Indianola Group. Gunnison and Wales reservoirs are available for boating.

The Skyline Drive should be improved and extended southward to State Highway 4 in Salina Canyon and to Fishlake in Sevier County. This is one of the most attractive scenic mountain routes in the West, and properly surfaced, would provide a cool summer route from the population centers of the north to Bryce and Zion canyons. Winter sports areas could be developed, greatly increasing and extending tourist traffic. More attention should be given to access and facilities in the canyons.

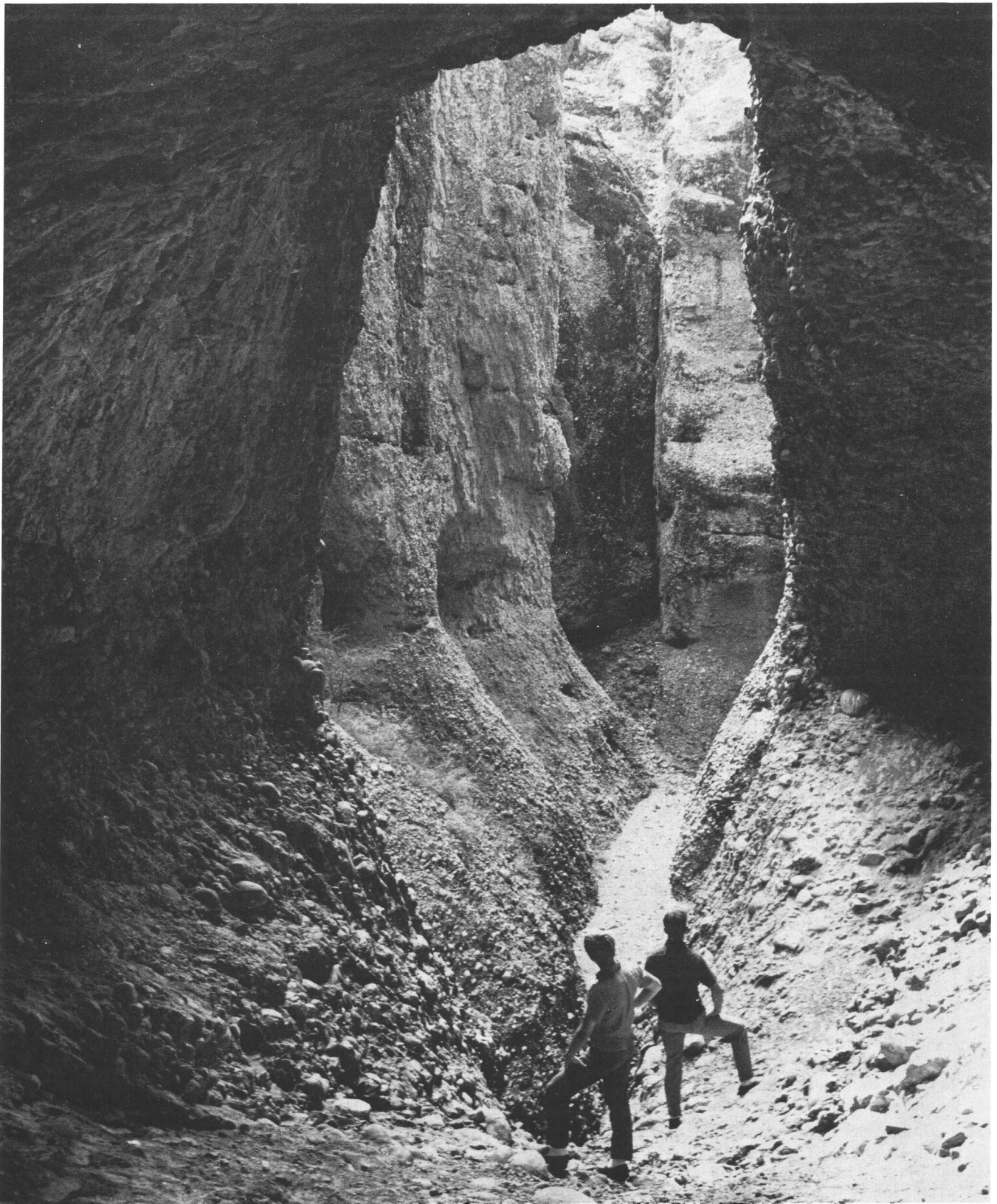


Figure 29. Maple Canyon and Box Canyon, west of Freedom, Utah. (Photo courtesy of Utah Travel Council, Salt Lake City.)

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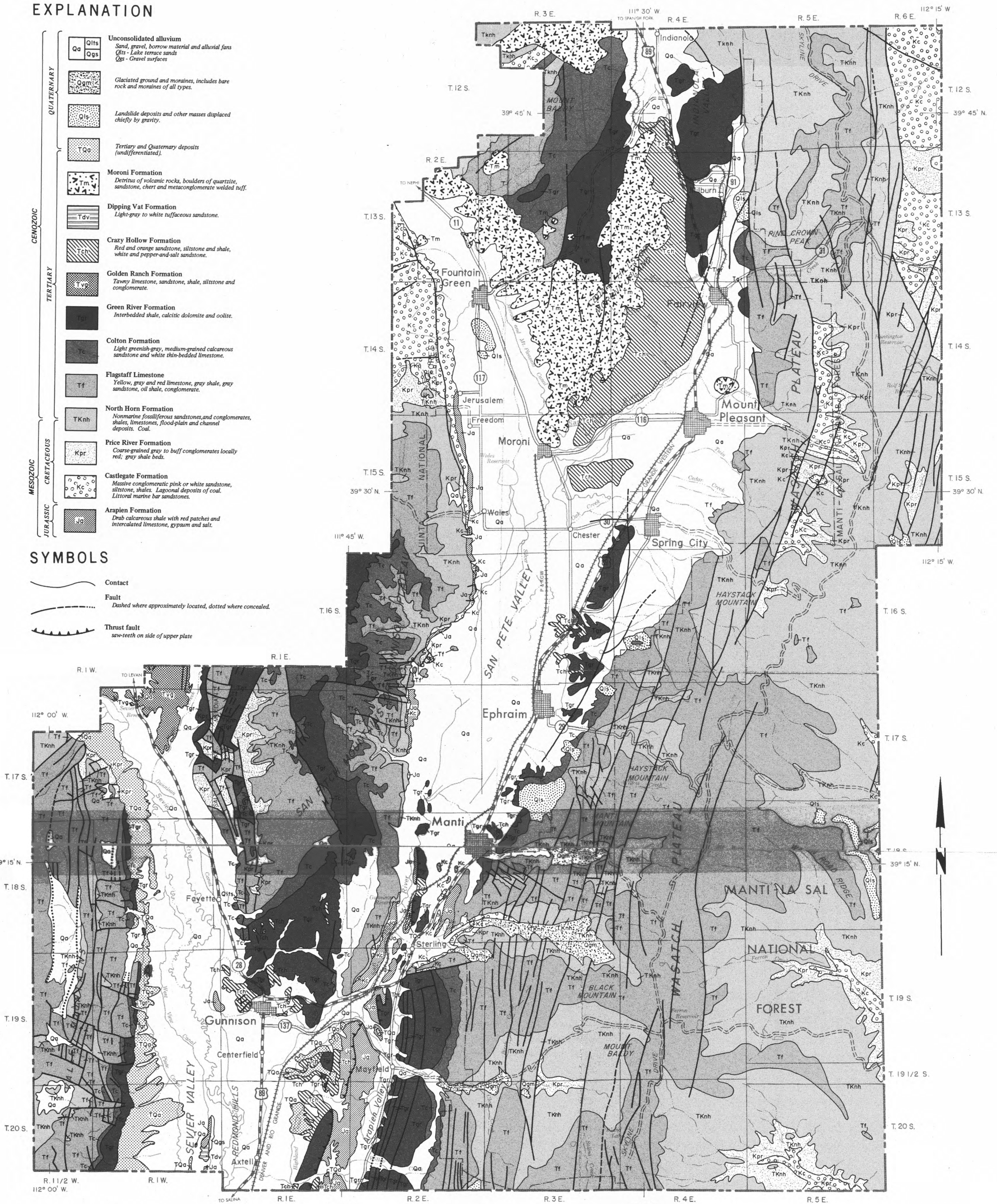
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EXPLANATION

- | | | |
|------------|--|--|
| QUATERNARY | | Unconsolidated alluvium
Sand, gravel, borrow material and alluvial fans
Qls - Lake terrace sands
Qgs - Gravel surfaces |
| | | Glaciated ground and moraines, includes bare rock and moraines of all types. |
| | | Landslide deposits and other masses displaced chiefly by gravity. |
| | | Tertiary and Quaternary deposits (undifferentiated). |
| | | Moroni Formation
Detritus of volcanic rocks, boulders of quartzite, sandstone, chert and metaconglomerate welded tuff. |
| | | Dipping Vat Formation
Light-gray to white tuffaceous sandstone. |
| | | Crazy Hollow Formation
Red and orange sandstone, siltstone and shale, white and pepper-and-salt sandstone. |
| | | Golden Ranch Formation
Tawny limestone, sandstone, shale, siltstone and conglomerate. |
| | | Green River Formation
Interbedded shale, calcitic dolomite and oolite. |
| | | Colton Formation
Light greenish-gray, medium-grained calcareous sandstone and white thin-bedded limestone. |
| TERTIARY | | Flagstaff Limestone
Yellow, gray and red limestone, gray shale, gray sandstone, oil shale, conglomerate. |
| | | North Horn Formation
Nonmarine fossiliferous sandstones and conglomerates, shales, limestones, flood-plain and channel deposits. Coal. |
| | | Price River Formation
Coarse-grained gray to buff conglomerates locally red; gray shale beds. |
| | | Castlegate Formation
Massive conglomeratic pink or white sandstone, siltstone, shales. Lagoonal deposits of coal. Littoral marine bar sandstones. |
| MESOZOIC | | Arapahoe Formation
Drab calcareous shale with red patches and intercalated limestone, gypsum and salt. |
| | | |

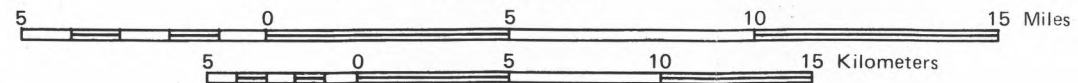
SYMBOLS

- | | |
|--|--|
| | Contact |
| | Fault
Dashed where approximately located, dotted where concealed. |
| | Thrust fault
saw-teeth on side of upper plate |



Map drafted by C. Nelson,
R. Holland and J. Robb

Scale 1:250,000



Base map taken from AMS sheets,
Price, Utah, 1953-62 and Delta,
Utah, 1956-62. 1:250,000.

Geology from W.L. Stokes, J.H.
Madsen, Jr., and L.F. Hintze,
1961-63. 1:250,000.

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Geology of Sanpete County