INTERIM GEOLOGIC MAP OF THE LUCIN NW QUADRANGLE BOX ELDER COUNTY, UTAH

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DESCRIPTION OF MAP UNITS

Qf Fill (Holocene)--Local material used to construct railroad grades.

Qal Alluvium (Holocene)--Unconsolidated gravel, sand, silt, and mud deposited in active washes. In many washes, consists primarily of reworked lacustrine marl.

Qaf_1 Younger alluvial fan deposits (Holocene)--Unconsolidated gravel, sand, and silt forming alluvial cones and fans, most of which issue from mountainous parts of quadrangle. Alluvial fans overlie deposits of Lake Bonneville.

Qai Alluvial silt (Holocene)--Unconsolidated silt, sand, and clay deposited by streams on the broad plain bordering Grouse Creek in northeastern part of quadrangle. Also present in depressions bounded by lacustrine beaches.

Qam Alluvial mud (Holocene)--Unconsolidated mud ponded in depressions behind lacustrine beaches. Typically coated by white reflective clay.

Qmc Mass-movement colluvium (Holocene)--Unconsolidated colluvial materials on steep slopes in the northwestern part of the quadrangle.

Qes Eolian sand and silt (Holocene)--Unconsolidated sand dunes and sheets of brown sand and silt. Deposits primarily flank Grouse Creek.

Qla Lacustrine and alluvial deposits, undivided (Holocene and Pleistocene)--Interlayered deposits of lacustrine and alluvial origins. In most places, unit consists of thin sheets of fine-grained alluvium on erratically exposed lacustrine marl and silt.

Qlms Lacustrine marl and sand (Pleistocene)--Unconsolidated marl, sand, and sandy marl deposited near Provo shoreline. Marl at base grades upward to sandy marl and sand as thick as 30 m (100 ft).

Qlm Lacustrine marl (Pleistocene)--Unconsolidated white and gray marl and clay, locally containing considerable silt deposited as deltaic facies.

Qlf Lagoon fines (Pleistocene)--Unconsolidated, poorly sorted, fine-grained sediment; in most places, deposited between barrier beaches.

Qls Lacustrine sand (Pleistocene)--Unconsolidated coarse sand and fine pebbles. In most places medium gray due to predominance of rhyolite clasts.

Qlgs Lacustrine gravel and sand (Pleistocene)--Unconsolidated gravel and coarse to medium sand. Forms narrow barrier beaches and sheets along upper part of Grouse Creek.

Qlg Lacustrine gravel (Pleistocene)--Unconsolidated cobble- and pebble-gravel and subordinate sand. Forms prominent barrier beaches.

Qaf_2 Older alluvial fan deposits (Pleistocene)--Moderately consolidated gravel, sand, and silt forming broad fans among mountains in northwest part of quadrangle.

Tbt Biotite tuff breccia (Miocene)--Tuff breccia containing blocks of moderately- to well-welded biotite rhyolite tuff in ash matrix. Locally includes welded biotite rhyolite ash-flow tuff in lower part. K-Ar ages are about 13 Ma.

Tsr Siliceous rhyolite (Miocene)--Resistant dark red, brown, and black highly silicified rock containing 5% fine- to medium-grained quartz and altered sanidine. Locally includes underlying thin black vitrophyre.

Ta Ash-flow and air-fall deposits (Miocene)--Moderately- to well-lithified light yellow deposits of (1) lithic airfall; (2) massive, variably welded ash; (3) tuff breccia; (4) debris flow or lahar deposits; and (5) welded ash flows. Most rocks rhyolitic.

Ts Sedimentary and volcanic rocks (Miocene)--Moderately-lithified thin-bedded siltstone, sandstone, shale, and conglomerate. All rocks commonly tuffaceous. Typically white, yellow, yellowish brown in color. Locally contains air-fall tuff with blocks up to 40 cm (17 in.).

Tr Rhyolite (Miocene)--Resistant, brown-weathering, medium-gray, quartz-sanidine rhyolite. Typically well foliated; outcrops with cavernous weathering and prominent joints. Phenocrysts medium- to coarse-grained and compose 15 to 20 % of rock. Includes several cooling units and flows. K-Ar ages are 8 to 9 Ma.

Trv Rhyolite vitrophyre (Miocene)--Black, cliff-forming vitrophyre lying under and above rhyolite flows (Tr). Locally contains abundant geodes.

Twa Welded ash (Miocene)--Pale brown, moderately welded, air-fall rhyolite carrying rhyolite vitrophyre fragments. Locally grades upward to massive rhyolite vitrophyre (Trv).

Trb Rhyolite breccia (Miocene)--Black, maroon, and brown breccia forming massive deposits. Most rhyolite clasts fine-grained (Trf) type. Deposit widely silicified.

Trf Fine-grained rhyolite (Miocene)--Resistant gray rhyolite with fine- to medium-grained quartz and sanidine phenocrysts composing about 10 to 15% of rock. Numerous small vugs lined by chalcedony.

Tda Dacite ash flow (Miocene)--Welded hornblende dacite tuff blocks in moderately welded ash matrix.

Tdf Dacite lava flows and domes (Miocene)--Hornblende dacite, fine- to medium-grained. Generally strongly foliated. Forms rubbly hills. Locally includes avalanche deposits.

Tc Conglomerate (Miocene)--Moderately-lithified, well-sorted pebble conglomerate.

TRd Dinwoody Formation (Triassic)--Yellow, reddish, and brown, thin- to medium-bedded, impure limestone, calcareous shale, and siltstone. Siliceous in places.

Pm Murdock Mountain Formation of Miller and others (1984) (Permian)--Dark- to pale-brown, thin-bedded chert and cherty dolomite. Typically highly fractured.

Pu Altered sandstone, undivided (Permian)--Jasperoid and silicified sandstone.

Phosphoria Formation (Permian)--

Ppm Meade Peak Phosphatic Shale Tongue--Dark-gray, dark-brown, and black shale, siltstone, and sandstone; and gray limestone. Thin-bedded, poorly exposed.

Park City Group (Permian)--

Ppg Grandeur Formation --Light-gray sandy dolomite, and medium-brown dolomitic sandstone. Medium to thick bedded.

bx Breccia (Devonian?)--Dark-brown and red-brown siliceous breccia overlying limestone of the Guilmette Formation. Altered sandstone lithologically identical to sandstone in upper part of Guilmette.

Dg Guilmette Formation (Devonian)--Medium- and dark-gray and black, medium-crystalline limestone. Fossiliferous; locally dolomitic.

Ds Simonson Dolomite (Devonian)--Alternating black and medium-gray thick beds of coarsely recrystallized dolomite, typically laminated.

UNITS SHOWN ONLY IN CROSS SECTION

Ptc Trapper Creek Formation (Permian)--Calcareous sandstone, thin- to medium-bedded.

ABSTRACT

The Lucin NW quadrangle, in northwestern Utah, consists of mostly flat piedmonts dotted by hills rising at most a few hundred meters above the surrounding gently-sloping piedmonts. Thick lake deposits that blanket much of the piedmonts record the most recent, and largest, pluvial lake in northern Utah. Bedrock in the hills ranges in age and rock type: Devonian to Permian rocks are mostly limestone and dolomite; Miocene rocks are mostly volcanic rocks and sedimentary rocks derived from volcanic materials.

Faults of possible Mesozoic age and faults of Miocene age cut bedrock in the hills, but none cut Quaternary materials. Some faults probably were active during volcanism in the Miocene, perhaps during tectonic extension in the vicinity.

Variscite is mined intermittently in the quadrangle, and other potential mineral resources include sand and gravel, phosphate, lignite, clay, and ornamental stone. Silicification of strata and fault breccia may be associated with disseminated gold mineralization, and uranium may be present in Miocene strata.

INTRODUCTION

The Lucin NW quadrangle is located in northwestern Utah in Grouse Creek Valley. State Route 30 traverses the southern part of the quadrangle, near the location of old emigrant trails. Much of the quadrangle is typified by nearly flat expanses of grass- and sage-lands, altitudes of which range from 1,285 m (4,220 ft) in lower Grouse Creek to 1615 m (5,300 ft) on the upper piedmonts. Small hills dot this flat terrain; the hills range in altitude from 1,465 m (4,800 ft) to 1,585 m (5,200 ft) in much of the quadrangle, but are much higher in the northwestern corner, where they typically are 1,770 m (5,800 ft) to 1,821 m (5,976 ft) in altitude.

Most flat lands are underlain by Quaternary sediment, much of it lacustrine. Small hills north of Highway 30 and along the course of Grouse Creek are composed of volcanic rocks, as are the higher hills in the northwestern part. Paleozoic strata crop out in hills along the west and south sides of the quadrangle. One of the more prominent hills, located southwest of Grouse Creek Junction, is informally termed "Utahlite" hill (Fig. 1) after the mineral mined there.

The Lucin NW quadrangle lies at the south end of a volcanic field studied by Fiesinger and others (1982), and near the Pilot Range and Grouse Creek Mountains (Figure 1). Doelling (1980) first distinguished most geologic map units of the area. Scarborough (1984) studied in detail the volcanic rocks of the northwestern corner of the quadrangle, following earlier studies of volcanic rocks to the north. Douglas (1984) studied the geology of the Jackson Spring quadrangle to the west. Compton (1983) and Jordan (1983) described the geology of the southern Grouse Creek Mountains and Miller (1985) and Miller and Schneyer (1985) published geologic maps of the northern Pilot Range.

DESCRIPTION OF MAP UNITS

Pleistocene lacustrine deposits of Lake Bonneville are the most widespread in the Lucin NW quadrangle. These deposits are considerably thicker along the course of Grouse Creek as a result of abundant sediment supply to deltas and nearshore lake environments by the creek. The lacustrine deposits rest on alluvium that, in turn, rests on Miocene volcanic and sedimentary rocks. Miocene rocks probably underlie about two-thirds of the quadrangle, mainly north of Highway 30, and there include the southern end of a major volcanic field. Rocks older than Cenozoic crop out in isolated hills across the southern and western parts of the quadrangle. Most pre-Cenozoic rocks are Permian in age, but a few small hills underlain by Devonian rock also are present.

DEVONIAN ROCKS

Simonson Dolomite

The Simonson Dolomite (Ds) crops out in two places in the southwestern part of the quadrangle; only a small part of the upper part of the Simonson is exposed. Most of the unit is coarsely recrystallized dolomite that ranges from light- to dark-gray and black. It is typically laminated. Alternating light-dark color changes in bedding units about 2 m thick, in combination with the lamination, mark the unit as the Simonson Dolomite. In the quadrangle, the dolomite is unusually coarse, with grains as large as 5 mm, suggesting that it is metamorphosed.

The Simonson is greater than about 70 m (230 ft) thick in the Lucin NW quadrangle. Nearby in the Pilot Range, the unit is 365 m (1,200 ft) thick and is Early and Middle Devonian in age (Miller and others, in press).

Guilmette Formation

The Guilmette Formation (Dg) underlies two hills in the southwestern part of the quadrangle. Outcrops of the lower part of the Guilmette are structurally overlain by siliceous breccia (bx). Limestone of the Guilmette is regularly bedded to massive, medium gray to chocolate brown and black in color. Limestone is medium crystalline, vaguely laminated, and commonly carries abundant white calcite vein fillings. Algal masses, solitary corals, and *Amphipora* are common. The unit is dolomitized locally.

The Guilmette Formation is about 82 m (270 ft) thick, apparently representing less than 1/4 of the typical section in the Pilot Range (Miller and others, in press). Stratigraphic continuity with the Simonson Dolomite, as well as interbedded limestone and dolomite characteristic of basal part of the Guilmette, suggest that only the lower part of the Guilmette is present in the Lucin NW quadrangle. In the Pilot Range, the Guilmette is Devonian in age (Miller and others, in press) and its upper part is early Late Devonian in age (Miller and others, 1991).

DEVONIAN(?) ROCKS

Breccia

Brecciated siliceous rocks (bx) lie structurally on the Guilmette Formation. The breccia typically is composed of dark-brown, medium-gray, or yellow-brown jasperoid. A few fragments of light-gray carbonate rock and brown, medium-grained sandstone are present. The breccia is similar in lithology and structural position to breccia in the Pilot Range and Jackson Mine area. Miller and Schneyer (1985), Douglas and Oriel (1984), and Miller and others (in press) considered these breccias to represent altered and tectonized sandstone lithologically identical to that in the upper part of the Guilmette Formation. The breccia in the Lucin NW quadrangle probably is equivalent to breccia derived from Devonian rocks in the Jackson Mine area and Pilot Range.

PERMIAN ROCKS

Grandeur Formation of the Park City Group

The Grandeur Formation (Ppg) underlies the west part of Utahlite hill and the neighboring hill to the southeast. The Grandeur mainly consists of well-bedded light-gray dolomite, medium-brown fine-grained dolomitic sandstone, and fossil-hash dolomite. Cherty beds compose about 10% of the unit; many of the chert nodules and beds apparently are localized by and derived from fossils and quartz-sand laminae and beds. Chert is light- to dark-gray. Length-slow white chalcedony blobs are common in the unit (Miller and others, 1984). Thick masses of chert grade laterally and vertically to dolomitic sandstone. Sand laminae in dolomite beds are cross-stratified. The uppermost 10 to 20 m (30 to 65 ft) is marked by vertical burrows replaced by chert. In part of the unit, lithologic packages about 1 m (3 ft) thick are rhythmically repeated over a 20 m (65 ft) thickness. In each package, gray chert, 10-15 cm (4-6 in.) thick, grades upward to brown dolomitic sandstone, also 10-15 cm thick, which in turn grades upward to light-gray dolomite about 70 cm (28 in.) thick. The dolomite layer contains sand laminae and wisps, and commonly is topped by upward-coarsening fossil hash, mainly containing crinoid fragments.

The Grandeur Formation is late Leonardian (Early Permian) in age in nearby mountains (Miller and others, 1984; Miller and Glick, 1986). The unit is incomplete in the Lucin NW quadrangle, with structural or erosional boundaries; about 300 m (1,000 ft) of the upper part of the unit is present at most. In the Leach Mountains about 35 km (21 mi) to the west, the unit is 698 m (2,290 ft) thick (Miller and others, 1984).

Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation

The Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation (Ppm) is present in northwestern Utah as a thin shale unit (Miller and others, 1984). It crops out above the Grandeur Formation in Utahlite hill. It is best exposed just below the Provo shoreline, where it consists of purple, red, rusty brown, and gray calcareous shale and siltstone, and rare black chert. The unit is thin bedded.

The Meade Peak Phosphatic Shale Tongue is about 105 m (320 ft) thick, somewhat thicker than in the Leach Mountains (40 m) and Lemay Island (59 m). However, we include in the upper part of our map unit sparse cherty beds separated by non-resistant shale, limestone, and siltstone; lithologically equivalent beds were placed in the basal part of the Murdock Mountain Formation in the Leach Mountains by Wardlaw and others (1979) and Miller and others (1984). The unit is late Leonardian (late Early Permian) in age in the region (Miller and others, 1984).

Murdock Mountain Formation

The Murdock Mountain Formation of Miller and others (1984) (Pm) is more resistant than other Paleozoic rocks, and therefore crops out widely in ridges and hills in the southern part of the quadrangle. In most outcrops, the unit consists of thin-bedded chert, with dolomite comprising 10 to 30% of the rock. Color varies widely from white, to light- and medium-gray, to purple, red, and yellow. Dolomite beds are medium-gray and carry wisps of brown sand or nodules of white chert.

Much of the Murdock Mountain Formation is highly fractured, making structures and stratigraphy difficult to decipher. An apparently complete section in Utahlite hill is about 420 m (1,380 ft) thick. The Murdock Mountain Formation, as used by Miller and others (1984), is 460 m (1,510 ft) thick at Murdock Mountain in the Leach Mountains. Apparent thickness of the unit is much greater at exposures along the west side of the quadrangle, but unmapped faults are probably present in the highly fractured rocks there. The Murdock Mountain is latest Leonardian and early Guadalupian (late Early Permian) in age in northwestern Utah and adjacent Nevada (Wardlaw and others, 1979). In much of northwestern Utah, the Murdock Mountain Formation is overlain by the Lower Permian Gerster Limestone. However, in the Lucin NW quadrangle it is overlain concordantly by Triassic rocks. The Gerster is absent to the east at Pigeon Mountain (Fig. 1), suggesting Late Permian erosional truncation in the Lucin-Pigeon Mountain area (Glick and Miller, 1987; Miller and others, 1991).

Altered sandstone, undivided

Highly silicified sandstone is assigned to the undivided altered sandstone unit (Pu). Where the rocks are not highly fractured, lithologic layering is well developed. However, all rocks are highly siliceous and only rarely is sandstone texture and lithology preserved. Most of the rocks are mottled red, orange, gray, and brown, and is jasperoidal. Doelling (1980) assigned these rocks to an undifferentiated Permian unit. Structurally, the unit lies near the top of a Permian section west of the quadrangle. It appears to be stratigraphically in place, and therefore the unit is thought to be Permian in age. Douglas (1984) described silicified Permian strata as jasperoid in a study of rocks in the Jackson Spring quadrangle west of Lucin NW.

TRIASSIC ROCKS

Dinwoody Formation

The Dinwoody Formation (TRd) crops out in narrow swales between ridges of the Murdock Mountain Formation at Utahlite hill. The unit consists of light-gray and brown calcareous siltstone, calcareous shale, and shaley limestone. It is consistently thin bedded. Thin black chert beds and gray shale are sparse. Rocks in the Dinwoody weather to distinctive yellow and red hues.

The Dinwoody Formation is Early Triassic in age at Pigeon Mountain (Glick and Miller, 1987) and elsewhere in northern Utah. It typically lies on the Gerster Limestone, which, in turn, lies on the Murdock Mountain Formation. In the Lucin NW quadrangle, the basal beds of the Dinwoody are concordant with the uppermost beds of the Murdock Mountain Formation. Although the Dinwoody strata do not give the appearance of lying on an erosional unconformity, a considerable section of rocks must have been eroded during the Late Permian. The Dinwoody is 110 m (335 ft) thick, but its top is faulted.

TERTIARY ROCKS

Volcanism across northern Utah produced mainly rhyolite and basalt and, therefore, was bimodal during its most voluminous production starting at about 17 Ma (e.g., Best and others, 1989; Miller, 1990). Volcanic rocks in many places cap sedimentary sequences that contain abundant reworked volcanic ash and that are poorly dated. Both bimodal volcanism and thick sedimentary sequences are characteristic of Basin-and-Range extensional tectonics, which was the tectonic regime of the Great Basin during the late Cenozoic (Miller, 1990). In the Lucin NW quadrangle, part of a thick sedimentary basin of Tertiary age is exposed, along with overlapping lavas of a large rhyolite field.

Conglomerate

Conglomerate (Tc) interbedded with fine-grained Miocene lacustrine strata (Ts) is mapped near the west side of the quadrangle. The conglomerate consists of well-sorted, well-rounded pebbles mostly 1-3 cm in diameter, but rarely up to 15 cm (6 in.), cemented by silica. The unit is well bedded and generally displays oppositely-dipping sets of crossbeds suggesting bimodal current directions. Most pebbles are of metamorphic rocks, probably derived from the nearby Grouse Creek Mountains; less common lithologies are derived from Mississippian and Permian strata. Bimodal crossbedding and sorting of pebbles suggest a beach environment of deposition.

Dacite lava flows and domes

Dacite lava (Tdf) crops out in two places in the northwestern corner of the quadrangle and one in the north-central part. The westernmost exposure may be a thick lava flow because it is roughly tabular, but other dacite forms dome complexes with associated avalanche deposits. The unit is poorly exposed, generally forming rubbly hills covered by loose, dark-weathered talus blocks of dacite.

All dacite outcrops and talus blocks have identical phenocryst assemblages of common hornblende (needles up to 6 mm long) and plagioclase (4 mm diameter); less common biotite, quartz, and orthopyroxene; and rare Fe-oxides (Fiesinger and others, 1982; Scarborough, 1984). Sparse outcrops and the intermixing of glassy and devitrified (stony) rocks in talus-block accumulations make it difficult to distinguish the boundaries of vitrophyric parts of the lavas.

The dacite outcrops in section 13, T9N, R19W, represent a composite dome complex. The southeastern exposure is a concentrically-flow-banded mass that we interpret as a 0.5 km-wide dome (section AA'). Adjacent dacite masses may also represent parts of domes or could be thick lava flows. Dacite deposits in the northeastern part of this outcrop area, along the map boundary, are probably avalanche deposits formed along the margins of growing domes.

Dacite underlies rhyolite flows in several places and overlies another rhyolite flow in at least one place, suggesting its age is intermediate with respect to rhyolitic extrusion. Dacite vitrophyre just north of the Lucin NW quadrangle was dated (Table 1) by $^{40}Ar/^{39}Ar$ at 12.4 ± 0.4 Ma (hornblende) and at 13.2 ± 0.5 Ma (biotite) at a location farther north (Scarborough, 1984; D.W. Fiesinger, 1991, written commun.). The rock dated at 12.4 Ma is part of a body continuous with outcrops in the Lucin NW quadrangle that underlie rhyolite (Tr). Dacite eruptions may have been episodic from about 13.2 to less than 12.4 Ma, or there may have been a single widespread eruptive event at 12.8 Ma (within the analytical error of both analyses).

Dacite ash flow

A thin ash-flow (Tda) of dacite composition is present in NW section 23, T. 9 N., R. 19 W.; about 1 m (3 ft) of slightly welded tuff breccia containing moderately welded blocks of dacite rests on vitrophyre (Trv) forming the upper part of a rhyolite flow. The tuff matrix and blocks are both dacitic, containing phenocrysts identical to those in dacite lava flows. The dacitic blocks contain pumice, indicating their probable origin from ash-flow tuff. Phenocrysts in the tuff are hornblende, biotite, and clinopyroxene. Dacite ash-flow tuff is bedded between rhyolite flows and therefore either was erupted during a protracted cycle of rhyolitic volcanism or between distinct rhyolite eruptive episodes.

Fine-grained rhyolite

Fine-grained rhyolite (Trf) underlies a small hill near the west edge of section 25, T. 9 N., R. 19 W., and two small areas at the south margin of the rhyolite field. The aphanitic matrix carries about 10-15% fine- to medium-grained crystals that are about equal amounts of quartz and sanidine. The fine-grained rhyolite is highly flow-banded and medium-gray, but weathers reddish brown in all exposures. The fine-grained rhyolite contains numerous small vugs, many of which are lined by chalcedony. The fine grain size of the phenocrysts is the distinguishing characteristic of this rhyolite unit, and it is lower in Ca_2O and higher in K_2O than most other rhyolite. The fine-grained rhyolite in section 36, T. 9 N., R. 19 W. is bordered by breccia 2 m thick in a subvertical sheet adjacent to the flow-banded central part of the body, a geometry that probably represents the steep edge of a dome or plug. This and other exposures of the fine-grained rhyolite is not bordered by vitrophyre, unlike all the other rhyolite lavas in the quadrangle.

The fine-grained rhyolite crops out over small areas, in comparison with coarser-grained rhyolite, and its age relations are relatively poorly known. It underlies coarser-grained rhyolite flows (Tr) in the southwestern outcrop of the unit, and appears to be surrounded by or overlapped by the welded ash unit (Twa). We therefore infer that the unit is among the older lavas in the field.

Its fine grain size is similar to that of the fine-grained siliceous rhyolite (Tsr), but fewer phenocrysts are present in the pervasively altered siliceous rhyolite, which overlies all other rhyolite lavas.

Rhyolite breccia

Massive rhyolite breccia (Trb) crops out along the southwest border of the rhyolite field in close proximity to fine-grained rhyolite lava, which is the primary constituent of the breccia. Common silicification takes the form of both chalcedony and opaline material. Fine-grained rhyolite clasts about 10 to 20 cm in diameter are commonly rounded, radially fractured, and lie in a matrix of crumbly jumbled rhyolite.

Rhyolite breccia lies on airfall tuff (Ta) locally, and is overlain by airfall tuff (Ta) and welded ash (Twa) as described below. The breccia was probably erupted at the same time as the fine-grained rhyolite because it is similar lithologically. Local thin deposits may represent autobrecciated flows, but most deposits are thick and probably represent avalanche breccia adjacent to rhyolite domes or thick flows.

Welded ash

Distinctive brown welded ash (Twa) crops out in two areas in the southern part of the rhyolite field (SW sec. 25, T. 9 N., R. 19 W.; NE sec. 30, T. 9 N., R. 18 W.). The pyroclastic rocks of this unit are well bedded, slightly to moderately welded, and locally grade upward into basal vitrophyre of thick rhyolite flows. These textural and genetic differences distinguish the welded ash unit from the ash-flow and air-fall deposits unit (Ta), which it discordantly overlies. The western of the two areas contains a complete section of the tuffs. Truncating the air-fall sequence at angles of 20 to 30 degrees is texturally massive, 4- to 20-meter-thick (12 to 56 ft) welded ash (Twa). In most places, the welded ash carries rectangular blocks of vitrophyre as much as 0.5 m long in a jumbled ash matrix; rarely the welded ash unit includes gravel deposits.

The jumbled deposits are matrix-supported and vitrophyre blocks are nearly equant and angular at the base. Upward, vitrophyre blocks are progressively flattened and ash matrix progressively welded, until the clasts are about 3:1 ratio of long to short axes and the matrix is dark brown and displays fluxion structure. The welded ash unit has a sharp contact with overlying basal rhyolite vitrophyre. At one locality (the eastern outcrop area of the unit), the deposit grades into massive rhyolite and basal vitrophyre with progressive flattening and welding.

Scarborough (1984) interpreted these relations as tuff breccia overlain by flow breccia, all overlain by lava flows, and we differ only slightly in our interpretation in that we consider all tuff and breccia to be coeval. At both outcrop areas of the welded ash unit, the overlying rhyolite is unusually thick, suggesting an origin as lava. We therefore interpret the gradational relations between welded ash and rhyolite flow as a crumble breccia of vitrophyre in pyroclastic deposits of ash, both of which were being deposited as the flow moved and were heated and strongly flattened by overriding lava (Christiansen and Lipman, 1966). The lava must have been hotter than many lavas of the southern margin of the Snake River Plain because most crumble breccias associated with lava flows are not flattened and welded by plastic processes (Bonnichsen and Kaufman, 1987). Lack of hydrous phases in rhyolite flows is consistent with high-temperature lava.

Rhyolite vitrophyre

Black and dark-brown, glassy rhyolite vitrophyre (Trv) commonly bounds the top and bottom of stony rhyolite flows (Tr). The rhyolite vitrophyre forms conspicuous ledges under rhyolite flows in several places, and its black color contrasts strongly with underlying white and yellow volcanic and sedimentary rocks, making it an easily mappable marker unit of the rhyolite flows and domes. The vitrophyre at the tops of lava flows locally contains abundant geodes. The rhyolite vitrophyre carries phenocrysts identical to the adjacent rhyolite (Tr) described below.

Vitrophyre at the bases of rhyolite flows ranges in thickness from 0 to about 20 m (65 ft). In many places, vitrophyre lies with sharp contact on pyroclastic rocks but in SW section 25, T. 9

N., R. 19 W., and NE section 30, T. 9 N., R. 18 W., vitrophyre lies on or grades upward from airfall tuff of the welded ash unit (Twa) as detailed in the description of that unit.

Vitrophyre at the tops of rhyolite flows is typically thicker than vitrophyre at flow bases and has distinctive structure and alteration. Upper vitrophyre, like basal vitrophyre, is not always present. It attains a maximum thickness of about 30 m (100 ft). Upper vitrophyre commonly is highly jointed and many blocks between joints are devitrified to punky, brown, ashy material. Abundant geodes, lined both with quartz crystals and chalcedony (purple and white), suggest extensive vapor-phase alteration at the tops of rhyolite flows.

Rhyolite

Rhyolite (Tr) crops out widely in the northwestern part of the quadrangle, where it forms dark-colored rounded hills. The stony rhyolite is crystal-rich, containing abundant sanidine and smokey quartz, a few percent plagioclase, and traces of biotite and iron oxides. Total crystal content is about 30 volume percent (Scarborough, 1984), and crystals are unbroken. Spherulites, lithophysae, and vugs are common. Flow-banding is nearly ubiquitous on a cm-scale, defined by alternating zones of different color or texture; it is steeply dipping in most outcrops. Although in a few places large-scale flow folds produced the steep dips, most rhyolite masses display flow-banding with consistent steep dips and variable strikes. These attributes are reminiscent of lava domes and thick lava flows, but in general the rhyolite masses are not easily separated into genetic types, so we refer to them as rhyolite flows without implication for origin. Although many flows and (or) domes are present in the quadrangle, the rhyolite is nearly identical in all outcrops.

Rhyolite flows form about 15 separate masses in the quadrangle. Many are about 100 to 300 m (330 to 1,000 ft) thick, on the basis of geometries inferred from cross sections. One flow, probably a lava flow, in the northwestern extreme of the quadrangle is traceable north-south for 2 km and east-west for 2 km; it may extend at least 1 km farther south if our fault interpretations are correct. Other flows are compound and massive, such as the mass underlying section 19, T. 9 N.,

R. 18 W., and adjacent areas. This rhyolite displays variations in jointing and folds that Scarborough (1984) interpreted as forming during dome emplacement. We suspect that vague concentric patterns of flow-banding in the central part, coupled with sharp contacts across which flow-banding and color change, indicate three or more flows, probably all domes. Sparse vitrophyre zones not recognized by Scarborough support a compound flow interpretation. If tabular geometry and gentle flow band dips are taken as indicators of lava flow origin, and all masses with steep flow bands are considered domes, about 10 domes and 5 lava flows (several of them derived from nearby domes) are present in the quadrangle.

Several lava flows are stacked in exposures at the north border of the quadrangle (section 4). The flows were erupted over a short time period, judging from two relations: 1) lack of angular unconformities between flows, and more importantly 2) intervening rocks are all locally-produced pyroclastic rocks. K-Ar ages for rhyolite support this conclusion (Table 1), with ages on sanidine of: 8.8±0.17 Ma (vitrophyre) and 8.4±0.16 Ma from a lava flow (Armstrong and others, 1976), and 7.6±0.9 and 9.3 ± 0.46 Ma from domes (Scarborough, 1984; J.K. Nakata, unpubl.). However, the lava flow dated by Armstrong and others is probably part of a dome/flow complex that physically rests on the dacite dome dated by Scarborough at 12.4 Ma, suggesting 4 to 5 m.y. of eruptive history. In addition, similar rhyolite about 10 km to the east in the southern Grouse Creek Mountains yielded a K-Ar (sanidine) age of 11.7±0.4 Ma (Compton, 1983) and rhyolite about 5 km to the northwest yielded 11.5 ± 1.2 and 11.3 ± 0.3 Ma for hornblende and sanidine, respectively (R.R. Compton, 1991, written commun.). Compounding these conflicting data is the 12- to 13-Ma age reported here of biotite tuff breccia, which caps the section locally. Although one possible solution is that the 7- to 8-Ma ages for rhyolite may be from Ar-retentive sanidine that incompletely degassed during analyses (McDougall and Harrison, 1988; Nielsen and others, 1990), and thus give artificially young ages, the 7.6 ± 0.9 and 9.3 ± 0.46 Ma ages were by the $^{40}Ar/^{39}Ar$ method, which is not susceptible to this error. At present, we do not know how to reconcile the conflicting geochronologic and field data.

Fiesinger and others (1982) and Scarborough (1984) attributed the rhyolite to fissure eruptions, lava flows, and domes, with which we concur. The rhyolite also has some features of rheomorphic ash-flow tuffs, which are unusually hot ash-flows that flowed like lava after being deposited by pyroclastic mechanisms (e.g. Bonnichsen and Kaufman, 1987). Features used to distinguish the two origins (Table 2) are not always present, leading to ambiguities. In addition, some features typical of each origin are present in the rhyolite unit. The greater than 100 m (330 ft) thickness of some rhyolite exposures suggests a lava-flow origin, whereas thinner and laterally persistent rhyolite (in secs. 14 and 23) could represent rheomorphic ash-flows. Gradations between the basal vitrophyre and underlying ash, described below, is identical to that attributed to large lava flows (Christiansen and Lipman, 1966). In total, characteristics of the rhyolite unit best support its origin as lava flows and domes.

Sedimentary and volcanic rocks

Most rocks in the sedimentary and volcanic rocks unit (Ts) are sedimentary, but nearly all rocks include a volcanic component, most commonly reworked in a lacustrine environment. Rock units consisting nearly entirely of volcanic flows and air-fall deposits (Ta) are distinguished separately, as are thick sequences of conglomerate (Tc). Main rock types in the sedimentary and volcanic rocks unit are tuffaceous sandstone, tuffaceous debris-flow deposits, calcareous siltstone and mudstone, altered tuffaceous mudstone, siliceous siltstone, marl, and fine-grained sandstone. Colors are typically yellow-brown, gray, and green, but altered ashy beds are white, and hues of red and purple are present locally. Much of the unit is very fine grained and thin-bedded, suggesting lacustrine depositional settings.

The sedimentary and volcanic rocks unit is Miocene in age, on the basis of relations with overlying middle to late Miocene volcanic rocks and lithic similarity with Miocene strata in the northern Pilot Range (Miller, 1985). Its thickness is unknown due to poor exposures, but probably exceeds 300 m (1,000 ft)

Ash-flow and air-fall deposits

A sequence of rhyolitic ash-flow and air-fall deposits (Ta) is associated with rhyolite flows in the northwestern corner of the quadrangle. The sequence is distinguished from the sedimentary and volcanic rocks unit (Ts) by its overwhelmingly volcanic composition and content of locally derived volcanic rocks.

Lithic tuff, tuff breccia, laharic deposits, and air-fall tuff are the main constituents of the unit. Most contain sanidine, quartz, and plagioclase, like the rhyolite flows. Locally, air-fall tuff is aphyric. A welded tuff lies in the ash-flow and air-fall deposits unit along the border between sections 13 and 14, T. 9 N., R. 19 W. Northward from these exposures, clasts of welded tuff lie in a breccia flow. Lithic tuff carries rhyolite, rhyolite vitrophyre, and silicified rocks, as well as abundant white pumice. Lahar deposits typically are brown, and form unsorted, massive beds 1-2 m (3-6 ft) thick. Clasts are matrix supported. Air-fall tuff typically forms well-bedded sequences of ash, pumice, and lapilli. The beds are normally graded, and, less commonly, cross-bedded. Green siltstone is rare in the section, and probably indicates local anoxic ponds. Also present near margins of lava flows are avalanche and slump deposits of lithic tuff breccia. An example is SW sec. 25, T. 9 N., R. 19 W., where thin-bedded air-fall lithic tuff lies concordantly on a vitrophyre rimming a steep margin of a rhyolite flow or dome. Bedding in the tuff generally fans upward, with dips decreasing. Some beds are wedge-shaped, pinching out down dip as can be expected in avalanche or slump deposits. Coarse lithic airfall tuff containing rhyolite, pumice, and siliceous clasts fines upward in this fanning sequence to pumice-rich graded beds near the top.

The ash-flow and air-fall deposits unit is over 70 m (230 ft) thick in east-central sec. 26, T. 9 N., R. 19 W., where angular lithic clasts as large as 50 cm (1.5 ft) are present in air-fall tuff. Elsewhere, the unit is thinner and finer grained, although it thickens to about 120 m (400 ft) near the corners of secs. 13, 14, 23, and 24 (T. 9 N., R. 19 W.). Tuff breccia at this locality carries rhyolite fragments as large as 10 cm (4 in.). The two areas with thick deposits and coarse material probably formed close to vents or other eruptive sites. The northern area contains rocks with high content of clay and chalcedony due to hydrothermal alteration, further indicating proximity to an eruptive site.

Siliceous rhyolite

The siliceous rhyolite unit (Tsr) differs from other rhyolite in being pervasively silicified, dark-colored, and thinly flow-banded. Phenocrysts of smoky quartz and sanidine are fine grained and constitute about 5% of the rock, but commonly the rock is so altered that phenocrysts are not recognizable. Siliceous rhyolite is black, dark purple, dark red, and dark gray. Lithophysae locally make up 50% of the rock. Breccia midway through the section may mark the boundary between two flows. Thin vitrophyre is locally present at the top and base of the compound unit. Small vugs lined with quartz crystals are common. The siliceous rhyolite unit is about 120 m (400 ft) thick in northern sec. 23, T. 9 N., R. 19 W. and thins north and south. It is the uppermost rhyolite lava flow in the quadrangle.

Biotite tuff breccia

Biotite tuff breccia (Tbt) overlies siliceous rhyolite (Tsr) in two places in the northwestern extreme of the quadrangle. The two outcrop areas are underlain by moderately-welded light-gray tuff and tuff breccia containing pumice, smoky quartz, sanidine, and sparse biotite. Presence of biotite distinguishes the biotite tuff breccia unit from other tuff and lava in the area. Biotite is more abundant in tuff of the eastern outcrop area, raising the possibility that eastern tuff represents a different unit. At the eastern location, tuff breccia seems to rest depositionally on siliceous rhyolite, as it does in the western outcrop area, but structural complexity at the eastern location makes the relations somewhat ambiguous. Quartz-sanidine rhyolite vitrophyre overlies the eastern outcrop area of tuff breccia; it is included in the biotite tuff breccia unit. The biotite tuff breccia unit is about 30 m (100 ft) thick, but its top is erosional. It is the stratigraphically youngest volcanic rock unit in the quadrangle. The K-Ar age of 13.6 ± 0.4 Ma on biotite and 40Ar/39Ar age of 12.3 ± 0.46 Ma on sanidine (Table 1) indicates a middle Miocene age for the unit and hence the entire underlying volcanic sequence. This age is in accord with one $^{40}Ar/^{39}Ar$ age for underlying dacite but is much older than K-Ar and $^{40}Ar/^{39}Ar$ ages for an underlying rhyolite flow and nearby rhyolite domes. Possible resolutions of the geochronometric inconsistency are: (1) some ages are faulty, perhaps because older phenocrysts were incorporated into flows, (2) the biotite tuff breccia unit may lie within a complex structural horst, or (3) exposures of unit represent remnants of older volcanic rocks around which younger rhyolites flowed. Neither alternative (2) nor (3) is likely, on the basis of field mapping.

QUATERNARY UNITS

Lacustrine and alluvial deposits are the most common Quaternary materials in the Lucin NW quadrangle. Pleistocene alluvial fans were overlapped by lacustrine sediments deposited during the rise of Lake Bonneville, the youngest and deepest of large pluvial lakes that formed in northern Utah. The lake rapidly rose across the Lucin NW area from about 20 ka to 18 ka and reached its maximum depth at about 15 ka, when it formed the Bonneville shoreline (Fig. 1). Shortly thereafter, the alluvial overflow threshold in southern Idaho catastrophically failed (Bonneville Flood) and the lake lowered to a stable threshold, forming the Provo shoreline. From about 14 ka to 12 ka the lake level fell to very low altitudes, leaving the Lucin NW area blanketed by marl, sand, and gravel. Subsequent erosion and alluvial deposition has modified the landscape only slightly.

The depositional record along Grouse Creek is unusual in most of arid northern Utah. Grouse Creek is an ephemeral stream that drains a large area in northwestern Utah and northeastern Nevada. During Lake Bonneville times it probably was a perennial stream with a relatively high discharge rate as indicated by deposits we interpret as fine- and coarse-grained deltaic facies. As Lake Bonneville regressed below the Provo shoreline, the base level for Grouse Creek was progressively lowered and the stream entrenched both its own deltaic deposits and the deep-water deposits of Lake Bonneville (Oviatt, 1991).

Older alluvial fan deposits

Unconsolidated, poorly-sorted gravel and sand is assigned to older alluvial fan deposits unit (Qaf_2) because they are overlain by deposits of Lake Bonneville. The older alluvial fan deposits unit underlies slightly dissected geomorphic fan surfaces and is present only in the extreme northwestern part of the quadrangle. Lithologically similar deposits in upland plains in section 24, T. 9 N., R. 19 W., are here mapped as the younger alluvial fan deposits extreme because much of the material shows evidence of recent sheetwash and fluvial transport.

Lacustrine gravel and sand deposits

Coarse-grained lacustrine deposits were widely deposited in shorezones of Lake Bonneville. In general, the coarsest deposits (Qlg) lie close to bedrock or to fluvial sources of coarse material. In many locations, less coarse material was available; we distinguish finer-grained deposits containing progressively more sand as lacustrine gravel and sand (Qlgs), and lacustrine sand (Qls) deposits. Distinctions among the three units are not rigorously defined, but the units are distinguished by the overall characteristic grain size of a given deposit. Distinguishing the units provides a general depiction of the geographic distribution of material available for waves to transport at any given lake depth.

Together, these three relatively coarse-grained deposits define many temporary shorelines of Lake Bonneville. The highstand (Bonneville shoreline) was at 1579 m (5180 ft). Shorelines intermediate between Bonneville and Provo are numerous; the prominent intermediate shorelines lie at 1551, 1526, 1519, 1513, 1512, 1507, 1500, 1490, and 1475 m (5090, 5005, 4985, 4965, 4960, 4945, 4920-22, 4890, and 4840 ft) altitude. The Provo shoreline is defined by a complex of splaying gravel beaches that range from 1473 to 1462 m (4832 to 4795 ft) in altitude. Most prominent are beach crests at 1469 to 1466 m (4820 to 4810 ft); an abrasion notch cut into rhyolite is about 1469 m (4820 ft). Regressive shorelines, produced during the decline of the lake from the Provo stage, consist of sand and gravel barriers and beaches built across regressive marl. These shorelines are well preserved east of Grouse Creek at 1457 to 1451, 1445, 1433, 1422, 1411, 1402, and 1390 m (4780 to 4760, 4740, 4700, 4665, 4630, 4600, and 4560 ft). The shoreline at about 1457 m (4780 ft) near the west edge of the quadrangle can be traced to lower altitude eastward toward Grouse Creek. The change in altitude suggests progressive building of a beach eastward as the lake level declined.

Lacustrine gravel (Qlg) was deposited at sites of Lake Bonneville having the proper combination of wave energy and sediment supply in the shifting shorezone, such as barrier beaches and near wave-battered bedrock prominences. Most deposits are located near Utahlite hill and other small hills, at the Provo stage deltaic system, and where streams issued from the northwest corner of the quadrangle.

Lacustrine gravel and sand deposits (Qlgs) include coarse materials deposited along Grouse Creek that formed in a deltaic setting and similar materials in narrow barrier beaches. These deposits formed where sand supply exceeded gravel supply. The deposits along Grouse Creek overlie the lacustrine marl and sand unit (Qlms) at the Provo level, and are composed of regressive gravel and sand that are similar to transgressive-phase deltaic gravel present south of the quadrangle (Oviatt, 1991). The contact between the regressive gravel and underlying Provo sand is probably disconformable in most sections--it is abrupt, and the thickness of the underlying lacustrine sand and marl is highly variable. This regressive gravel and sand thins laterally away from Grouse Creek and merges with piedmont lacustrine or alluvial deposits. Because of this distribution and its compositional similarity to transgressive deltaic gravel, the regressive gravel is interpreted as deltaic gravel of Grouse Creek that has been reworked by waves at the mouth of the stream (Oviatt, 1991). This gravel forms arcuate beach ridges on each side of the stream near and below the Provo shoreline, and at lower altitudes in the Lucin and Pigeon Mountain quadrangles (Miller, 1985; Glick and Miller, 1987), indicating that the delta coastline had a cuspate form.

Lacustrine gravel and sand also underlies narrow barrier beaches, most of which formed on piedmonts far from bedrock sources. Many beaches were built over fine-grained lacustrine materials, so their coarse grain size and lack of nearby sources indicates a coarser sediment source than is evident nearby; long-distance transport, either of coarse material along shorelines or by streams and subsequent reworking at shorelines may account for these relations. If so, many barrier beaches east of Grouse Creek resulted from transport along shorelines and many of those west of Grouse Creek resulted from reworked stream sediment transported over relatively fine-grained lacustrine deposits.

Lacustrine sand deposits (Qls) consist of coarse sand and minor fine gravel. Most deposits flank Grouse Creek at altitudes above the Provo shoreline, and formed as beach sands derived from reworked Tertiary sedimentary and volcanic rocks. Minor sand mapped within the Provo beach complex west of Grouse Creek represents elutriated fines deposited in low-energy parts of the mainly gravel deposit. Lacustrine sand deposits form a barrier beach south of Route 30 near the east border of the quadrangle. In this area, sandy regressive marl is extensively reworked by alluvial and eolian processes, evidence that an abundant sand supply was available during lake regression.

Lagoon fines

Fine-grained lagoon deposits (Qlf), consisting mainly of poorly sorted fine sand and mud, are present in a lagoonal setting between gravel beaches within the Provo shoreline complex west of and along Grouse Creek, and in similar settings at lower altitudes about 1.5 km north of Grouse Creek Junction. Lagoon deposits consist of calcareous sand or sandy marl, and contain reworked ostracodes and a few small gastropods. These deposits are coarser and less well sorted than many deposits between barrier beaches that are mapped as alluvial silt (Qai) or mud (Qam), but probably do not contain any alluvial materials. Lagoon deposits are the same age as deposits forming in nearby beach and offshore lacustrine environments.

Lacustrine marl

Lacustrine marl (Qlm) lies on alluvial deposits and bedrock. It forms sequences of laminated marl grading upward into dense gray marl. The laminated marl, which is only found in exposures along Grouse Creek, is conspicuous from a distance because it weathers to form an almost pure white, in contrast to the grayer marl above it. Matrix-supported pebbles are not uncommon in the marl; these are interpreted as dropstones. Bedding in the gray marl is indistinct, and at most consists of diffuse, thin layering. Ostracodes are abundant throughout the marl. The marl ranges in thickness from less that one m (3 ft) to over 20 m (65 ft).

We interpret the lacustrine marl in this area as representing open-water to deep-water deposition in Lake Bonneville. Other than exposures along Grouse Creek, which include transgressive, deep-water, and regressive marl, most marl of this unit exposed in the quadrangle is regressive, sandy marl that was deposited as the lake level fell. Regressive marl has particularly high sand content near and south of Grouse Creek Junction.

Lacustrine marl and sand

Marl, sand, and sandy marl (Qlms) crop out widely along Grouse Creek near Provo beach ridges. Sandy marl lies directly above an abrupt contact that marks the Bonneville Flood and grades upward into marl that is similar to the lacustrine marl unit in many respects, although the lacustrine marl and sand unit (Provo marl and sand unit of Oviatt, 1991) is generally sandier or may have laminations. The marl grades upward into calcareous sand which, near the Provo shoreline, reaches a thickness of over 30 m (100 ft). The sand in this unit has a primary dip of as great as 15° down valley, and interfingers with deltaic gravel in the upper part of the sequence. These dipping strata are close to the Provo shoreline and suggest foreset (prograding) deltaic deposition during the prolonged stillstand at the Provo level. A few gastropod shells are present in the sand, and many of the ostracodes appear to be reworked.

The Provo marl and sand is a sequence that coarsens upward, and is interpreted as having been deposited during both the formation of the Provo shoreline and the post-Provo regression. Its lower boundary is marked by the Bonneville Flood contact at about 14.5 ka. The age of its upper boundary is time-transgressive, and at any one section is dependent on altitude and the amount of truncation.

Lacustrine and alluvial deposits, undivided

Thinly layered deposits of lacustrine and alluvial origins are mapped as an undivided unit (Qla) along the piedmonts flanking Grouse Creek. In most places, this unit consists of thick regressive lacustrine marl that is overlain by thin alluvial fan deposits. Because the sandy regressive upper marl is reworked as alluvium in these low-energy settings, the undivided lacustrine and alluvial deposits unit is difficult to distinguish.

Eolian sand and silt

Eolian sand (Qes) is present in small fields of dunes and less common sand sheets, mostly in deposits less than 2 m (6 ft) thick. Most eolian deposits border the east side of Grouse Creek, and represent reworked sand and silt from the deltaic complex built along the creek. Other mapped eolian sand is present southeast of Grouse Creek Junction, where abundant sand in regressive marl has been reworked. Unmapped, minor dunes have formed in most deposits of lacustrine sand (Qls). Dune forms indicate sediment transport to the southeast.

Mass-movement colluvium

Colluvial deposits (Qmc) are common along steep slopes in the northwest corner of the quadrangle. The colluvium consists of conglomerate, gravel, and sand derived from volcanic and sedimentary units of Miocene age.

Alluvial mud

Alluvial mud and minor silt (Qam) is present in depressions bounded by barrier beaches. Although the deposits probably overlie lagoon fines, alluvial and playa processes formed those deposits at the surface. The deposits consist of white to tan mud with reflective clay coatings, and are generally devoid of vegetation. The alluvial mud unit grades into the vegetated alluvial silt unit in the Provo beach complex west of Grouse Creek.

Alluvial silt

Extensive thin sheets of alluvial silt (Qai) with subordinate fine sand and clay lie on lacustrine gravel in upper Grouse Creek and minor alluvial silt deposits are present in lagoonal settings as described above. The alluvial sheets formed a broad low-gradient plain above deltaic gravel at the Provo shoreline. These deposits are bounded by gradational contacts with the undivided lacustrine and alluvial deposits unit (Qla).

Younger alluvial fan deposits

Unconsolidated stream and fan deposits (Qaf_1) of poorly sorted gravel, sand, and silt postdate the development of the Bonneville and younger shorelines. These deposits are found as steep alluvial fans at mouths of canyons and gullies, and as broad alluvial fans that grade locally to floodplains bordering streams. The largest alluvial fan accumulations lie in the west-central part of the quadrangle, where washed-out roads indicate repeated and frequent episodes of deposition and erosion. The younger alluvial fan deposits in the plain in section 24, T. 9 N., R. 19 W., are probably underlain by bedrock at shallow depth as suggested by the presence of several small bedrock outcrops and a lack of fan-shaped surfaces.

Alluvium

Extensive thin sheets of alluvium (Qal) lie on piedmonts flanking Grouse Creek. Thicker alluvium floors much of the wash of Grouse Creek. Alluvium consists of gravel, sand, and mud, with grain size generally decreasing downstream.

STRUCTURE

The Lucin NW quadrangle lies near rocks that have complex structural histories. Late Paleozoic faulting (Miller and others, 1991), and Mesozoic thrusts, normal faults, and metamorphism (Miller and others, 1987; Miller, 1990) are documented in Paleozoic rocks. Cenozoic rocks record two extensional tectonic events (Compton and others, 1977; Compton, 1983; Miller, 1985; Miller, 1990) characterized by coeval volcanism and normal faulting. Structures stemming from any of these tectonic events may be present in rocks of the Lucin NW quadrangle. Unfortunately, many exposures of pre-Quaternary materials are poor, complicating identification and interpretation of structures. Widespread late Pleistocene and Holocene sediment is well exposed in many places and is not cut by structures, suggesting that late Quaternary tectonism has not affected rocks of the quadrangle.

Faults in Paleozoic rocks

Paleozoic rocks exposed across the southern part of the quadrangle are cut by at least two sets of faults striking northeast and northwest. Both sets consist of high- to moderate-angle faults, judging from rare measurements of fault planes and the geometry of fault traces in areas with topographic relief. Detailed mapping just west of the quadrangle by Douglas (1984) showed northeast-striking faults to be the older fault set, a conclusion consistent with our mapping.

Northwest-striking faults cut the northeast-striking faults and seem to offset rock units (section CC') more than the older fault set. Most faults offset strata down to the west and are normal. Geometry of faults and strata suggests that tilting of stratal blocks was accomplished by the northwest-striking faults, consistent with faulting in an extensional setting. These faults, therefore, are probably late Cenozoic in age and associated with Basin and Range extension, but could be related to earlier Cenozoic extension (Miller, 1990) or even Jurassic extension (Allmendinger and Jordan, 1984; Miller and Allmendinger, 1991). Further adding to uncertainty in this interpretation is the effect of Cenozoic rotations on the older faults. Miocene strata in one small outcrop south of Grouse Creek Junction dip 23° west-southwest. If it is assumed that faults exposed in bedrock at Utahlite hill were tilted by the same event that tilted the Miocene strata, those faults once were moderately west-dipping but were normal faults. Alternatively, an east-dipping normal fault could have produced the tilting of Miocene strata, without tilting rocks and faults exposed at Utahlite hill (section CC'). Douglas (1984) showed that northwest-striking faults are cut by north-striking faults of late Miocene or younger age.

Faults in Miocene rocks

Faults cutting Miocene rocks are difficult to identify because linear terminations of lava flows and tephra deposits can be controlled by pre-existing topography and blunt flow margins, as well as by faults. We mapped faults where planar flow bases appeared to be offset and identified a few faults by silicified breccia zones.

Most exposed faults strike west to northwest; these are cut by one exposed north-striking fault and an inferred fault of similar orientation. All appear to be normal faults, despite variable dip and strike directions. The west- to northwest-striking faults dip steeply to moderately toward the north and south, and generally displace strata by a few tens of meters. In some cases, these faults separate units of drastically different thicknesses, suggesting that they were active during deposition of the volcanic rocks.

North-striking faults dip steeply to moderately toward the east and have fairly large separations of 300-600 m (1,000 to 2,000 ft). These faults parallel linear valleys, in which additional unmapped faults could be present. However, conduits that erupted volcanic rocks also trend north (Scarborough, 1984, and may also have contributed to this linear physiography. A fault just west of the quadrangle places Tertiary sediment on the east against Permian strata; it probably belongs to the north-striking young set of faults.

Bouguer gravity for Grouse Creek Valley (Cook and others, 1989) depicts a north-decreasing gradient toward a gravity low north of the Lucin NW quadrangle (Fig. 1). We infer that the Paleozoic rocks exposed in the southern part of the quadrangle are shallowly buried by Cenozoic sediments (Section CC') but northward are buried by increasingly thicker low-density material. Values in the Bouguer gravity low north of the quadrangle are 25 mgal less than those at Route 30. However, part of that gradient, at least 10 mgal, is expressed in Paleozoic bedrock east and west of the quadrangle as part of a regional gravity gradient, indicating that at most about 15 mgal is due to near-surface low-density sediments. We infer that a basin filled with material roughly 1,000 to 1,500 m (3,300 to 5,000 ft) thick creates the gravity low; it is perhaps half that thick in the northern Lucin NW quadrangle.

ECONOMIC GEOLOGY

Mining districts lie on either side of the Lucin NW quadrangle, but only two prospected localities are known in the quadrangle. To the west, the Tecoma District hosts several silver, zinc, and gold occurrences related to low-angle faults in and near the top of the Devonian Guilmette Formation (Doelling, 1980; Douglas and Oriel, 1984). About 10 km to the east, the Rosebud District (Fig. 1) hosts mainly tungsten, with less silver, lead, copper, and gold (Doelling, 1980). The Rosebud occurrences are spatially associated with outcrops of an Eocene granitoid.

Semi-precious minerals and ornamental stone

Variscite has been mined discontinuously from the largest outcrop of Permian rocks at Utahlite hill. Variscite, also known as lucinite and utahlite, is a green aluminous phosphate that is valuable as a substitute for turquoise in jewelry. It is found as breccia filling and replacement in highly fractured chert of the Murdock Mountain Formation. Doelling (1980) estimated tens of tons were produced at this site, and stated that production has been episodic. During our studies (1989-91) sporadic mining occurred.

Rhyolite flows and tuff carry minerals and display alteration structures of ornamental value. Most rhyolite contains small crystals of smoky quartz, but none larger than a few mm are present. Vugs lined with quartz crystals are common in rhyolite flows. Geodes are abundant locally in the upper vitrophyre of rhyolite flows; an example is SW sec. 13, T. 9 N., R. 18 W. Opal and chalcedony replacement of lacustrine sediment occurred in a few places. Notable localities are at prospect pits in center, sec. 26, T. 9 N., R. 19 W., and along the west border, sec. 11, T. 8 N., R. 19 W.

Silicified rocks

Siliceous breccia (jasperoid) hosts disseminated gold mineralization (Douglas, 1984; Douglas and Oriel, 1984) at the Tecoma deposit west of the quadrangle (Fig. 1). A similar structural and stratigraphic setting is present in the quadrangle (secs. 13 and 24, T. 8 N., R. 18 W.), where jasperoid breccia lies on the faulted Guilmette Formation. Considerable shallow subsurface exposures of the jasperoid are probably present.

Silicified rocks and structures may mark hydrothermal mineralization. Silicified faults and contacts are exposed in several places within the volcanic rocks of the northwestern part of the quadrangle (contact between units Tdf and Tr, SW Sec. 13, T. 9 N., R. 19 W.; faults at SE and SW sec. 14, T. 9 N., R. 19 W.). Altered Permian rocks (Pu) are present in the western part of sec. 26, T. 9 N., R. 19 W.; similar rocks continue south, just west of the quadrangle border, to section 11. These rocks are highly silicified, jasperoid-like masses. Douglas (1984) noted similarly altered, and apparently unmineralized, rocks in the quadrangle to the west.

Phosphate, lignite, uranium, and clay

Very low grade phosphate resources are present in the Meade Peak Phosphatic Shale Tongue of the Phosphoria Formation in northwestern Utah (Doelling, 1980; Glick and Miller, 1987). The Meade Peak crops out in the southern part of the quadrangle and probably is shallowly buried by Cenozoic materials in this area. It was not tested for P_2O_5, because the most favorable lithology, oolitic grainstone, was not observed.

Lignite, uranium in carbon-rich shale and lignite, and various clays are present in Tertiary sedimentary rocks of the Grouse Creek Valley (Doelling, 1980). No lignite or black shale was observed in the Lucin NW quadrangle, but it likely is present in subsurface, judging from the common occurrence of lignite and carbonaceous shale farther north in Grouse Creek Valley. Bentonite and other clays are present in the strata, as are abundant resources of volcanic glass.

Sand and gravel

Sorted gravel and sand deposits along the shores of ancient Lake Bonneville may be suitable for construction aggregate. Thickest accumulations are mapped as lacustrine gravel (Qlg) and lacustrine gravel and sand (Qlgs).

GEOLOGIC HAZARDS

Although there is no evidence for young faulting in the Lucin NW quadrangle, Pleistocene and Holocene faulting to the south of the quadrangle in the Pilot Range is indicated by rounded scarps, linear terraces, and well-developed linear arrays of springs (Miller and Schneyer, 1985; Miller and others, in press). These youthful faults could give rise to moderate or large earthquakes, typical of other parts of the Basin and Range Province. Thus, groundshaking from earthquakes and related liquefaction of water-saturated sand are potential hazards in the Lucin NW quadrangle. Additionally, landslides and talus slopes potentially could be activated by earthquakes, excessive rainfall, or other destabilizing processes.

Alluvial fans and alluvium in canyons were emplaced primarily by destructive debris flows, sheet washes, and other floods. In many sites, alluvium is currently being deposited or erosion is taking place. Floods are nearly seasonal in the constricted channels of Grouse Creek. As a result, there is great potential for destructive floods and debris flows, particularly close to the hill fronts and within and near the channel of Grouse Creek.

Eolian sand rimming Grouse Creek and elsewhere is subject to migration if its fragile vegetative cover is disturbed. Roads and other constructions, if located carefully, may avoid the dangers of drifting sand dunes. The extensive clay-rich sediment in the quadrangle, including various lacustrine and alluvial deposits, suggest that expansive soils could be present.

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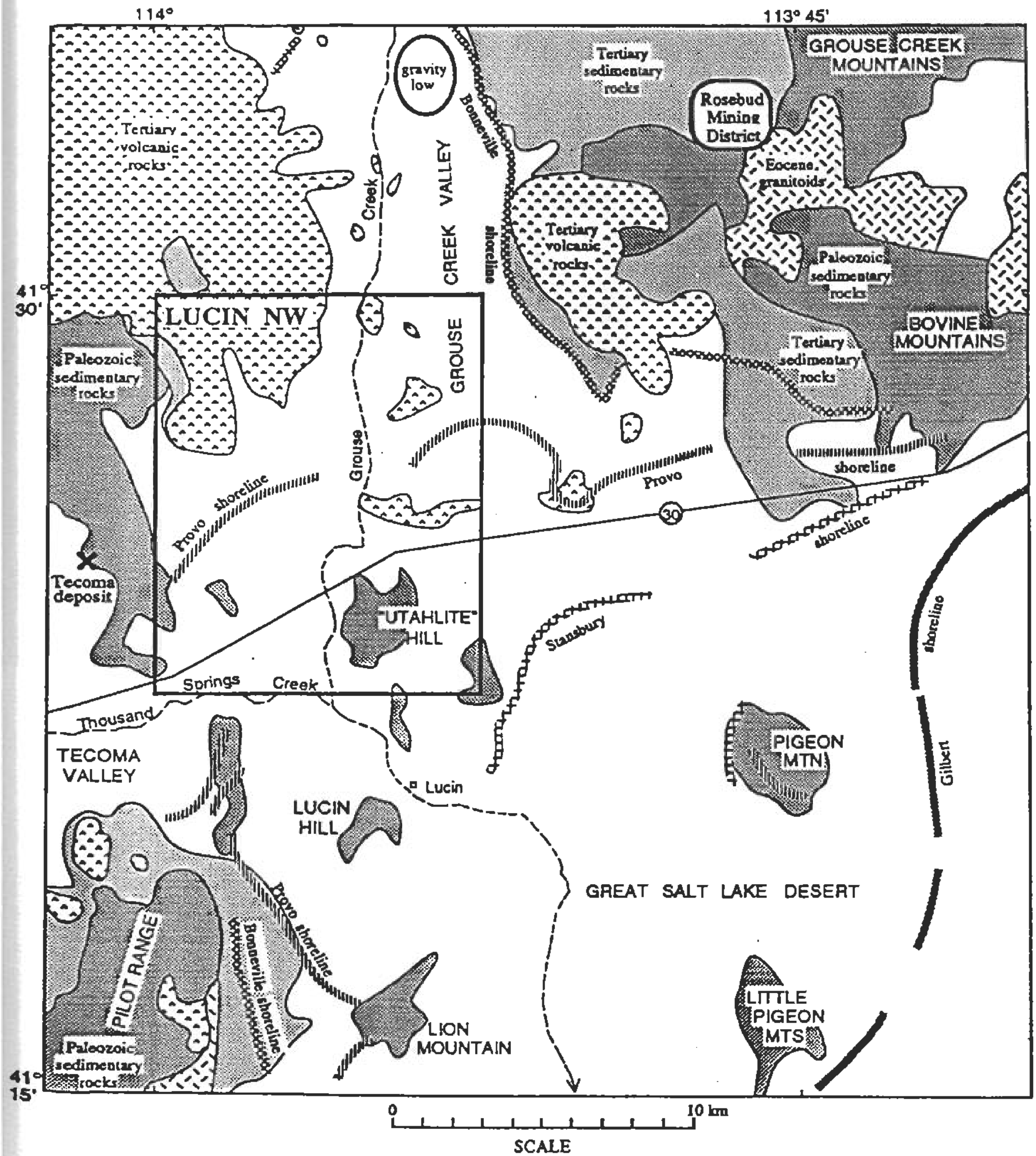
Figure Captions

Figure 1. Regional geology in the vicinity of the Lucin NW quadrangle. Prominent Lake Bonneville shorelines are indicated by broad patterned lines. Geology modified from Doelling (1980), Miller (1985), Miller and Schneyer (1985), and Glick and Miller (1987).

10/8/91



114°
113° 45'
41° 30'
41° 15'
gravity low
Tertiary volcanic rocks
Tertiary sedimentary rocks
GROUSE CREEK MOUNTAINS
Rosebud Mining District
Eocene granitoids
Paleozoic sedimentary rocks
BOVINE MOUNTAINS
Bonneville shoreline
GROUSE CREEK VALLEY
Grouse Creek
LUCIN NW
Provo shoreline
Tecoma deposit
"UTAHLITE" HILL
Stansbury shoreline
30
Thousand Springs Creek
TECOMA VALLEY
Lucin
LUCIN HILL
PIGEON MTN
Gilbert shoreline
GREAT SALT LAKE DESERT
PILOT RANGE
LION MOUNTAIN
LITTLE PIGEON MTS
0
10 km
SCALE

TABLE 1. Geochronologic data for the Lucin NW quadrangle

Map no.	Sample no.	Sample site Lat.	Sample site Long.	Rock unit	Mineral dated	Age (Ma) K-Ar	Age (Ma) $^{40}Ar/^{39}Ar$	Reference
1	M90LU-61	41°29'39"	113°59'07"	Biotite tuff breccia (Tbt)	Biotite Sanidine	13.6±0.4	 12.3±0.46	J.K. Nakata, 1991, unpublished
2	YU-1A-AY	41°28'32"	113°59'15"	Rhyolite vitrophyre (Trv)	Sanidine	8.8±0.17*		Armstrong and others (1976)
3	YU-1-AY	41°28'32"	113°59'13"	Rhyolite (Tr)	Sanidine	8.4±0.16*		Armstrong and others (1976)
4	LV82-19	41°29'50"	113°57'41"	Rhyolite (Tr)	Sanidine		7.6±0.9	Scarborough (1984)
5	M89LU-47	41°27'54"	113°54'20"	Rhyolite (Tr)	Sanidine		9.3±0.46	J.K. Nakata, 1991, unpublished
	LV82-41	41°30'06"	113°57'57"	Dacite vitro-phyre**	Hornblende		12.4±0.4	Scarborough (1984)
	TCV82-55	41°32'26"	113°59'35"	Dacite**	Biotite		13.2±0.5	Scarborough (1984)

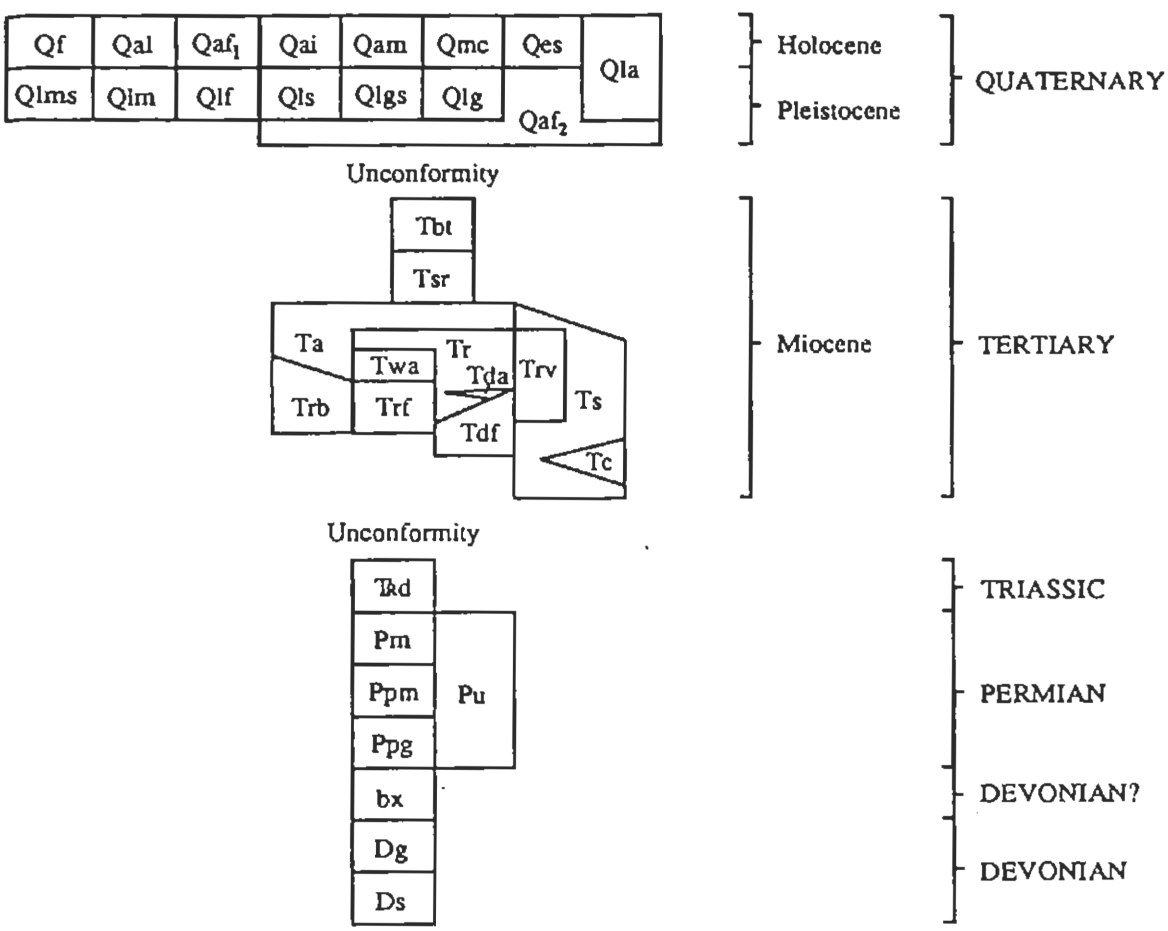
* Recalculated using new decay constants of Steiger and Jäger (1977).

** Sampled from dacitic units of Scarborough (1984) north of Lucin NW quadrangle; probably correlates with the dacite lava flows and domes unit (Tdf).

TABLE 2. Distinctions between lava flows and rheomorphic ash flows
[*feature of one or more rhyolite flows in Lucin NW quadrangle]

Lava flow	Rheomorphic ash flow
*Generally thick, stubby geometry	Generally thin, widespread sheet
Lower temperature at eruption	Higher temperature at eruption
*No hydrous phases	Commonly has hydrous phases
$SiO_2 < 75\%$	*$SiO_2 > 72\%$
*No pumice or ash	May contain relic pumice and ash
*Lithic fragments uncommon	Lithic fragments present
Tight folds in basal vitrophyre	*Basal vitrophyre rarely folded
*Broken phenocrysts uncommon	Broken phenocrysts abundant
*Thick, brecciated flow margins (>25 m)	Thin, simple margins
Lies on older rocks	*Lies on comagmatic ash deposits
*Convoluted transition to upper vitrophyre	Planar boundary at base of upper vitrophyre
*No swarms of lithophysae in basal vitrophyre	Swarms of lithophysae in basal vitrophyre
*Thick upper vitrophyre with breccia	Thin upper vitrophyre
Central part of flow is massive	Central part may show compound cooling units
*Little internal chemical variation	Vertical and lateral chemical variations
*Breccia at base, especially near margin	Sometimes lacks basal breccia

CORRELATION OF MAP UNITS



—— - - - ·····	CONTACT--Dotted where covered, dashed where gradational
54	HIGH-ANGLE FAULT--Dashed where location inferred, dotted where concealed; bar and ball on downthrown side; dip indicated
—△—·······	FAULT PARALLEL TO BEDDING, dotted where concealed
	ORIENTATION OF BEDDING
12	Inclined
—+—	Vertical
	ORIENTATION OF IGNEOUS FOLIATION (Flow banding)
18	Inclined
	Vertical
→ 27	LINEATION--Showing trend and plunge
⇒	DIRECTION OF SEDIMENT TRANSPORT
▫2	LOCATION OF GEOCHRONOLOGY SAMPLE
—B—B—	BONNEVILLE SHORELINE
—I—I—	INTERMEDIATE SHORELINE
—P—P—	PROVO SHORELINE
—R—R—	REGRESSIVE SHORELINE
Qlf / Qlg	THIN DEPOSITS RESTING ON OTHER DEPOSITS