

INTERIM GEOLOGIC MAP OF THE BRIGHAM CITY 7.5-MINUTE QUADRANGLE, BOX ELDER AND CACHE COUNTIES, UTAH

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ABSTRACT

The Brigham City 7.5-minute quadrangle contains parts of the lower Bear River Valley and of the Wellsville Mountains. The mountain front is a part of the Wasatch Front, along the Wasatch fault zone. The largest geologic structure in the Wellsville Mountains, a northeast-dipping homocline, contains one of the more complete Cambrian sections in northern Utah and a well-exposed record of Paleozoic continental shelf deposition. The mountains are broken by numerous faults and contain evidence for contraction during the Cretaceous to early Tertiary Sevier orogeny. A segmented major fault, transverse to the mountain front, divides the mountains into geologically different blocks. The mountain front and subsurface data constrain the timing of and displacement during late Tertiary to present-day extension along the Brigham City segment of the Wasatch fault zone. Latest Pleistocene Lake Bonneville and two earlier Pleistocene lakes occupied the lower Bear River Valley. The Box Elder Canyon delta, a significant source of sand and gravel, formed in Lake Bonneville on the southeastern margin of the quadrangle. A deep well in the quadrangle provided additional data on Proterozoic rocks, the Sevier orogeny, and Cenozoic extension in northern Utah.

INTRODUCTION

The Brigham City 7.5-minute quadrangle is located in northern Utah on the western side of the Wellsville Mountains and eastern side of the lower Bear River Valley (figure 1), along the northern Wasatch Front. The Wasatch Front is the eastern transitional boundary of the Basin and Range Province into the Middle Rocky Mountains Province (Stokes, 1986). Within the quadrangle, the Wasatch fault zone trends about N25°W along the mountain front from the

southeastern border to the center of the northern edge (figures 1 and 2). East of the Wasatch fault zone, bedrock is exposed in a northeast-dipping (30° to 50°) homocline in the Wellsville Mountains. The rest of the quadrangle is in the Bear River Valley, where unconsolidated sediments are exposed. Another major structure in the quadrangle is a large-displacement (up to about 1 mile [1.6 km] of stratigraphic offset) fault that trends roughly $N25^{\circ}E$, transverse to the Wellsville Mountains. This structure, herein referred to as the Wellsville Mountains (WM) transverse fault, cuts the northeastern corner of the quadrangle and extends into the Honeyville and Wellsville quadrangles (plate 1; Davis, 1985). The WM transverse fault is broken into several segments by other faults (figure 2), and divides the Wellsville Mountains into two blocks with different geologic characteristics.

Geographically, the quadrangle is in Box Elder County, except for the northeastern edge, which is in Cache County. Parts of the communities of Brigham City, Corinne, and Bear River City are in the quadrangle. The Bear River flows through the quadrangle from the northwestern corner to the southwestern corner, and is joined by the Malad River south of Bear River City. Box Elder Creek flows through Brigham City.

The names used for several canyons in the Wellsville Mountains have changed on maps over time or are ambiguous (compare Williams, 1948; Gelnett, 1958; 1955, 1969 and 1988 Brigham City 7.5-minute quadrangle topographic maps; 1955, 1969, 1988 and 1991 Mount Pisgah 7.5-minute quadrangle topographic maps) such that the locations of some geologic features, and measured and type sections are uncertain (for example Walcott, 1908; Eardley and Hatch, 1940; Maxey, 1958; Gelnett, 1958; Beus, 1958). Almost all the names used in this report are those shown on the 1988 Brigham City 7.5-minute quadrangle topographic map (base map for plate 1). The exceptions, Silver Mine Hollow ($N1/2$ section 19, T.10N., R.1W.) and Hansen Canyon (referred to as "two" Hansen Canyon in this report; $NW1/2$ section 6, T.9N., R.1W.), are not shown on the base map, but are shown on figure 2, and the 1991 Mount

Pisgah, and 1969 and 1955 Brigham City 7.5-minute quadrangle topographic maps.

Previous Work

Several geologic maps covering the Brigham City quadrangle were available to us. Gelnett (1958) mapped the southern half of the Wellsville Mountains, including the bedrock in the Brigham City quadrangle, and was the first to recognize the Wellsville Mountains transverse fault and the geologically different blocks. Doelling (1980) studied and mapped the geology of Box Elder County, and Davis (1985) compiled a geologic map of the northern Wasatch Front that encompassed the quadrangle. Surficial geologic maps that cover the Brigham City area include a preliminary map by Miller (1980) and a small-scale map by Personius (1990). The soil survey of the eastern part of Box Elder County (Chadwick and others, 1975) covered the Bear River Valley in the Brigham City quadrangle, and was used to help delimit some of the Quaternary map units. The most detailed gravity map of the area, though regional in scope, was produced by Peterson (1974; see also Zoback, 1983).

Previous geologic mapping in adjacent 7.5-minute quadrangles provided control for our mapping (quadrangle names shown on figure 1). Adjacent maps at 1:24,000-scale cover the: (1) Mantua and Willard (Crittenden and Sorensen, 1985); (2) Bear River City (Jensen, 1994); and (3) Honeyville (Oviatt, 1986a) quadrangles. Adjacent maps at other scales cover: (1) a small area just east of Brigham City in the Mount Pisgah quadrangle (Sorensen and Crittenden, 1976); (2) the Logan 30-minute quadrangle, which includes the Wellsville and Mount Pisgah quadrangles (Williams, 1948); and (3) the Logan 30 x 60-minute quadrangle, which includes the Wellsville and Mount Pisgah quadrangles (Dover, 1985).

Several discrepancies exist where our map of the Brigham City quadrangle (plate 1) adjoins the Honeyville quadrangle map of Oviatt (1986a). Differences in Quaternary deposit mapping are discussed under the specific Quaternary unit. Differences in Cambrian contacts

near Precipice Canyon occur because several previously unmapped faults on the south side of Precipice Canyon extend into the Honeyville quadrangle, and an outcrop of Bloomington Formation extends into Lake Bonneville deposits. Contacts of Ordovician and Silurian strata don't precisely match because it is difficult to plot contacts on steep slopes and subdivision of the Laketown Dolomite is ambiguous (see description in stratigraphy section). The discrepancies in identification of Mississippian, Pennsylvanian, and Permian strata are due to different stratigraphic interpretations on opposite sides of the WM transverse fault (see description in structural geology section), which barely enters the Honeyville quadrangle.

STRATIGRAPHY

Rocks exposed in the Brigham City quadrangle range in age from Precambrian to Pennsylvanian. Exposed Precambrian, Mississippian and Pennsylvanian rocks were penetrated by a deep bore hole in the Bear River Valley, as were additional, unexposed Precambrian and Tertiary rocks (table 1). Surficial deposits are Quaternary in age. Bedrock, from the earliest Cambrian Geertsen Canyon Quartzite to the Pennsylvanian West Canyon Limestone of the Oquirrh Group, is well exposed in the Wellsville Mountains. Precambrian (upper Proterozoic) rocks are exposed in a single isolated outcrop near Kotter Canyon (figure 2; plate 2, lithologic column). These rocks were deposited on a rifted and then slowly subsiding continental-shelf margin (Hintze, 1988). The Cambrian section east of Calls Fort is well-studied, and is probably as nearly complete as any section in northern Utah (see Maxey, 1958). Maxey (1941, 1958) measured sections from the base of the upper member of the Geertsen Canyon Quartzite to the Ordovician Garden City Formation. As noted in the following descriptions, some unit thicknesses are different on opposite sides of the WM transverse fault.

Precambrian

Proterozoic

Several upper Proterozoic formations were encountered in a deep bore hole (#1 Davis, Utah Joint Steam Venture, geothermal well; section 16, T.10N., R.2W.) in the quadrangle (table 1). W.A. Yonkee of Weber State University first identified these formations from drill cuttings archived at the Utah Geological Survey (this report). King examined the cuttings, and geophysical and lithologic logs of the hole, and concurred with Yonkee's identifications. The bore hole penetrated (in descending order) the Caddy Canyon, Papoose Creek, Kelley Canyon and Maple Canyon Formations. Because the contacts between some formations are gradational, the exact depths of these contacts are subject to interpretation. The Upper Proterozoic Inkom, Mutual and Browns Hole Formations that overlie the aforementioned formations in the adjacent Mantua, Willard and Mount Pisgah quadrangles (Crittenden and Sorensen, 1985; Sorensen and Crittenden, 1976) were not in the bore hole. Rocks in the Inkom, Mutual and Browns Hole Formations are so unique that, if present, they would have been easily identified in drill cuttings. The Papoose Creek, Caddy Canyon, Inkom, Mutual, Browns Hole, and Geertsen Canyon Formations were formally defined to the east in the Huntsville, Utah area, and comprise (in ascending order) the Brigham Group (Crittenden and others, 1971). The only Proterozoic formations exposed in the quadrangle are in an isolated outcrop near Kotter Canyon that contains the Caddy Canyon-Papoose Creek contact.

Maple Canyon Formation (Zmc; subsurface only)

Crittenden and others (1971), and Crittenden and Sorensen (1985) recognized three informal members in the Maple Canyon Formation. Only the upper member was encountered in the bore hole. In outcrop, the upper member reportedly contains two, coarse-grained to conglomeratic, white quartzite units or two, coarse-grained to conglomeratic, green arkosic

quartzite units. Olive-drab to green laminated siltstone or argillite separate the white or green quartzites. At the type locality near Huntsville, Utah this upper member is 60 to 500 feet (18 to 150 m) thick, but is typically 200 feet (60 m) thick. The middle member is a green arkosic quartzite (Crittenden and others, 1971; Crittenden and Sorensen, 1985). In the #1 Davis geothermal well (total depth 11,005 feet [3,354 m]), white quartzites were in drill cuttings from the last 415 to 575 feet (126 to 175 m) of the hole.

Kelley Canyon Formation (Zkc; subsurface only)

The Kelley Canyon Formation is dominantly thin-bedded, dark-gray to black argillite or phyllite that conformably overlies the Maple Canyon Formation. A distinctive 10-foot- (3-m-) thick bed of dolomite is present at the base of the Kelley Canyon at the type section near Huntsville. This dolomite and the lenticular, thin-bedded, silty limestones in the middle portion of the formation are examples of the rare carbonates in upper Proterozoic rocks in Utah. This formation is about 600 feet (180 m) thick in exposures near Brigham City (Crittenden and others, 1971; Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985). About 2,000 feet (610 m) of Kelley Canyon is exposed near Huntsville, where the overlying Papoose Creek Formation is absent (Crittenden and others, 1971; Sorensen and Crittenden, 1979).

In the geothermal well, the Maple Canyon-Kelley Canyon contact was picked by King at a depth of 10,590 feet (3228 m), based on dolomite in drill cuttings over an interval of about 20 feet (6 m). From cuttings, most of the Kelley Canyon is interpreted as dark phyllite containing scattered, unbedded calcite; other interpreted units are a well-indurated siltstone (quartzite) and limestone near the base, and a limestone near the top of the lower third of the formation. The basal Kelley Canyon was picked at the top of the first quartzite, at a depth of about 10,430 feet (3,179 m), by W.A. Yonkee.

The contact of the Kelley Canyon Formation with the overlying Papoose Creek

Formation was placed at a depth of 8,864 feet (2,702 m) in the bore hole by W.A. Yonkee. This pick was apparently based on a change in the sonic logs, though the character of the geophysical well logs changes at several depths between 8,854 and 8,900 feet (2,699 and 2,713 m). From cuttings, a gradational change from dark-gray, argillitic (to phyllitic) siltstone and gray quartzite (Papoose Creek) to dark-gray, almost black phyllite (or argillite)(Kelley Canyon) occurs over an interval of about 100 feet (30 m)(8,850 to 8,950 feet [2,697 to 2,728 m]). Therefore, the Kelley Canyon is 1,480 to 1,736 feet (451 to 529 m) thick in the bore hole, far greater than the thickness (600 feet [180 m]) in nearby outcrops.

Papoose Creek Formation (Zpc)

In exposures near Brigham City, the Papoose Creek Formation is reportedly gray, brown, and greenish-brown siltstone with interbedded, similarly colored, fine-grained, quartzitic sandstone and medium- to coarse-grained quartzite. The unit is distinguished by fine-grained sandstone dikelets that fill apparent shrinkage fractures normal to bedding. The Papoose Creek Formation conformably overlies and is gradational into the Kelley Canyon Formation, and is 750 to 1,500 feet (225 to 455 m) thick in this area (Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985). W.A. Yonkee placed the upper contact of the Papoose Creek Formation at a depth of 7,932 feet (2,418 m) in the geothermal well, apparently based on a change in gamma-ray response. King noted definite Papoose Creek siltstone fragments in the well cuttings at a depth of about 7,970 feet (2,429 m). Therefore, the Papoose Creek is about 890 to 930 feet (271 to 283 m) thick in the bore hole.

The lower 30 feet (9 m) of an isolated outcrop just south of Kotter Canyon has been identified as the Papoose Creek Formation because this interval contains interbedded, light-gray to greenish-gray, fine- to medium-grained quartzite, and darker-colored argillite or siltstone with greenish, micaceous bedding surfaces. Both quartzite and argillite weather dark yellowish

brown, and bedding is largely defined by the argillite. The outcrop is mostly very thin bedded, though it varies from laminated to medium bedded. Bedding surfaces show apparent relict mud cracks filled with quartzite. The conformable contact with the overlying unit was placed at a sharp change to the lighter weathered colors and thicker bedding of the overlying Caddy Canyon Quartzite. This contact is apparently the same as the Papoose Creek-Caddy Canyon contact of Sorensen and Crittenden (1976) in the Mount Pisgah quadrangle, even though they stated that the contact is gradational rather than sharp.

Caddy Canyon Quartzite (Zcc)

In exposures near Brigham City, the Caddy Canyon Quartzite reportedly conformably overlies and grades into the Papoose Creek Formation, and is about 1,000 feet (305 m) thick (Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985). The Caddy Canyon is fine- to medium-grained, medium- to thick-bedded, vitreous quartzite that varies in color (tan, green, blue-green or purple, and locally light gray to white and pink)(Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985). Drill cuttings from a depth of about 7,880 feet (2,400 m) in the geothermal well are dominantly vitreous quartzite chips with the variety of colors found in the Caddy Canyon. Cuttings above this depth contain probable Lodgepole Limestone (table 1) and a fault has been inferred at a depth of about 7,845 feet (2,391 m). Therefore, only about 100 feet (30 m) of the basal Caddy Canyon Quartzite is present in the bore hole.

The upper 100 feet (30 m) of the isolated outcrop south of Kotter Canyon is Caddy Canyon Quartzite. The rocks are light-gray and greenish-gray, medium- to thick-bedded, fine-grained quartzite that is not vitreous. The quartzite looks like the quartzite in the underlying Papoose Creek and weathers to dark-brown-stained outcrops. This darker staining distinguishes the Caddy Canyon outcrops from similar Geertsen Canyon Quartzite exposures upslope.

Inkom Formation (Zi; subsurface only)

Near Brigham City, complete exposures of the Inkom Formation are about 150 feet (45 m) thick. The Inkom includes a lower, laminated, green-weathering siltstone, with lenses of silver- to gray-weathering, black tuff; and an upper, dark-green, very fine-grained sandstone (Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985).

Mutual Formation (Zm; subsurface only)

In exposures near Brigham City, the Mutual Formation is 2,200 to 2,600 feet (670 to 790 m) of medium- to coarse-grained, locally pebbly, gray quartzite that weathers to distinct dark shades of purple, grayish red, and less commonly green or brown. The quartzite is locally feldspathic and commonly cross bedded (Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985).

Browns Hole Formation (Zbh; subsurface only)

The Browns Hole Formation rests conformably on the Mutual Formation at the type section near Huntsville, Utah (Crittenden and others, 1971), but this contact is unconformable in the Brigham City area where the lower member is missing (Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985). In the Mantua quadrangle, the informal lower (or volcanic) member of the Browns Hole is present, and contains basaltic or andesitic to trachytic flows and volcanic breccias that are locally reworked into volcanic conglomerates. The volcanic member is up to about 150 feet (40 m) thick, but is not present in all areas. The informal upper (or quartzite) member is about 350 feet (105 m) thick in the Brigham City area and about 100 to 270 feet (30 to 85 m) thick to the south, and is a white to terra-cotta colored, well-sorted, medium- to fine-grained, medium-bedded, vitreous quartzite (Sorensen and Crittenden, 1976; Crittenden and Sorensen, 1985). A K-Ar date of 570 Ma was obtained from a cobble from the

lower member, so the Browns Hole is considered latest Proterozoic in age (Crittenden and Sorensen, 1985).

Paleozoic

Cambrian

Geertsen Canyon Quartzite (Cgl, Cgu)

The Geertsen Canyon Quartzite exposures northeast of Brigham City are at least part of the type locality of the Brigham Formation of Walcott (1908), and measured sections of the Brigham Quartzite of Eardley and Hatch (1940). Maxey (1958) described, measured and correlated rocks we mapped as Geertsen Canyon with the Pioche(?) Formation and Prospect Mountain Quartzite. The exact locations of these earlier localities and measured sections are unknown. These incompletely described and vaguely located sections were replaced with type sections near Huntsville, Utah (Crittenden and others, 1971; Sorensen and Crittenden, 1976), when the Brigham was elevated to group status. The Geertsen Canyon Quartzite is the top formation in the Brigham Group. The Geertsen Canyon Quartzite is presently considered early Cambrian in age (Crittenden and Sorensen, 1985).

Near Huntsville, the Geertsen Canyon was divided into two informal members, and is about 3,900 to 4,200 feet (1,190 to 1,280 m) thick (Crittenden and others, 1971). The lower member is about 1,200 feet (365 m) of mostly coarse-grained, typically green or gray, or locally maroon or purple arkose. Grain size and feldspar content decrease upward such that the upper 800 feet (345 m) are white- to tan-weathering quartzite. The upper informal member is about 3,000 feet (915 m) thick, and is a pale-buff to white or pale-pink, medium- to coarse-grained, medium- to thick-bedded quartzite with local pale-red or pale-purple streaks. *Skolithos* tubes (vertical burrows) are abundant in the uppermost beds. Abundant cross bedding and pebble

thick bedded, with some oolitic beds and fenestral fabric. Maxey (1958) and Hay (1982) measured 805 and 812 feet (245.4 and 247.5 m) of Blacksmith north of Cataract Canyon, respectively. The fossil-poor Blacksmith is Middle Cambrian in age based on its position between two Middle Cambrian units, whose ages are based on fossils (Maxey, 1958). Hay (1982) provided additional details on the lithology and origin of the Blacksmith.

Bloomington Formation (Cbh, Cbm, Cbc)

Following Maxey (1958), the Bloomington Formation has been divided into three members for this study. The members, oldest to youngest, are the Hodges Shale (Cbh), a middle limestone (Cbm), and the Calls Fort Shale (Cbc). Each member is easily mapped. The Hodges Shale Member (Cbh) is mostly light-olive- to light-brown-weathering shale interbedded with light- to dark-gray, silty limestone. The limestones contain irregularly interbedded and intermingled thin beds and masses of siltstone and shale that are more resistant than the limestone. The middle limestone member (Cbm) is dark to light gray, very fine to medium crystalline, argillaceous, and forms cliffs. This middle limestone is very thick bedded at the base and gradually becomes thin bedded at the top. The Calls Fort Shale Member (Cbc) is mostly a light-olive- to light-brown-weathering shale with some thin beds of gray limestone. The shale contains distinctive, 1- to 2-inch- (2.5- to 5-cm-) long, limestone nodules that weather out, leaving holes in the shales and littering gentle slopes. We placed the thin-bedded limestone that caps the Calls Fort Shale in the shale because it is more similar to the limestones in the Bloomington Formation than to the conformably overlying Nounan Formation dolomites. Based on fossil data, the Bloomington is Middle Cambrian in age (Maxey, 1958; Oviatt, 1986a; table 2). Maxey (1958) measured 335 feet (102.1 m) of Hodges, 515 feet (157.0 m) of middle limestone, 200 feet (61.0 m) of Calls Fort, and 35 feet (10.7 m) of capping limestone near Calls Fort Canyon, for a total of 1,085 feet (330.7 m).

Nounan Formation (Cnl, Cnu)

In the quadrangle, the Nounan Formation is divisible into two map units: a lower unit (Cnl) of mostly light- to medium-gray, fine- to medium-crystalline, thick-bedded dolomite; and an upper unit (Cnu) of gray and tan, interbedded dolomite, sandy and silty dolomite, and limestone. We mapped the contact between the Nounan units between a 10- to 20-foot- (3- to 6-m-) thick, lighter gray dolomite, and an overlying tan, sandy dolomite, which is the oldest Nounan sandy dolomite. This is apparently the same contact that Oviatt (1986a) used in the Honeyville quadrangle just to the north, and is the contact between Gardiner's (1974) middle and upper members of the Nounan. Our lower map unit weathers to light- and medium-gray, sugary surfaced outcrops that form crags and cliffs; these outcrops are generally lighter colored, thicker bedded and more resistant than the capping and middle limestones of the Bloomington Formation. Our upper Nounan map unit is mostly less resistant and thinner bedded than the lower map unit, though cliffs are present. The upper Nounan map unit forms continuous slopes in the Honeyville quadrangle where relief is lower. The upper map unit commonly contains non-marine sediment, that is more abundant at the base and near the top of the unit. This sand and silt form partings in the gray carbonates, and weather tan. Local brownish to reddish-brown lenses of quartzose dolomite in the upper unit contrast with the grays and tans. Because the top of the Nounan and bottom of the St. Charles Formation are lithologically similar, the Nounan contact with the conformably overlying St. Charles Formation is difficult to distinguish in the field. This is especially true in outcrops where the basal Worm Creek Quartzite Member of the St. Charles is absent. Williams (1948) reported that the Nounan was Late Cambrian in age, using unpublished fossil collections (in part from Maxey, 1941). Oviatt (1986a) reported the upper Nounan was Dresbachian (Late Cambrian) in age based on its trilobite fauna. Gardiner (1974) and Maxey (1941) provided additional details on the formation. Where contacts are most exact, the lower Nounan is about 650 feet (200 m) thick (plate 1 outcrop widths, topography and

dips from 3 sites). Gardiner (1974) and Oviatt (1986a) reported lower Nounan thicknesses of 601 and 729 feet (183.2 and 222.2 m) near Dry Canyon and just north of the quadrangle, respectively. The upper Nounan is about 550 feet (168 m) thick (this report; Gardiner, 1974; Oviatt, 1986a). Therefore, the total Nounan is about 1,200 feet (365 m) thick, and the 828 foot (252.4 m) total thickness reported by Maxey (1941) doesn't appear accurate.

St. Charles Formation (Csl, Csu)

The St. Charles Formation was divided into two map units. The lower unit (Csl) includes the Worm Creek Quartzite, and about 100 feet (30 m) of overlying, slope-forming, interbedded, thin-bedded, silty and sandy limestone. The Worm Creek Quartzite forms the base of the lower map unit, and consists of 0 to 6 feet (0 to 1.8 m) of light-gray to white quartzite with about 70 feet (21 m) of overlying thin-bedded, sandy dolomite and limestone, and siltstone and shale. The upper map unit (Csu) is about 980 feet (300 m) thick, and is medium- to dark-gray, finely crystalline dolomite that typically weathers to gray, resistant exposures that were easily mapped along the mountain front. The middle portion of the upper map unit contains a distinct, almost-white-weathering, resistant dolomite. From map portrayal (plate 1), the upper map unit appears at least 10 percent thinner south of the WM transverse fault. The uppermost St. Charles contains light colored, commonly pink, elongate, 1- to 12-inch- (2.5- to 30-cm-) long, and 1-inch- (2.5-cm-) thick, chert nodules that are aligned parallel to bedding, and layers of clastic material that are much less resistant than the dolomite and weather into tan recesses. For additional information see Maxey (1941). As determined from trilobite and conodont fossils, the St. Charles Formation is Late Cambrian and earliest Ordovician in age in the Bear River Range (Taylor and others, 1981).

Ordovician

Garden City Formation (Ogc)

The Garden City Formation is mostly medium-gray, thin- to thick-bedded, finely crystalline to micritic limestone and silty limestone, with some intraformational conglomerate and silt partings. The formation is exposed in light-gray to tan ledges, cliffs and steep slopes, but is not massive. The basal part of the formation contains interbeds of less resistant, light-tan, calcareous sandstone, siltstone and some shale that are as much as one inch (2.5 cm) thick. The basal Garden City is also chert-bearing, and, therefore, looks much like the top of the underlying St. Charles Formation. They can be separated because the Garden City is slightly lighter in color and contains less clastic material higher in the section. Near the top of the Garden City, 1- to 10-inch- (2.5- to 25-cm-) thick, black chert nodules and stringers are abundant in the limestone. Above this cherty zone the uppermost Garden City is dark-gray dolomite and dolomitic limestone. The Garden City is 1,330 to 1,390 feet (405 to 424 m) thick both north of the quadrangle (Morgan, 1988; Oviatt, 1986a) and in the quadrangle south of the WM transverse fault (Ross, 1951). Morgan (1988) reported additional information on the petrology and origin of the Garden City Formation. The Garden City is Early Ordovician to earliest Middle Ordovician in age as determined from its rich trilobite fauna, and disconformably overlies the St. Charles Formation (Ross, 1951; see also Taylor and others, 1981).

Swan Peak Formation (Osp)

Regionally, the Swan Peak Formation is divisible into three units (Francis, 1972; Oaks and others, 1977). We mapped the Swan Peak as a single unit because it is relatively thin in the quadrangle. Francis (1972), and Oaks and others (1977) provided details on the Swan Peak and its divisions. The Swan Peak is about 260 and 300 feet (80 and 90 m) thick in well-

documented measured sections in the Wellsville Mountains (Francis, 1972), about 2 miles (3 km) south and 3 miles (5 km) north of the WM transverse fault, respectively. Because the Swan Peak also thickens to the north in the Bear River Range (Francis, 1972), the WM transverse fault may not be a factor. Other measured thicknesses in the Wellsville Mountains (about 380 and 435 feet [115 and 133 m]; Oviatt, 1986a and Gelnett, 1958, respectively) appear inaccurate. The Swan Peak contains quartzite, shale and limestone, and is usually visible as thick ledges and a capping cliff of quartzite. The lowermost unit is poorly exposed, and contains interbedded shale, quartzite and limestone. The middle unit is interbedded quartzite and shale, and contains abundant fucoidal trace fossils (horizontal feeding burrows) identified as *Annelidichnus* by Francis (1972). The uppermost unit is a distinctive, roughly 60-foot- (18-m-) thick, pink-orange-tan to white, fine- to medium-grained quartzite, in which the colors look like staining. Vertical burrows (*Skolithos* trace fossils) are abundant, and trace fossils on bedding are present (identified as *Scolicia* by Francis, 1972). The lower Swan Peak is earliest Middle Ordovician in age based on trilobites (Ross, 1951). Oaks and others (1977) showed a Middle Ordovician (early Champlainian) age for the entire Swan Peak, though this age has not been documented with fossil data. Table 2 contains other fossil information.

Fish Haven Dolomite (Ofh)

The Fish Haven Dolomite unconformably overlies the Swan Peak and is a dark-gray, almost black-weathering, finely crystalline, thick- to very thick-bedded, massive-weathering, cliff-forming dolomite. The contact with the overlying Laketown Dolomite is placed at the change to lighter gray dolomite, and is usually accompanied by changes to thinner bedding, greater resistance and weathering to pinnacles and spires. This is the historic contact that Williams (1948, 1958) mapped in the Bear River Range. Fish Haven thicknesses of 178 and 140 feet (54.3 and 42.7 m) have been measured in the Wellsville Mountains (appendix; Gelnett, 1958).

From our examination of his field notes and aerial photographs, Oviatt (1986a) apparently placed the Fish Haven--Laketown contact at the base of the first thin-bedded dolomite, making his Fish Haven about 185 feet (56 m) thick rather than the 197 feet (60.0 m) he reported. The Fish Haven contains abundant corals, particularly rugose corals, and tabulate (*Favosites* and *Halysites* species) corals. Based on fossil corals collected from the Fish Haven in north-central Utah, the age of our Fish Haven map unit is probably late Late Ordovician (Cincinnatian) (after Williams, 1948; Gelnett, 1958). Budge and Sheehan (1980) presented more detailed data, but they used a different Fish Haven-Laketown contact.

Silurian

Laketown Dolomite (SII, Slu)

We divided the Laketown Dolomite into two map units, but it was difficult to consistently map the contact between them. Both units are light- and dark-gray, medium- to very thick-bedded, massive-weathering, cliff-forming dolomites, with irregular blebs, stringers, and layers of chert at various horizons. The lower unit (SII) is finely to coarsely crystalline, contains *Thalassinoides* trace fossils, and is occasionally banded light and dark gray. In contrast, the upper unit (Slu) is sugary surfaced, medium crystalline, and contains more chert. Good exposures of the lower map unit are dark gray, or banded light and dark gray at the bottom, and dark gray higher in the unit. Good exposures of the upper unit are usually light gray in the bottom portion and dark gray in the top portion. Therefore, the internal contact was mapped at a diffuse change from darker to lighter gray, as Oviatt (1986a) did in the Honeyville quadrangle. Because the upper map unit is noticeably thinner than the lower map unit south of the Calls Fort Canyon area (plate 1), this contact appears to climb or shift in the Laketown Dolomite in the Brigham City quadrangle. The Laketown Dolomite is about 1,100 to 1,200 feet (305 to 365 m)

thick in the Wellsville Mountains on both sides of the WM transverse fault (Oviatt, 1986a; after Gelnett, 1958). Using our Fish Haven-Laketown contact, the Laketown is late Late Ordovician and middle Early through Middle Silurian, and locally earliest Late Silurian in age in northern Utah (after Budge, 1966; Budge and Sheehan, 1980; Leatham, 1985).

We do not assign any member names to our Laketown map units because the Laketown members were defined biostratigraphically in the Bear River Range (Budge and Sheehan, 1980; Leatham, 1985). Further, they used an unmappable and different Laketown-Fish Haven contact than we used, and the lithologies present in the Wellsville Mountains are different from those reported in the Bear River Range by Budge and Sheehan (1980).

Devonian

Water Canyon Formation (Dwl, Dwm, Dwu)

The Water Canyon Formation was divided into three lithologically distinct map units using the same contacts that Oviatt (1986a) used in the Honeyville quadrangle. However, these contacts are difficult to map because the units are easily eroded and the resulting detritus mantles underlying units. The Water Canyon disconformably overlies the Laketown Dolomite (Williams and Taylor, 1964; Taylor, 1963). The Water Canyon is Early Devonian based on fish fossils found in the Wellsville Mountains (Oviatt, 1986a) and in northern Utah (Taylor, 1963; Williams and Taylor, 1964).

The lower map unit (Dwl) is a light-gray-weathering, finely crystalline, thin- to medium-bedded, ledge- and slope-forming dolomite that Oviatt (1986a) equated with the type Card Member of Williams and Taylor (1964). Gelnett (1958) apparently mapped our lower unit as part of his Laketown Dolomite (figure 3). The lower map unit (Dwl) is lighter in color and less resistant than the underlying Laketown Dolomite, and contains detrital material. A change to

thinner beds in the lower map unit has been widely reported but is not always present. Oviatt (1986a) reported the lower map unit was 428 feet (130.5 m) thick, while Beus (1958) and Gelnett (1958) measured about 370 to 410 feet (113 to 125 m) of comparable rocks in the Laketown Dolomite (figure 3).

The middle map unit (Dwm) is a grayish-yellow-orange-weathering, slope-forming, fine-grained sandstone, and interbedded sandy dolomite and limestone. The middle map unit is closest lithologically to rocks in the type Grassy Flat Member of Williams and Taylor (1964), though near Honeyville they divided our middle map unit between their two members (figure 3). Williams and Taylor (1964) apparently based their correlation on the Water Canyon--Laketown contact chosen by Beus (1958) and Gelnett (1958), which is stratigraphically higher than the contact used by Oviatt (1986a) and in our study (figure 3). Oviatt (1986a) placed the middle and upper map units in the Grassy Flat Member of Williams and Taylor (1964). The upper map unit (Dwu) is a light-gray- to white-weathering, slope-forming, fine-grained dolomite that is traceable along the mountain much like the lower unit. The middle and upper Water Canyon are 400 and 450 feet (122 and 137 m) thick, respectively, as calculated from topography, dip, and outcrop width on plate 1. These are about the same as the thicknesses reported by Oviatt (1986a). Thicknesses reported by Williams and Taylor (1964) and Gelnett (1958) were apparently based on different Water Canyon contacts (figure 3).

The Water Canyon--Hyrum Dolomite contact is not precisely defined (figure 3). Like Oviatt (1986a), we have used the darker color and greater resistance of the overlying Hyrum Dolomite to delineate this contact. This mapped contact might not be the same as the contact chosen by Williams and Taylor (1964) in their type section near Logan, Utah. Eliason (1969) reported that this contact was obscure, while Taylor (1963) noted that the Hyrum was darker in color and fossiliferous. Oviatt (1986a; written communications, 1983, 1984, 1985) and Gelnett (1958) did not see the intraformational breccias at the top of the Water Canyon that Williams

and Taylor (1964) reported. However, the uppermost 175 feet (53.3 m) of Water Canyon rocks were covered in the section measured by Oviatt (written communication, 1983, 1984, 1985). Without this interval, Oviatt's (1986a) reported Water Canyon thickness (1285-175=1110 feet [338 m]) would be about the thickness measured by Williams and Taylor (1964) near Honeyville (683 feet [208 m]), plus the 370 to 410 feet (113 to 125 m) of probable lower Water Canyon rocks (1053 to 1093 feet [321 to 333 m]) that were previously placed in the Laketown Dolomite (figure 3).

Hyrum Dolomite (Dh)

The Hyrum Dolomite is a dark-gray, medium-crystalline dolomite that contains calcite-filled vugs. Quartzite strata are at two horizons in the formation, one near the base and another in the upper part. In the Brigham City quadrangle, the Hyrum Dolomite is unconformably overlain by the Lodgepole Limestone (figure 3), because the Beirdneau and Leatham Formations, which separate the Lodgepole and Hyrum in the Bear River Range (Williams, 1971; Sandberg and Gutschick, 1979), are absent. The Beirdneau is present to the west on Little Mountain (Jensen, 1994) and in the Honeyville quadrangle, and thickens to the north (Oviatt, 1986a)(figure 3). The Hyrum thins rapidly southward below the unconformity, from about 450 feet (138 m) thick northeast of Honeyville (Oviatt, 1986a) to about 50 feet (15 m) thick at the head of Moss Rock Canyon in the Brigham City quadrangle. The Hyrum Dolomite is absent on the eastern side of the Wellsville Mountains. For more information on the Hyrum, see Oviatt (1986a), Beus (1958) and Gelnett (1958). Beus (1958) and Gelnett (1958) included the Hyrum strata in their Jefferson Formation (figure 3). However, their Jefferson-capping, cherty limestone probably belongs in the Lodgepole Limestone, and the underlying roughly 250 feet (76 m) of locally cherty dolomite is probably the Beirdneau Formation (figure 3). A Middle Devonian age was assigned to the Hyrum based on fossils from the base (and possibly middle

portion) of the formation in the Wellsville Mountains, Bear River Range and West Hills, and the presence of Late Devonian (early Famennian) fossils in the upper portion of the overlying Beirdneau Formation in northern Utah (Oviatt, 1986a; Williams, 1971).

Mississippian

Lodgepole Limestone (MI)

The Lodgepole is a medium- to dark-gray limestone and cherty limestone, that commonly contains black chert nodules. The Lodgepole generally forms cliffs, but the lower portion is a slope former at the northern margin of the quadrangle. The Lodgepole is about 1,000 feet (305 m) thick in the Wellsville Mountains; it contains crinoid, coral, brachiopod, bryozoan, and some branch-like fossils. Based on conodonts, crinoids and corals, the Lodgepole is Kinderhookian and early Osagean (Early Mississippian) in age (Sandberg and Gutschick, 1979; Oviatt, 1986a).

Little Flat Formation (Mlfd, Mlf)

The Little Flat Formation is equivalent to rocks in the adjacent Honeyville quadrangle that Oviatt (1986a) mapped and labeled Deseret Limestone and Humbug Formation (figure 3). We called these rocks Little Flat because they are more like the type Little Flat Formation in the Chesterfield Range in southeastern Idaho (W.J. Sando, written communication, 1988; see Dutro and Sando, 1963 for type descriptions).

Phosphatic rocks at the base of this stratigraphic interval are widespread in northern Utah and are the basal Delle Phosphatic Member of the Woodman Formation, Deseret Limestone and Little Flat Formation (Sandberg and Gutschick, 1984). Oviatt (1986a) reported phosphatic limestone at the base of this interval (his Deseret), but other geologists haven't

reported phosphatic rocks in the Wellsville Mountains. We didn't identify phosphatic rocks in the basal Little Flat sandstone or cherty limestone during our field work. Near Dry Lake in the Mount Pisgah quadrangle, Williams (1943, 1948; Williams and Yolton, 1945) probably looked for phosphatic rocks in shales and may have missed a phosphatic limestone. Similarly, Gelnett (1958) and Beus (1958) didn't recognize phosphatic rocks and placed about 90 feet (27 m) of thin-bedded, black, chert-bearing limestone (Oviatt's [1986a] Deseret) in their uppermost Lodgepole Limestone (figure 3).

In the Brigham City quadrangle the Little Flat Formation is divisible into what is probably the basal Delle Phosphatic Member (Mlfd) and overlying strata (Mlf). Our Delle contains a basal fine-grained sandstone and an overlying cherty limestone. Though Oviatt (1986a) mapped this sandstone and limestone as Deseret Limestone on his aerial photographs and plate 1, he depicted (his plate 2) and described the unit as only about 90 feet (27 m) of phosphatic, cherty limestone. The overlying Little Flat Formation strata (Mlf) are light-gray, medium- to coarse-grained sandstone, dolomitic and calcareous sandstone, and darker gray, sandy carbonate and limestone. These thin- to medium-bedded rocks weather to light-brown slopes and ledges. The entire Little Flat is probably 900 feet (275 m) thick in the quadrangle, but it is incompletely and poorly exposed. In the Bear River Range, the Little Flat is early Osagean to middle Meramecian (Early and Late Mississippian) in age, based on conodonts, and is an approximate time-equivalent of the Deseret Limestone (Sandberg and Gutschick, 1979).

Great Blue Limestone (Mgl, Mgm, Mgu)

The Great Blue Limestone is only exposed in the northeastern part of the Brigham City quadrangle, and was divided into three map units. The basal unit (Mgl) is a medium- to dark-gray limestone that forms cliffs, ledges, and steep slopes, and is about 800 feet (245 m) thick. Our middle map unit (Mgm) is interbedded olive-gray mudstone and shale, and medium-gray,

thin- to medium-bedded limestone, with more limestone in the upper part. The unit forms pale-yellowish-brown slopes and light-gray ledges. The mudstones contain micrite nodules that are up to 5 inches (13 cm) in length. The limestones contain brachiopods, crinoid stems, horn coral, and dark chert. The upper map unit (Mgu) is dark-gray, fine- to medium-crystalline limestone that forms slopes and ledges, and commonly contains silicified brachiopods, crinoid stems, and horn and rugose corals. The unit contains chert as nodules and layers up to 1 foot (0.3 m) thick; chert is more abundant in the lower 200 feet (61 m). In upper Cataract Canyon, the middle and upper map units are 600 and 742 feet (182.9 and 226.2 m) thick, respectively (appendix). Their combined thickness (1,342 foot [409.0 m]) is roughly the thickness (1,420 feet [432.8 m]) reported for the same interval near Dry Lake (Williams and Yolton, 1945; Williams, 1943), about six miles (10 km) to the southeast in the Mount Pisgah quadrangle (figure 3). Regionally, the Great Blue Formation is Meramecian and Chesterian (middle to late Mississippian) in age from fossil data (Sando and Bamber, 1985; Oviatt, 1986a). Additional details on the Great Blue are provided in Lindsay (1977) and Sweide (1977). However, Lindsay's (1977) Great Blue includes parts of the Little Flat (Humbug) and Oquirrh formations of this or previous reports (Williams, 1948, 1958; Beus, 1958; Gelnett, 1958; Oviatt, 1986a) on the Wellsville Mountains. Sweide's (1977, figure 9) contacts remain unevaluated because he didn't examine the Dry Lake section of Williams and Yolton (1945), and Williams (1948, 1958) didn't map contacts of the Great Blue equivalent [Brazer] units shown in figure 3.

Our basal Great Blue unit appears to be equivalent to the lower Great Blue unit that Oviatt (1986a) mapped to the north in the Honeyville quadrangle (figure 3); but, his unit is only 550 feet (167.6 m) thick (Oviatt, 1986a) versus our 800 foot (245 m) thickness. The upper Great Blue unit of Oviatt (1986a) is not equivalent to either our middle or upper map unit, or to both units, despite similar lithologic characteristics. His upper unit is far thinner (475 versus 1,342 feet [145 vs. 409 m] thick) than our map units. The contacts on the two maps do not

match due to these disparate thicknesses.

From these data, the Great Blue Limestone is much thinner north of the WM transverse fault than south of it (about 1,025 feet [312 m], Oviatt [1986a] and Beus [1958], versus at least 2,100 feet [640 m], this report, Gelnett [1958], Williams and Yolton [1945]; figure 3). Because about 1,820 feet (555 m) of Great Blue equivalent rocks (Brazer units 2, 3 and 4) were measured in the Mount Pisgah quadrangle near Dry Lake by Williams (1943; Williams and Yolton, 1945), King attributes this thinning to faulting (see Manning Canyon section). Previously, Beus (1975 personal communication in Lindsay, 1977, p. 117; see also Beus, 1958, p. 37-38) ascribed the thinning from Dry Lake to Honeyville to Mississippian and Pennsylvanian erosion, which completely removed the overlying Manning Canyon Shale in the Honeyville area (see below).

Manning Canyon Shale (Mmc)

The Manning Canyon Shale is only present in the northeastern part of the Brigham City quadrangle, and consists of interbedded gray, silty, cherty, fossiliferous, thin-bedded, fine-crystalline limestone and light-olive-gray to black shale. The Manning Canyon is poorly exposed, and the shale weathers into depressions between limestone hills and ledges. Individual limestone and shale beds are 37 to 118 and 18 to 30 feet (11.3 to 36.0 and 5.5 to 9.1 m) thick, respectively (appendix). Jensen measured 600 feet (180 m) of Manning Canyon in the best exposures, located on the western flank of the range (appendix), but these exposures are incomplete and within fault blocks. Using topography, outcrop widths and dips (plate 1), the complete Manning Canyon is about 900 feet (275 m) thick in Rattlesnake Canyon. Using the same contacts, Williams and Yolton (1945) measured 950 feet (290 m) of Manning Canyon (their Brazer unit 5) near Dry Lake in the Mount Pisgah quadrangle (figure 3). Sadlick (1955) used different contacts near Dry Lake, so his 1,130-foot (344.4 m) Manning Canyon thickness

can not be used for comparison. Near Dry Lake, the Manning Canyon (Brazer unit 5) was assigned a Chesterian age based on fossils by Williams and Yolton (1945). Miller and others (1991) reported a Mississippian and Pennsylvanian age for the Manning Canyon to the west in the Blue Spring Hills (Lampo Junction quadrangle), but their upper Manning Canyon might be equivalent to our West Canyon Limestone.

The Manning Canyon Shale is present in the Wellsville Mountains south of the WM transverse fault (figure 2; plate 1), but is missing at Deweyville (Beus, 1958; Oviatt, 1986a), north of this fault (figure 3). This disappearance has been attributed to thinning between Dry Lake and Deweyville (Beus, 1958; Gelnett, 1958; Oviatt, 1986a; Jensen, 1988), due to a Mississippian-Pennsylvanian unconformity (see Great Blue Limestone text). However, from three lines of evidence, King proposes that the disappearance is due to thrust faulting. First, the Manning Canyon Shale and Great Blue Limestone do not thin appreciably south of the WM transverse fault. They are about as thick at Dry Lake as they are just south of this fault (preceding paragraphs; Gelnett, 1958, p. 47). Second, north of the WM transverse fault, Oviatt (1986a) did not map any Manning Canyon, and Beus (1958) did not depict thinning of his Brazer Formation (which includes the Manning Canyon). Finally, the Manning Canyon is commonly a glide plane for Mesozoic thrust faults in the area (Allmendinger and others, 1984). If a thrust fault is present, the Great Blue-West Canyon contact in the Honeyville quadrangle is a thrust fault and the WM transverse fault is a lateral-ramp on this thrust fault.

Pennsylvanian

West Canyon Limestone (IPwc)

Poorly exposed, interbedded, thin- to medium-bedded, light-gray, cherty limestone, calcareous sandstone, and sandy limestone, that weather light gray to pale grayish yellow to

yellowish brown, unconformably overlying the Manning Canyon Shale in the extreme northeastern corner of the quadrangle. The entire unit is not present in the Brigham City quadrangle, but Oviatt (1986a) tentatively equated these strata with the West Canyon Limestone. He based this correlation on lithology, stratigraphic position, and identification of middle Morrowan (late Early Pennsylvanian) conodonts from the uppermost beds in the Honeyville quadrangle. The West Canyon Limestone is the basal formation of the Oquirrh Group in the southern Oquirrh Mountains (Welsh, 1983). The West Canyon contact with overlying Oquirrh Group strata is nebulous in the Wellsville Mountains, so Oviatt (1986a) reported a West Canyon thickness of about 400 feet (122 m), while Jensen estimated a thickness of about 710 feet (215 m) where the four quadrangle corners meet.

Cenozoic

Tertiary

Tertiary Undivided (Tu, subsurface only)

Tertiary rocks are not exposed in the quadrangle, but at least 4,295 feet (1,309 m) of Tertiary and Quaternary basin fill are present in the Bear River Valley. This estimate is from cuttings and geophysical logs of the #1 Davis, Utah Joint Steam Venture geothermal well, and the regional gravity map by Peterson (1974). Campbell, in Doelling (1980, p. 211), reported that 3,800 feet (1,160 m) of Tertiary Salt Lake Group rocks and a total of 4,380 feet (1,335 m) of Cenozoic basin fill were penetrated in this well. The well is located about two miles (3 km) southeast of Bear River City near Interstate 15, about 1.5 miles (2.4 km) west of the Wasatch fault zone (plate 1; figure 2), and is shown on cross-section A-A' (plate 2). Before the well was drilled, Peterson (1974) prepared a 2-dimensional gravity profile and schematic cross-section between the West Hills and Brigham City. He showed the thickest Cenozoic valley-fill as about

7,000 feet (2,100 m) thick, northwest of Brigham City along Interstate 15 and 4.5 miles (7.2 km) west of the Wasatch fault zone. From the gravity map of Peterson (1974), about 5,000 feet (1525 m) rather than 4,300 feet (1,310) of Cenozoic valley fill should have been penetrated in the geothermal well. Therefore, the thickest valley fill in the quadrangle is probably less than 7,000 feet (2,100 m) thick.

Upper Tertiary rocks in northern Utah are commonly assigned to the Salt Lake Group or Formation (Hintze, 1988). The Salt Lake contains a "hodge-podge" of poorly consolidated strata in which individual rock types can not be traced laterally or vertically for any great distance. These rock types include: (1) bimodal volcanic rocks that vary from tuff to lava flows; (2) lacustrine deposits including limestone, marl, claystone, and volcanic ash; (3) conglomerates with pebble- to boulder-sized clasts; (4) carbonaceous shale and lignite; and (5) clastic rocks such as shale, mudstone, siltstone, and sandstone that contain varying amounts of reworked volcanic material. The Salt Lake Group is reportedly Miocene and Pliocene in age, but few accurate and well-documented isotopic dates are available (for example, Williams, 1962, 1964; Doelling, 1980; Oviatt, 1986b; Bryant and others, 1989; Miller and Schneyer, 1994). From cuttings in the #1 Davis geothermal well, Salt Lake strata in the quadrangle are mostly reworked and altered tuff, with minor poorly to well-sorted, lithic sandstone and conglomerate, and calcareous siltstone and claystone. Cuttings also contain traces of shell fragments, limestone, pyrite, and organic material.

Quaternary

Poorly consolidated to unconsolidated Quaternary (Pleistocene and Holocene) sediments cover most of the Brigham City quadrangle. These sediments include: (1) lacustrine and near-shore deposits of Lake Bonneville; (2) alluvial deposits of the Bear River and smaller streams; (3) deposits in marshes and deltaic plains; (4) alluvial-fan deposits; (5) eolian

deposits; and (6) mass-wasting deposits. In addition, Quaternary tufa deposits on bedrock and cementing other Quaternary deposits were noted near the mouths of Cataract, Yates and Baker Canyons, and at two sites on the mountain front between Moss Rock and Yates Canyons. These deposits are shown by a T on plate 1 since their exact extent could not be mapped. Human activities have filled and disturbed some areas so that natural deposits are obscured.

The thickness of Pleistocene and Holocene basin fill in the Bear River Valley in the quadrangle is uncertain. Campbell, in Doelling (1980, p. 211), reported 580 feet (177 m) of Quaternary deposits (his Lake Bonneville Group) in the #1 Davis geothermal well. From geophysical logs of this well, basin fill becomes more consolidated at a depth of about 680 feet (207 m). King believes this change defines the contact between less-consolidated Quaternary deposits and more-consolidated Tertiary basin fill. However, the well cuttings do not exhibit a distinct lithologic change until a depth of about 2,100 feet (640 m)(table 1). A log of a water well about 1 mile (1.6 km) west of the geothermal well (Bjorklund and McGreevy, 1973, p. 17) penetrated about 600 feet (180 m) of probable Quaternary deposits, interbedded sand and clay. Another water well on the southern edge of the quadrangle (section 22, T.9N., R.2W.)(Bjorklund and McGreevy, 1973, p. 16) penetrated about 700 feet (210 m) of probable Quaternary deposits, comprised by interbedded lacustrine silt and sand.

Our Quaternary units and contacts are mostly the same as those used by Personius (1990). Minor differences exist in contact and compositional details rather than in locations and kinds of deposits. The greatest differences are that Personius (1990) mapped some debris flows separately, and assigned different ages to some alluvial-fan deposits. We couldn't consistently see his distinctions.

The Quaternary deposits in the Brigham City quadrangle are largely the product of lake processes in the Bonneville basin, including the Great Salt Lake. At least two, Pleistocene, pre-

Bonneville, lake cycles occupied the Bear River Valley (Scott and others, 1983; Oviatt and others, 1987; Oviatt and Currey, 1987), but no evidence for these lake cycles is exposed in the quadrangle. Limestone, shell fragments, and well-sorted, coarse, sand-sized Paleozoic carbonate grains (beach? sands) are present in Quaternary cuttings from the #1 Davis geothermal well. The ages and interpretations of regional, pre-historic, Lake Bonneville-cycle events in the following paragraphs are from Currey and others (1984a, 1984b), Currey and Oviatt (1985), Murchison (1989), and Oviatt and others (1992). The Bonneville-, Provo-, and Gilbert-shoreline elevations are from this study and mapping in nearby quadrangles (Oviatt, 1986a, 1986b; Jensen, 1994).

Lake waters in the Bonneville basin began to rise about 30,000 years ago. Water levels stabilized or oscillated for about 2,000 years, beginning about 22,000 years ago. This stillstand formed the Stansbury shoreline at an elevation of about 4,500 feet (1,372 m). The Stansbury shoreline is not prominent or well preserved in the Brigham City quadrangle, but might be present in the SE1/4 SW1/4 section 36, T.10N., R.2W. at an elevation of about 4,480 feet (1,366 m). Oviatt and others (1990) reported fine-grained, Stansbury-level deposits in a cut-bank in the Bear River near Bear River City (base of unit 2 in measured section BC3, appendix; Oviatt, 1985, written communication). From about 20,000 to 15,300 years ago, Lake Bonneville rose to its highest level. For the next 1,000 years lake levels were largely controlled by the elevation of the outlet into the Snake River drainage near Preston, Idaho (Zenda threshold). The Bonneville shoreline formed at an elevation of about 5,165 feet (1,574 m) during the highest stand. Most of the Brigham City quadrangle was under water from 15,300 to about 14,300 years ago.

Prior to 14,300 years ago, the threshold at Zenda failed, resulting in a catastrophic flood in the Snake River drainage, and the water level in Lake Bonneville dropped about 360 feet (110 m). The Box Elder Canyon delta probably formed soon after this rapid drop in lake level

(after Personius, 1990). The lake remained at this level until about 13,900 years ago, forming the Provo shoreline at an elevation of about 4,780 to 4,790 feet (1,457 to 1,460 m). This shoreline is visible along the mountain front in the quadrangle, below the Bonneville shoreline.

Lake levels in the Bonneville basin have been much lower since the Provo stillstand. Between approximately 12,000 to 11,000 years ago lake levels were at least as low as historic lowstands in Great Salt Lake. A small, lake-level rise followed this decline; so that between roughly 10,900 and 10,300 years ago, the Gilbert shoreline formed at an elevation of about 4,250 feet (1,295 m). Gravel along a slight change in slope at this contour south of Bear River City is the manifestation of this shoreline in the Brigham City quadrangle. Lake Bonneville receded from the Gilbert shoreline about 10,000 years ago. In the last 9,500 years lake levels have fluctuated but have not reached the Gilbert shoreline. A level as high as about 4,220 feet (1,286 m) elevation was reached between 3,400 and 1,400 years ago. A prehistoric, Little Ice Age, late-Holocene shoreline (not documented in the quadrangle) formed at an elevation of approximately 4,217 feet (1,285 m) in the last several hundred years (estimated at 1600 to 1700 A.D.)(Murchison, 1989). The Great Salt Lake rose to historic high elevations of 4,211.5 feet (1,283.7 m) in 1873 (estimated by Arnou and Stephens, 1990) and 4,211.85 feet (1,283.8 m) in 1986 (Harty and Christensen, 1988), flooding the lower reaches of the Bear River Valley.

Lacustrine Silt Deposits (Qli)

Lacustrine silt deposits of Lake Bonneville cover most of the Bear River Valley, and therefore most of the western half of the Brigham City quadrangle. These sediments were deposited in deep or relatively quiet lake water, and consist of interbedded silt, clay and very fine- to fine-grained sand that are laminated to thin bedded. The deposits are medium dark to dark gray when fresh, and oxidize to light and dark yellowish brown, pale olive and light olive gray. This unit locally contains ostracods, and is cross bedded in some sand layers. The sand

is subrounded to rounded and moderately sorted. Remnants of this unit (Qli) are present in the Bear River deltaic plain (Qdp) and floodplain (Qal) as isolated topographic highs. The deposits are at least 24 feet (7.3 m) thick (appendix).

Lacustrine Sand Deposits (Qls)

Lacustrine sand deposits are present in the northwestern part of the quadrangle, and consist of very fine-grained, subrounded to rounded, moderately sorted sand, which overlies unit Qli (interbedded clay, silt and very fine sand). Both map units are exposed in the banks of the Bear River east of Bear River City (appendix). The lacustrine sand is up to 25 feet (7.6 m) thick, laminated to medium bedded and cross bedded. Locally, the sand is fine to medium grained. On the surface, the lacustrine sand unit grades into the lacustrine silt map unit (Qli) by becoming finer grained. The soils map of Chadwick and others (1975) aided in differentiating this sand unit from the lacustrine silt unit.

Lacustrine sand deposits are also exposed in the gravel pits northeast of Calls Fort, below about 2 to 10 feet (0.5 to 6 m) of lacustrine and alluvial gravel (Qlg, Qaf). The sand in the pits lacks organic material, is very light yellow to off-white in color, is better sorted and coarser grained than the other lacustrine sands, and therefore might be beach deposits. The pits have been recontoured and the walls have sloughed, so pit margins have been used as contacts where natural contacts are obscured. Though poorly exposed, the sand is apparently 20 or more feet (6+ m) thick.

Lacustrine Gravel and Sand Deposits (Qlg)

Lacustrine gravel and sand deposits are present along the mountain front in the eastern part of the quadrangle, and were deposited in the beach and nearshore environments of Lake Bonneville. The unit is comprised by subrounded to well-rounded pebbles, cobbles, and rare

boulders that are mixed with sand. The gravel is locally cemented by calcareous tufa (T on plate 1); tufa deposits are also present on bedrock. The lacustrine gravel and sand deposits are commonly slightly modified by mass movement on steeper slopes, having undergone later mass-movement or being covered by mass-movement deposits that can not be delimited at map scale. From exposures and drilling records in other parts of northern Utah, lacustrine gravels overlie pre-Lake Bonneville alluvial fans and some of these lake gravels are probably reworked older alluvial fans. Alluvial fan gravels are far more angular but show rounding where they grade into the lacustrine gravels.

Mixed Lacustrine and Alluvial Deposits (Qla)

Mixed lacustrine and alluvial deposits consist of sand, silt, clay, and some gravel. These sediments are in: (1) alluvial fan deposits that are slightly reworked by lacustrine processes; (2) the distal portion of the Box Elder Canyon alluvial fan and lacustrine delta, probably including pro-delta deposits; and (3) lacustrine deposits with a thin cover of alluvium. This mixed unit is characteristically gravel-bearing and generally becomes coarser upslope (finer downslope). The contact with finer grained lacustrine deposits (Qli), located downslope, is approximate and is based on the soil survey of Chadwick and others (1975). From a water well log (section 11, T.9N., R.2W.)(Bjorklund and McGreevy, 1973, p. 16), the gravelly distal portion of the Box Elder fan-delta (Qla) is about 55 to 70 feet (16 to 21 m) thick and rests on fine-grained lacustrine deposits (Qli), possibly including some pro-delta deposits. In the Honeyville quadrangle, Oviatt (1986a) mapped most low-angle slopes below alluvial fans as sandy, lacustrine deposits (Qls), rather than gravel-bearing mixed deposits (Qla) as we have done. His unit labeled Qla is similar to our unit Qla.

Fan Delta Deposits (Qad)

This unit of gravel, sand, silt, and clay was deposited at the mouth of Box Elder Canyon. Personius (1990) wrote that deposition was in an alluvial fan after the recession of Lake Bonneville from the Provo shoreline. However, the sediments appear to be Provo-level lacustrine deltaic deposits (possibly pro-delta), reworked materials from the delta, and overlying alluvial-fan deposits. Deposits are coarser grained upslope toward deltaic gravels (Qdg). A log of a Brigham City water well on the fan-delta (section 19, T.9N., R.1W.)(Bjorklund and McGreevy, 1973, p. 16) is interpreted as showing the fan-delta is 125 feet (38 m) thick, with 45 feet (14 m) of underlying fine-grained Lake Bonneville deposits, and 240+ feet (73+ m) of pre-Lake Bonneville alluvial-fan gravel below the lacustrine deposits.

The fan-delta deposits are grayish orange to pale yellowish orange, clast supported, poorly bedded and contain no calcareous cement, are locally cross bedded, and locally contain equal proportions of gravel and sand. The clasts are subangular to well rounded, poorly to moderately sorted, and up to 8 inches (20 cm) in length.

Deltaic Gravel (Qdg)

This gravel and sand unit was deposited in a delta at the mouth of Box Elder Canyon during the Provo stand of Lake Bonneville. These deposits slope downward from the Provo shoreline and contain more gravel than sand. These pebble and cobble gravels are subrounded to rounded, moderately to poorly sorted and clast-supported in a matrix of sand and silt. The unit contains foreset beds, and capping topset beds that are less well sorted. Personius (1990) mapped the foreset and topset beds separately (his units lpd and alp, respectively), and reported a combined thickness of about 80 feet (24 m) in exposures east of the quadrangle. Data in Smith and Jol (1992) suggest the deltaic deposits are 400 feet (120 m) thick in the Mount Pisgah quadrangle. However, from examination of the same gravel pit, King

estimates that the deltaic deposits are about 250 feet (75 m) thick. In the Brigham City quadrangle, almost all exposures of deltaic gravel have been extensively excavated for production of sand and gravel.

Alluvium (Qal)

Alluvial deposits of sand, silt, clay, and gravel are located along the Bear River, and other active and abandoned stream channels. The map unit includes terraces less than 20 feet (6 m) above the present flood plain, and locally includes sediments deposited in marshes. Meandering stream channels that post-date the Gilbert shoreline have cut into lacustrine sediments along the Bear River. One alluvial channel cuts and reworks the Box Elder Canyon delta and fan-delta; these alluvial deposits are clast-supported, pebble and cobble gravels in a sand and silt matrix, and sand lenses. Alluvial-terrace-deposit contacts mapped by Personius (1990; his unit al2) above this channel are indistinct except in their upper reaches, and these upper reaches are apparently parts of a distributary system. So we mapped his terraces in our fan-delta deposits (Qad).

Lacustrine and Alluvial Mud Flat and Marsh Deposits (Qlam)

These deposits are near the center of and next to deltaic-plain deposits on the southern margin of the quadrangle. This map unit is characterized by a high water-table, marshes, slow-moving, low-gradient streams, and waters with high salt content. The deposits in the center of the quadrangle, around North Lake and the Cement Ponds, are yellowish gray to light olive gray to very dark gray (organic) in color. They include both thin Holocene lacustrine, marsh and minor alluvial silt, clay and sand, and underlying Lake Bonneville lacustrine clay, silt and some sand. The marsh deposits on the southern margin of the quadrangle are the product of high water levels of the Great Salt Lake during the 1980s and previous Holocene flooding. These

sediments are very dark gray (organic) and muddy. The contacts with fine-grained lacustrine deposits (Qli) are approximate because the deposits are similar.

Deltaic Plain Deposits (Qdp)

This unit includes sand, silt, and clay deposited in the deltaic plain of Great Salt Lake by the Bear River south of Corinne. The deposits are in marshes, oxbow lakes, channels, point bars, and natural levees. The deltaic plain is subject to flooding from the Bear River and high-water levels in the Great Salt Lake.

Alluvial Terrace Deposits (Qat)

Terrace deposits appear to rest on remnants of lacustrine sand and silt (Qls, Qli), on which the Bear River flowed after Lake Bonneville receded and before later incision. The terrace deposits consist of alluvial silt, very fine- to coarse-grained, sub-rounded to rounded sand, and gravel that are above the present flood plain of the river. The terrace surfaces are lower than nearby lacustrine deposits. Terrace-surface elevations are at least 20 feet above river level and increase upstream from about 4,225 to 4,235 feet (1,288 to 1,291 m). This increase led us to conclude that these deposits are terraces rather than lacustrine deposits tied to a lake level (see following paragraph). The terrace deposits are at least 15 feet (4.5 m) thick.

Similar terrace-like features, caps of sand and silt deposits with flat-topped surfaces, have been reported upstream along the Malad and Bear Rivers. However, their age is uncertain along the Malad River, and their age and origin is in question along the Bear River. Along the Malad River, Elder (1992) reported that cut-bank samples in terraces, taken at elevations of about 4,232 and 4,230 feet (1,290 and 1,289 m), were dated at about 2,400 and 7,700 years ago, respectively. Miller (1980) showed a date on terraces in the same area of about 4,000 years ago. On the northern edge of the Bear River City quadrangle, the uppermost

terrace surfaces of the Malad River (tentatively correlated by Jensen with our Qat) are at an elevation of about 4,240 feet (1,292 m). Along the Bear River, Oviatt (1986a, 1986b) mapped flat-topped features (his Qls1) and reported that their upper surfaces were at a nearly constant elevation of 4,245 to 4,250 feet (1,294 to 1,295 m). He therefore interpreted these capping sediments as deposits in a narrow estuary during the Gilbert level (4,250 feet [1,295 m] elevation) of Lake Bonneville. However the age and origin are uncertain because he reported a date of about 7,500 years ago on interfingering deposits, and the upper surfaces appear to be at an elevation of 4,240 feet (1,292 m) on the Honeyville 7.5' quadrangle topographic map.

Oxbow Lake Deposits (Qab)

This unit consists of fine-grained, organic-rich sediments that are being and were deposited in oxbow lakes in the cut-off meanders of the Bear River. The thickness of these deposits is not known because they are in uneroded depressions.

Alluvial Gravel (Qag)

A single exposure is located in the south bank of the Bear River southeast of Bear River City. From the geomorphic expression, the sediments are apparently confined to a paleo-channel that formed after Lake Bonneville receded. The unit contains gravel, up to pebble size, and sand that, except for the upper 3 to 4 feet (0.9 to 1.2 m), are cemented with calcite or tufa. Where exposed, this unit is less than 10 feet (3 m) thick.

Alluvial Fan Deposits (Qaf)

This unit contains poorly sorted, angular boulders, cobbles, pebbles, sand, silt, and clay that were deposited in alluvial fans at the base of the mountain front in the eastern part of the quadrangle. On the fan-delta at Brigham City these deposits contain reworked, rounded

material from the Provo level delta (Qdg, Qad). The fans are graded approximately to modern stream levels and have distinct distributary channels and interchannel bars. This unit is mostly active alluvial fans, but probably includes some deposits in inactive older Holocene alluvial fans. We were unable to consistently separate and map two ages of Holocene alluvial fans, as done by Personius (1990; his units af1 and af2). Personius (1990) apparently separated his two Holocene fan units on the basis of the fresher appearance of channels in his unit af1.

The maximum thickness of Holocene alluvial fan deposits probably exceeds 35 feet (18 m). The new Corinne water well near the middle of the alluvial fan at the mouth of Yates Canyon probably penetrated about 35 feet (18 m) of alluvial fan gravel. Unfortunately the remainder of the lithologic log for the 442-foot (135 m)-deep hole defies simple interpretations. A log of the old Corinne water well (Case, 1985, well no. 141) shows about 27 feet (8.2 m) of probable alluvial fan gravel overlying 30 feet (9 m) of Pleistocene lacustrine gravel, in turn overlying about 80 feet (24 m) of Pleistocene alluvial and/or lacustrine gravel. From a log of a water well drilled in the distal portion of the alluvial fan at the mouths of Cataract and Moss Rock Canyons (Bjorklund and McGreevy, 1973, p. 17), these distal fan deposits are 17 feet (5 m) thick, or more than 72 feet (5 or 22+ m) thick if the mixed clay and gravel interval between 17 and 38 feet (5 and 11.5 m) isn't lacustrine.

Our alluvial fan unit (Qaf) contains debris flow deposits because debris flow borders are indistinct. Debris flow deposits were observed on fans from Precipice, Calls Fort, Donation, Yates, Baker, Dry, Antimony, Hansen, "two" Hansen (unlabeled in NW1/2 section 6, T.9N., R.1W.), and Kotter Canyons. Miller (1980) and Personius (1990) mapped some debris flows separately, but their mapped debris flows appear to us to have the same characteristics as other features they mapped as alluvial fans.

Older Alluvial Fan Deposits (Qaf_o)

This unit contains deposits of poorly sorted, angular boulders, cobbles, pebbles, sand, silt, and clay that are remnants of older alluvial fans. These remnants are usually located near the heads of and are cut by the present generation of alluvial fans (Qaf). Older fans are present near the mouths of Donation, Cataract, Moss Rock, Baker and Dry Canyons, and Miners Hollow, and downslope west of Hansen Canyon. Upper surfaces on the older fans are higher in elevation than those of the adjacent fans (Qaf). These surfaces lack distinct channels and interchannel bars. The older fans are post-Provo level in age, and might be graded to the Gilbert shoreline or to some Holocene lake level. This unit is not equivalent to the unit labeled Qaf₂ on the Honeyville quadrangle (Oviatt, 1986a; age--pre-Provo level), or to the post-Lake Bonneville older alluvial fans (af₂) of Personius (1990). Our older alluvial fans were mapped as unit afp by Personius (1990; Provo-level alluvial fans), even though they are below the Provo shoreline.

North of Baker Canyon, and more prominently near Donation Canyon and Miners Hollow, these older fan deposits appear to incompletely mantle lacustrine deposits. At these sites, fault(?) and Lake Bonneville shoreline scarps, that are visible in adjacent lacustrine gravel deposits (Qlg), show, though subdued, through the fan deposits.

Colluvium and Alluvium (Qac, Qacf)

This unit contains gravelly colluvium and alluvium, and locally some talus. The unit is present in wider canyons in the Wellsville Mountains (Qac), and on some mountain front slopes between Miners Hollow and Cataract Canyon, and south of Dry Canyon (Qacf). Because it is impossible to show a fault and concealing deposits in the same cleft in the mountains, unit Qac was not mapped in such clefts. In canyons with larger drainage basins, such as Moss Rock Canyon, present channels are 30 feet (9 m) below apparent terraces, so the colluvial and

alluvial deposits are at least 30 feet (9 m) thick. These terraces(?) might be graded to the Provo or a lower level of Lake Bonneville, or to a Holocene lake level (similar to or like unit Qafo).

The deposits on mountain front slopes (Qacf) are gravelly, have a fan shape, head in clefts, and appear to mantle lacustrine gravels. However, unlike alluvial fans, they are on steep slopes, lack a well-developed source drainage and head in undivided mass-movement deposits. They have been mapped as mixed alluvium and colluvium because they were probably deposited by both processes. Their (Qacf) setting and shape is distinct from the canyon deposits of alluvium and colluvium (Qac).

Mass-Movement Deposits, Undivided (Qm)

This unit encompasses various types of mass-movement deposits that can not be mapped separately at map scale, or that are so intimately intermixed that deposit type can't be differentiated. The unit is generally present on the south sides of canyons, and includes talus and colluvium, and possibly minor debris flows and landslides. The contact with lacustrine gravels (Qlg) is based on the presence of gravel stripes in the mass-movement deposits. Many small exposures of this mass-movement unit are not shown on plate 1, because mapping them would obscure the fault that is located in the same cleft in the mountains. Other unmappable slumps and slides are located along the Bear River north of Corinne; the scarps for these mass-movements are shown as hachured lines on plate 1.

Talus (Qmt)

Talus at the base of steep cliffs along the front of the Wellsville Mountains were mapped separately from other Quaternary deposits. Talus contacts with undivided mass-movement deposits (Qm) were occasionally difficult to delineate due to the small size of talus stripes and the gradational nature of the contact. Talus, as opposed to undivided mass-movement

deposits, was mapped where scree slopes are large enough to show at map scale, and are not stabilized by vegetation.

Landslide Deposits (Qms)

Landslide deposits and associated scarps are present on the Manning Canyon Shale in Rattlesnake Canyon in the northeastern corner of the quadrangle. King thinks a much larger landslide, comprising all of Stoddard Hill, extends from the Mount Pisgah quadrangle west just into the Brigham City quadrangle, north of Silver Mine Hollow (unlabeled in N1/2 section 19, T.10N., R.1W.). King bases this interpretation on: (1) the rotated, block-like shape of Stoddard Hill; (2) the discontinuous, visible bedding with highly variable orientations in the Hill; (3) a location on strata that are susceptible to mass movement (Little Flat Formation); and (4) Dover's (1985) previous mapping.

Eolian Sand (Qes)

This unit is comprised by a few small dunes (≤ 5 feet [1.6 m] high) of very fine- to fine-grained sand on the mud flats near the Cement Ponds.

Fill Material and Disturbed Areas (Qhl, Qhs, Qhf, Qhd)

These deposits include: (1) the Brigham City sanitary landfill, located east of I-15 and south of Forest Street (Qhl); (2) sewage treatment ponds, located south of Corinne and east of the rest area on I-15 (Qhs); (3) scattered areas of fill (Qhf); and (4) other sites where human activities have obscured natural surficial deposits (Qhd).

Extensive fill (Qhf) was used in the construction of Interstate Highway I-15, several state secondary roads, railroad right-of-ways, and the Brigham City airport. Fill was also emplaced southeast of the I-15--Utah Highway 13/83 interchange prior to construction of the Vulcan plant.

Levees and dikes have been constructed in the marshy area (Qlam) west of I-15 and along the Bear River. Fill has also been dumped into the oxbow lake east of Corinne.

From examinations of 1937 and 1966 aerial photographs, 1988 and 1993 field examinations, and the 1988 topographic map, it is evident that parts of the north-south elongate depression in Brigham City have been filled (Qhf), in some cases prior to 1937. North Pond is impounded by what looks like fairly recent fill (pimpled surface) on the 1937 photos. Some, small, arcuate parts of the upslope margin of the depression look like small alluvial fans on the aerial photographs, so some fill could be natural. Parts of the alluvial channel of Box Elder Creek have also been filled. Only the two largest areas of alluvial-channel fill are shown on plate 1 (Qhf). Other natural contours in Brigham City have probably been modified.

From the same examinations, the natural surficial deposits at five other sites in the quadrangle have been obscured by human activities. These disturbances (Qhd) include: (1) cut-and-fill prior to warehouse construction west of the railroad tracks in Brigham City; (2) a gravel pit west of the tracks that might be filled with off-site material; (3) sand and gravel operations in the floodplain of Box Elder Creek east of Brigham City; (4) a pile of off-site(?) material southeast of the Harper Ward cemetery, shown as a gravel pit on topographic maps; and (5) an abandoned gravel pit south of Bear River City that might be filled with off-site material.

STRUCTURAL GEOLOGY

The Brigham City quadrangle is located in northern Utah on the eastern margin of the Great Basin (figures 1 and 2). Upper Proterozoic and Paleozoic rocks exposed in the Wellsville Mountains have been subjected to Mesozoic and early Cenozoic folding and thrust faulting, and late Cenozoic normal faulting. Bedding in these rocks dips about 30° to 50° northeast within a

northeast-dipping homocline, in which lower Paleozoic strata are well-exposed. The Wellsville Mountains are bounded by large-displacement, late-Cenozoic, normal-fault zones, the Wasatch fault zone on the west and the West Cache fault zone of Evans (1991) on the east. Cenozoic basin-fill in the Bear River Valley is probably at most 7,000 feet (2,100 m) thick, and is late Cenozoic (Miocene and younger) in age (see Cenozoic section, this report). As shown by Peterson (1974) and Zoback (1983), this basin is asymmetric with the steeper margin on the eastern side next to the Wellsville Mountains. Holocene normal-fault offsets have been noted in Quaternary surficial deposits along the mountain front north and east of Brigham City, both in this quadrangle and in the adjoining Mount Pisgah quadrangle (Personius, 1988, 1990, 1991). These fault offsets demonstrate that the Wasatch fault zone has been active in these quadrangles during the last 10,000 years.

Various measured and calculated attitudes of faults and associated features are reported in the following descriptions because faults in the Wellsville Mountains are poorly exposed and measured attitudes of fault-related features at a given site seldom indicate the actual fault-plane attitude (W.A. Yonkee, verbal communication, 1994).

Mesozoic and Early Cenozoic Folding and Thrust Faulting

The Upper Proterozoic and Paleozoic rocks in the quadrangle were folded, thrust-faulted and transported eastward during the Cretaceous and Paleocene Sevier and Laramide orogenies (for example Allmendinger and others, 1984; Yonkee, 1992). Prior to this study, the only definitive evidence for these orogenies in the Wellsville Mountains were the Box Elder thrust fault and the northeast-dipping homocline. The homocline probably formed when post-Willard (Crawford and Absaroka) thrust faults ramped upward near the Wasatch Front and carried overlying rocks eastward (Yonkee, 1992). The Wellsville Mountains (WM) transverse fault that we mapped is also evidence for these orogenies. Strata exposed in the Wellsville

Mountains are interpreted as being in the upper plate of the Willard thrust fault. Jensen (1994; after Allmendinger and others, 1984) placed the Samaria Mountain thrust (Hansel plate) west of Little Mountain, while W.A. Yonkee (unpublished cross-section) placed it just east of Little Mountain, making Little Mountain part of the Hansel plate (see figure 1 for geographic locations). In the Wellsville Mountains, Sorensen and Crittenden (1976) mapped the low-angle Box Elder thrust fault in the Mount Pisgah quadrangle, north of Box Elder Canyon, and to the south in the Mantua quadrangle. Link and Smith (1992) implied that this low-angle fault is a late Cenozoic extensional feature, but it is offset by several northeast-trending faults.

No definitive evidence for a thrust fault was seen in the cuttings or geophysical logs from the deep (11,000 feet [3,353 m]) geothermal well in the Brigham City quadrangle, despite previous interpretations (table 1). A thrust might be present in the well if the West Canyon Limestone overlies the Great Blue Limestone without the intervening Manning Canyon Shale (table 1, text on WM transverse fault).

The Box Elder thrust fault of Sorensen and Crittenden (1976) appears to extend into the Brigham City quadrangle, but Cenozoic normal faulting along the mountain front complicates any interpretation. Projection of the thrust to northwest from the Mount Pisgah quadrangle places the fault trace near the base of the Wellsville Mountains, along the Wasatch fault zone and concealed by Quaternary deposits. The projected trace is east of the isolated outcrop near Kotter Canyon that we believe is Papoose Creek Formation and Caddy Canyon Quartzite. This interpretation requires a concealed low-angle normal or thrust fault between this isolated outcrop and exposures of Geertsen Canyon Quartzite farther up slope.

Wellsville Mountains (WM) Transverse Fault

In the Wellsville Mountains, a major transverse fault, the Wellsville Mountains (WM) transverse fault, cuts the homocline from near the mouth of Moss Rock Canyon to the

northeastern corner of the quadrangle (figure 2), and continues into the Honeyville quadrangle. Because it has several discontinuities in trend and style, the origin and age of this fault are uncertain. The structure is either one fault cut into three segments, our preferred interpretation, or three faults. Stratigraphic offset on the WM transverse fault(s) appears to decrease to the southwest and northeast along strike. As much as 5,800 feet (1,770 m) of apparent right-lateral strike-slip offset is present on the fault(s). Gelnett (1958) reported 3,700 and 4,500 feet (1,128 and 1,372 m; his plate 9 and text, respectively) of stratigraphic displacement on a single large WM transverse fault. From south to north, each segment or fault is described in separate paragraphs.

From near Moss Rock Canyon to the mouth of Cataract Canyon, the southern fault segment is inferred beneath surficial deposits between exposures of Geertsen Canyon Quartzite and Bloomington Formation, and trends roughly north-south (plate 1). This fault is inferred because inadequate space is present between the exposures to accommodate the normal stratal thicknesses between these formations. This concealed fault is offset or truncated by an east-west trending fault just south of and sub-parallel to Cataract Canyon.

Between Cataract and Donation Canyons, the middle fault segment trends roughly north-south, cuts almost straight across topography, and is apparently a high-angle fault. However, the attitude of the fault is uncertain. The best-fit on intersecting cross sections yielded a dip of about 65°E (plate 2). The best constrained three-point solution yielded a dip of about 50°ESE , and other three-point solutions yielded dips as low as about 35° , and to the southeast rather than east. Stratigraphic offset just north of Cataract Canyon is about 4,200 feet (1,280 m), while it is about 5,200 feet (1,580 m) near Donation Canyon.

North of Donation Canyon, the visible portion of the northern fault segment changes trend from north-south to northeast-southwest, and "snakes" around ridges and canyons indicating it has a low dip. Farther to the northeast, the WM transverse fault is apparently

concealed by low-angle normal-fault blocks, and then reappears in the Honeyville quadrangle (plate 1). About 7,000 feet (2,130 m) of the projected trace is concealed. The actual attitude on this fault segment is uncertain. Using three-point solutions and the extent of the low-angle fault block, the northeast-trending portion of this segment dips at an angle greater than 35°SE, if not offset by other concealed faulting. Intersecting cross sections show a dip of about 65°SE (plate 2). Stratigraphic offset along the northern fault segment of the WM transverse fault decreases from about 4,700 feet (1,430 m) north of Donation Canyon to less than 3,700 feet (1,130 m) in the Honeyville quadrangle.

The WM transverse fault(s) divides the Wellsville Mountains into two geologic domains, as first noted by Gelnett (1958). South of the WM transverse fault(s), the Manning Canyon Shale is present, the Great Blue Limestone is much thicker (see Mississippian and Pennsylvanian stratigraphy), and smaller displacement transverse faults are more numerous and longer. See Davis (1985) for a synoptic map presentation of the Wellsville Mountains, and note the abrupt thinning of upper Mississippian rocks and the termination of the WM transverse fault in the base of the Oquirrh Group.

The age and origin of the WM transverse fault(s) is uncertain due to cover, segmentation, and differing characteristics. Gelnett (1958) first interpreted the fault(s) as a single, unsegmented, southeast-dipping fault with normal, dip-slip, down-to-the-southeast movement. Oviatt (1986a) portrayed the northern fault segment as a tear fault (right-lateral strike-slip fault) related to thrusting. More recently, the middle segment was interpreted as an east-dipping fault with normal, dip-slip, down-to-the-east movement (Jensen, 1988). The roughly north-south trend (perpendicular to tear fault trends) and apparent high angle implies the WM transverse fault(s) is neither simply a tear nor a normal fault related to Mesozoic-early Tertiary thrust faulting. Further, parts of the WM transverse fault(s) are covered by low-angle normal-fault blocks, and cut by faults with apparent dip-slip, down-to-the-south movement.

Therefore, the WM transverse fault(s) is older than late Cenozoic extension, and might be older than some Mesozoic-early Cenozoic thrust faulting. This leaves a thrust ramp or some complex fault interaction as the possible origin for the WM transverse fault(s).

Using these and other lines of reasoning, King interprets the WM transverse fault as a lateral ramp down section that has been offset (segmented) during later faulting. Because the Manning Canyon Shale is commonly a glide plane for and entirely cut out by thrust faults in northwestern Utah (Allmendinger and others, 1984), the missing Manning Canyon Shale and thinner Great Blue Limestone north of the WM transverse fault (and in the geothermal bore hole) implies the presence of a previously unrecognized Mesozoic-early Cenozoic thrust fault. This thrust fault would separate the Great Blue Limestone and West Canyon Limestone on the northern Wellsville Mountains (Honeyville quadrangle), and ramp up or down along the WM transverse fault. We didn't find duplicated strata, and strata aren't duplicated at Dry Lake, five miles (8 km) to the south in the Mount Pisgah quadrangle (see Mississippian and Pennsylvanian stratigraphy), so thrust duplication south of the WM transverse fault was eliminated as a possible scenario. Because the WM transverse fault has apparent right-lateral strike-slip movement, it does not appear to be a lateral ramp up into the Great Blue-Manning Canyon interval. The fault appears to ramp down from the Manning Canyon-Great Blue interval to lower Cambrian or Proterozoic strata, and might be a continuation of the Box Elder thrust fault of Sorensen and Crittenden (1976).

Some evidence supports the interpretation that the missing section north of the WM transverse fault is due to an unconformity; this implies the WM transverse fault is not a thrust ramp. First, very few faults with lateral ramps down section have been documented in fold and thrust terrains (W.A. Yonkee and J.C. Coogan, verbal communications, 1994). Also, the middle and upper Cambrian strata (Ute Formation through St. Charles Formation) are at least 10 percent thinner south of the WM transverse fault. This is unlikely if the carbonate rocks south of

the fault were transported from depositional sites farther to the west than the carbonates north of the fault. Carbonates typically become thicker to the west on the Cambrian, Utah-Nevada, continental shelf (Hintze, 1988, figure 17). However, the evidence for an unconformity is also ambiguous (see Mississippian and Pennsylvanian stratigraphy).

Other Faults

The Wellsville Mountains homocline is cut by numerous faults that have much smaller displacements than the WM transverse fault (figure 2); these other faults have uncertain ages and senses of movement. The northeast- to east-southeast-trending faults, with mostly small apparent strike-slip offsets, can be simplistically interpreted as tear faults that formed during Mesozoic-early Cenozoic contraction. North- to east-trending faults, with mostly small normal offsets, may have formed during contraction, during late Cenozoic extension, or during both contraction and extension.

In the quadrangle, separating normal faults from strike-slip faults is not simple, because most slickensides demonstrate oblique slip. Also, few faults have orientations that conform with contraction or extension alone. In attempts to decipher any pattern and to facilitate fault descriptions, the faults were divided into five fault sets and some "unique" faults by King, based on trend and apparent dip (figure 2). Some faults did not fit into any category (dashed on figure 2). Four of the fault sets trend east of north, including: (1) roughly east to east-northeast; (2) roughly northeast, with apparent steep dips; (3) roughly northeast, with shallow to moderate dips; and (4) roughly north-northeast. The fifth set has various trends with shallow to moderate dips, appears to have formed during Cenozoic extension, and is discussed under the heading "Low-Angle Normal Faults".

Set-1 Faults

Set-1 faults (E to ENE trend) are the most numerous in the quadrangle, and observed attitudes and slickensides show oblique relative movement to the west on vertical to near vertical faults (Antimony Canyon, Dry Lake mine, upper Yates Canyon), and northwest reverse movement on the south-dipping Dry Lake mine fault. Reverse movement may have occurred on the Baker Canyon fault (south dipping) and the fault north of Cataract Canyon (north dipping?), but attitudes were measured on nearby fractures rather than on the fault planes. Dips along other faults could not be observed. Relative movement is assumed to be oblique to the northwest and southwest on these faults, except for a possible reverse fault north of Moss Rock Canyon. Apparent strike-slip offset on set-1 faults is typically less than 100 feet (30 m), but is about 1,000 feet (300 m) on the fault in Antimony Canyon, and the two faults near "two" Hansen Canyon (unlabeled in NW1/2 section 6, T.9N., R.1W.) that bound a graben in the Mount Pisgah quadrangle.

The fault north of the ridge between Yates and Moss Rock Canyons has the trend of set-1 faults, but the relative movement is problematic. Different senses of movement on the fault (plate 1) suggest two episodes of faulting and reuse of only a part of the fault during the latter episode. The fault in lower Cataract Canyon might be a set-1 fault given the apparent 70°S to 70°N dip (three point solutions) and sinuous trace like the set-1 fault in Antimony Canyon.

Set-2 Faults

Set-2 faults trend northeast, have steep dips, and are both short (<1,200 feet [365 m]) and long (up to about 5,000 feet [1,600 m]). Long set-2 faults include: (1) the pair between Cataract and Donation Canyons; (2) a pair of faults that might cross Moss Rock Canyon (concealed); and (3) possibly a fault between Cataract and Moss Rock Canyons. The northern fault of the Cataract-Donation pair has apparent normal and right-lateral relative movement, with

apparent strike-slip offset up to 750 feet (230 m). The exact fault dip is uncertain. The measured dip was 65°SE, while three-point solutions yield dips of about 60°SE, and the best fit on the cross sections is about 55°SE (plate 2). Other faults in set-2 have apparent right- and left-lateral movement, with minimal to about 500 feet (150 m) of offset. Given trend and relative sense of movement, the fault in upper Donation Canyon in the low-angle fault block might be a set-2 fault or a tear that developed during low-angle normal faulting.

Two faults have characteristics of both set-2 and set-3 faults. A fault south of Calls Fort Canyon has a northeast trend, fractures that dip 90° to 75°N, and about 600 feet (180 m) of relative right-lateral, reverse movement. But three-point solutions indicate southeast dips of 35° to 40°, with down to the south, normal movement, like set-3 faults. Because the fault between Cataract and Moss Rock Canyons is concealed at the mountain front and has an apparent dip of 32°SE (three point solution), it might also be a set-3 fault. That is, if the 70°SE dip wasn't really measured on the fault plane.

Set-3 Faults

Set-3 faults are mostly over 3,000 feet (900 m) long, trend roughly northeast, dip moderately to the southeast, and have right-lateral, down-to-the-south relative movement. Measured dips were 30° to 57°SE, a 65°SE dip was reported, and three-point solutions yielded roughly 30° to 45°SE dips (plate 1; see also Gelnett, 1958; Perry in Doelling, 1980). Despite these low fault-plane dips, fractures dip as much as 75° and even 90° where fault planes are not visible. Set-3 faults are sub-parallel to ridges, and those that reach the mountain front then change trend to the southwest. Set-3 faults are located: (1) between Yates and Baker Canyons; (2) between Baker and Dry Canyons, including the Baker mine area; and (3) between Dry and Antimony Canyons; and are possibly located: (1) northeast of the Baker mine; (2) between Cataract and Moss Rock Canyons (as noted in set-2 description); (3) south of Calls Fort Canyon

(as noted in set-2 description); (4) between Precipice and Calls Fort Canyons (this fault might be a set-2 fault that meets a set-1 fault); and (5) just south of Precipice Canyon (these faults might be set-1 faults). Slickensides exposed in workings on the ridge between Baker and Dry Canyons indicate mostly dip-slip movement on faults that are placed in set 3 with certainty, though Gelnett (1958) reported horizontal movement. South of Precipice Canyon, bedding attitudes above and below the fault(s) are different. Relative strike-slip offset on faults that are clearly set-3 faults is up to 500 feet (150 m) and is typically more than the offset on set-1 faults. Most long set-3 faults "die out" into the mountains and are apparently scissor faults. It has been suggested that these longer faults are related to the development of the Wasatch fault zone, and hence are late Cenozoic in age (W.A. Yonkee and J.P. Evans, verbal communications, 1994).

Set-4 Faults

Set-4 faults trend north-northeast, and are significant though limited in number. The fault on the mountain front between Moss Rock and Yates Canyons has about 1,500 feet (450 m) of apparent right-lateral offset, down-to-the-east movement, and appears to dip west (fractures 75°W ; three-point solution 78°W). This indicates possible reverse movement. The other faults in this set have less offset, and in contrast to the general pattern are more abundant north of the WM transverse fault. Though it has the same trend, the north-northeast-trending fault between Cataract and Donations Canyons is the middle segment of the WM transverse fault.

Unique Faults

Unique faults are discussed due to their length and uncommon characteristics. They trend both west and east of north. One north-northwest-trending fault (north of "two" Hansen

Canyon, unlabeled in NW1/2 section 6, T.9N., R.1W.) is apparently a Cenozoic moderate-angle normal fault (69°W dip). Another fault trends west-northwest, dips about 85° (fractures indicate NNE and three-point solution indicates SSW) between Dry and Antimony Canyons, and has about 1,000 feet (300 m) of apparent left-lateral offset (tear fault?). Two(?) other unique faults "snake" around ridges and canyons. In upper Cataract Canyon and across the Wellsville Mountains divide, one such fault changes trend from east-northeast to northeast; yet from a three-point solution at the divide, the fault dips about 75°SE. A fault or several faults are present in the bottom of Moss Rock Canyon. Apparent changes in trend might be due to interactions between several faults rather than a change in trend of a single fault. Cover precluded a more accurate assessment.

Late Cenozoic Normal Faulting

Several moderate-angle, late Cenozoic, normal faults are located in the area. Exposed faults along the base of the Wellsville Mountains are part of the Brigham City and Collinston segment of the Wasatch fault zone (Personius, 1988, 1990, 1991). The Wasatch fault zone is the east and steepest side of a late Cenozoic, asymmetric graben in the Bear River Valley. This fault-bounded basin becomes shallower to the north; it is about 7,000 feet (2,100 m) deep on the southern margin and about 5,000 to 6,000 feet (1,525 to m) deep on the northern margin of the quadrangle (after Peterson, 1974; Zoback, 1983). The western fault of the graben is concealed (Jensen, 1994) and is located west of Brigham City in the Bear River City quadrangle near Little Mountain (Zoback, 1983).

At least one large-displacement, moderate-angle, late Cenozoic, normal fault is present in the quadrangle. This fault is located along the mountain front in the Brigham City segment of the Wasatch fault zone and trends about N25°W; others, to the east and west, might be

concealed by surficial deposits in the Bear River Valley (plates 1 and 2).

In addition to these extensional features, late Cenozoic, low-angle normal faults are present in the Wellsville Mountains (Sprinkel, 1979; Oviatt, 1986a; this report) and the Mantua and Willard quadrangles (Crittenden and Sorensen, 1985), and might be concealed along the mountain front near Brigham City (see section on Mesozoic and early Cenozoic folding and thrust faulting; Link and Smith, 1992).

Low-Angle Normal Faults

Several low-angle normal faults are present in the northeastern corner of the Brigham City quadrangle (plate 1; figure 2). None have the geologic characteristics of the low-angle, normal faults mapped in the Willard and Mantua quadrangles by Crittenden and Sorensen (1985), or the low-angle normal faults along former thrust fault planes that Sprinkel (1979) proposed. One low-angle normal fault extends from the Honeyville quadrangle (Oviatt, 1986a) into the Brigham City quadrangle (plate 1). Two other blocks of displaced strata above low-angle normal faults are present in the Brigham City quadrangle; they have 8,474- and 8,657-foot summit elevations. The disparity of dips within the larger block and apparent counter-clockwise rotation support a low-angle origin. Faults within the larger block may have formed before the low-angle normal faults, in particular the northwest-trending fault that apparently dips 55°NE (three point solution) and the northeast-trending, near-vertical fault in upper Donation Canyon. The north- to north-northeast-trending faults in the larger block might be tear faults that formed during transport.

Moderate-Angle Normal Faults

Several moderate-angle, late Cenozoic, normal faults are visible or inferred (concealed) in the quadrangle (plates 1 and 2; figure 2). Some of these faults have Quaternary offset, and

all are probably part of the Brigham City segment of the Wasatch fault zone. These faults are termed moderate-angle, rather than high-angle, because late Cenozoic normal faults along the northern Wasatch and nearby East Cache fault zones dip about 20° to 60° (33° to 39° from best data) and 45° (Smith and Bruhn, 1984; Evans, 1991; respectively). Zoback (1983) reported dips of 40° to 80° on late Cenozoic normal faults in Utah, but these dips are not as well constrained.

The fault or faults with the greatest displacement are along the mountain front, and are concealed and very approximately located except in the vicinity of Rees Spring (plates 1 and 2). Offset along this fault zone has been variously estimated. Zoback (1983, figure 6) estimated the vertical offset on this fault zone is 11,155 feet (3.4 km). Sorensen and Crittenden (1976) used a different type of offset measure, and suggested that at least 15,000 feet (4.5 km) of stratigraphic offset is present along the fault zone. Using subsurface data from the #1 Davis geothermal well, King came up with a similar figure; about 15,500 feet (4,725 m) of strata (lowermost Caddy Canyon Quartzite to at least lower Lodgepole Limestone; table 1 and plate 2, lithologic column) are missing across a fault encountered at a depth of about 7,850 feet (2,390 m) in the well. Because the well is about 1.5 miles (2.4 km) west of the mountain front, a fault projected between the well and mountain front would dip 35° to 40° W. Because this dip is within the range of the best data for the northern Wasatch fault zone (33° to 39°), the fault in the well is interpreted as the down-dip extension of the concealed normal-fault zone along the mountain front (plates 1 and 2). Vertical offset on the mountain-front fault zone is probably more than 12,200 feet (3,720 m), based on subtracting the elevation of the Lodgepole Limestone in the bore hole from the elevation of the Lodgepole in the Wellsville Mountains in the Honeyville quadrangle (perpendicular to dip). Alternatively, the fault in the geothermal well might be part of a buried fault system west of the mountain front that dips about 60° W (not shown on plates 1 and 2), the dip of many normal faults in extensional terrains (Smith and Bruhn, 1984; Zoback, 1983).

Several other moderate-angle normal faults are present or suspected in the quadrangle (plates 1 and 2). Two possible faults appear to cut lacustrine gravels (Qlg) near the mouths of Miners Hollow and Donation Canyon (queried on plate 1), east of the mountain-front fault zone (dotted fault on plate 1). The queried faults are probably strands of the Wasatch fault zone. From construction of cross-section A-A' (plate 2), these faults would be penetrated by the #1 Davis geothermal well unless they dip less than 35°W (join the main fault west of the well) or dip greater than 45° (project below the bottom of the well). If these queried faults dip greater than 45°, about 5,000 feet (1,525 m) of vertical offset appears to have occurred on them. If the queried faults dip less than 35°, some fault or geologic structure must be present between the well and the homocline of the Wellsville Mountains, because strata are duplicated and the Caddy Canyon-Papoose Creek contact is offset vertically about 4,300 feet (1,300 m) between the well and the homocline. The shallow north-south elongate depression in the western part of Brigham City might be the surface expression of a late Cenozoic moderate-angle normal fault along a more westerly strand of the Wasatch fault zone (after Personius, 1990). The Cement Poncs flat and marsh (Qlam) might be evidence of an antithetic fault or drag along the Wasatch fault zone, given the depression and tilted surface shown by Personius (1990). The 1/2-mile (0.8 km)-long normal fault with north-northwest trend and 69°W dip in bedrock (unit Cgl) north of "two" Hansen Canyon (unlabeled in NW1/2 section 6, T.9N., R.1W.) might be part of the Wasatch fault zone.

Personius (1990) shows numerous faults with Quaternary offset where changes in slope (scarps) occur along the mountain front in the Brigham City quadrangle. Most of Personius' (1990) faults parallel topographic contours. Through trenching and trench stratigraphy determined in the Box Elder Canyon delta just east of the Brigham City quadrangle, McCalpin and Forman (1994) demonstrated that some faults mapped by Personius (1990) are not faults. Therefore, we were conservative in mapping faults with Quaternary offset, and did not map

slope changes as faults where they might be Lake Bonneville shorelines, margins of alluvial fans, mass movement lobes, or manifestations of buried, differentially eroded bedrock.

Eliminating ambiguous scarps, we mapped one fault that cuts Holocene alluvial-fan deposits (Qaf), along the mountain front on the southeastern margin of the quadrangle near Rees Spring. Personius (1990) showed scarp heights of 13.1 and 26.2 feet (4 and 8 m) on different parts of the fault. To the northwest and southeast this normal fault is concealed (dotted on plate 1) and the fault location is very approximate. Trenching to the south-southeast in the Box Elder Canyon delta indicates that five Holocene faulting events have occurred along the delta portion of the Brigham City segment of the Wasatch fault zone. Details on offsets, dates and recurrence intervals are presented in McCalpin and Forman (1994), and Personius (1988, 1990, 1991).

In the vicinity of Miners Hollow and Donation Canyon, several breaks in slope occur in lacustrine gravel (Qlg) below the Provo shoreline. These short breaks in slope cross topographic contours and might be faults (hence the query on plate 1). Older alluvial fans (Qafo) appear to mantle rather than completely conceal the scarps, and the scarps do not cut these fans. Therefore the scarps are latest Pleistocene to Holocene in age. Personius (1990) showed scarp heights of 19.7 and 26.2 feet (6 and 8 m) on these queried faults south of Miners Hollow.

The two other features in the Brigham City quadrangle that Personius (1990) interpreted as fault scarps, and showed scarp heights, are in Provo shoreline deposits between Baker and Dry Canyons, and southeast of Rees Spring (heights of 62.3 and 78.7 feet [19 and 24 m] respectively). Because both features parallel topographic contours, and are far larger than features interpreted in this report as fault scarps and fault scarps in the Mount Pisgah quadrangle (Personius, 1988, 1990, 1991), we have not mapped them as faults.

Personius (1990) noted remnants of a fault zone (two wedges of fault scarp colluvium) in

the gravel pit about 2,700 feet (825 m) northeast of Calls Fort. He interpreted three earth-rupturing fault events of post-Provo shoreline (latest Pleistocene to Holocene) age from his observations. In the pit area, he mapped two faults parallel to topographic contours in lacustrine gravel below the Provo shoreline. We think the mapped scarps are shorelines or bedrock manifestations, and didn't see faults in either Calls Fort gravel pit, so we do not show exposed faults on plate 1. However, because recontouring and sloughing have degraded pit exposures, the fault scarp colluvium Personius saw could now be destroyed or concealed.

The north-south elongate, shallow depression in Brigham City is similar to others located just to the south (after Personius, 1990), and is roughly colinear with a fault mapped by Personius (1990) in the Wasatch fault zone south of the quadrangle. This depression could have formed due to lateral spread failure (see seismic hazards) or might be a small graben above a normal fault (plate 1). The relief and roughly colinear trend are consistent with the graben interpretation (after Personius, 1990). From comparisons of 1937 and 1966 aerial photographs, 1969 and 1988 topographic maps, and field observations, this depression is now mostly obscured by fill and recontouring. Where not disturbed, the depression has surface relief of about 3.3 to 9.8 feet (1 to 3 m). The estimated original scarp locations of the graben are shown on plate 1.

MINERAL RESOURCES

Gravel and Sand

Abundant gravel and sand were deposited near the mountains in the Brigham City quadrangle through wave action and deltaic processes in Lake Bonneville, and in alluvial fans. Sand and gravel pit outlines are shown as short, dashed, hachured lines on plate 1. The largest

deposits of extractable material are in remnants of the Provo-level delta at the mouth of Box Elder Canyon (Qdg; some Qad); most of this material is in the adjacent Mount Pisgah and Mantua quadrangles. These deltaic deposits contain more gravel than sand, and little finer grained material. This delta has been and, in 1994, was still being extensively excavated, reducing its size. The next largest pits are located northeast of Brigham City and Calls Fort in lacustrine gravels (Qlg) and in lacustrine sediments under alluvial fans (Qaf). These pits typically contain more angular and finer grained material than the deltaic deposits. The southern Calls Fort pit was being used in 1992, while the northern Calls Fort pit and the pit northeast of Brigham City had been recontoured. Well-sorted lacustrine beach(?) sand (Qls) is present below lacustrine and alluvial gravel in the Calls Fort pits. Beach sands might be concealed by gravel elsewhere along the mountain front. Other smaller sand and gravel deposits are present along the mountain front in lacustrine gravels and alluvial fans between the largest pits; these deposits contain more silt and clay than deposits in the larger pits. The sand and gravel deposits in the quadrangle have been used for base and surface gravel, and for borrow in highway construction. Additional data on some of these deposits is contained in a materials inventory by the Utah State Department of Highways (1965).

Cement Raw Materials

Marl and an underlying clay from the Cement Ponds at Baker Spur were excavated by the Ogden Portland Cement Company to produce portland cement at a plant about 5.5 miles (9 km) northwest of Brigham City (Burchard, 1911, p. 525-526; Eckel, 1913). The plant ruins are located between Interstate Highway 15 and the Cement Ponds in section 33, T.10N., R.2W., and were shown on the 1969 Brigham City 7.5-minute quadrangle topographic map. Figure 3 shows the excavation equipment, deposits, and ponds, probably during Burchard's field investigation (after McGregor and Abston, 1994). Salty water now fills these excavations in the

mud flats (Qlam). Eckel (1913) provided other details, though he didn't mention the source for gypsum, often used to slow hardening of cement.

Limestone, Dolomite, and Quartzite

Numerous limestone- and dolomite-bearing units that are exposed in the quadrangle have been used for lime production and aggregate elsewhere in northern Utah (Williams, 1958; Doelling, 1980; Tripp, 1991). Historically, the major consumer of lime in the area was the sugar-beet processing industry, but all Utah plants were closed by 1993 (Bryce Tripp, verbal communication, 1993). The end use of these rocks determines the required qualities and no data are available on the qualities of these rocks in the quadrangle. Similarly the utility of the Geertsen Canyon Quartzite for silica is unknown.

Limestone, dolomite, and quartzite from the quadrangle might be used for decorative stone because stone with a wide variety of colors and various hardnesses is available in outcrops and alluvial fans along the mountain front. As examples, stones from alluvial fans were used to construct the Calls Fort monument and a building just east of State Highway 69 about 1.5 miles (2.4 km) south of the Calls Fort monument (shown as a church in the SW1/4 NW1/4 section 23, T.10N., R.2W. on the 1988 topographic map).

Salt

In the past, water was diverted from Salt Creek into evaporation ponds in the center N1/2 of section 17, T.10N., R.2W. to recover sodium chloride (NaCl). The source of Salt Creek is Crystal Hot Spring in the Honeyville quadrangle. Bjorklund and McGreevy (1974, table 8) reported that water from the spring contained 39,700 milligrams per liter (mg/l) total dissolved solids, with 23,000 mg/l chloride, 14,000 mg/l sodium, 810 mg/l calcium and 670 mg/l potassium. Doelling (1980, table 10) reported a similar analysis. A rough idea of the salt

content is indicated by the fact that lower, cool reaches of Salt Creek do not freeze in the winter. Bjorklund and McGreevy (1974) reported additional information on the spring, and on the salt load the creek introduces into the Bear River.

Metallic Minerals

Several mines and numerous exploration workings for metallic minerals were excavated in the Box Elder mining district in the quadrangle. Major workings are in Cambrian limestones in close proximity to transverse faults in and near Baker and Antimony Canyons (map numbers 1, 2, and 3 on table 3 and plate 1). Minor production of copper, gold, silver and antimony was reported from the district, and most workings contained oxidized, highly limonitic (gossans?), lead-, zinc- and silver-bearing mineralization, with minor copper showings. Stibnite was mined from a quartz vein in Cambrian limestone (map number 3); the vein also contained calcite, limestone fragments, clay, and a small amount of malachite. Butler and others (1920), Perry (in Doelling, 1980, p. 184, 186-187, 203-206), Perry and McCarthy (1977), Utah Geological Survey Utah Mineral Occurrence System (UMOS) files, and table 3 contain more specific information on the district, production, workings, and mineralization.

Other small adits and prospect pits are in carbonate and quartzite strata in the Wellsville Mountains, where abundant limonite, hematite and calcite, and minor copper carbonates (malachite and azurite) are present. The largest of these workings in the quadrangle are listed in table 3. This type of mineralization, with trivial lead, zinc and silver, was usually located along and near major and minor faults. Mineralization along faults also included dolomitization of limestone and dolomite fracture fillings.

Oil and Gas

No productive oil or gas wells have been documented in the Brigham City quadrangle

(table 4), but natural gas was produced for local use from several wells in Box Elder County south of the quadrangle (Campbell in Doelling, 1980) and possibly in the quadrangle (Kaliser, 1976). Sources of the gas are probably bacterially attacked peat deposits in Quaternary sediments (Campbell in Doelling, 1980; Clem and Brown, 1985). Older bore holes were apparently designed to explore for the shallow biogenic (marsh) gas that had been reported in water wells, springs, and seeps along the eastern shore of Great Salt Lake. The wells drilled in 1981 may have been attempts to find hydrocarbons that were thermally generated from Tertiary lacustrine deposits, like the oil and gas reported in Great Salt Lake by Patton and Lent (1980), and Bortz (1984). For additional details see table 4, Kerns (1987), Clem and Brown (1985), Campbell in Doelling (1980), and Kaliser (1976).

WATER RESOURCES

In the quadrangle, surface water is mostly used for irrigation and stock watering, and minor amounts of ground water are used for municipal and domestic supplies, irrigation and stock watering. The Bear River supplies irrigation water for much of the valley and is supplemented by some shallow ground water. Most irrigated land is underlain by silty Lake Bonneville deposits that are poor sources of ground water. The major ground-water sources are the sand and gravel deposits in alluvial fans (Qaf), along shorelines of Lake Bonneville (Qlg, Qlg), and in the Box Elder Canyon fan-delta (Qad). The ground-water potential of these surficial deposits and bedrock aquifers is unknown for the quadrangle. For more details see Bjorklund and McGreevy (1973, 1974), and Price and Jensen (1982).

Data on municipal water supplies obtained in the Brigham City quadrangle is reported in table 5. Part of the Brigham City water supply comes from wells in the fan-delta (Qad) on the eastern side of town, but most of their water comes from Mantua Valley (Bjorklund and

McGreevy, 1974). Most of the Corinne municipal water supply comes from well(s) in the alluvial fan (Qaf) at the mouth of Yates Canyon. Some water for Corinne and all the water for West Corinne comes from springs in Yates and Baker Canyons, respectively. These springs are along faults in the bottoms of the canyons, so it is not known how much water is coming from bedrock or is near-surface flow down the fractured canyon bottoms.

GEOHERMAL RESOURCES

Several hot and warm springs and wells are present near Brigham City, and the potential exists for low-temperature hydrothermal energy in the area (Goode, 1978; Klauk and Budding, 1984; Oviatt, 1986a). Because the #1 Davis geothermal exploration well (11,005 feet [3,354.3 m] deep)(table 4) had a bottom-hole temperature of only 232°F (111°C) and thermal logging showed lower temperatures (<220°F [104°C])(UGS well-log files), a higher temperature geothermal resource is unlikely. The water in this well was a brine (85,000 mg/l total dissolved solids), and the well was reportedly plugged and abandoned (Goode, 1978, p. 104). However, an uncapped 12-inch (30 cm) casing, with a water level about 1 foot (30 cm) down, was observed at the site in 1994, and unconfirmed reports indicate that the #1 Davis well is a monitor well for Crystal Hot Spring, located in the Honeyville quadrangle.

GEOLOGIC HAZARDS

Seismic Hazards

Because the Wasatch fault zone passes through the Brigham City quadrangle, the area is in the highest seismic-risk zone (3) in the state of Utah (after International Conference of

Building Officials, 1991, p. 194). However, potential peak ground accelerations are reportedly lower than those in the Ogden and Salt Lake City areas (Youngs and others, 1987). Scarps and trenching along the Brigham City segment of the Wasatch fault zone indicate that six surface-rupturing earthquakes have occurred on this segment during the last 13,000 years. Surface displacements of about 3.3 to at least 8.2 feet (1.0 to >2.5 m) have occurred about every 1,150 to 2,070 years in the last 10,000 years, and were probably associated with earthquakes of about magnitude 7 (after McCalpin and Forman, 1994; Personius, 1988, 1990, 1991). Seismic hazards within the quadrangle include ground shaking, and surface fault rupture and deformation, with resulting effects such as liquefaction, slope failure, and flooding. Because the small depression in the western part of Brigham City is apparently a faulted graben that cuts Holocene materials, it warrants further examination with respect to seismic hazards.

The extensive Quaternary units that contain finer-grained sediments (map units Qal, Qdp, Qli, Q'a, Qls and Qlam) and have shallow ground-water levels (see Bjorklund and McGreevy, 1974, plate 3) are those most prone to damage from ground shaking. Given the same earthquake, ground shaking is more severe on this unconsolidated valley fill than on bedrock, which is present in the Wellsville Mountains. Liquefaction occurs when ground shaking takes place in sandy, water-saturated sediments. These materials lose strength due to increased pore-water pressure, causing buildings and other construction to settle and tilt due to loss of support. Liquefaction features were observed in the Bear River Valley following the 1962 Cache Valley earthquake (Lander and Cloud, 1964). Note that Interstate Highway I-15, state secondary roads, the Brigham City airport, and railroads in the Bear River Valley are all built on fill on fine-grained, likely saturated deposits that are prone to damage from ground shaking.

Details of potential liquefaction hazards in the quadrangle, including a map, are presented in Bay (1987). Moderate to high liquefaction potential is present in the Bear River

Valley due to saturated soils. In contrast, a very low potential is mapped in the Wellsville Mountains, and the alluvial fans and lacustrine delta along the mountain front where ground water is deeper. Brigham City is located on the Box Elder Creek fan-delta such that most of the city has a very low liquefaction potential, though the edge of the fan-delta (Qdp and Qaf contact with Qla) has moderate to low potential (Bay, 1987, plate 3).

Various kinds of slope failures are a potential hazard in areas with steeper slopes. Liquefaction, even of buried fine-grained sediments, can lead to lateral spread of material on slopes as low as 0.5 percent and flow landslides on slopes steeper than 5 percent. This frequently leads to the failure of stream banks and dikes, like those along the Bear River (plate 1). Other serious slope-failure seismic hazards in the quadrangle are quake-induced rock falls and landslides in the mountains and along the mountain front.

The damage from surface rupture and deformation is greatest along and adjacent to the faults. Any development along a fault, be it a building, pipeline, power line, railroad or highway, is subject to damage, because scarps as high as 26.2 feet (8 m) are present in Holocene deposits

Earthquake-related flooding can result from dam or dike failure, canal failure, landslides damming drainages, diversion of streams, lowering and tilting of ground levels, Great Salt Lake seiches, and rupturing of water lines. In this quadrangle, flooding due to tilting is well displayed in the marshy area north-northwest of Brigham City, which includes North Lake and the Cement Ponds (after Personius, 1990).

Mass Movements

The potential exists for landslides, rock falls, and debris flows in the quadrangle, though most habitation is presently distant from the steep slopes and canyons in the Wellsville Mountains, where mass movements are most likely. The greatest danger is probably along the

Bear River north of Corinne, where numerous landslide and slump scarps are present (plate 1). The two landslides mapped on the east side of the Wellsville Mountains (Qms, plate 1) might pose some threat in the Mt. Pisgah quadrangle. Earthquake-induced or other rock falls are a potential hazard along the mountain front. Late Holocene debris flows were mapped by Personius (1990) at the mouths of Calls Fort, Donation, Baker, Hansen and "two" Hansen (unlabeled in NW1/2 section 6, T.9N., R.1W.) Canyons, and an unnamed canyon two canyons north of Hansen Canyon. Most of the young alluvial fans (Qaf) we mapped in the Brigham City quadrangle probably include a debris flow component, and are therefore hazard areas.

Shallow Ground Water

Shallow ground water is a potential hazard across the western two-thirds of the quadrangle. Bjorklund and McGreevy (1974, plate 3) portray the potentiometric surface as being at or above ground level for all the deposits in the Bear River Valley (Qli, Qls, Qal, Qlam, Qla, Qdp, Qat) that are lower in elevation than alluvial fans. In contrast, Brigham City and the alluvial fans along the mountain front do not have shallow ground water; these sites are shown as having depths to ground water of about 10 to 50 feet (3 to 4.5 m) by Bjorklund and McGreevy (1974, plate 3). Shallow ground water hampers any excavation and foundation construction, and can preclude installation of septic tanks and subsurface structures. Shallow ground water also increases the possibility of liquefaction during an earthquake. Placing underground storage tanks, landfills, and solid and hazardous waste sites in areas where ground water is at or near the surface is ill-advised.

Floods

In the Brigham City quadrangle, the Bear River delta below 4,212 feet (1,284 m) elevation was flooded by Great Salt Lake during the historic high level in 1986. Because

thresholds between Great Salt Lake and the expansive Great Salt Lake Desert are at elevations of 4,213 to 4,217 feet (1,285 m), 4,217 feet (1,285 m) is considered the maximum height of significant flood hazard from Great Salt Lake in the quadrangle. This level was attained during the Little Ice Age several hundred years ago (Currey and others, 1984b; Harty and Christensen, 1988). A water-level rise to 4,217 feet (1,285 m) would inundate the southwestern corner of the quadrangle, and further raise the level of shallow ground water.

Canyons in the quadrangle are susceptible to flash flooding during heavy rainfall and rapid snowmelt, like flooding that struck the Ogden area in 1983 (see Wieczorek and others, 1989, 1983). Snowmelt flooding occurred on Box Elder Creek in Brigham City in February, 1911 (James and others, 1980). Both types of flooding can be accompanied by debris flows (see mass movement section). The younger alluvial fans (Qaf) are sites of potential flash flooding and debris flow outrun. Note in particular the residential area on the fan in Brigham City, and see James and others (1980) for details on the flood hazard.

Cloudburst flooding was reported on August 18, 1881 at Brigham City, and an October 17, 1937 cloudburst caused a landslide in Box Elder Canyon, which blocked the highway (Woolley, 1946). Cloudburst flooding was also reported in Brigham City on June 3, 1963 and June 24, 1969 (Butler and Marsell, 1972), and other cloudbursts have been reported in the area (Woolley, 1946; Butler and Marsell, 1972).

Flow in the Bear River is regulated by numerous upstream impoundments, so the flows reported here are mostly evidence for wet years. In roughly the last 40 years, reported maximum flows of the Bear River north of Corinne were 14,770 (May 19, 1984), 12,000 (February 20, 1986), 9,770 (June 4, 1983) and 9,400 (April 8, 1985) cubic feet per second (418.3, 339.8, 276.7 and 266.2 cubic meters/second)(U.S. Geological Survey Water Yearbooks for Utah).

A flood hazard exists along the lower Bear River in the unlikely event that Cutler Dam

fails. Assuming a worst-case scenario, complete and instantaneous failure like that caused by an earthquake, Case (1984) calculated that the flood-wave-crest elevation would be about 4,257 feet (1,297.5 m) at Bear River City and about 4,232 feet (1,290 m) at Corinne. This worst-possible flood would inundate part of eastern Bear River City and all of Corinne; for details see Case (1984).

Federal Emergency Management Agency (FEMA) flood insurance rate maps can be consulted for information on the flooding potential along the Bear River, Malad River, Box Elder Creek, and in the marshy area northwest of Brigham City (Cement Ponds-North Lake). However, these maps do not present hazards due to flash flooding. For example, James and others (1980) present data on historic flash-flooding and flooding potential along Box Elder Creek in Brigham City.

Flammable Gas

Flammable gas from Cenozoic deposits is a potential problem in the Bear River Valley. Such gas has been reported in several wells, and in springs or seeps along the southern margin of the quadrangle (Kaliser, 1976; this report, Oil and Gas section). The gas could cause explosions and fire. This phenomena has not been adequately documented.

Expansive Soils

Expansive soils of Chadwick and others (1975) do not correlate well with any of our Quaternary map units, but most wet areas in the quadrangle (units Qal, Qdp, Qlam) contain soils with high shrink-swell potential, including the area from Brigham City west to Black Slough. Site specific studies are recommended prior to construction in the Bear River Valley at elevations lower than deltas and alluvial fans.

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APPENDIX

Measured section BC1

Starting location approximately 0.4 mile southeast of mouth of Antimony Canyon. Section was measured up the north side of Chimney Rock (center SE1/4 section 36, T.10N., R.2W.). Measured by M. E. Jensen on May 13, 14, and 19, 1986 using a Jacobs staff.

Formation
<u>Member/Unit</u>
Description
Thickness

Ute Formation

Interbedded shale and limestone.

Langston Formation

Upper map unit

9. Dolostone--medium light gray to yellowish gray fresh; pale grayish orange, medium dark gray, and medium light gray weathered; medium to very coarsely crystalline, very thick bedded, blocky splitting, forms ledges, good exposure, contains fossil fragments and cross bedding, weathers to a sandy surface. Crossed fault with uncertain offset and measured 23 feet to the top of this unit. Part of section may be duplicated.

118 feet

8. Limestone--medium gray fresh and weathered, fine to medium crystalline, thin bedded, slabby splitting, forms a cliff, good exposure, contains small shell fragments, contains coarse- and fine-crystalline layers, local calcite-filled or replaced vugs, sharp contact with underlying unit.

80 feet

7. Dolostone--similar to unit 9, except medium dark gray and medium light gray are not present as weathered colors.

64 feet

262 feet Total thickness of upper map unit

Spence Shale Member

6. Shale and limestone, interbedded.

Shale--dark gray and light gray fresh, medium dark gray and moderate yellowish brown weathered, non-calcareous, laminated to very thin bedded, platy to flaggy splitting, forms ledgy slopes, fair exposure, locally silty, contains horizontal burrows.

Limestone--silty, medium dark gray fresh, medium light gray and moderate orange weathered, very fine to finely crystalline, laminated to very thin bedded, shaly to flaggy splitting, locally fossiliferous. Fossil samples BC-1 and BC-2a to g are from 140 and 148 feet above the base of Spence Shale Member, respectively. See Table 2 for fossil identifications.

225 feet Total thickness of Spence Shale Member

Naomi Peak Member

5. Limestone--medium gray fresh and weathered, medium grained, medium to very thick bedded, slabby splitting, forms a ledge, good exposure, contains layers of light-brown weathering sandstone.

21 feet

4. Sandstone--medium light gray fresh, moderate to dark yellowish brown weathered, fine grained, dolomite cemented, thick to very thick bedded.

15 feet

36 feet Total thickness of Naomi Peak Member

523 feet Total thickness of the Langston Formation

Crossed to north side of fault to measure Langston Formation. Rocks probably not not duplicated or omitted in section.

Geertsen Canyon Quartzite

Upper map unit

3. Quartzite--dark gray fresh, moderate brown (5YR 3/4) weathered (weathers darker than unit 1), medium to coarse grained, subrounded to rounded, moderately to well sorted, clear quartz grains, thick to very thick bedded, blocky to massive splitting, forms a cliff, good exposure, sharp contact with underlying unit, contains cross-bedding, contains *Skolithos* in upper part of unit, also contains horizontal burrows along bedding planes. Crossed a small fault with approximately 5 feet of displacement.

328 feet

2. Quartzite with bedding due to argillite--medium gray to medium light gray fresh, light brown (5YR 5/6) to moderate brown (5YR 3/4) to medium light gray weathered, medium grained, well sorted, quartz grains, laminated to thin bedded, medium bedded near base, platy to slabby splitting, forms slight recess in cliff, good exposure, thinner beds are micaceous, ripple marked, and contain 10% moderate brown earthy grains.

28 feet

356 feet Total thickness of upper map unit

Lower map unit (exposed portion)

1. Quartzite--grayish orange pink, pale reddish orange (10R7/6), and medium dark gray fresh, grayish orange pink, pale reddish orange, and light olive gray (10G 6/2) weathered, medium to coarse grained, rounded, moderately sorted, medium to very thick bedded, slabby to massive splitting, forms light-colored blocky cliffs, good exposure, contains pebble conglomerate layers up to 1 foot thick, locally contains pebbles along bedding planes, contains iron staining and cross bedding, cross-bed surfaces contain sand and granules, contains argillaceous partings and lenses up to 0.5 feet thick. Lower contact not exposed, conceal by lacustrine gravel. Scattered outcrops of quartzite are exposed farther down the slope below the bottom of the measured section, and are surrounded by lacustrine gravel.

1,561 feet

1,917 feet Measured thickness of the Geertsen Canyon Quartzite

Estimated thicknesses of lower map unit and Geertsen Canyon Quartzite are greater than 3,500 and greater than 3,860 feet, respectively. This estimate is based on exposures in Mount Pisgah and Brigham City quadrangles (using outcrop width, dip and topography), and the probable presence of a concealed fault at the base of these exposures (plate 1).

Measured Section BC2

Reconnaissance section located on ridge on north side of Cataract Canyon, approximately 0.6 mile northeast of mouth of Cataract Canyon (SE1/4 NW1/4 SW1/4 section 13, T.10N., R.2W.). Measured on August 14, 1986 by Mark E. Jensen using a Jacobs staff.

Formation

Member/Unit

Description

Thickness

Laketown Dolomite

3. Dolostone--medium light gray (N6) fresh, medium gray (N5) weathered, very finely crystalline, very thick bedded, forms cliffs, bioturbated, contains chert nodules.

thickness not measured

2. Dolostone, banded light and dark gray. At 117 feet from base of unit is the first appearance of what appears to be *Thalassinoides* trace fossils.

Light bands--dark gray (N3) fresh, medium light gray to light gray (N6-N7) weathered, very finely crystalline, medium to very thick bedded, contains white to dark gray chert blebs. Top of the last light-colored band contains chert nodules.

Dark bands--dark gray (N3) weathered, very finely crystalline, medium to very thick bedded, forms banded cliffs and ledges, contains chert stringers.

243 feet

Total thickness of Laketown Dolomite not measured.

Fish Haven Dolomite

1. Dolostone--medium dark gray (N4) and dark gray (N3) fresh and weathered, finely crystalline, very thick bedded, slabby splitting, forms cliffs, locally contains blobs of light chert, contains rugose corals and small tabulate corals (i.e. small *Favosites* sp. and *Halysites* sp.). Lower contact is covered, but upper surface of quartzite appears to have only a few inches of relief.

178.2 feet

178 feet Total thickness of the Fish Haven Dolomite

Swan Peak Quartzite

Quartzite, white to moderate reddish orange.

Measured Section BC3

Section is located on the south bank of Bear River (SE1/4 NW1/4 NW1/4 section 7, T.10N., R.2W.). This section was first measured by Dr. C.G. "Jack" Oviatt (his section H9, unpublished notes) on October 28, 1983 during field work on the adjoining Honeyville quadrangle, and was remeasured by Mark E. Jensen on April 23, 1987 using a Jacobs staff.

Member/Unit

Description

Thickness

Lacustrine sand deposits (Bonneville Lake cycle)

3. Sand--medium gray (N5) mottled with light brown (5YR5/6), very fine grained, moderately sorted, laminated to medium bedded, contains cross-bedding. This unit continues to top of bluff.

25 feet

25 feet Measured thickness of lacustrine sand deposits

Lacustrine silt deposits (Bonneville Lake cycle)

2. Clay--silty, medium dark gray (N4) fresh, pale olive (10Y6/2) and dark yellowish brown (10YR4/2) oxidized, laminated to thin bedded, blocky splitting, silt content varies vertically through unit, contains sand in laminated to very thin beds, and ostracods.

19.0 feet

1. Sand--medium gray (N5) and grayish orange (10YR7/4), very fine to fine grained, moderately sorted, laminated in part but mostly poorly bedded, upper 1.0 foot contains interbedded sand, silt, and clay.

4.6 feet

Covered, alluvial and colluvial material. Bear River at a low stage when measured.

23.6 feet Measured thickness of lacustrine silt deposits

Measured Section BC4

Section measured on the west bank of Bear River on Holmgren farm, south of the Gilbert shoreline near confluence of the Bear and Malad Rivers (NW1/4 SW1/4 section 19, T.10N., R.2W.). Measured by Mark E. Jensen on April 23, 1987 using a Jacobs staff.

Member/Unit

Description

Thickness

Lacustrine silt deposits (Bonneville Lake cycle)

5. Silt, with very fine-grained sand--pale yellowish brown (10YR6/4), laminated to very thin bedded. This unit extends to top of river bank.

14.4 feet

4. Clay--silty, dark yellowish gray (5Y6/2) with thin bands of dark yellowish orange (10YR6/6), contains dark-colored laminations and stringers, laminated to very thin bedded.

1.6 feet

3. Sand, with silt--pale yellowish brown (10YR6/2) fresh, very fine grained, contains low-angle crossbedding, laminated to very thin bedded, blocky splitting.

1.0 feet

2. Clay--silty, fresh color light olive gray (5Y6/1) with laminations of light brown (5YR5/6), oxidized colors same as fresh colors, laminated bedding, upper 1.2 feet contain interbedded sand which is very fine grained and very thin bedded.

2.8 feet

1. Clay--silty, mostly covered, grayish black (N2) and medium dark gray (N4) fresh, light olive gray (5Y5/2) and dark yellowish brown (10YR4/2) oxidized, laminated bedding, contains lighter and darker colored laminations.

4.5 feet

Bear River at low stage.

24.3 feet Measured thickness of deposits

Measured Section BC5

Starting location on the north side of Cataract Canyon and extended up over a ridge with elevation label of 8657 feet (NW/14 NW1/4 NE1/4 section 13, T.10N., R.2W.). Measured by Mark E. Jensen on August 27, and September 1, 1987, using a Jacobs staff.

Formation

Member/Unit

Description

Thickness

Manning Canyon Shale (incomplete)

17. Covered. Measured to approximate position of fault.

70 feet

16. Limestone--platy splitting, mostly covered.

10 feet

15. Shale--black fresh, dark gray weathered, laminated bedding, noncalcareous.

18 feet

14. Limestone--medium light gray weathered, laminated to thin bedded, upper 1 foot is bleached, poor exposure.

37 feet

13. Shale--pale yellowish brown fresh, laminated to very thin bedded, covered.

18 feet

12. Limestone--medium light gray to medium gray weathered, becomes medium dark gray weathered upsection, very fine grained, very thin to thin bedded, contains beds of black chert up to 6 inches thick, contains brachiopods, contains crinoid stems near top of unit, good exposure.

87 feet

11. Shale--light olive gray (5Y6/1) fresh, pale grayish orange weathered, noncalcareous, laminated bedding, forms a depression between limestone units, poor to fair exposure. Basal 2 feet of this unit weathers dark gray and has iron staining, appears to have a higher iron content than the rest of this unit.

30 feet

10. Limestone--medium gray weathered, fine grained, contains black chert, very thin bedded, upper part is medium bedded, forms small ledges and slopes, fossiliferous, fair exposure, upper 2 feet of unit is bleached.

118 feet

9. Shale--light olive gray (5Y6/1) fresh, pale grayish orange weathered, noncalcareous, laminated bedding, forms a depression between limestone units, poor to fair exposure.

30 feet

418 feet Measured thickness of Manning Canyon Shale

Great Blue Limestone

Upper map unit

8. Limestone--dark gray fresh, medium dark gray weathered, fine to medium grained, medium bedded, blocky splitting, contains less chert than unit 6, chert occurs as nodules and beds up to 1 foot thick, fossiliferous, contains horn coral, fair exposure, forms slopes and ledges, upper 2 feet of unit appears bleached.

437 feet

7. Limestone--interbedded very thin and thicker bedded limestone, poor exposure.

102 feet

6. Limestone--dark gray fresh, medium dark gray weathered (weathers darker than underlying unit), fine to medium grained, medium bedded, blocky splitting, contains very thin to thin bedded chert (which locally makes up 5-10% of the rock), fossiliferous, forms slopes and ledges, fair to good exposure.

203 feet

742 feet Total thickness of upper map unit

Middle map unit

5. Interbedded limestone, siltstone, mudstone, and shale; forms slopes and ledges below steeper slopes of upper member, upper contact is covered.

Limestone--medium gray weathered, very fine grained, medium to thick bedded, blocky splitting, contains crinoid stems, brachiopods, horn coral, and dark chert nodules, some beds contain pisolite-like structures up to approximately 3 inches in diameter, one bed contains brecciation along the top.

Siltstone ("shale")--dark gray fresh, grayish orange and light olive gray (5Y5/2) weathered, very fine sand and silt, very thin to medium bedded, flaggy splitting, variable calcareous cement, contains rough "nodules" of limestone (up to about 6 inches long).

Mudstone--minor, greenish gray (5GY6/1) weathered, thin bedded.

Shale--black shale in some covered slopes between ledges.

355 feet

4. Mudstone ("shale")--greenish gray (5GY6/1) fresh and weathered, also dark yellowish brown weathered, contains limestone "nodules" (more abundant near top), grades to limestone at top of ledge, contains laminations but is thick bedded, contains brachiopods, forms a ledge, good exposure.

26 feet

3. Interbedded limestone, mudstone, and shale.

Limestone--medium dark gray fresh, very fine grained, thick bedded, forms ledges and slopes, fair to good exposure, some beds contain abundant fossil fragments.

Mudstone--grayish orange, dark yellowish gray, and yellowish gray weathered, with "nodules" of limestone up to 5 inches in length set in the mudstone matrix and limestone as very thin to thin beds, "nodules" weather medium gray, contains brachiopods; mudstone is thin to medium bedded, and forms ledges and slopes.

Shale (mudstone)--medium light gray to dark gray fresh, light olive gray weathered, slightly calcareous, very thin to medium bedded.

64 feet

2. Covered slope, probably same as unit 1.

65 feet

1. Interbedded mudstone, shale, and limestone. Unit grades upward from shale to mudstone with limestone "nodules" to limestone, then a sharp boundary and a shale begins again. Abundant brachiopods at top of this unit.

Mudstone--grayish orange, dark yellowish gray, and yellowish gray weathered, with "nodules" of limestone up to 5 inches in length set in the mudstone matrix and limestone as very thin to thin beds, "nodules" weather medium gray, contains brachiopods; mudstone is thin to medium bedded, and forms ledges and slopes.

Shale (mudstone?)--medium light gray to dark gray fresh, light olive gray weathered, slightly calcareous, very thin to medium bedded.

Limestone--medium gray weathered, very fine grained, medium bedded.

90 feet

600 feet Total thickness of middle map unit

1,342 feet Total thickness of upper and middle map units

Lower map unit

Limestone, medium dark gray weathered, very fine to fine grained, medium bedded, forms ledges.

Figure 1. Index map of the Brigham City area. Names of 7.5-minute quadrangles are underlined.

Figure 2. Location map of various features and faults in the Brigham City 7.5-minute quadrangle, with fault classification by trend, dip and, where known, age.

Figure 3. Correlation chart for Devonian and Mississippian strata mapped in the Wellsville Mountains, and described at Dry Lake and Honeyville. Chart shows correlations used in this report (queried where uncertain) Stratal thicknesses are to scale. Upper chart hung on the base of the Oquirrh Formation. Lower chart hung on the top of the Water Canyon Formation.

Figure 4. Excavation equipment, marl and clay deposits, and resulting pond at Ogden Portland Cement Company operation on Baker Spur, north-northwest of Brigham City. Photograph from McGregor and Abston (1994); they attributed the photograph to Burchard. This photograph of the Cement Ponds was probably taken during examinations for Burchard's (1911) report.

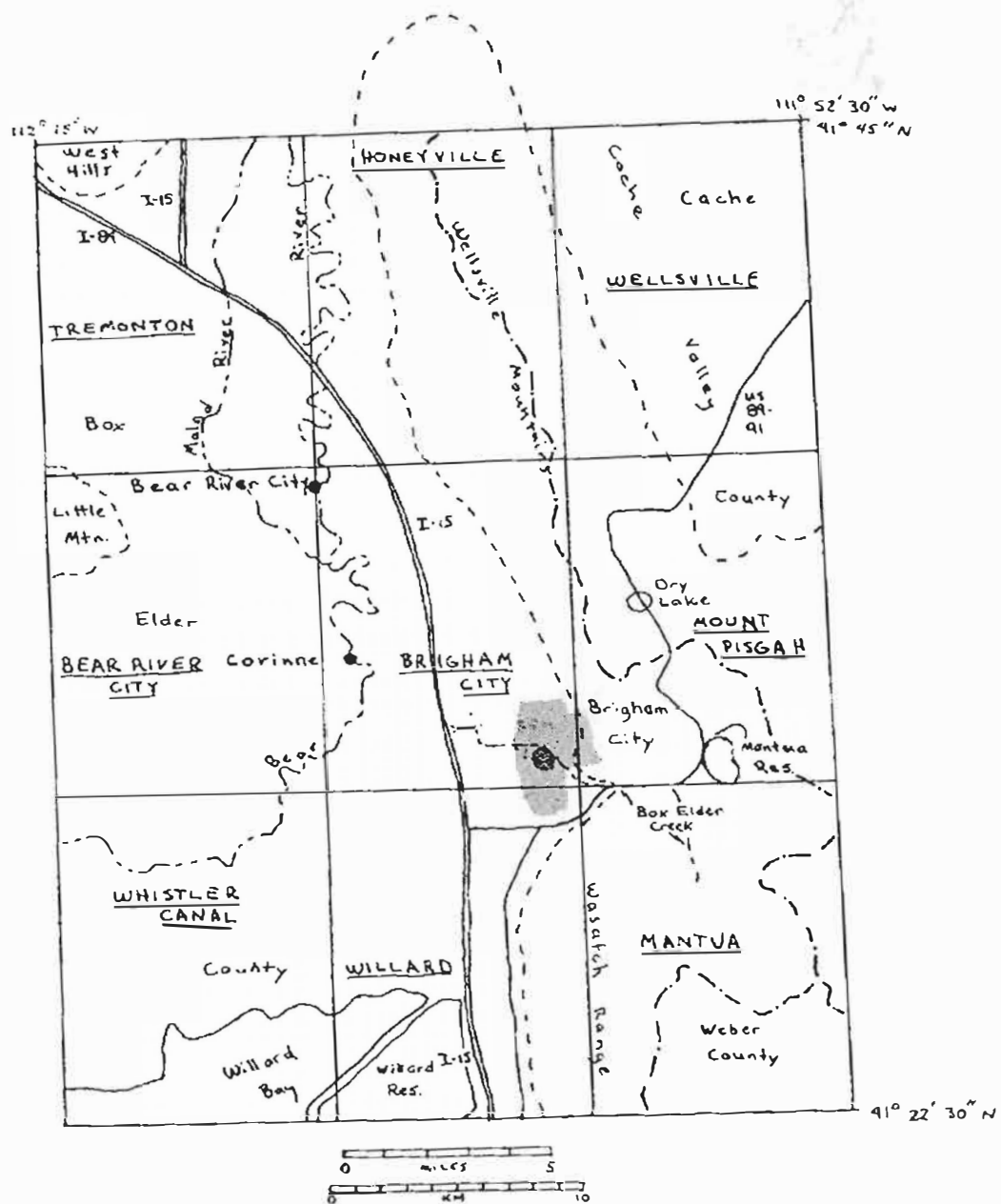


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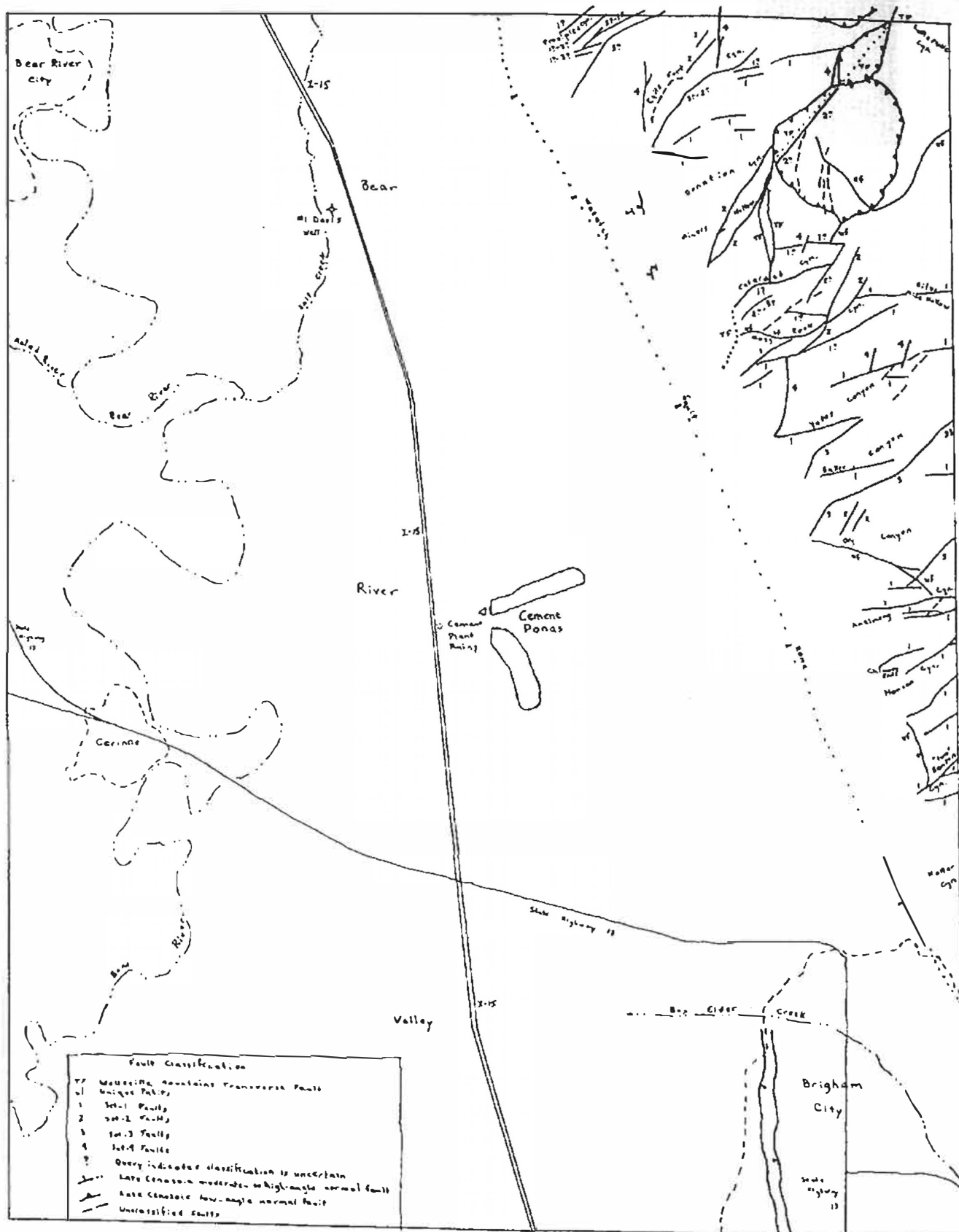


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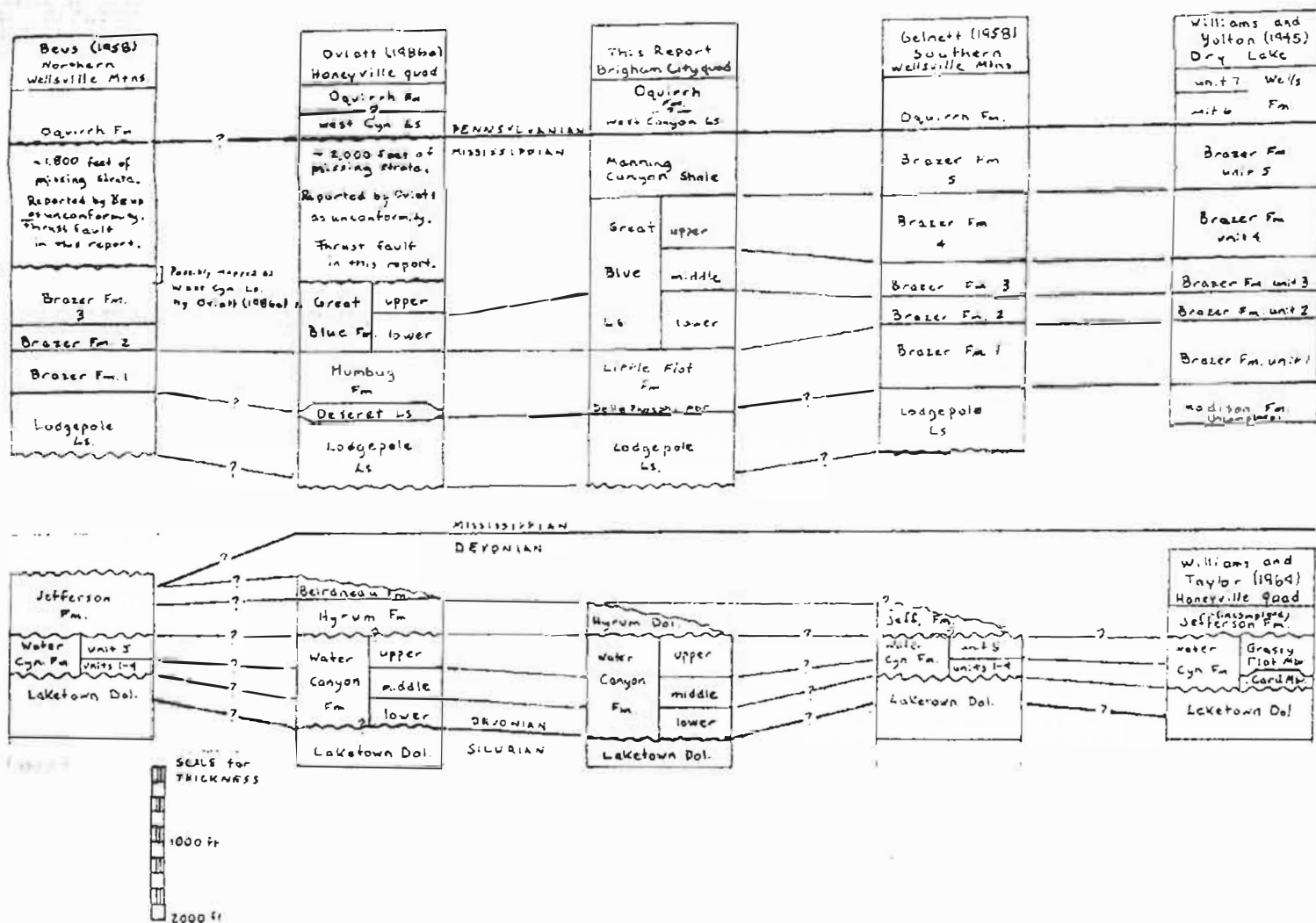


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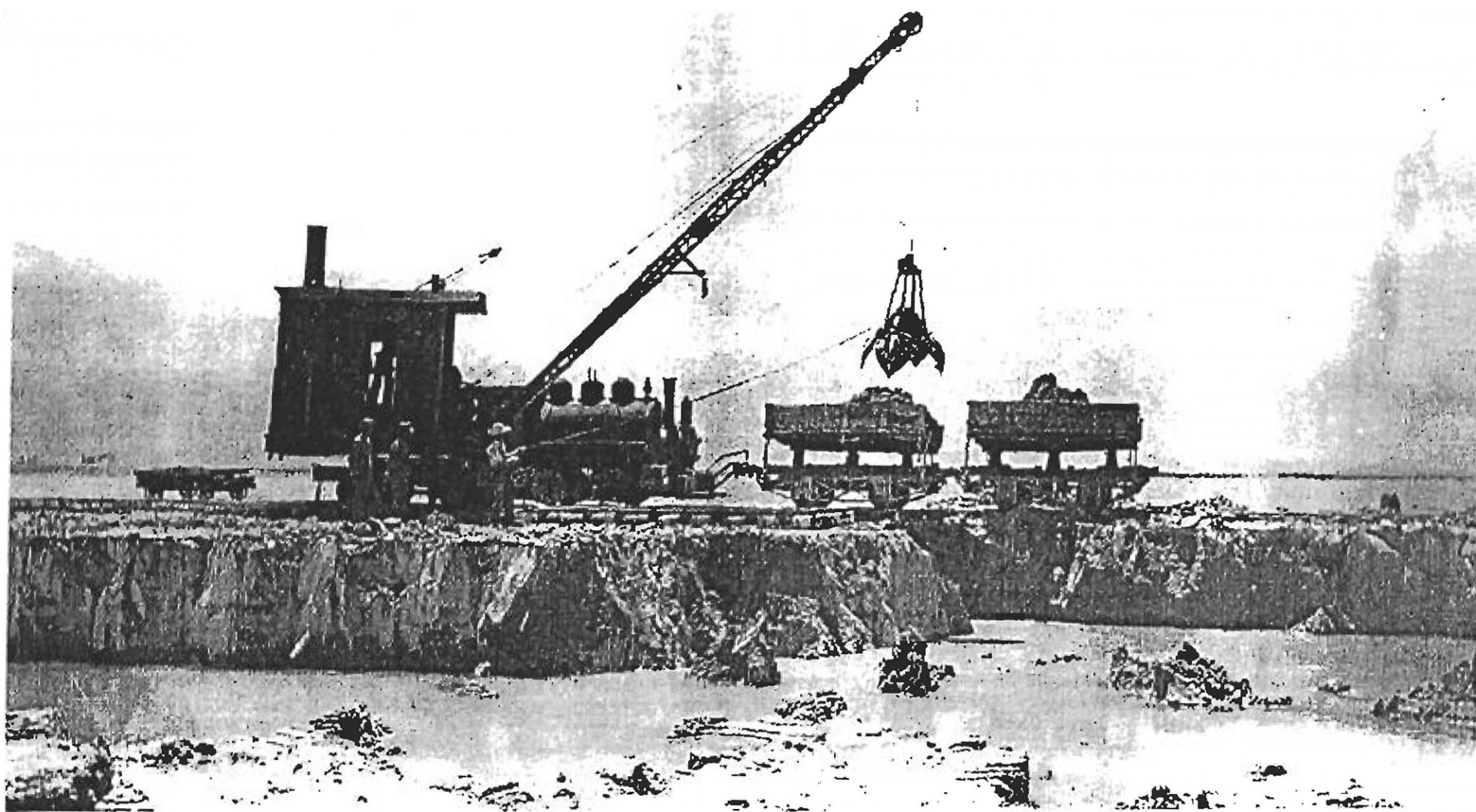


Figure 4. Excavation equipment, marl and clay deposits, and resulting pond at Ogden Portland Cement Company operation on Baker Spur, north-northwest of Brigham City. Photograph from McGregor and Abston (1994); they attributed the photograph to Burchard. This photograph of the Cement Ponds was probably taken during examinations for Burchard's (1911) report.

Table 1. Formation and unit tops in the #1 Davis, Utah Joint Steam Venture (Geothermal Kinetics) geothermal exploration well (SW1/4 SW1/4 SW1/4 section 16, T.10N., R.2W.). Tops used in cross section A-A' (plate 2) are underlined.

Ground level--4,251 feet
 Surface material--Quaternary deposits
 Total depth--10,986 or 11,005 feet

UNIT TOPS AND DEPTH IN FEET BY SOURCE
 [notes in brackets]

<u>Campbell</u> (in Doelling, 1980)	<u>Morgan and Yankee</u> (unpublished, 1990-1)	<u>King</u> (this report)
580 Salt Lake Formation ———	580 Salt Lake Formation	no pick
no pick	no pick	<u>680 Salt Lake Formation</u>
no pick	no pick	2110 more consolidated Salt Lake
no pick	no pick	4295 lithic sandstone of
		dark carbonate. Paleogene(?)
4380 Jefferson Formation	no pick	no pick
[Little Flat]		
no pick	<u>4440 West Canyon Limestone</u>	4440 sandstone?, Great Blue(?)
no pick	<u>4790 Great Blue Limestone</u> — ? —	4790 carbonate? or shale?,
	[40% too thick]	Great Blue(?)
5360 thrust fault	no pick	no pick
5360 Manning Canyon Shale ? ———	no pick	? 5365 shale, Manning Canyon(?)
6210 Great Blue Limestone	no pick	no pick
no pick	<u>6230 Humbug Formation</u> — ? —	6230 carbonate?, Great Blue(?)
[section incomplete—	<u>[Little Flat]</u>	or Little Flat(?)
900 feet of		
Little Flat missing]		
no pick	6870 Deseret Limestone	6870 sandstone?
no pick	6958 Lodgepole Limestone	<u>6958 Delle Phosphatic Member</u>
		<u>of Little Flat(?)</u>
7102 <u>Lodgepole Limestone</u> ———	no pick	7100 limestone, <u>Lodgepole(?)</u>
[section incomplete—		
at least 2500 feet of		
Devonian and Silurian		
missing]		
7840 Swan Peak Formation	no pick	no pick
no pick	<u>7845 FAULT</u> ———	<u>7845 FAULT</u>
no pick	<u>7845 Caddy Canyon Formation</u> —	<u>7845 Caddy Canyon Formation</u>
no pick	<u>7932 Papoose Creek Formation</u> —	no pick
no pick	no pick	7970 Papocse Creek Formation
8300 thrust fault	no pick	no pick
[Geertsen Canyon Quartzite:		
Clem and Brown, 1985]		
no pick	8340 dolomite	no pick
no pick	no pick	8850 Kelley Canyon(?) Formation
no pick	<u>8864 Kelley Canyon Formation</u> —	no pick
no pick	no pick	8890 Kelley Canyon Formation
no pick	no pick	10390 limestone
10400-10480 [samples missing]		
no pick	10430 Maple Canyon Formation	no pick
no pick	no pick	10570-10590 dolomite
no pick	no pick	<u>10590 Maple Canyon Formation</u>

Table 2. Fossils collected by M.E. Jensen in the Brigham City quadrangle, with identifications.

Stratigraphic unit/sub-unit

Age--zone

(Location)

Number Identified by

Description

Langston Formation/Spence Shale Member

earliest Middle Cambrian--*Glossopleura* zone

(NW1/4 NW1/4 SW1/4 section 31, T.10N., R.1W.)

BC2a	L.F. Gunther	brachiopod- <i>Acrothele</i> sp. (immature)
BC2b	L.F. Gunther	trilobite- <i>Athabaskia bithus</i>
BC2c	L.F. Gunther	trilobite- <i>Spencia typicalis</i>
BC2d	L.F. Gunther	trilobite- <i>Athabaskia bithus</i>
	L.F. Gunther	trilobite- <i>Bythicheilus typicum</i>
BC2e	L.F. Gunther	brachiopod- <i>Acrothele</i> sp.
BC2f	L.F. Gunther	trilobite- <i>Alokistocare</i> sp. (head)
	L.F. Gunther	trilobite- <i>Bythicheilus typicum</i>
BC2g	L.F. Gunther	trilobite- <i>Bythicheilus typicum</i>

Bloomington Formation/Hodges Shale Member

Middle Cambrian--*Bolaspidella* zone

(SE1/4 SE1/4 SW1/4 section 11, T.10N., R.2W.)

BC17a	L.F. Gunther	brachiopod- <i>Acrothele affinis</i>
BC17b	L.F. Gunther	brachiopod- <i>Acrotreta</i> sp.
BC17c	L.F. Gunther	brachiopod- <i>Iphidella grata</i>
BC18	L.F. Gunther	brachiopod- <i>Acrothele affinis</i>

Swan Peak Quartzite/lower part

Middle Ordovician (Whiterockian)--*Orthambonites michaelis-Orthidiella* zone

(NE1/4 SW1/4 NW1/4 section 30, T.10N., R.1W.)

BC3	L.F. Hintze	brachiopod- <i>Orthambonites swanensis</i>
		(SW1/4 NW1/4 NW1/4 section 30, T.10N., R.1W.)
BC4	L.F. Hintze	trilobite- <i>Eleutherocentrus petersoni</i>
	M.E. Jensen	orthocone cephalopod?
		(NE1/4 NW1/4 SE1/4 section 24, T.10N., R.2W.)
BC7	L.F. Hintze	brachiopod- <i>Orthambonites swanensis</i>

Table 3. List of mine and exploration workings in the Brigham City 7.5 minute quadrangle.

Mine-Workings	Location	Mineralization and Description	Host Formation/Unit (see plate 1)	Ref./ Loc. Ref.
Baker mine (production) multiple workings	upper Baker Canyon	Pb-Zn-Ag, with minor Cu & Au values in limonitic fault zone; no sulfides seen; large dump, though production trammed away; fluorite on dump of adit above main adit	Garden City	A, D A, B
Dry Lake Antimony mine (production) multiple workings	Antimony Canyon (mis-labeled Copper Blossom on topographic map)	3-10 foot wide stibnite (Sb) bearing quartz vein that contains calcite and carbonate fragments; in fault zone; large dump at lower adit not indicative of mineralization	uppermost Blacksmith	A, B A
Copper Blossom mine multiple workings	ridge south of Baker Canyon (label at wrong site on topographic map)	limonite gossan along brecciated fault zone, with Pb-Zn-Cu values; moderate sized dump though transport on nearby Baker mine tram was possible	upper and lower Nounan	A, B A, B
adit (caved)	Cataract Canyon (not on topo. map)	in limestone along fault; small to moderate sized dump	uncertain Cambrian carbonate	A, B A, B
adits (caved) & prospect	ridge north of Cataract Canyon	fault zone in limestone; limonite stained breccia zone; tiny dumps	Hodges Shale(?)	A, B A, B
adit	near mouth of Calls Fort Canyon	crush zone with calcite fracture fillings; quartz on dump; about 50 ft. long; tiny dump	upper Blacksmith	B C
	upper Miners Hollow	dump contains calcite, malachite, azurite, limonite, hematite; rock is fractured and brecciated; along fault; about 80+ feet long; tiny dump	upper middle Blacksmith	B B, C
adit (north)	ridge north of Cataract Canyon	limonite along fractured zone along fault; about 30 ft. long and up to 6 ft. wide; hematite stained small dump	lower Laketown	B C, B
adit & prospect	ridge north of Yates Canyon	limonite stained fault zone	lower Nounan	B B.
	south of Precipice Canyon	tiny dump	Blacksmith	B B
prospect	north of Calls Fort Canyon		Blacksmith--Hodges Shale contact	B B
	north of Calls Fort Canyon	brecciated zone with calcite matrix and milky quartz; about 50 ft. long; tiny dump	Blacksmith	B B
prospects	south of Calls Fort Canyon	limonite gossan with hematite and dolomite	upper Blacksmith	B B
	mouth of Miners Hollow		upper Geertsen Canyon	B B
prospect	south of Miners Hollow	limonite gossan on fault	upper Langston	B B

16	prospect(s)	ridge south of Miners Hollow	limonitic zone over 4 ft. wide. irregular; fault zone; friable yellow brown sandy siltstone - (?) alteration	upper Blacksmith	B B
17	prospect	ridge north of Miners Hollow	fault zone	lower-upper Nounan contact	B B
18	prospect	ridge north of Miners Hollow	hematite, malachite, calcite and limonite in dolomitized fault zone with dolomite fracture fillings	middle Bloomington	B B
19	prospect	upper Miners Hollow		Calls Fort Shale	B B
20	adit & prospect	north of mouth of Cataract Canyon	some limonite at 40 ft. adit in Naomi Peak Limestone; limonite in prospect in Spence Shale	lower Langston	B B
21	adit	south of mouth of Cataract Canyon	no mineralization; 8 ft. long; near fault	basal Nounan	B B
22	prospect	south of Moss Rock Canyon	iron oxides along fault zone	uppermost Garden City	B B
23	adits (3), 2 caved	south of Moss Rock Canyon	limonite, calcite and rare hematite on dump at fault intersection	Hodges Shale	B B
24	prospect	Yates Canyon		upper Blacksmith	B B
	adits (caved) & prospect	mouth of Baker Canyon	azurite, malachite, calcite, quartz and limonite on dump and pit; small to moderate sized dump that might be partly from Baker and Copper Blossom workings	upper Blacksmith	B B
26	adit	north of Baker mine	limonite and hematite staining; tiny to small dump	upper St. Charles or Garden City	B B
27	adit (caved)	above Baker mine	calcite vein along small fault; limonite and quartz on dump; tiny to small dump	lower Laketown	B B
28	prospect	upper Baker Canyon	limonite near fault	lower Laketown	B B
29	adit	mouth of Dry Canyon	fault zone	Blacksmith(?)	B B
30	adit	Hansen Canyon	75+ feet long; tiny to small dump	lower Geertsen Canyon	B B
31	adit	south of Hansen Canyon	30 feet long, iron oxide staining in quartzite; malachite on dump; small dump, yet too big for length	lower Geertsen Canyon	B B

References (ref.)

A Perry and Doelling (1980)

B This report

C 1988 Brigham City 7.5 minute topographic map

D Perry and McCarthy (1977)

Table 4. Significant boreholes in the Brigham City area (data from Clem and Brown, 1985; Kerns, 1987; Campbell in Doelling, 1980; Utah Geological Survey files; Utah Division of Oil, Gas and Mining files). See also Table 1.

Name/ Company	Location (sec-T-R) (ft from sec. line)	Completion Date/Status	Tests	TD (feet)	Unit Tops (feet)
#1 Corinne Oil and Gas	31-T10N-R2W	?-10-18 D&A	Quaternary & Tertiary gas open 1920	976	surface Quaternary TD Salt Lake(?)
#1 Nichols P.S. Stacey et. al.	CNENW 21-T9N-R2W	8-15-55 D&A (capped)	gas shows	1220 1035?	surface Quaternary TD Salt Lake(?)
#1 Stanley Admantia Corp.	CNENE 31-T10N-R3W (660fsl, 660fel)	2-8-56 D&A		80 to 100	surface Quaternary
#1 Knudson Rhine Petroleum	NESW 30-T9N-R2W (3476fsl, 1523fwl)	4-3-58 D&A	gas show	2308	surface Quaternary TD quartzite
#1 Davis (Joint Steam Venture) Geothermal Kinetics	SWSWNW 16-T10N-R2W	7-28-74 water well	geothermal no oil or gas shows	10986 11005	See Table 1.
#1-9 Christensen Burnett Oil	NESE 24-T9N-R3W (1980fsl, 820fel)	8-4-81 plugged back to 895 ft. water well	Tertiary(?) gas	6000	<1010 Salt Lake 3550 Laketown 3940 Fish Haven (4850 Fish Haven) 5140 Swan Peak 5410 Garden City TD Garden City
#1 Chesapeake Energy Burnett Oil	NWNWSW 27-T9N-R3W (1995fsl, 655fwl)	5-18-81 junked	not tested	273	
#1-A Chesapeake Energy/Burnett Oil	NEWWSW 27-T9N-R3W (1995fsl, 555fwl)	9-2-81 D&A	tested no shows	4610	surface Quaternary 815 Salt Lake? 1650 Laketown 2770 Fish Haven 3048 Swan Peak 3260 Garden City 4436 St. Charles
#1 Corrinne[sic] unknown	8-T9N-R2W	pre-1961 open?	surface gas shows	?	?
#1 Brigham City Cristion & Davis	22-T9N-R2W	1944 spud open?	gas shows	1250	TD Salt Lake?
#2 Brigham City Cristion & Davis	22-T9N-R2W	pre-1961 open?	gas shows	?	?
#1 Brigham City unknown	23-T9N-R2W	pre-1937? open?	surface gas shows	?	?

Abbreviations

sec-section, T-Township, R-Range, N-North, W-West

NE-NE1/4, NW-NW1/4, SE-SE1/4, SW-SW1/4, C-center

FSL-feet from south line, FNL-feet from north line, FWL-feet from west line, FEL-feet from east line

D&A-drilled and abandoned, TD-total depth

Table 5. Municipal water supplies in the Brigham City quadrangle (after Utah Department of Environmental Quality, Division of Drinking Water)

Water System	Source Name	Source Type	Flow (gpm)	Latitude (N) d m s	Longitude (W) d m s
Brigham City	Cooley well	well	1160	41 30 51.0	112 00 08.0
Brigham City	Cemetery #1	well	1000	41 30 11.5	112 00 18.3
Brigham City	Cemetery #2	well	1000	41 30 11.5	112 00 18.5
Corinne	Batty spring aka Yates Canyon Spring	spring	65	41 34 55.0	112 01 19.0[?]
Corinne	#1 well	well	--	41 34 48.0	112 01 14.0*
Corinne	Cutler well aka new (1989)	well	245	41 34 48.5	112 01 38.0
					112 01 33.5[?]
					112 01 35.0*
West Corinne	lowest spring	spring	50	41 31 37.0[?]	112 01 10.0
				41 34 37.0*	
West Corinne	second lowest	spring	50	41 34 41.0	112 00 56.0
West Corinne	third lowest	spring	50	41 34 42.0	112 00 53.0
West Corinne	main spring aka Baker spring	spring	235	41 34 41.0[?]	112 00 50.0
				41 34 42.0*	

Abbreviations

N--north

W--west

gpm--gallons per minute

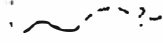
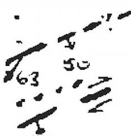
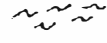
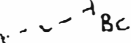
d m s--degrees, minutes, seconds

[?]-reported location uncertain

aka--also known as

*--data from this report

EXPLANATION

-  **Contact**, dashed where approximately located, queried where existence uncertain or location is very poorly constrained.
-  **Faults**, dashed where approximately located, queried where existence uncertain, dotted where concealed. Arrow indicates dip. Diamond arrow indicates trend and plunge of movement inferred from linear features in fault plane.
-  **High-angle normal fault**, or fault with mostly dip slip movement. Bar and ball on downthrown side. Arrows show relative movement on cross sections.
-  **Low angle normal fault** ($<30^\circ$). Open teeth on downthrown side. Teeth on both sides indicate abutting low-angle fault blocks. Arrows show relative movement on cross sections.
-  **Strike-slip fault**, or fault with mostly strike-slip movement. Arrows show relative movement.
-  **Oblique-slip fault**, approximate sense of movement shown by broken arrow. Only used when relative amounts of dip and strike slip are uncertain. Cross sections show movement by T-towards, and A-away.
-  **Thrust fault** (concealed trace near Kotter Canyon). Solid teeth on hanging wall.
-  **Fault zone** (map units uncertain)
-  **Lake Bonneville shorelines**; dashed where approximately located.
- | | | |
|---|---|------------------------|
|  | B | Bonneville shoreline |
|  | P | Provo shoreline |
|  | S | Stansbury(?) shoreline |
|  | G | Gilbert shoreline |
|  | X | unnamed shoreline |
-  **Strike and dip of bedding** (in degrees)
-  **Strike and dip of fracture** (in degrees, offset uncertain)
-  **Headscarp of slide or slump**
-  **Spring** (with name when known)
-  **Tufa deposit**
-  **Fossil sample location** (see table 2)
-  **Location of cross section**
-  **Location of measured section** (see appendix)
-  **Drill hole** (significant oil and gas exploration, geothermal and water wells, with name; see table 4)
-  **Outline of gravel pit**
- Exploration and mine workings** (numbers are those used in table 3)
-  **Adit** (crossed where caved)
-  **Glory hole**
-  **Prospect**

BRIGHAM CITY 7-1/2 MINUTE
QUADRANGLE
MAP UNITS

QUATERNARY

- Qhd** Human disturbance - Origins uncertain or multiple; obscure natural deposits.
- Qhl** Landfill - Present west of Brigham City.
- Qhs** Sewage treatment ponds - Present south of Corinne and northeast of the I-15 rest stop.
- Qhf** Fill material - Highway and railroad right-of-way fill, levees and dikes, building foundation fill, and other fill.
- Qes** Eolian sand - Small dunes of fine-grained sand present in the mud flats north of Brigham City.
- Qm** Mass-movement deposits, undivided - Includes talus and colluvium, and possibly minor debris flows and landslides.
- Qms** Landslide deposits - Derived from Manning Canyon Shale in Rattlesnake Canyon, and Little Flat Formation on the east edge of the quadrangle.
- Qmt** Talus deposits - Angular debris restricted to steep slopes in the Wellsville Mountains.
- Qac** Colluvium and alluvium - Mostly gravelly deposits mapped in canyons in the Wellsville Mountains.
- Qacf** Colluvium and alluvium - Mostly gravelly, fan-shaped deposits mapped on mountain-front slopes of the Wellsville Mountains.
- Qaf** Alluvial-fan deposits - Active fans with debris flow levees and distinct channels. Contain poorly sorted, angular boulders, cobbles, pebbles, and finer grained sediments.
- Qafo** Older alluvial-fan deposits - Remnants of older fans with higher and degraded surfaces. Contain poorly sorted angular boulders, cobbles, pebbles, and finer grained sediments.
- Qag** Alluvial gravel - Pebble gravel and sand, partially cemented with calcite or tufa. Only present in a linear depression southeast of Bear River City, apparently in a paleo-channel.
- Qab** Oxbow lake deposits - Fine-grained, organic-rich sediments deposited in oxbow lakes in the Bear River flood plain.

- Qat Alluvial-terrace deposits - Alluvial silt, sand and gravel deposited on terrace surfaces 20+ feet (6+ m) above present Bear River flood plain and below nearby lacustrine deposits.
- Qdp Deltaic-plain deposits - Sand, silt, and clay deposited in the Bear River delta of Great Salt Lake. Includes deposits in marshes, oxbow lakes, channels, point bars, and natural levees.
- Qlam Lacustrine and alluvial mud-flat and marsh deposits - Silt, clay, and sand deposited around North Lake and the Cement Ponds, and near the Bear River delta.
- Qal Alluvium - Sand, silt, clay, and gravel deposited in flood plains and stream channels, and terraces along the Bear River <20 feet (6 m) above the floodplain.
- Qdg Deltaic gravel - Clast-supported gravel with a sand and silt matrix, deposited in the Box Elder Canyon delta during the Provo stand of Lake Bonneville.
- Qad Fan-delta deposits - Clast-supported gravel, with sand and finer grained sediment deposited in Lake Bonneville lacustrine delta and alluvial fan at the mouth of Box Elder Canyon.
- Qla Mixed lacustrine and alluvial deposits - Lacustrine sand, silt, clay and some gravel that are interbedded with, reworked, and covered with alluvial gravel, sand and mud. Present at the distal end of Box Elder fan-delta, and down slope from alluvial fans along mountain front.
- Qlg Lacustrine gravel and sand deposits - Rounded pebbles, cobbles, and rare boulders, mixed with sand; deposited along the shore of Lake Bonneville and includes reworked material from pre-Lake Bonneville alluvial fans.
- Qls Lacustrine-sand deposits - Fine-grained, organic-rich, deltaic(?) sand, and coarser grained, clean beach(?) sand deposited in Lake Bonneville; exposed in the northwestern portion of the quadrangle and in the gravel pits north of Calls Fort Canyon, respectively.
- Qli Lacustrine-silt deposits - Silt, clay, and fine-grained sand deposited in Lake Bonneville.
- Qu Quaternary deposits, undivided (only on cross section)

TERTIARY

- Tu Tertiary rocks and deposits, undivided (only on cross section)

PENNSYLVANIAN

- Pwc West Canyon Limestone - Interbedded cherty limestone, calcareous sandstone, and sandy limestone; basal 160 feet (49 m) in quadrangle.

MISSISSIPPIAN

- Mmc Manning Canyon Shale - Interbedded silty, thin-bedded, gray limestone and olive-gray to black shale; fossiliferous; about 900 feet (275 m) thick.

- Mgu Upper map unit, Great Blue Limestone - Dark-gray, cherty, ledge- and slope-forming limestone; fossiliferous; 740 feet (225 m) thick.

- Mgm Middle map unit, Great Blue Limestone - Interbedded, olive-gray mudstone and shale, and gray limestone, that form slopes and ledges, respectively; 600 feet (183 m) thick.

- Mgl Lower map unit, Great Blue Limestone - Medium- to dark-gray, cliff-, ledge- and slope-forming limestone; fossiliferous; about 800 feet (245 m) thick.

- MLf Little Flat Formation - Brown-weathering, calcareous sandstone with sandy limestone and dolomite; about 900 feet (275 m) thick including Delle Phosphatic Member.

- MLfd Delle Phosphatic Member of the Little Flat Formation - Resistant, cherty limestone, with underlying less resistant, calcareous sandstone.

- ML Lodgepole Limestone - Gray, typically cherty limestone; about 1,000 feet (305 m) thick.

DEVONIAN

- Dh Hyrum Dolomite - Dark-gray, thick-bedded dolomite with some sandstone (quartzite) beds; thins rapidly to the south; 0 to 450 feet (0 to 137 m) thick.

- Dwu Upper map unit, Water Canyon Formation - Light-gray dolomite; 450 feet (137 m) thick.

- Dwm Middle map unit, Water Canyon Formation - Yellowish sandstone and interbedded sandy dolomite and limestone; 400 feet (122 m) thick.

Dwl Lower map unit, Water Canyon Formation - Light-gray, relatively thin-bedded dolomite; about 400 feet (122 m) thick.

SILURIAN

Slu Upper map unit, Laketown Dolomite - Dolomite, usually lighter colored than lower map unit; thickness variable. Total Laketown about 1,100 to 1,200 feet (335 to 365 m) thick.

Sll Lower map unit, Laketown Dolomite - Medium- to dark-gray dolomite, interlayered light and dark color in lower part; thickness variable. Total Laketown about 1,100 to 1,200 feet (335 to 365 m) thick.

ORDOVICIAN

Ofh Fish Haven Dolomite - Very dark-gray, dolomite; less resistant than overlying Laketown Dolomite; about 180 feet (55 m) thick.

Osp Swan Peak Formation - Quartzite, shale, and limestone, with capping, pale-orange, cliff-forming quartzite; 260 to 300 feet (79 to 91 m) thick.

Ogc Garden City Formation - Ledge-forming limestone, with some intraformational conglomerate; chert is common in lowermost and uppermost parts; 1,330 to 1,390 feet (405 to 424 m) thick.

CAMBRIAN

Csu Upper map unit, St. Charles Formation - Dolomite, resistant, contains interbedded sand and silt, and in upper part chert; 980 feet (299 m) thick.

Csl Lower map unit, St. Charles Formation - Worm Creek Quartzite Member at base, overlying part is thin-bedded, sandy limestone; 180 feet (55 m) thick.

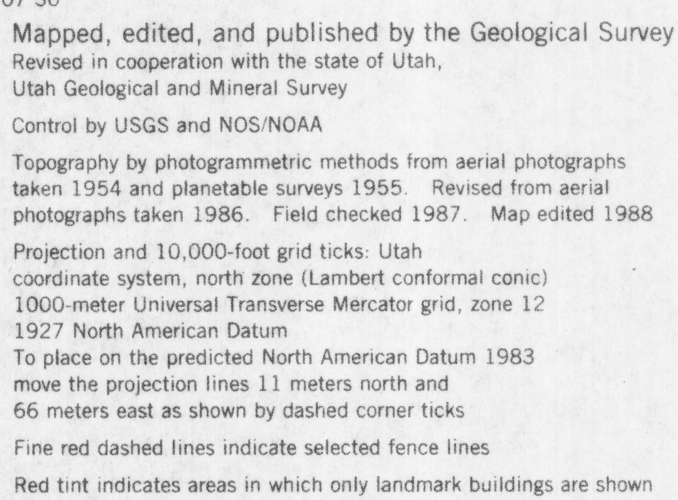
Cnu Upper map unit, Nounan Formation - Interbedded light-colored dolomite, sandy and silty dolomite, and limestone; 545 feet (166 m) thick.

Cnl Lower map unit, Nounan Formation - Gray dolomite; 650 feet (198 m) thick.

Cbc Calls Fort Shale Member, Bloomington Formation - Brown-weathering shale with some interbedded thin-bedded limestone; about 235 feet (70 m) thick.

- Cbm Middle limestone member, Bloomington Formation - Gray, resistant limestone; 515 feet (155 m) thick.
 - Cbh Hodges Shale Member, Bloomington Formation - Brown-weathering shale with interbeds of silty limestone; fossiliferous; 335 feet (102 m) thick.
 - Cbl Blacksmith Formation - Light- to medium-gray, cliff-forming dolomite; about 810 feet (245 m) thick.
 - Cu Ute Formation - Interbedded limestone and shale, sandy in upper part; about 690 feet (210 m) thick.
 - Clu Upper map unit, Langston Formation - Dolomite and limestone, forms ledges and cliffs; about 250 feet (76 m) thick.
 - Cll Lower map unit, Langston Formation - Shale and interbedded limestone (Spence Shale Member), with limestone and dolomite, and locally sandstone (Naomi Peak Member) at base; about 230 feet (70 m) thick.
 - Cgu Upper map unit, Geertsen Canyon Quartzite - Brown-weathering, medium- to coarse-grained, quartzite and interbedded argillite; contains, cross bedding, *Skolithos* (vertical burrows) and horizontal worm burrows; 360 feet (110 m) thick.
 - Cgl Lower map unit, Geertsen Canyon Quartzite - Light colored, medium- to coarse-grained quartzite; contains cross bedding, and pebble layers and lenses; estimated 3,500 feet (1067 m) thick in the Wellsville Mountains.
- PRECAMBRIAN
- Zbh Browns Hole Formation (only in cross section)
 - Zm Mutual Formation (only in cross section)
 - Zi Inkcm Formation (only in cross section)
 - Zcc Caddy Canyon Quartzite - Gray-green quartzite; only exposure near Kotter Canyon; basal 100 feet (30 m) exposed.
 - Zpc Papoose Creek Formation - Interbedded dark-weathering quartzite and argillite; bedding surfaces are green and micaceous; only exposure near Kotter Canyon; top 30 feet (9 m) exposed.
 - Zkc Kelley Canyon Formation (only in cross section)
 - Zmc Maple Canyon Formation (only in cross section)

BRIGHAM CITY QUADRANGLE
UTAH
7.5 MINUTE SERIES (TOPOGRAPHIC)



UTM GRID AND 1988 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET
DIAGRAM IS APPROXIMATE

There may be private inholdings within
the boundaries of the National or State
reservations shown on this map

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

BRIGHAM CITY, UTAH
41112-E1-TF-024

1988

DMA 3567 I SE-SERIES V897

Correlation of Map Units

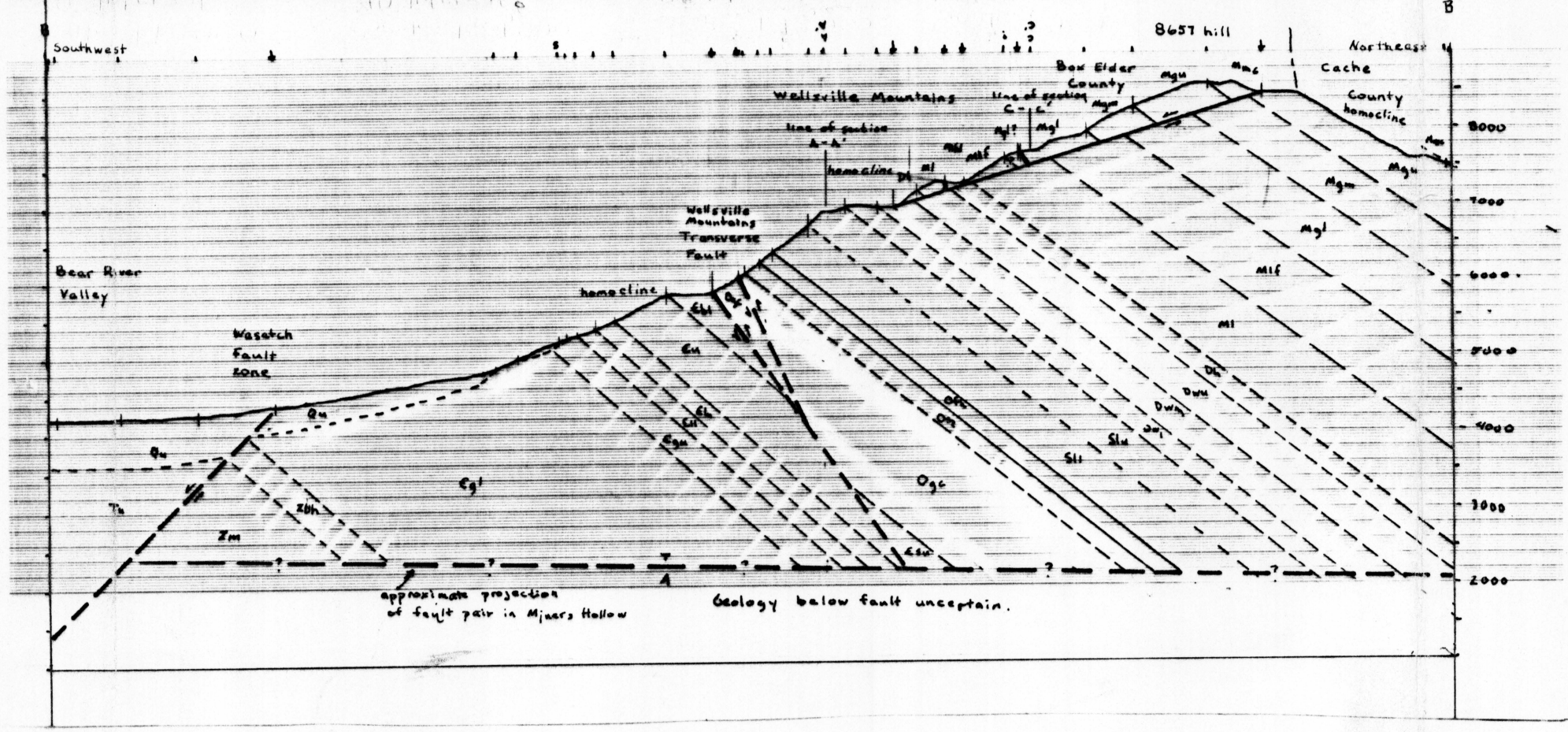
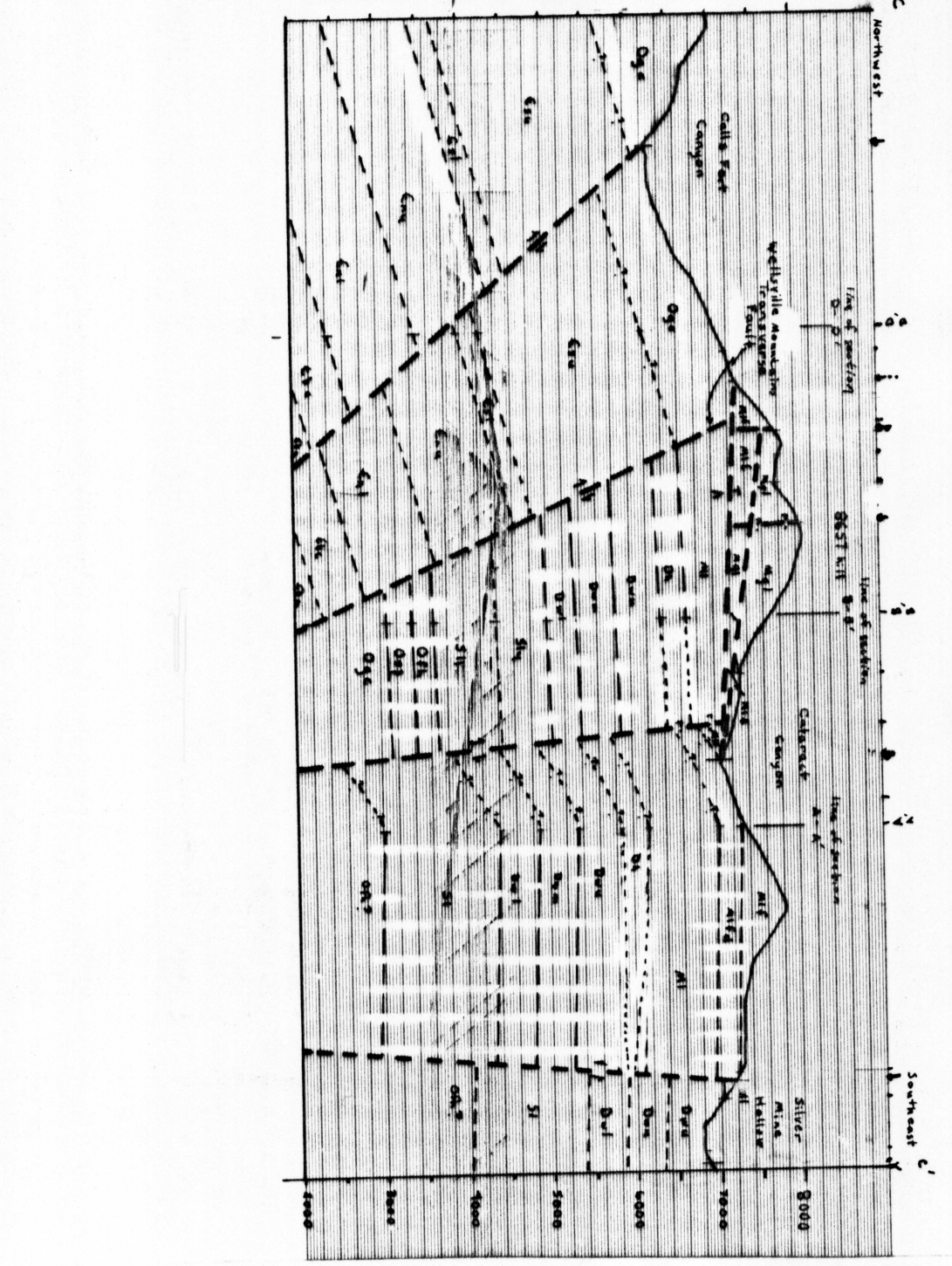
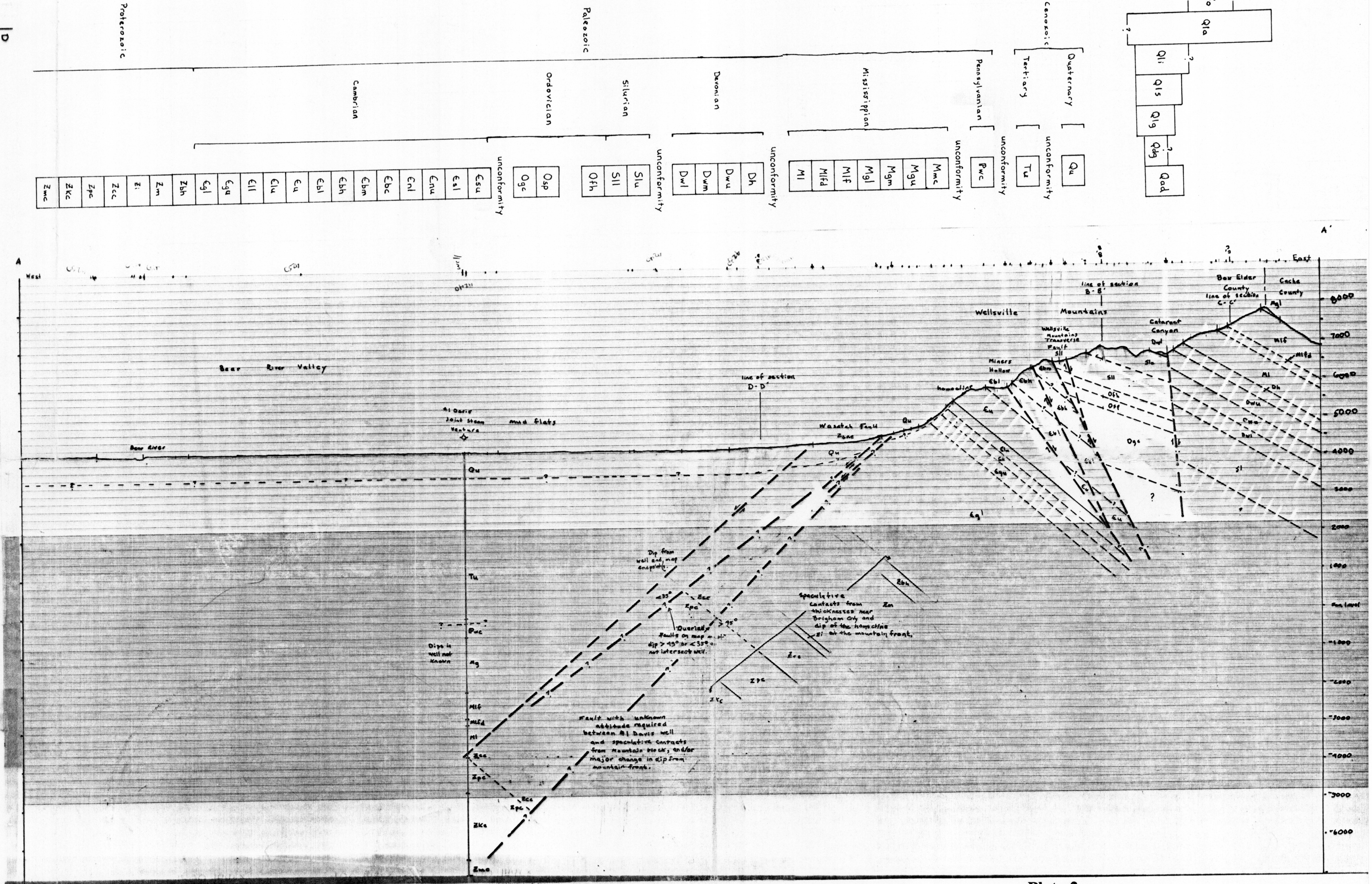
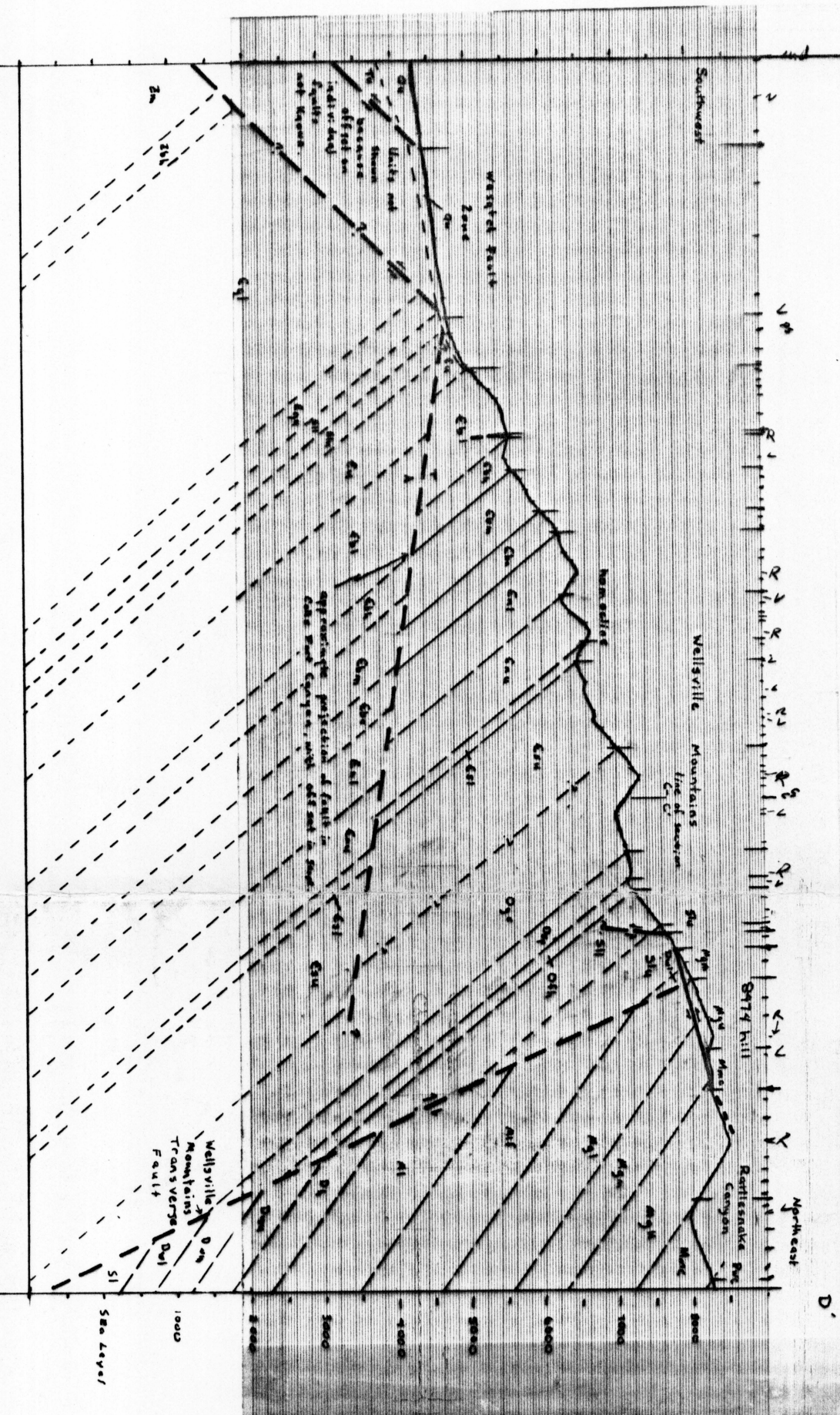
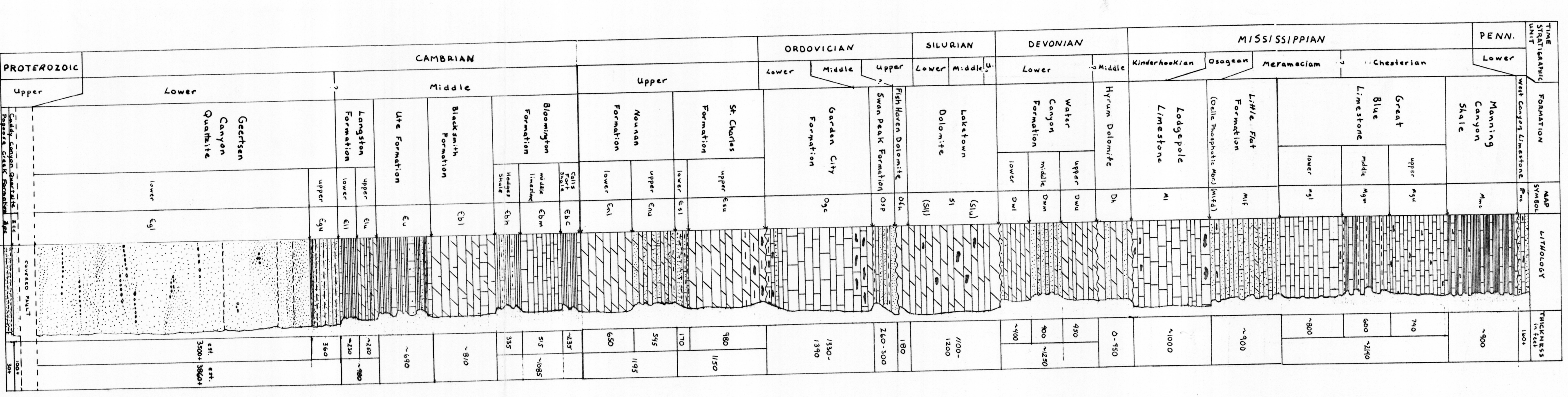
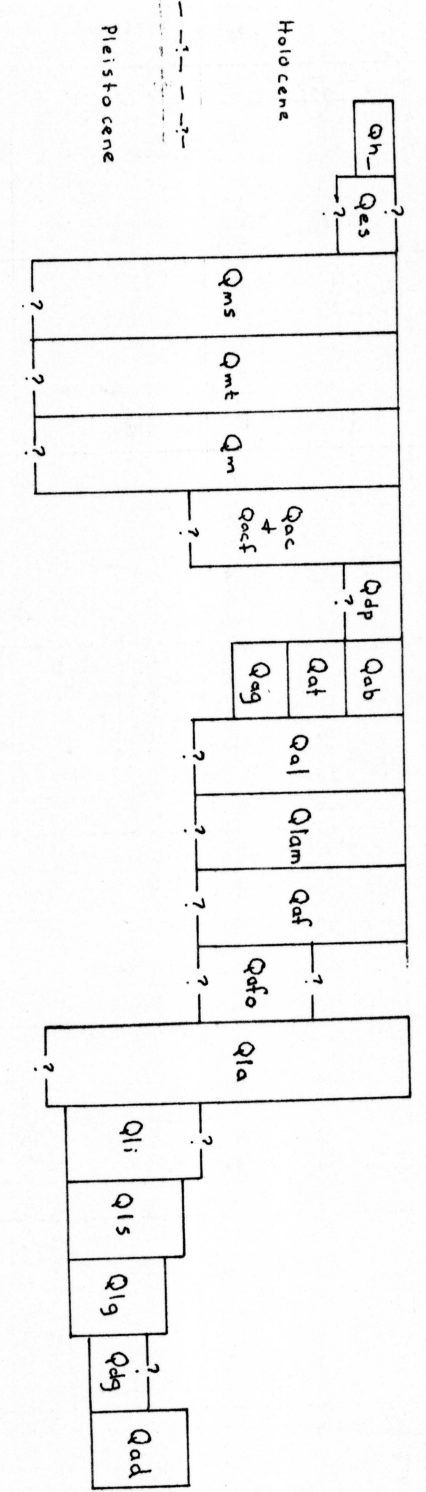


Plate 2
Interim Geologic Map of the Brigham City 7.5-Minute Quadrangle,
Box Elder and Cache Counties, Utah
by
Mark E. Jensen and Jon K. King
Utah Geological Survey Open-File Report 315 February 1995