GEOLOGIC MAP OF THE BEAR LAKE SOUTH QUADRANGLE, RICH COUNTY, UTAH

by
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MISCELLANEOUS PUBLICATION 97-1 1997
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

ISBN 1-55791-383-8

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10/96

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ABSTRACT

The Bear Lake South and adjacent Sheeppen Creek quadrangles cover part of southern Bear Lake Valley, western Bear Lake Plateau, and the eastern foothills of the Bear River Range in Rich County, Utah. Geologic interest in the area has increased in the past two decades because of oil and gas discoveries in adjacent areas of the Wyoming-Idaho-Utah portion of the Cordilleran thrust belt, earthquake hazards along the eastern Bear Lake fault zone, and recreational development demands along the Bear Lake shoreline.

Cambrian, Triassic, Jurassic, and Eocene sedimentary rocks, and Quaternary sediments are exposed in the Bear Lake South quadrangle, and a complete Triassic to Cambrian sedimentary section is known to underlie the surface exposures from outcrops and wells in adjacent areas. The Paleozoic through Jurassic miogeoclinal strata were shortened in a series of north-trending thrust faults and associated folds as part of the Cretaceous to early Eocene Sevier thrust belt. The lower Eocene Wasatch Formation consists of fluvial clastic rocks and lacustrine limestones that were deposited in a piggyback basin after main-phase folding and thrusting.

Principal thrust structures in Bear Lake South quadrangle include the Willard thrust sheet, the subsurface Meade-Laketown thrust sheet, the Gypsum Spring décollement, and folds and imbricate thrusts in the hanging wall of the Home Canyon thrust. Folding of the Gypsum Spring décollement above the Home Canyon thrust sheet and folding of the Home Canyon thrust above Sheep Creek anticline in the adjacent Sheeppen Creek quadrangle together demonstrate that thrust faulting progressed from west to east across the area.

Mesozoic thrust structures are locally overprinted by late Cenozoic extensional faults along the eastern Bear Lake fault zone in eastern Bear Lake South quadrangle, and normal faults that cut the Wasatch Formation in southwestern Bear Lake South quadrangle. The eastern Bear Lake fault zone is the site of several historic earthquakes, and fault scarps in Quaternary sediments along the eastern lakefront indicate earthquake magnitudes of 6.9 to 7.4 for individual rupture events.

Hydrocarbon exploration in the area has centered on attempts to produce gas from the Phosphoria and Dinwoody Formations of the Crawford and Sheep Creek thrust sheets based on production from the Hogback Ridge gas field located 1.5 miles (2.5 km) south of the adjacent Sheeppen Creek quadrangle. Relatively low thermal maturities for Paleozoic source rocks of the Meade-Laketown thrust sheet indicate that buried structures of the thrust sheet may be prospective beneath Bear Lake graben. There is additional potential for hydrocarbon generation from upper Cenozoic lacustrine rocks in Bear Lake graben.

INTRODUCTION

The Bear Lake South and adjacent Sheeppen Creek quadrangles cover part of southern Bear Lake Valley, western Bear Lake Plateau, and the eastern foothills of the Bear River Range in Rich County, Utah. The present valley and plateau morphology across the two quadrangles is the result of late Cenozoic normal faulting along the Bear Lake Valley fault zone. Subsidence of Bear Lake Valley, which lies at elevations near 5,900 feet (1,800

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m), is the result of relative downward displacement of the hanging wall of the eastern Bear Lake normal fault zone. Bear Lake Plateau, which rises above 7,000 feet (2,135 m) elevation, has been formed by relative uplift of flat-lying beds of the Eocene Wasatch Formation in the footwall of the fault zone. The flat-lying Wasatch strata have been dissected by downcutting of the North Eden and South Eden drainages commensurate with lowering of the Bear Lake Valley base level. North-northeast-trending ridges of Jurassic and Triassic strata are exposed along the lower reaches of the North Eden and South Eden drainages where the Wasatch Formation has been completely eroded.

The quadrangles lie near the center of the Wyoming salient of the Early Cretaceous through Eocene Cordilleran fold and thrust belt (Royse and others, 1975; Blackstone and DeBruin, 1987) and are underlain by the Willard, Meade-Laketown, Home Canyon, Sheep Creek, and Crawford thrust faults (figure 1). The thrust structures are locally overprinted by late Cenozoic extensional faults along the eastern Bear Lake normal fault zone. Geologic interest in the area has increased in the past two decades because of oil and gas discoveries in adjacent areas of the thrust belt, earthquake hazards along the eastern Bear Lake fault zone, and recreational development demands along the Bear Lake shoreline.

The area including the Bear Lake South and Sheeppen Creek quadrangles was originally mapped at a scale of 1:125,000 by Richardson (1941) as part of his study of the geology and mineral resources of the Randolph 30′ quadrangle. Willard (1959) mapped the surficial geology of the Bear Lake Valley in Utah. McClurg (1970) mapped part of eastern Bear Lake South and western Sheeppen Creek quadrangles at 1:24,000 scale as part of a geologic study of the North Eden Creek drainage area. Valenti (1980, 1982a, 1982b) mapped the Laketown 7.5′ quadrangle immediately south of the Bear Lake South quadrangle, and discussed oil and gas exploration in the area. Dover (1995) remapped the area during compilation of the Logan 30′ x 60′ quadrangle at a scale of 1:100,000. This report incorporates modern stratigraphic studies and data from oil and gas exploration wells to provide the first detailed description of the surface and subsurface geology of the Bear Lake South and Sheeppen Creek quadrangles. Geologic mapping for this report and a companion report on the Sheeppen Creek quadrangle (Coogan, 1996) was completed in 1988 and 1989 as part of a Ph.D. dissertation (Coogan, 1992a). Please refer to Coogan (1996) for details on the geology of the Sheeppen Creek quadrangle.

The increased stratigraphic resolution of Triassic and Jurassic map units in this report and in Coogan (1996) produced minor disagreement with the adjacent geologic map of the Laketown quadrangle (Valenti, 1980, 1982a, 1982b) along the southeastern border of the Bear Lake South quadrangle. Through the mapping of formation members, a revision to the northeastern corner of the Laketown quadrangle is presented in figure 2 to show the continuity of a thrust fault that places upright hanging wall strata of the Ankareh Formation (Lanes Tongue), Thaynes Formation (Timothy Sandstone and Portneuf Limestone) and Higham Grit over an overturned section of the Ankareh Formation (Wood Shale Tongue) and Nugget Sandstone. The upright orientation of the hanging wall strata is based on the superposition of units. The overturned orientation of footwall strata is likewise based on the superposition of Ankareh and Nugget strata, as well as trough cross-bedding within the Nugget Sandstone and the superposition of Nugget and Twin Creek strata in previously unmapped (Valenti, 1980, 1982a, 1982b) or misidentified (Dover, 1995) outcrops in Pine Canyon.

STRATIGRAPHY

Lower and Middle Cambrian, Triassic, Jurassic, and Eocene rocks, and Quaternary deposits are exposed in the Bear Lake South quadrangle. In addition, a complete Triassic to Cambrian sedimentary sequence has been drilled in the subsurface in the Meade-Laketown thrust sheet beneath Bear Lake Valley in Idaho and in the Crawford thrust sheet of eastern Bear Lake Plateau in Wyoming (Coogan, 1992a). The Paleozoic section of the Meade-Laketown thrust sheet is much thicker than the correlative sections in the Sheep Creek and Crawford thrust sheets. The thickness contrast is the result of regional east-west shortening of the Paleozoic miogeocline to shelf transition along thrust faults. This portion of the text provides detailed descriptions of the exposed stratigraphic units in Bear Lake South and Sheeppen Creek quadrangles. Subsurface stratigraphic units, shown on the structural cross sections (plate 3), are presented in the description of map units (plate 2).

Cambrian

Geertsen Canyon Quartzite (Ꞓgc)

The Lower and Middle Cambrian Geertsen Canyon Quartzite (Crittenden and others, 1971; Crittenden and Wallace, 1973) is exposed along Meadowville anticline in the southwest corner of the Bear Lake South quadrangle. These rocks are part of the upper Proterozoic to Middle Cambrian Brigham Group and were previously mapped as Brigham Quartzite by Richardson (1941) and Valenti (1980, 1982a, 1982b). The quartzite interval designated as the Geertsen Canyon Quartzite in this report follows the usage of Dover (1985), and is based on the similar lithology, stratigraphic position, and thickness of this interval to the upper member of the Geertsen Canyon Quartzite mapped by Crittenden (1972) in the Browns Hole quadrangle along structural trend to the south (leading edge of the Paris-Willard thrust sheet). The Geertsen Canyon Quartzite is medium- to thick-bedded, white to pink, pebble to granule conglomerate and trough cross-bedded sandstone and quartzite. Outcrops immediately adjacent to Bear Lake are penetratively fractured white quartzite and show evidence for hydrothermal alteration such as iron oxide along fractures. The exposed thickness of the Geertsen Canyon Quartzite in the Bear Lake South quadrangle is estimated at over 1,200 feet (365 m). The contact between the Geertsen Canyon Quartzite and the overlying Middle Cambrian Langston Dolomite is exposed 1 mile (1.6 km) west of the quadrangle boundary (Dover, 1995). A cross-section thickness of approximately

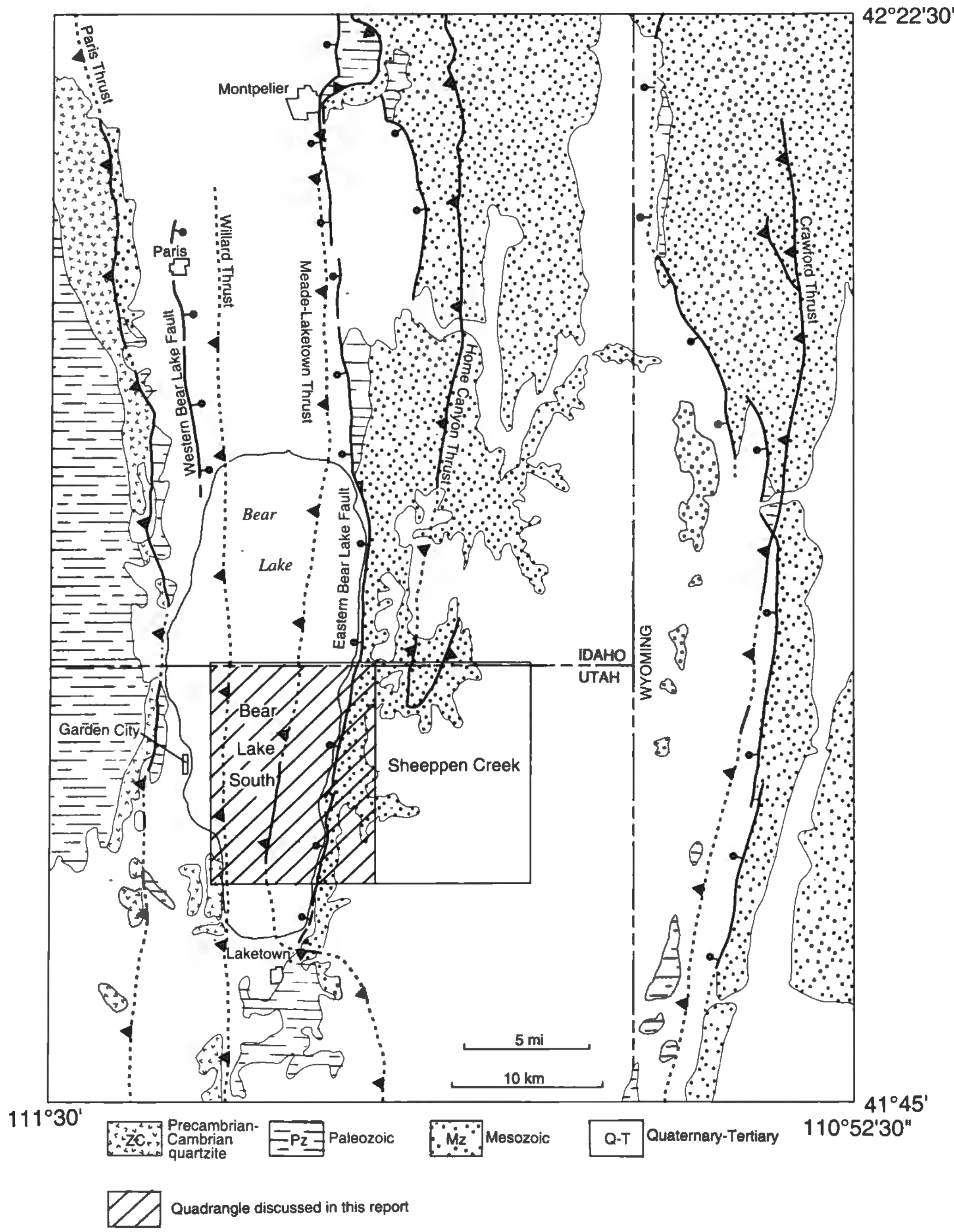

Figure 1. *Geologic index map for the Bear Lake South and Sheeppen Creek quadrangles.*

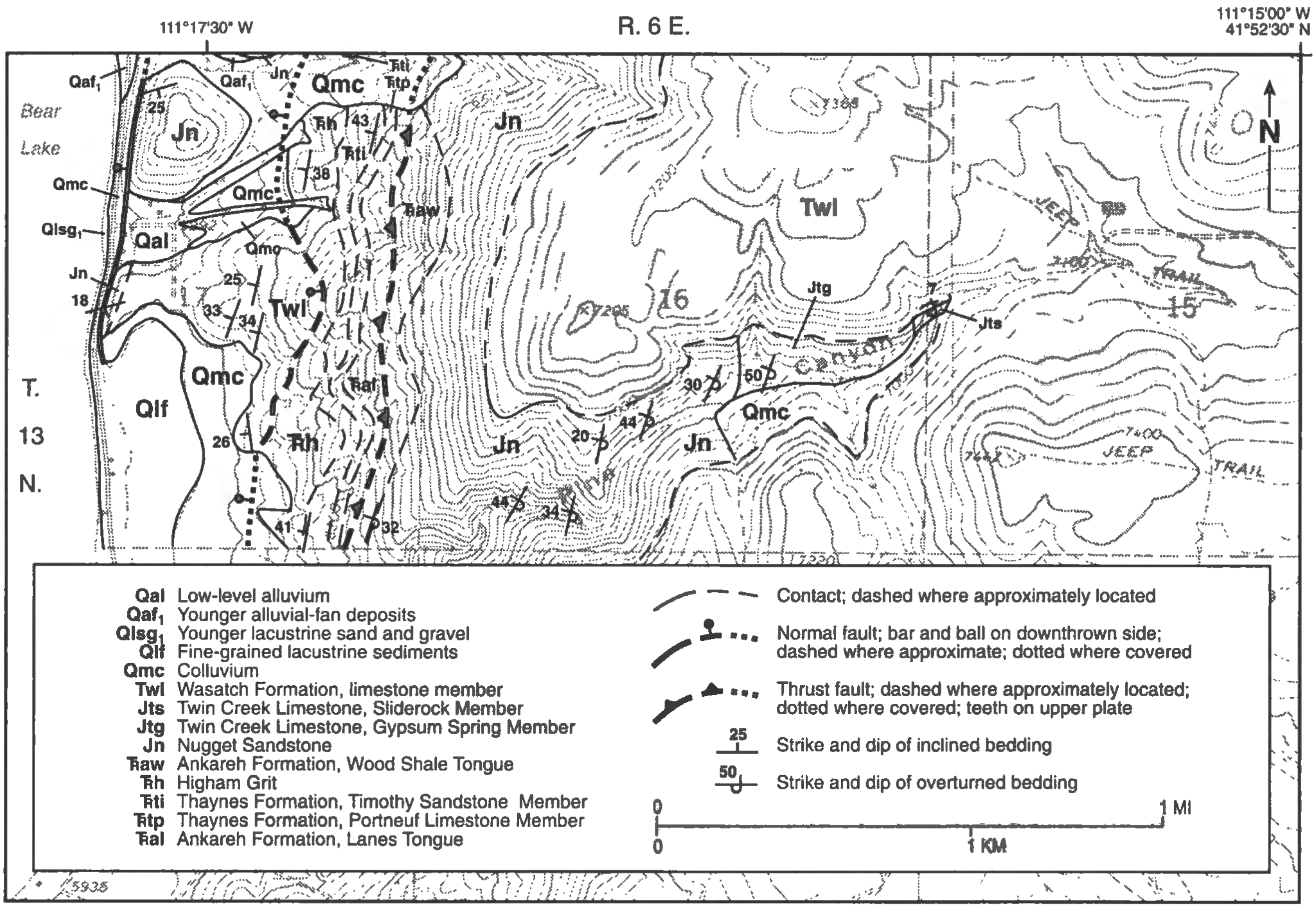

Figure 2. Revised geologic map of the northeastern corner of the Laketown quadrangle from field reconnaissance, air photo interpretation, and modification of mapping by Valenti (1980, 1982a, 1982b).

3000 feet (900 m) is estimated between this contact and the lowest quartzite beds exposed in the core of Meadowville anticline. This thickness is consistent with that measured in the upper member of the Geertsen Canyon in the Browns Hole area (Crittenden, 1972). The throws on normal faults mapped by Dover (1995) between Meadowville anticline and the Langston Dolomite contact are minor and do not significantly affect this estimate.

Triassic

Ankareh Formation

Lanes Tongue (TRal): An incomplete section of the Lower Triassic Lanes Tongue of the Ankareh Formation (Kummel, 1954) is exposed in the southeastern corner of the Bear Lake South quadrangle where it is underlain by a small thrust fault. The Lanes Tongue is dull, dark-red to purple-red shale, siltstone, and fine-grained sandstone that forms slopes below the more resistant and grayish Portneuf Limestone Member of the Thaynes Formation. Kummel (1954) measured 508 feet (155 m) of the Lanes Tongue at the Bear Lake Hot Springs, Idaho section at the northeastern corner of Bear Lake. The Lanes Tongue is 580 feet (176 m) thick in the upper part of the American Quasar #2-41 Eden State well in section 2, T. 14 N., R. 6 E. of the Sheeppen Creek quadrangle.

Thaynes Formation

Portneuf Limestone Member (TRtp): The Lower Triassic Portneuf Limestone Member of the Thaynes Formation (Kummel, 1954) overlies the Lanes Tongue of the Ankareh Formation in the southeastern part of the Bear Lake South quadrangle. The Portneuf Limestone Member contains gray to pink, mottled, thick-bedded, cherty limestone. Chert occurs as gray to brown nodules and lenses that are most abundant in the upper part of the member. The Portneuf Limestone Member is poorly exposed in the southeastern part of the quadrangle. It is 67 feet (23 m) thick at Bear Lake Hot Springs, Idaho (Kummel, 1954), and 64 feet (20 m) in the American Quasar #2-41 Eden State well in the Sheeppen Creek quadrangle. The upper contact of the Portneuf Limestone Member is marked by an abrupt lithologic change to red sandstone, siltstone and shale of the Timothy Sandstone Member of the Thaynes Formation.

Timothy Sandstone Member (Ŧti): The Lower Triassic Timothy Sandstone Member of the Thaynes Formation (Kummel, 1954) is poorly exposed in the southeast corner of Bear Lake South quadrangle. The lower half of the Timothy Sandstone is dominantly red sandstone and dark-red siltstone and shale. The upper part of the Timothy Sandstone consists of gray-green, glauconitic, calcareous, medium-grained sandstone and white, fine-grained sandstone. The measured thickness at Bear Lake Hot Springs, Idaho is 125 feet (38 m) (Kummel, 1954).

Higham Grit (Ŧh):

The Upper Triassic Higham Grit is exposed in the southeastern corner of Bear Lake South quadrangle (Kummel, 1954). The Higham Grit is white to light purple, trough cross-bedded sandstone and pebble conglomerate. A resistant, pebble-conglomerate bed lies above the basal unconformable contact with the less resistant, gray-green Timothy Sandstone (Lower Triassic). The Higham Grit is 135 feet (41 m) thick at Bear Lake Hot Springs, Idaho (Kummel, 1954).

Ankareh Formation

Wood Shale Tongue (Ŧaw): An incomplete section of the Upper Triassic Wood Shale Tongue of the Ankareh Formation (Kummel, 1954) crops out in the southeastern part of the Bear Lake South quadrangle where the section is interrupted by normal faults, and along the Hot Springs anticline. The Wood Shale is composed of bright-red to red-orange siltstone and shale that form slopes below the more resistant Nugget Sandstone. The bright-red color distinguishes the Wood Shale from the underlying Higham Grit and the dull-red Lanes Tongue of the Ankareh Formation. The Wood Shale is 400 feet (120 m) thick where it was measured by Kummel (1954) north of the quadrangle at Bear Lake Hot Springs, Idaho, but approximately 570 feet (175 m) thick in the American Quasar #2-41 well in the Sheeppen Creek quadrangle. The Wood Shale Tongue is separated from the overlying Nugget Sandstone by the regional J0 unconformity (Pipiringos, 1968; Pipiringos and O'Sullivan, 1978). However, the Wood Shale and Nugget Sandstone share an interfingering contact zone in outcrop northeast of Hot Springs, Idaho and in wells through the area. Thus the J0 unconformity may not exist as a discrete surface in the Bear Lake South area.

Jurassic

Nugget Sandstone (Jn)

The Lower Jurassic Nugget Sandstone (Veatch, 1907; Pipiringos, 1968) is exposed continuously along the eastern edge of the Bear Lake South quadrangle where it forms the steepest slopes of the mountain front east of Bear Lake. The unit is medium- to fine-grained, well-rounded, quartz sandstone that occurs in thick to medium, cross-bedded sets. Most of the Nugget Sandstone is friable and distinctively red-orange in color, however the upper 100 to 200 feet (30 to 60 m) of the Nugget is often well-indurated, white sandstone. The white sandstone appears to be the result of bleaching by removal and/or reduction of the iron oxide cements found in the red-orange sandstone. The white sandstone is limited to the uppermost part of the Nugget Sandstone. This stratigraphically restricted diagenesis probably occurred before folding and thrust faulting. The Nugget Sandstone is locally very well cemented by silica along the lakefront ridge of northeastern Bear Lake South quadrangle. Both the upper and lower contacts of the Nugget Sandstone are exposed along a canyon transect of the lakefront ridge immediately south of Cisco Beach, where the cross-section thickness of the Nugget is approximately 1,300 feet (400 m), which is also the thickness in both the American Quasar #2-41 and #12-1 Eden State Federal wells (sections 2 and 12 respectively, T. 14 N., R. 6 E.) in the Sheeppen Creek quadrangle. The upper contact of the Nugget Sandstone is overlain by interbedded red and yellow sandstone and red shale at the base of the Gypsum Spring Member of the Twin Creek Limestone. The regional J1 unconformity (Pipiringos, 1968; Pipiringos and O'Sullivan, 1978) lies along the contact at the base of the lowest, nonresistant, red shale of the Gypsum Spring Member.

Twin Creek Limestone

Gypsum Spring Member (Jtg): The Middle Jurassic Gypsum Spring Member of the Twin Creek Limestone (Imlay, 1967) is exposed along the limbs of Indian Creek syncline and along the lakefront ridge south of South Eden Canyon. The Gypsum Spring Member consists of red shale, siltstone, and sandstone; yellow sandstone; light-gray, gray-brown, and dark-gray dolomite and brecciated dolomite. Anhydrite was noted in all sample logs from wells that penetrated the Gypsum Spring Member, but it is not exposed in outcrop. The Gypsum Spring Member is 350 feet (105 m) thick on the east limb of Indian Creek syncline on the north side of North Eden Canyon in the Sheeppen Creek quadrangle, but it is tectonically thickened elsewhere. The Gypsum Spring Member has a well-defined internal stratigraphy throughout the map area despite structural complications associated with the member, which is an important décollement horizon throughout the region (Coogan and Boyer, 1985). A thin, yellow to orange sandstone lies approximately 25 feet (8 m) above the base of the member. Two of the thicker dolomite beds are useful for mapping the structural deformation of the Gypsum Spring in the study area. The lower dolomite bed lies about 100 feet (30 m) above the base of the Gypsum Spring Member and consists of light-gray to white weathering, light-gray-brown dolomite that is thinly laminated and locally brecciated. The upper dolomite bed consists of gray weathering, dark-gray, pervasively brecciated dolomite that contains many small, calcite-spar-filled vugs, and has a fetid odor when fractured. The base of the upper dolomite bed is mapped as marker horizon "D" in South Eden Canyon and along the west limb of Indian Creek syncline. The main décollement horizon in the Gypsum Spring Member (Gypsum Spring décollement) lies between the two dolomites, although multiple décollement horizons exist within the member. The upper contact of the Gypsum Spring Member is the regional J2 unconformity (Pipiringos, 1968; Pipiringos and O'Sullivan, 1978) located at the base of a ledge where resistant, gray grainstones of the Sliderock Member lie above nonresistant, red shales of the Gypsum Spring Member.

Sliderock Member (Jts): The Middle Jurassic Sliderock Member of the Twin Creek Limestone (Imlay, 1967) forms resistant ridges and ledges along the flanks of Indian Creek syncline and in the fold belt in South Eden Canyon in the Bear Lake South quadrangle. The Sliderock Member is approximately 500 feet (150 m) thick in surface exposures, but it thins to 250 to 300 feet (75 to 90 m) in wells immediately east of the Sheeppen Creek quadrangle. The lower half of the member consists of gray, resistant, sandy, lime packstone to grainstone with pelecypod and crinoid fragments, dominantly from *Gryphaea* and *Pentacrinus*. The upper half of the member consists of lime packstone, wackestone, and micrite. The upper part of the member is less resistant and has more pervasive cleavage than the lower part. Cleavage intensity appears to be related to grain size and clay content, with closely spaced cleavage in clay-rich micrites and widely spaced cleavage and bedding-normal stylolites in lime grainstones. The contact with the overlying Rich Member is lithologically gradational between the packstones and wackestones of the Sliderock Member and the micrites of the Rich Member.

Rich Member (Jtr): The Middle Jurassic Rich Member of the Twin Creek Limestone (Imlay, 1967) is exposed in the South Eden Canyon fold belt in the Bear Lake South quadrangle. The member consists of massively bedded, gray to light-gray, lime micrite with pervasive pencil cleavage at a high angle to bedding. The upper contact, exposed in the Sheeppen Creek quadrangle, is placed at the base of a red-brown shale zone in the overlying Boundary Ridge Member. The Rich Member has undergone a large amount of internal structural thickening and attenuation throughout the area. The Rich Member is 730 feet (220 m) thick on the east flank of Sheep Creek anticline in the northern part of the Sheeppen Creek quadrangle and thins eastward to 550 to 600 feet (165 to 180 m) thick in wells immediately east of the Sheeppen Creek quadrangle.

Tertiary

Wasatch Formation

Gently dipping strata of the Eocene Wasatch Formation overlie a regional angular unconformity above highly folded Paleozoic and Mesozoic rocks in the Bear Lake South and Sheeppen Creek quadrangles. The age of the Tertiary strata of Bear Lake Plateau has been a matter of disagreement between workers in Utah and Idaho. Oriel and Platt (1980) mapped the Tertiary strata in the Bear Lake North and Pegram Creek quadrangles, Idaho as Miocene-Pliocene Salt Lake Formation, whereas Richardson (1941), McClurg (1970), and Valenti (1982a) mapped the same strata as Eocene Wasatch Formation in adjacent areas of Utah. The Tertiary strata in Idaho were dated as Miocene-Pliocene by a single collection of *Lepldorae* teeth from tuffaceous conglomerates in a gravel pit in the northwestern corner of Bear Lake Plateau in the Pegram Creek quadrangle, Idaho (Oriel and Tracey, 1970). Subsequent mapping (Coogan, 1992a, 1992b) demonstrated that these tuffaceous conglomerates overlie redbeds of the Wasatch Formation mapped by Richardson (1941), McClurg (1970), Valenti (1982a), and Dover (1995). The Wasatch redbeds are also overlain and truncated by the Oligocene basalt of Black Mountain in the Sheeppen Creek quadrangle (Coogan, 1996). The only local biostratigraphic control within the Wasatch Formation is from Eocene gastropods in limestones reported by H.P. Buchheim (Loma Linda University, verbal communication, October, 1989) in the vicinity of the southeast corner of the Sheeppen Creek quadrangle. The Wasatch Formation is divided into three informal members for the reports on the Bear Lake South quadrangle and adjacent Sheeppen Creek quadrangle: (1) the quartzite conglomerate member, which is only exposed in the Sheeppen Creek quadrangle; (2) the limestone member; and (3) the main body. The sedimentology, depositional setting, and tectonic implications of the Wasatch Formation of Bear Lake Plateau are discussed by Coogan (1992b). A measured section from the Sheeppen Creek quadrangle is included in the report on the Sheeppen Creek quadrangle (see Coogan, 1996).

Limestone Member (Twl): Eocene limestones are mapped informally as the limestone member of the Wasatch Formation in this report following the usage of Dover (1995). The limestone member of the Wasatch Formation consists of oncolitic limestone, algal limestone, and limestone conglomerate. Oncolites within the limestone are generally 0.5 to 1.5 inches (1.3 to 3.8 cm) in diameter with nuclei of granule-sized chert, quartz, and carbonate grains that are surrounded by concentrically zoned carbonate layers. Laminated limestone and limestone, flat-pebble conglomerate in the limestone member resemble algal-mat structures. Limestone conglomerate beds are made up of coated and non-coated pebbles in a micritic and/or sparry limestone or calcareous, sandstone matrix. The limestone member forms the base of the Wasatch Formation in the Bear Lake South quadrangle. At least two major and many smaller tongues of the limestone member terminate eastward in central and western Sheeppen Creek quadrangle, where they interfinger with the main body of the Wasatch Formation. The limestone member map unit therefore contains a significant amount of the red mudstone, sandstone, and conglomerate lithologies in the Sheeppen Creek quadrangle, along its eastward transition with the main body of the Wasatch Formation. The limestone member thickens southwestward to a maximum preserved thickness of 400 feet (120 m) in southeastern Bear Lake South quadrangle.

Limestone beds in the Wasatch Formation were mapped as the Cowley Canyon Member of the Wasatch Formation by McClurg (1970) in Sheeppen Creek quadrangle, based on its lithologic similarity to the type section of the Cowley Canyon Member south of Logan Canyon, Utah, 17 miles (27 km) southwest of the quadrangle (see Williams, 1948). Direct stratigraphic or biostratigraphic correlation to the Cowley Canyon type section is tenuous and is not justified at this time. The localized distribution of the limestone and its intertonguing relations with the main body of the Wasatch Formation indicate that the Cowley Canyon and Bear Lake Plateau limestone beds may have been deposited in separate local basins at different times (compare Oaks and Runnells, 1992; and Coogan, 1992a, 1992b).

Main Body (Tw): The main body of the Wasatch Formation consists of poorly exposed red and red-orange mudstone, sandstone, and minor conglomerate. Mudstone comprises approximately 85 percent of the main body along the eastern boundary of the Sheeppen Creek quadrangle, where it is interbedded with laterally discontinuous channel sandstone beds and conglomeratic sandstone beds. Conglomerate beds in the main body are locally well developed along the western shore of Bear Lake in the Bear Lake South quadrangle and near the headwaters of South Eden Creek in the Sheeppen Creek quadrangle. Detailed descriptions of the main body are included in the appendix (measured section) of the report on the Sheeppen Creek quadrangle (see Coogan, 1996). The main body is up to 700 feet (210 m) thick beneath Black Mountain in the Sheeppen Creek quadrangle and up to 600 feet (180 m) thick beneath the plateau surface of eastern Sheeppen Creek quadrangle. The main body interfingers westward with the limestone member of the Wasatch Formation.

Quaternary

The Quaternary system is represented by a wide variety of alluvial, deltaic, lacustrine, and mass-wasting surficial deposits. The distribution of Quaternary deposits in Bear Lake South quadrangle is directly related to the tectonically influenced subsidence and sedimentation history of Bear Lake Valley, and the resultant changes in the position of the Bear Lake shoreline. Bear Lake presently lies in a closed drainage basin in which the lake is supplied by streams draining the Bear River Range to the west and Bear Lake Plateau to the east. Bear Lake has existed for at least 28,000 years in southern Bear Lake Valley (Williams and others, 1962), during which time there may have been multiple periods of lake expansion and connection to the Bear River. The internal stratigraphy of Bear Lake basin is poorly known, and no consistent correlation scheme has yet been proposed for the basin. Robertson (1978) used results from shallow, jet-rig-borehole sampling to propose four episodes of Pleistocene through Holocene deposition, based on the correlation of interpreted shoreline facies between boreholes. From oldest to youngest, Robertson's (1978) episodes include the Ovid, Liberty, Wardboro, and Lifton episodes. The Wardboro episode is mainly represented by loess deposition, and it is the only episode which can be lithologically correlated to other studied sites within the basin. The Wardboro loess may be correlative with the thick loess and reworked loess succession dated between 12.2 and 7.6 thousand years ago by McCalpin (1990), based on radiocarbon ages and accumulation-rate estimates in samples from fault-scarp trenches on North Eden delta. Thus, the Wardboro loess may provide a correlation datum that spans the Pleistocene-Holocene boundary. Williams and others (1962) recognized three Holocene high-stand shoreline stages based on surface terrace and bar morphologies along the south, west, and north sides of the lake that are radiocarbon dated between 8.3 and 7.7 thousand years ago. These stages are the Willis Ranch stage at 5,948 feet (1,813 m), the Garden City stage at 5,938 feet (1,810 m), and the Lifton stage at 5,929 feet (1,807 m) elevation. These stages cannot be confidently correlated to the east side of the lake because of local tilting and faulting along the eastern Bear Lake fault zone. Descriptions of the Quaternary deposits of Bear Lake South quadrangle are presented in order of relative age, from oldest to youngest.

Older Deltaic Deposits (Qd_2)

Older deltaic deposits are unconsolidated, crudely stratified gravel, sand, and silt located between 5,980 and 6,160 feet (1,823 and 1,876 m) elevation at the mouths of North Eden and South Eden Canyons. Younger deltaic deposits (Qd_1) are incised into these deposits. The older deltaic sediments were deposited as part of alluvial fans and deltas, and some beaches that formed during middle late Pleistocene(?) time (McCalpin, 1990), possibly during the Ovid and Liberty episodes of deposition associated with the oldest recorded highstands of Bear Lake recognized by Robertson (1978) in northern Bear Lake Valley, Idaho. The estimated range of thicknesses for the older deltaic deposits is 0 to 180 feet (0 to 55 m).

Older Lacustrine Sand and Gravel ($Qlsg_2$)

Unconsolidated sand and gravel along State Highway 30 in the southwestern corner of Bear Lake South quadrangle compose the older lacustrine sand and gravel map unit. These deposits are near and above 5,940 feet (1,811 m) elevation, and are associated with the Willis Ranch shoreline of Williams and others (1962). These elevated beach and shoreline deposits may be associated with the Liberty and/or Wardboro episodes of Bear Lake deposition recognized by Robertson (1978). If these deposits are correlative to the Liberty and Wardboro episodes, they are latest Pleistocene and early Holocene in age (see McCalpin, 1990). The older lacustrine sand and gravel varies from 0 to approximately 30 feet (0 to 9 m) in thickness.

Fine-grained Lacustrine Sediments (Qlf)

Poorly exposed, unconsolidated, fine-grained lacustrine sediments were mapped in the southwestern corner of the Bear Lake South quadrangle at lower elevations than adjacent beach deposits ($Qlsg_2$). The map unit probably includes lagoonal and marsh sediments deposited behind the beach deposits ($Qlsg_2$). The fine-grained lacustrine sediments were interpreted by Robertson (1978, p. 68) as associated with the Liberty episode of deposition in northern Bear Lake Valley, Idaho. If associated with the Liberty episode, the deposits are latest Pleistocene and early Holocene in age. These fine-grained deposits are approximately 0 to 40 feet (0 to 12 m) thick.

Younger Deltaic Deposits (Qd_1)

Unconsolidated, crudely stratified and stratified gravel, sand, and silt capped by loess were mapped as younger deltaic deposits. They are between approximately 6,000 and 5,935 feet (1,829 and 1,809 m) in elevation on North Eden and South Eden deltas. The deposits have a delta form and are incised into the older deltaic deposits (Qd_2). The younger deposits actually include interbedded sediments that were deposited in a variety of beach, lagoon, alluvial-fan, alluvial-channel, and delta-plain environments from latest Pleistocene into Holocene time (McCalpin, 1990). Radiocarbon ages of 12.78 ± 0.14 ka and 9.15 ± 0.11 ka were reported from the base of a 5-foot-thick (1.5 m), capping loess and reworked loess interval by McCalpin (1990), that may be correlative to the Wardboro Loess mapped by Robertson (1978) in northern Bear Lake Valley, Idaho. These younger deltaic deposits are cut to the east by Holocene fault scarps along the eastern Bear Lake fault zone, and are locally crossed to the west by arcuate and linear ridges of sand and gravel interpreted as beach deposits along former shorelines of Bear Lake. Two sets of beach ridges are mapped across North Eden and South Eden deltas from air photos. The two shorelines record a relative decrease in the Bear Lake elevation through late Pleistocene and Holocene time and have a slight west to southwest tilt that might be caused by tectonic rotation associated with normal faulting and/or compaction of underlying sediments in the Bear Lake graben. The thickness of the younger deltaic deposits ranges from 0 to 75 feet (0 to 23 m).

Alluvium (Qa)

Alluvium consists of unconsolidated gravel, sand, silt, and clay located in a small area east of the Nugget Sandstone ridge between North and South Eden canyons, the eastern reach of Little Creek, and Cottonwood Creek south of South Eden Canyon. The age(s) of these general alluvial deposits (Qa) is/are difficult to establish relative to Holocene low-level alluvium (Qal) because these two units are not in contact. However, east of the Nugget Sandstone ridge, the alluvium (Qa) appears to locally grade into colluvial deposits (Qmc) that might be older than low-level alluvium (Qal). Thus, general alluvium (Qa) is considered the same age as and/or older than the Holocene low-level alluvium. The alluvium is 0 to 10 feet (0 to 3 m) thick.

Landslides and Slumps (Qms)

Small landslides and slumps are present on slopes underlain by the Wasatch Formation and Twin Creek Limestone near the Indian Creek syncline on the eastern edge of the Bear Lake South quadrangle. These mass-movement deposits originated in the Sheeppen Creek quadrangle (see Coogan, 1996). Landslide and slump deposits are Holocene and possibly older in age, and are generally less than 100 feet (30 m) thick.

Talus (Qmt)

Talus deposits are composed of unconsolidated, matrix-free, angular, pebble- to boulder-sized debris. These deposits are common on the steep lakefront dipslopes of Nugget Sandstone where the talus fills in gullies along the mountain front, and coalescing talus cones form where the gullies terminate above Bear Lake. Talus is Holocene and possibly older in age. Talus deposits are generally less than 10 feet (3 m) thick on Nugget slopes, but may be as thick as 50 feet (15 m) in talus cones at the base of slopes.

Colluvium (Qmc)

Colluvium consists of unconsolidated and largely unstratified, mostly angular, silt- to boulder-sized debris that is present along the lakefront ridges and the sides of major drainages. Along Bear Lake, colluvium is present below exposures of Geertsen Canyon Quartzite on the west side of the lake and the Nugget Sandstone on the east side of the lake. Colluvial deposits lie immediately down slope from bedded outcrops of the Wasatch Formation in the eastern part of Bear Lake South quadrangle. Colluvial deposits are Holocene and possibly older in age, and are generally 0 to 20 feet (0 to 6 m) in thickness.

Younger Lacustrine Sand and Gravel ($Qlsg_1$)

Younger lacustrine sand and gravel comprise unconsolidated deposits that form the present shoreline of Bear Lake near the normal lake elevation of 5,923 feet (1,805 m), modern storm beaches near 5,930 feet (1,807 m) elevation, and deposits at higher elevations. These deposits are associated with the Holocene Lifton and Garden City shorelines recognized by Williams and others (1962). These shoreline deposits were included in the Lifton episode of deposition in Bear Lake Valley (≤8,000 years ago) by Robertson (1978). The younger lacustrine sand and gravel deposits vary from 0 to 15 feet (0 to 5 m) thick.

Deltaic Marsh Deposits (Qdma)

Saturated, unconsolidated mud and sand are present in a marsh at the south end of North Eden delta. The marsh lies a few feet above lake level and it is separated from the lake by a Holocene beach ridge of younger lacustrine sand and gravel along Cisco Beach ($Qlsg_1$). The marsh deposits are Holocene in age and less than 10 feet (3 m) thick.

Younger Alluvial-Fan Deposits (Qaf_1)

Younger alluvial-fan deposits are unconsolidated, crudely stratified, poorly sorted, clay- to boulder-sized material forming fan-shaped deposits at the mouths of small, steep drainages along the eastern shore of Bear Lake, and the mouths of small tributary drainages to South Eden Creek. These deposits grade laterally into Holocene low-level alluvium (Qal), and are 0 to 40 feet (0 to 12 m) thick. Older alluvial fans are present in the Sheeppen Creek quadrangle (see Coogan, 1996).

Low-Level Alluvium (Qal)

Unconsolidated deposits of gravel, sand, and mud that lie in the valley bottoms of North Eden and South Eden canyons were mapped as low-level alluvium. Valley gradients are graded to, and slightly above, modern Bear Lake levels, so the deposits are Holocene in age. The grain size and mineral constituents of alluvium in North Eden Canyon were reported by McClurg (1970). These alluvial deposits are generally less than 15 feet (5 m) thick.

STRUCTURE

Introduction

The Bear Lake South quadrangle is located in the center of the Wyoming salient of the Cordilleran fold and thrust belt where Cretaceous to early Tertiary thrust-related structures are overprinted by late Tertiary and Quaternary normal faults. The principal thrust faults that controlled the early structural development of the area include: (1) the Willard thrust fault, the trace of which is located in the subsurface of the western Bear Lake South quadrangle; (2) the Meade-Laketown thrust fault located beneath Bear Lake in the Bear Lake South quadrangle; (3) the Home Canyon thrust, which crops out in the northern Sheeppen Creek quadrangle (see Coogan, 1996) and is only present in subsurface in the Bear Lake South quadrangle; (4) imbricate thrust faults exposed in southeastern Bear Lake South quadrangle; (5) the Sheep Creek thrust, which has been drilled beneath the Sheeppen Creek quadrangle (see Coogan, 1996) and is only present in subsurface in the Bear Lake South quadrangle; and (6) the Gypsum Spring décollement, which crops out in South Eden Canyon in the Bear Lake South quadrangle. Folds in the map area are generally related to thrust faulting. The eastern Bear Lake fault zone transects the earlier formed thrust faults and folds along the Bear Lake shorefront in eastern Bear Lake South quadrangle. Refer to Coogan (1996) for descriptions of structural features in the Sheeppen Creek quadrangle, and Coogan (1992a) for details on the structural geology of the area.

Thrust Faults

Willard Thrust Fault (not exposed)

The subsurface trace of the Willard thrust is mapped along the western side of the Bear Lake South quadrangle, east of highly sheared outcrops of the Geertsen Canyon Quartzite along the east limb of Meadowville anticline. The location of the concealed trace is based on this shearing and folding, and Geertsen Canyon Quartzite outcrops of the Willard hanging wall are projected into the Bear Lake South quadrangle along a trend of Geertsen Canyon exposures above the Willard thrust trace that originate in the Woodruff Creek-Walton Canyon, Utah, area 25 miles (43 km) to the south. Although the inferred Willard thrust trace is covered in the quadrangle, there is approximately 6,000 feet (1,800 m) of stratigraphic throw between the Geertsen Canyon Quartzite and outcrops of the Ordovician Garden City Limestone in the thrust footwall in the northwestern Laketown quadrangle (Valenti, 1982a, 1982b). Willard thrust footwall rocks are not exposed in the Bear Lake South quadrangle. North of the quadrangle, the buried Willard thrust trace is thought to be continuous with an imbricate thrust in front of the Paris thrust trace; the imbricate thrust has been defined using seismic reflection data and was penetrated by the Murphy Oil #1 Worm Creek well (section 34, T. 14 S., R. 43 E.) and Texaco #1 Archie Parker well (section 8, T. 13 S., R. 43 E.) in Idaho (Coogan and Royse, 1990).

Meade-Laketown Thrust Fault (not exposed)

Subsurface correlation between wells in Bear Lake Valley, Idaho and the Laketown quadrangle, Utah demonstrate that the Meade-Laketown thrust sheet underlies Bear Lake graben in the Bear Lake South quadrangle (Coogan, 1992a). The Meade thrust fault is exposed north of the Bear Lake South quadrangle where it places Mississippian rocks over Triassic and Jurassic strata near Meade Peak and Montpelier Canyon, Idaho. Wells in northern Bear Lake Valley, Idaho (Ladd Petroleum Bennington 3-24, section 3, T. 12 S., R. 46 E.; and American Quasar Jensen 22-1, section 22, T. 13 S., R. 44 E.) penetrated the Meade thrust sheet (Coogan, 1992a), which carries the same stratigraphic section in the same structural position as the Meade(?) thrust mapped by Valenti (1982a, 1982b) at Laketown, Utah. As a result, the Meade-Laketown thrust is used here to describe the continuous thrust sheet that underlies Bear Lake Valley between Meade Peak, Idaho and Laketown, Utah.

Imbricate Thrust Faults Southeast of Bear Lake

A complex zone of broken folds and thrust faults involves Triassic and Jurassic strata in the southeastern part of the Bear Lake South quadrangle. The southernmost thrust places a west-dipping panel of Thaynes Formation (Portneuf Limestone and Timothy Sandstone), Higham Grit, and Ankareh Formation (Lanes and Wood Shale Tongues) over overturned Nugget Sandstone beds in section 9, T. 13 N., R. 6 E. Immediately northeast, a second thrust trace places the Nugget Sandstone over an upright section of the Gypsum Spring Member. The opposing dips of the strata separated by the two thrust faults, indicate that the faults probably formed by failure along the axial plane and front limb of a preexisting overturned anticline.

Farther north, a third thrust is exposed at the mouth of South Eden Canyon. The thrust places overturned and tightly folded Nugget Sandstone of the east limb of Hot Springs anticline against upright Nugget Sandstone and Gypsum Spring Member in the footwall. Like the two thrusts to the south, this thrust lies in the hanging wall of the Home Canyon thrust, and the thrust appears to have formed by failure along the axial plane of a preexisting fold, which, in this case, is Indian Creek syncline. The fault had been mapped in previous studies as a major throughgoing thrust that was continuous into Idaho north of the quadrangle (McClurg, 1970; Oriel and Platt, 1980; Blackstone and DeBruin, 1987; Dover, 1995). Mapping in this report indicates that the fault is only exposed near South Eden Canyon and has limited stratigraphic throw. Although it may continue to the north beneath the Gypsum Spring décollement, it is not considered to be present as far north as cross section A-A′ (plate 3). Late reactivation of the thrust plane as a normal fault is evident by the offset of both older and younger Quaternary delta deposits at the mouth of South Eden Canyon at the south end of the fault.

A fourth imbricate thrust fault is exposed 0.6 miles (1 km) east of the mouth of South Eden Canyon. This thrust places Nugget Sandstone over the Gypsum Spring Member. The thrust merges northward with the overlying Gypsum Spring décollement. The four thrust faults in the southeastern Bear Lake South quadrangle are believed to be hanging wall imbricates of the

Home Canyon thrust, which is exposed to the northeast in the Sheeppen Creek quadrangle and exhibits similar repetition of Triassic and lower Jurassic strata.

Gypsum Spring Décollement

Anhydrite beds in the Gypsum Spring Member of the Twin Creek Limestone form important local décollement horizons throughout the thrust belt (Coogan and Boyer, 1985). The Gypsum Spring décollement in the eastern Bear Lake South quadrangle forms the footwall décollement zone for the imbricate thrusts in South Eden Canyon and along the lakefront slope to the south, as well as the upper décollement, or "roof thrust" (Boyer and Elliott, 1982) to the eastern imbricate thrust and folds in South Eden Canyon. In Bear Lake South quadrangle, the décollement is best exposed immediately north of South Eden Canyon, where it underlies Indian Creek syncline. The approximate position of the décollement is delineated by tight folding in the upper dolomite bed (bed "D" in plate 1) of the Gypsum Spring Member that is disharmonic with respect to folds in the underlying Nugget Sandstone. In the Sheeppen Creek quadrangle, the Gypsum Spring décollement forms the frontal décollement zone of the Home Canyon thrust, and forms the footwall décollement of the blind Sheep Creek thrust; it also underlies the tight folds in the Twin Creek Limestone in the North Eden and South Eden fold belts. Folding of the Gypsum Spring décollement by underlying structures of the Home Canyon and Sheep Creek thrust sheets is consistent with a general sequence of thrusting getting younger to the east across the map area.

Crawford Thrust Fault (not exposed)

West-dipping Cambrian through Jurassic rocks of the Crawford thrust sheet underlie the Bear Lake South and Sheeppen Creek quadrangles (cross sections A-A′ and B-B′). The west dip of the thrust sheet reflects folding above the principal footwall ramp of the Crawford thrust, along which the thrust cuts obliquely across Cambrian through Jurassic strata. The location of the ramp is to the east beneath Sheeppen Creek quadrangle (Coogan, 1996) and is constrained by well control and seismic-reflection data.

Folds

Meadowville Anticline

Meadowville anticline is an overturned, east-vergent anticline in the Geertsen Canyon Quartzite located at the southwestern corner of Bear Lake South quadrangle. The anticline plunges to the north, with 10 to 35 degree northwest and west dips on the west limb, and 60 to 70 degree overturned west dips on the east limb. The overturned east limb of the fold is extensively sheared. The quartzite shows evidence of hydrothermal alteration relative to the less well-cemented quartzite of the western limb. Trough cross strata and other subtle bedding features are widely preserved on the western limb, but are largely obliterated on the eastern limb by fracturing and alteration. The strong asymmetry and vergence of the fold as well as the deformation of the eastern limb indicate that the anticline directly overlies a buried thrust fault. The Willard thrust is projected into the quadrangle beneath the Meadowville anticline because these exposures are along a trend of Geertsen Canyon Quartzite exposures that originate above the Willard thrust trace in the Woodruff Creek-Walton Canyon, Utah, area 25 miles (43 km) to the south.

Hot Springs Anticline

Mansfield (1927) named and mapped the north-south- trending Hot Springs anticline for a distance of about 10 miles (16 km) along the western edge of Bear Lake Plateau in Idaho, north of the Bear Lake South quadrangle. Hot Springs anticline is cored by the lower part of the Pennsylvanian Wells Formation north of Bear Lake Hot Springs at the northeast corner of Bear Lake. The east limb and the southeastern part of the south-plunging nose of the anticline in the Triassic Thaynes Formation were mapped by McClurg (1970) one mile (1.6 km) north of the Bear Lake South quadrangle. In the northeastern part of the Bear Lake South quadrangle, the south-plunging anticlinal nose is expressed by a lone outcrop of the Wood Shale Tongue of the Ankareh Formation on the overturned east limb in section 9, T. 14 N., R. 6 E., and by shallow west limb dips in the Nugget Sandstone in section 16 (same township). Elsewhere, the west limb is absent where it is buried in the hanging wall of the Bear Lake normal fault. The overturned panel of Nugget Sandstone on the east limb of Hot Springs anticline forms the persistent lakefront ridge along the northeast and east-central part of the Bear Lake South quadrangle. This east limb is underlain by a thrust fault near the mouth of South Eden Canyon. As discussed previously, the fault may be related to failure of the overturned synclinal hinge beneath the east limb of Hot Springs anticline. Overall, the steep forelimb and faulted synclinal hinge east of Hot Spring anticline are consistent with models of fault propagation folds (Mitra, 1990; Suppe and Medwedeff, 1990). The anticline is interpreted as a fault-propagation fold along an imbricate thrust that joins the Home Canyon thrust at depth.

Folds in Nugget Sandstone in South Eden Canyon

The folds beneath the Gypsum Spring décollement in South Eden Canyon in the Bear Lake South quadrangle are interpreted as small fault-bend folds (Suppe, 1983) that are associated with small displacement imbricate thrusts that sole at depth into the Home Canyon thrust.

Indian Creek Syncline

Indian Creek syncline is a gently north-plunging fold in the Twin Creek Limestone that lies along the boundary between Bear Lake South and Sheeppen Creek quadrangles north of South Eden Canyon. The syncline is underlain southward by the Gypsum Spring décollement. Indian Creek syncline is an asymmetric syncline with west limb dips up to 80 degrees east and very shallow east limb dips. Along the west limb of the syncline, the moderately to steeply east-dipping Sliderock Member is decoupled from the overturned, west-dipping Nugget Sandstone by a general zone of disharmonic folding and detachment in the Gypsum Spring Member, rather than by a single discrete décollement surface.

South Eden Fold Belt

Folds in the Twin Creek Limestone along South Eden Canyon in Sheeppen Creek and eastern Bear Lake South quadrangles form the South Eden fold belt. The westernmost folds are exposed in the Cottonwood Creek drainage in Bear Lake South quadrangle as an inverted anticline-syncline pair in the Gypsum Spring, Sliderock, and Rich Members. Combined with exposures in the Sheeppen Creek quadrangle, the inverted folds comprise the 0.5-mile-wide (0.8 km), recumbent limb of an overturned synform. The well control in cross section B-B′ (plate 3) indicates that the synform lies in the hanging wall of the Home Canyon thrust. In addition, the synform has a top-to-east shear sense, possibly as the result of fault-parallel shear immediately beneath a large displacement, east-directed thrust fault, such as the Meade-Laketown thrust (figure 1). The Meade-Laketown thrust is now eroded above the synform as well as displaced westward along the eastern Bear Lake normal fault zone (plate 3).

Normal Faults

Eastern Bear Lake Fault Zone

The steep mountain front along the eastern shore of Bear Lake is the main morphologic feature of the eastern Bear Lake fault zone. The mountain front does not exhibit the true facets often associated with eroded fault scarps. Instead, the slope of the mountain front reflects the dip of the Nugget Sandstone that forms the main lakefront ridges. The eastern Bear Lake South quadrangle lies along the southern segment of the eastern Bear Lake fault zone, between segment boundaries near Dingle, Idaho and Laketown, Utah (McCalpin, 1990). A continuous series of fault scarps offset Quaternary surficial deposits along the lakefront in a zone of faulting that shows significant Holocene displacement. The fault scarps are developed in older and younger deltaic deposits of North Eden and South Eden deltas and in colluvium and alluvial-fan deposits at the base of the lakefront ridge. McCalpin (1990) estimated that there has been 75 feet (23 m) of total throw since the late Pleistocene across two fault scarps that were trenched on the North Eden delta, including 34 feet (10 m) of throw in the past 4,600 years. Several normal faults cut Jurassic and Triassic strata south of South Eden Canyon in a left-stepping, echelon pattern. The left-stepping pattern may be the result of southward displacement transfer toward the southern termination of the eastern Bear Lake fault, similar to the left-stepping pattern reported by McCalpin (1990) at the north end of the southern segment of the eastern Bear Lake fault zone near Hot Springs, Idaho. The left-stepping fault pattern may be inherited from preexisting zones of weakness along thrust structures. For example, the eastern Bear Lake fault zone trends near the axial trace of Hot Springs anticline between Dingle, Idaho and South Eden Canyon; the fault zone then steps east along the main thrust décollement horizon of the Gypsum Spring Member between South Eden Canyon and the Bear Lake Boy Scout Camp; and finally, the fault zone steps eastward to include the normal faults in Triassic and Jurassic rocks within the southernmost imbricate thrust sheet at the south end of the quadrangle.

The individual surface features of the fault zone exhibit relatively minor displacement; however, seismic-reflection data from the north end of Bear Lake indicate that, given a range of realistic seismic velocities, there are between 10,500 and 13,500 feet (3,200 and 41,15 m) of Tertiary through Quaternary sediments beneath eastern Bear Lake Valley (F. Royse, Jr., Chevron U.S.A., verbal communication, 1987), which are probably floored by the unconformity at the base of the Wasatch Formation. Deposition of upper Miocene Salt Lake Formation strata in Bear Lake Valley, Idaho (Yen, 1946) is the earliest record of the growth of Bear Lake graben. Therefore, given a 60 degree west dip on the Bear Lake fault zone, the thickness of graben-fill sediments, and the present 7,000 foot (2,134 m) elevation of the basal Wasatch Formation unconformity east of the fault zone, there has been displacement of approximately 12,300 to 16,700 feet (3,759 to 5,100 m) on the eastern Bear Lake normal fault zone since late Miocene time.

Western Bear Lake Fault Zone

Two normal faults in southwestern Bear Lake South quadrangle may be a southern extension of the western Bear Lake fault zone mapped by McCalpin (1990) near Bloomington, Idaho. The southern fault dips steeply to the northeast and juxtaposes the Cambrian Geertsen Canyon quartzite in the footwall against the Wasatch Formation in the hanging wall. The northern fault dips 62 degrees toward the northwest where it cuts the Wasatch Formation in a roadcut on Utah Highway 30. Unlike the faults at Bloomington, however, there is no offset of exposed Quaternary units in southwestern Bear Lake South quadrangle.

ECONOMIC GEOLOGY

Oil and Gas

The Wyoming-Idaho-Utah portion of the Cordilleran thrust belt was the site of extensive oil and gas exploration which culminated in the discovery of 27 oil and gas fields from 1975 to 1982 (Kluth and Lamerson, 1988). At present, economic production is limited to 24 fields on the southern Absaroka thrust sheet, where hanging wall anticlines in Mesozoic and Paleozoic reservoir rocks are juxtaposed against footwall Cretaceous source rocks (Lamerson, 1982; Warner, 1982).

No exploration wells have been drilled in Bear Lake South quadrangle, and no hydrocarbon shows were reported from four wells drilled through Triassic and Paleozoic rocks of the Meade thrust and the Paris thrust footwall in Bear Lake Valley, Idaho. However, exploratory wells were drilled in the Sheeppen Creek and surrounding quadrangles. Information from these wells provide an insight into petroleum potential in the Bear Lake South quadrangle.

The Sheeppen Creek quadrangle became an exploration target following the October, 1977 discovery of Hogback Ridge field, a subsurface anticline located in section 20, T. 3 N., R. 7 E. on the hanging wall of the Crawford thrust, 1.5 miles (2.5 km) south of the quadrangle. Hogback Ridge field produced a total of 5.8 billion cubic feet (164.24 million cubic meters) of dominantly methane and nitrogen gas from fractured carbonate reservoir intervals in the Dinwoody Formation (Triassic) until depletion and abandonment in 1981 (Walker, 1982). Two of the three offset wells to the field yielded gas shows in Triassic and Permian intervals without commercial flows. Fourteen other wells were drilled to test Triassic and Permian reservoirs of the Crawford and Sheep Creek thrust sheets in the Sheeppen Creek and adjacent quadrangles (Clem and Brown, 1985; Coogan, 1992a). Of these, the Marathon #1-15 South Eden Canyon well (section 15, T. 13 N., R. 6 E.), 1,800 feet (550 m) south of Bear Lake South quadrangle, reported three minor gas shows on drill-stem tests in imbricated Triassic rocks beneath the Sheep Creek thrust sheet; and the American Quasar #14-44 Nebeker well (section 14, T. 14 N., R. 7 E.) 4,000 feet (1,200 m) east of Sheeppen Creek quadrangle (see Coogan, 1996) reported minor gas on a drill stem test in the Dinwoody Formation of the Crawford thrust sheet. No shows were reported in the two wells drilled in the Sheeppen Creek quadrangle (#2-41 Eden and #12-1 Eden) in the Sheep Creek thrust sheet.

The main limitation for the traditional hydrocarbon plays in the area appears to be the timing of anticlinal traps with regard to source rock thermal maturation. Marine Cretaceous rocks, which are the source for hydrocarbon accumulations in the Absaroka thrust sheet, are absent in the footwall of thrust sheets in and adjacent to the Bear Lake South quadrangle. The presumed source rock for all reported hydrocarbon shows in the area are phosphatic shales of the Permian Phosphoria Formation. The lack of complex hydrocarbons in Hogback Ridge gas analyses indicates that hydrocarbon generation from Phosphoria source rocks may have been limited to a very mature phase of residual dry gas generation near the time of structural entrapment. Peak Phosphoria hydrocarbon generation and expulsion probably preceded thrust sheet emplacement and associated folding in this part of the thrust belt (Warner, 1982; Valenti, 1987), and probably coincided with initial burial of the area beneath the foreland basin clastic wedge in early Cretaceous time (Aronson and Elliott, 1985). However, Mississippian rocks of the Meade-Laketown thrust sheet exposed near Laketown, Utah have relatively low conodont alteration indices of 1.5 to 2 (Sando and others, 1981). Phosphoria samples from the Meade hanging wall near Soda Springs, Idaho also have low thermal maturities (Desborough and others, 1988), which indicate that upper Paleozoic rocks of the Meade-Laketown thrust sheet may not have been as deeply buried prior to thrusting and folding as rocks of the Crawford and Absaroka thrust sheets to the east, and they may be capable of further hydrocarbon generation. Thus, areas of the Meade-Laketown thrust sheet beneath Bear Lake Valley remain prospective for hydrocarbon generation.

The Tertiary basin in Bear Lake graben may also be prospective for minor hydrocarbon accumulations. A thick accumulation of Pliocene-Miocene Salt Lake Formation rocks is portrayed on the cross sections from seismic-reflection data. Using the Cache Valley and Great Salt Lake basin, Utah as analogs, deep burial of Salt Lake Formation lacustrine source rocks in the Bear Lake basin depocenter could generate hydrocarbons for entrapment in sandstone or other reservoirs that intertongue with finer grained rocks (see Bortz, 1984). Minor oil and gas production from Tertiary grabens has been established elsewhere in northern Utah in the Rozel Point field north of Great Salt Lake in Box Elder County (Kerns, 1987), and locally in the Cache Valley north of Logan (Clem and Brown, 1985).

Building Materials

Sand and Gravel

Sources of well-rounded sand and gravel include Quaternary deltaic and lacustrine sediments along North Eden and South Eden deltas, particularly lacustrine beach and bar deposits, as well as individual, poorly consolidated gravel beds in the Wasatch Formation. Colluvial aprons and alluvial fans locally contain poorly sorted angular gravel adjacent to Geertsen Canyon Quartzite outcrops in southwest Bear Lake South quadrangle, adjacent to Nugget Sandstone outcrops along the eastern lakefront, and in North Eden and South Eden Canyons.

Road Metal

Most gravel roads across Bear Lake Plateau and the eastern shore of Bear Lake are paved with limestone road metal from various members of the Twin Creek Limestone. Colluvial aprons adjacent to Twin Creek outcrops, and highly cleaved and fractured outcrops are easily quarried sources of road metal. The Watton Creek member of the Twin Creek Limestone is presently quarried for road metal in the southwestern corner of section 26, T. 14 N., R. 6 E. on the south side of South Eden Canyon in the adjacent Sheeppen Creek quadrangle.

Riprap and Fill

Riprap and fill material for civil engineering purposes are plentiful in talus, alluvial fan, and some colluvial deposits adjacent to Nugget Sandstone outcrops along the eastern lakefront.

Building and Paving Stone

Friable intervals of the Nugget Sandstone that exhibit clean parting planes along cross bedding have been historically quarried along western Bear Lake Plateau immediately north of the Sheeppen Creek quadrangle. Quarries in the Pegram Creek quadrangle, Idaho were the source of Nugget Sandstone building stone for the Mormon tabernacle in Paris, Idaho (Kaliser, 1972). Sandstone of similar quality is exposed in the upper part of the Nugget Sandstone in South Eden Canyon. Elsewhere, particularly along the lakefront ridge in northeastern Bear Lake South quadrangle, the Nugget Sandstone is highly indurated and intensely fractured quartzite.

Cement Rock

Elemental analysis for cement-rock quality was performed on a sample from the Rich Member of the Twin Creek Limestone collected on the north side of South Eden Canyon (NE¼SW¼SE¼ section 27, T. 14 N., R. 6 E.) in the Sheeppen Creek quadrangle (see Coogan, 1996). This sample contains too much silica to be used as cement rock (J.K. King, verbal communication, July, 1993). The Twin Creek Limestone is mined for cement rock in northern Utah at Devils Slide in Morgan County, about 65 miles (105 km) to the southwest. It is possible that unsampled intervals of the Twin Creek might contain suitable cement rock in the Sheeppen Creek quadrangle.

WATER

Surface Water

Bear Lake is used locally for recreation, and for crop irrigation on North Eden and South Eden deltas. The lake is also used as a reservoir for power generation, irrigation, and flow regulation of the Bear River through connection by the Bear Lake inlet canal in Idaho, and the Bear Lake outlet and pumps at Lifton, Idaho. Surface water was impounded for irrigation and livestock along North Eden and South Eden Creeks in the Sheeppen Creek quadrangle prior to failure of the dams during flooding on April 20, 1980 (Utah Division of Water Rights, 1980).

The level of Bear Lake has been regulated since 1918. The useable storage capacity is 1,421,000 acre feet (1.75 billion cubic meters), with the upper limit of 5,923.65 feet (1,805.53 m) along the beach on the north shore in Idaho and a lower limit of 5,902.00 feet (1,798.93 m) set by the pumps at Lifton. The historic maximum level is 5,923.68 feet (1,805.54 m) on June 10, 1923, while the historic low was below pump limits from November 9 through 19, 1935 (ReMillard and others, 1990).

Ground Water

Shallow aquifers in Bear Lake South quadrangle are limited to permeable intervals of the Wasatch Formation on Bear Lake Plateau and shallow Quaternary sediments of North Eden and South Eden deltas. Kaliser (1972) reported the water quality chemistry for several Wasatch Formation springs, and wells in alluvial and lacustrine-deltaic sediments in and near Bear Lake. Both Wasatch and alluvial waters were of generally good quality for domestic and agricultural uses, with less than 400 ppm (parts per million) total dissolved solids (Kaliser, 1972, figure 7). However, waters from lacustrine-deltaic sediments in wells along the east shore of Bear Lake in Bear Lake South quadrangle locally showed high concentrations of sulfate, nitrate, and surfactant (synthetic detergent) (Kaliser, 1972). High sulfate concentrations are probably derived from organic-rich lacustrine sediments, whereas high nitrate values probably indicate pollution from fertilizer and animal and/or human wastes. Many springs in southeastern Bear Lake South quadrangle discharge near the contact between the limestone member and the overlying main body of the Wasatch Formation. These springs include Cottonwood and associated springs along Cottonwood Creek. The springs result from downward infiltration of water through the main body of the Wasatch Formation to fractured aquifers that are underlain by impermeable zones in the limestone member. Most of these springs discharge from a fractured, oncolitic limestone at the top of the limestone member.

Small perennial and intermittent springs along Cottonwood Creek in southeastern Bear Lake South quadrangle and southwesternmost Sheeppen Creek quadrangle lie down dip from a recharge area along the lakefront ridge in southeastern Bear Lake South quadrangle. The lakefront recharge area, and a recharge area along the drainage and ground-water divide at the southern edge of Sheeppen Creek quadrangle, supply small perennial and intermittent springs along the middle and east branches of the South Fork of South Eden Creek.

GEOLOGIC HAZARDS

Earthquakes

The eastern Bear Lake Valley fault zone has been the site of Pleistocene and Holocene surface rupture (McCalpin, 1990) and is thought to be the locus of an estimated magnitude 6 earthquake in 1884 (Pechmann and others, 1992). Fault scarps that cut Holocene alluvial fans, colluvium, and deltaic sediments are continuous along the east shore of Bear Lake in Bear Lake South quadrangle. McCalpin (1990) estimated paleoearthquake recurrence and magnitudes from trenches across two Quaternary fault scarps on North Eden delta, with minimum recurrence intervals of 9,100 to 10,100 years and 500 to 2,500 years respectively, and minimum magnitudes of 6.9, 7.1, and 7.4 for different faulting events across the scarps. Ground shaking from earthquakes of this magnitude could produce liquefaction in saturated and unconsolidated Quaternary deltaic and lacustrine deposits along the eastern shore of Bear Lake, rockfall on talus-laden slopes above the lakefront, damage to ranch and park facilities, and damage to earthen dams upstream in the North Eden and South Eden drainages in the Sheeppen Creek quadrangle. Individual slip events in the past 4,600 to 2,100 years produced throws of 18 and 8.5 feet (5.6 and 2.6 m) across the western scarp examined by McCalpin (1990). The eastern Bear Lake fault zone therefore presents significant hazard for large earth movements across the eastern shore roadbed, as well as for ranch and park facilities that lie astride the fault zone.

Flooding may occur along Bear Lake as a secondary effect of earthquakes due to seiches (lake-surface oscillations caused by shaking; see Lowe, 1993) and tectonic subsidence of the land surface due to downward displacement of the hanging wall of the eastern Bear Lake fault zone. Flooding in upland areas may result from surface drainage disruptions caused by landslides and dam failures, as well as from increased ground-water discharge from shallow aquifers (Lowe, 1993).

A magnitude 4.8 earthquake and a large magnitude 4.3 aftershock occurred on November 19, 1988 beneath the Bear River Range near the Utah-Idaho border, approximately 3 miles (5 km) west of the Bear Lake South quadrangle. Monitoring of aftershocks by portable seismographs defined aftershock hypocenters between 4.4 and 7.5 mile (7 and 12 km) depth (Pechmann and others, 1992). A preliminary focal-mechanism computation for the November 19 main shock indicated a focal depth of 45,000 ± 15,500 feet (13.8 ± 4.7 km) on a normal fault that is either of N-S strike and nearly vertical dip, or one that is nearly horizontal (Pechmann and other, 1992). The earthquake hypocenter lies at the west edge of cross section A-A′ near the regional décollement zone near 35,000 feet (10.7 km) depth that is estimated from regional seismic-reflection profiles. The Bear Lake normal fault merges with the nearly horizontal regional décollement zone near this depth and location. As a result, the nearly horizontal fault-plane solution for the November 19, 1988 earthquake can be explained by slip at depth on the Bear Lake normal fault system.

Flooding

Upper North Eden, lower North Eden, and South Eden dams in the adjacent Sheeppen Creek quadrangle failed due to overtopping associated with apparent heavy run-off on April 20, 1980 (Utah Division of Water Rights, 1980). The combined capacity of the North Eden dams was 571 acre-feet (704,000 cubic meters) and the release washed out the canyon road and covered 60 acres (24 hectares) of farmland in the Bear Lake South quadrangle with rocks and debris. The North Eden dams have not been rebuilt. The reported release from South Eden dam was 47 acre-feet (57,950 cubic meters), with no reported downstream damage. The South Eden dam has subsequently been rebuilt to a height of 20 feet (6.1 m), but it is not operational pending construction of a spillway to regulate the hydraulic height to 17 feet (5.2 m) (D.K. Marble, written communication to J.K. King, February 24, 1993).

Other Hazards

None of the slides, slumps, or talus deposits mapped are near habitations, so they do not constitute a major hazard to existing development. No problem soils are known (Campbell and Lacey, 1982). Ground water within 15 feet (4.5 m) of the surface is possible along the lake below elevations of about 5,940 feet (1,810.5 m) given maximum lake level of about 5,924 feet (1,805.6 m). Shallow ground water and surface water are likely present for much of the year in the deltaic marsh deposits of North and South Eden deltas as well as the fine-grained lacustrine deposits in the southwestern corner of the Bear Lake South quadrangle.

ACKNOWLEDGMENTS

I thank Jon K. King, W. Adolph Yonkee, and Mark Jensen for their supervision of this project through its various phases. Mark Jensen, Hellmut H. Doelling, Grant C. Willis, and Suzanne Hecker provided helpful contributions to the field review. Jon K. King, Douglas A. Sprinkel, Mike Hylland, Bryce Tripp, and Douglas S. Neves provided thorough reviews of the manuscript and plates that greatly improved the content and presentation of this report. H. Paul Buchheim shared his knowledge of the regional stratigraphy of the Wasatch Formation. Jim McCalpin provided reprints, preprints, and helpful discussion of his work on the eastern Bear Lake fault zone. I thank Frank Royse, Jr. and Gerald Valenti of Chevron for their helpful discussions of regional geology and local seismic data.

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Plate 1
Utah Geological Survey Miscellaneous Publication 97-1
Geologic Map of the Bear Lake South Quadrangle

Base map from the U. S. Geological Survey
Bear Lake South 7.5′ Quadrangle, 1986

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS

14°8′
251 mils

1997 MAGNETIC DECLINATION
AT CENTER OF SHEET

UTAH
QUADRANGLE LOCATION

Lori J. Douglas, Cartographer

GEOLOGIC MAP OF THE BEAR LAKE SOUTH QUADRANGLE, CACHE COUNTY, UTAH

by

James C. Coogan

1997

The Miscellaneous Publication Maps provide an outlet for authors who are not Utah Geological Survey staff. Not all aspects of this publication have been reviewed by the UGS.

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DESCRIPTION OF MAP UNITS

- **Qa** Alluvium - *Gravel, sand, silt, and clay located above major streams (probably older than Qal) and at isolated locations in other drainages (age uncertain).*
- **Qal** Low-level alluvium - *Gravel, sand, and mud in valley bottoms of major streams.*
- **Qaf₁** Younger alluvial-fan deposits - *Poorly sorted, clay- to boulder-sized material in crudely stratified, fan-shaped deposits.*
- **Qd₁** Younger deltaic deposits - *Gravel, sand, and silt capped by loess in delta-shaped exposures along Bear Lake; deposits are crudely stratified to stratified, and include two linear, beach ridges of sand and gravel.*
- **Qd₂** Older deltaic deposits - *Crudely stratified gravel, sand, and silt apparently deposited in alluvial fans and at lower elevations in deltas in Bear Lake.*
- **Qdma** Deltaic marsh deposits - *Mud and sand in a marsh behind a beach ridge at the south end of North Eden delta.*
- **Qlf** Fine-grained lacustrine sediments - *Undifferentiated lacustrine sediments deposited behind beach ridges in the southwest corner of the Bear Lake South quadrangle.*
- **Qlsg₁** Younger lacustrine sand and gravel - *Beach deposits near elevations of about 5,930 feet (1,807 m), including present shoreline.*
- **Qlsg₂** Older lacustrine sand and gravel - *Beach deposits near and above 5,940 feet (1,810.5 m) elevation.*
- **Qmc** Colluvium - *Angular, silt- to boulder-sized material from nearby outcrops.*
- **Qms** Landslides and slumps - *Largely derived from the Wasatch Formation.*
- **Qmt** Talus - *Matrix-free, angular, pebble- to boulder-sized debris from the Nugget Formation along lakefront dip slopes.*

Wasatch Formation

- **Tw** Main body - *Poorly exposed, red mudstone, and lesser sandstone and conglomerate.*
- **Twl** Limestone member - *Oncolitic and algal limestone, limestone flat-pebble conglomerate, and light-gray siltstone; interfingers with the main body such that this limestone map unit contains significant main-body lithologies in easternmost exposures.*

Twin Creek Limestone

- **Jtr** Rich Member - *Massive, micritic limestone with pervasive pencil cleavage; has undergone extensive structural thickening and thinning.*
- **Jts** Sliderock Member - *Upper half - limestone packstone, wackestone, and micrite, grading up into the Rich Member; lower half - gray, resistant, sandy, lime packstone and grainstone with fossil fragments.*
- **Jtg** Gypsum Spring Member - *Red shale, siltstone, and sandstone; yellow sandstone; gray dolomite and brecciated dolomite; anhydrite in subsurface.*
- **Jn** Nugget Sandstone - *Red-orange, friable, medium- to fine-grained, quartz sandstone; capping by white, well-indurated sandstone is common.*

Ankareh Formation

- **Ŧaw** Wood Shale Tongue - *Not completely exposed; exposures are bright-red siltstone and shale.*
- **Ŧh** Higham Grit - *White to light purple, cross-bedded sandstone and pebble conglomerate.*

Thaynes Formation

- **Ŧti** Timothy Sandstone Member - *Upper half - gray-green, glauconitic, medium-grained, calcareous sandstone and white, fine-grained, quartzose sandstone; lower half - red sandstone, siltstone, and shale.*
- **Ŧtp** Portneuf Limestone Member - *Gray to pink, mottled, massive, cherty limestone that is poorly exposed.*

Ankareh Formation

- **Ŧal** Lanes Tongue - *Dull dark-red to purple-red shale, siltstone, and fine-grained sandstone.*
- **Ꞓgc** Geertsen Canyon Quartzite - *White to pink quartzite and pebble to granule conglomerate.*

CROSS SECTIONS ONLY

- **Q** Quaternary undivided
- **Tsl** Salt Lake Formation
- **Twu** Wasatch Formation undivided

Outer Shelf Sequence - rocks of the Paris, Willard, and Meade-Laketown thrust sheets.

- **Ogc** Garden City Formation - *Laminated to thin-bedded limestone, locally argillaceous.*
- **Ꞓsc** St. Charles Formation - *Thick-bedded limestone and dolomite.*
- **Ꞓn** Nounan Formation - *Massive to medium-bedded limestone and dolomite.*
- **Ꞓbo** Bloomington Formation - *Shale and nodular limestone.*
- **Ꞓbl** Blacksmith Dolomite - *Thick-bedded dolomite.*
- **Ꞓu** Ute Formation - *Thick-bedded limestone and dolomite above and below interbedded, thin limestone and shale.*
- **Ꞓl** Langston Dolomite - *Thin- to thick-bedded limestone and dolomite.*
- **Ꞓgc** Geertsen Canyon Quartzite - *Mostly quartzite, but some argillite locally.*

Transitional Shelf Sequence - rocks of the Home Canyon thrust sheet; same as Inner Shelf Sequence for Jurassic through Mississippian rocks.

- **D** Devonian undivided - *Probably includes Leatham Formation (where present), Beirdneau Formation, Hyrum Dolomite, and Water Canyon Formation, or Three Forks and Jefferson Formations.*
- **Sl** Laketown Dolomite - *Thick-bedded dolomite.*
- **O** Ordovician undivided - *Probably includes Fish Haven Dolomite, Swan Peak Formation (where present), and Garden City Limestone.*
- **Ꞓ** Cambrian undivided - *As depicted probably includes upper Cambrian rocks, St. Charles and Nounan Formations.*

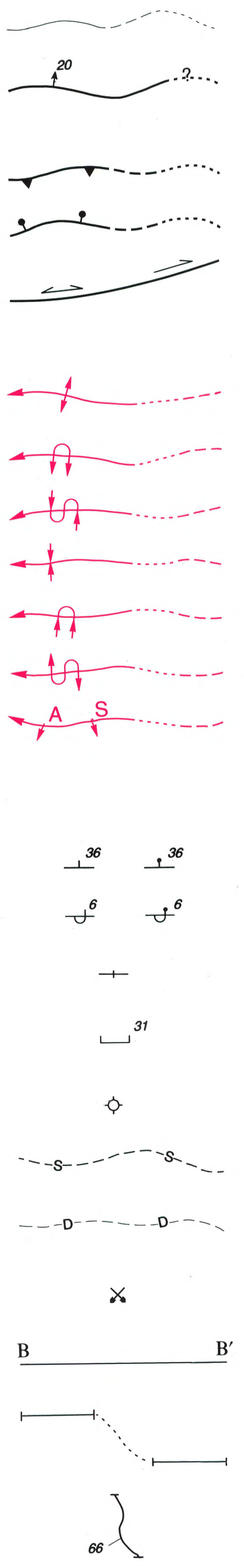
Inner Shelf Sequence - rocks of the Sheep Creek, Crawford, Absaroka, and other thrust sheets exposed east of the Bear Lake Plateau.

- **Jp** Preuss Redbeds - *Sandstone and shale, with salt.*

Twin Creek Limestone

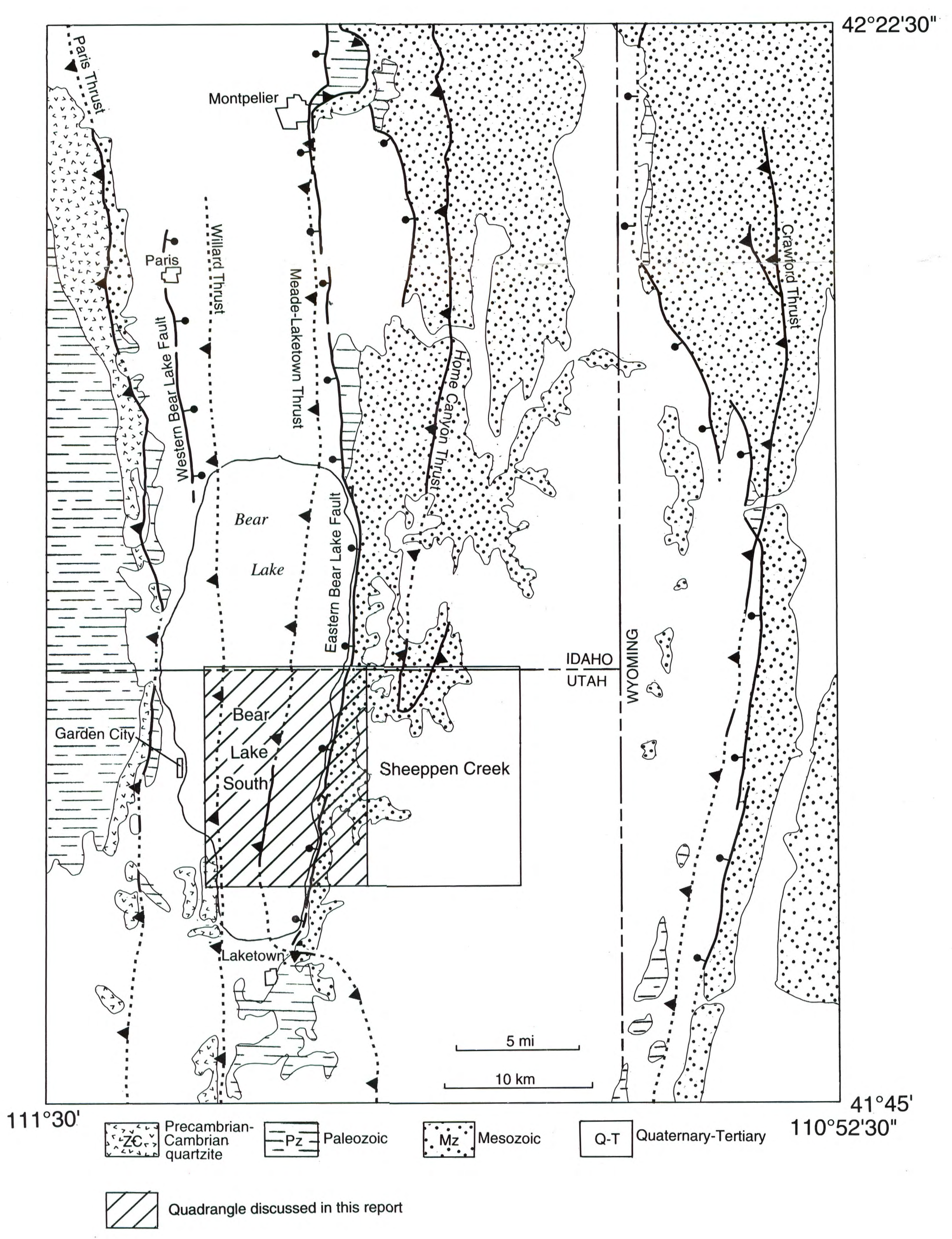
- **Jtgc** Giraffe Creek Member - *Calcareous sandstone and limestone.*
- **Jtl** Leeds Creek Member - *Limestone.*
- **Jtw** Watton Canyon Member - *Limestone.*
- **Jtb** Boundary Ridge Member - *Shale and limestone.*
- **Jtc** Twin Creek Limestone, undivided - *Mostly limestone with some shale; siltstone, sandstone, dolomite, and anhydrite in basal member (Gypsum Springs).*
- **Jn** Nugget Formation - *Sandstone.*
- **Ŧaht** Wood Shale Tongue of the Ankareh Formation, Higham Grit, Timothy Sandstone and Portneuf Limestone Members of the Thaynes Formation, and Lanes Tongue of the Ankareh Formation - *Mixture of shale, siltstone, sandstone, and limestone.*
- **Ŧt** Thaynes Formation - *Shale and limestone.*
- **Ŧtw** Woodside and Dinwoody Formations - *Shale and siltstone.*
- **PPM** Phosphoria, Wells, and Amsden Formations - *Limestone, chert, phosphatic shale, and sandstone.*
- **Mm** Madison Group - *Includes Mission Canyon Formation (=Brazer Dolomite) and Lodgepole Limestone - Thick-bedded dolomite and limestone.*
- **Dd** Darby Formation - *Shale, sandstone, and dolomite; sometimes called the Three Forks and Jefferson Formations in the Cordilleran fold and thrust belt.*
- **Ob** Bighorn Dolomite - *Thick-bedded dolomite.*
- **Ꞓg** Gallatin Limestone and Gros Ventre Formation - *Thin-bedded, silty limestone, oolitic limestone, and shale.*
- **Ꞓf** Flathead Sandstone - *Arkosic sandstone.*
- **pꞒx** Crystalline basement rocks - *Precambrian*

MAP AND CROSS SECTION SYMBOLS



- Contact - *dashed where approximately located; dotted where concealed*
- Fault - *dashed where approximately located; dotted where concealed; queried where uncertain; arrow shows dip*
- Thrust - *sawteeth on upper plate*
- Normal - *ball and bar on downthrown side*
- Arrow on cross sections show relative motion. *Double-headed arrows indicate separate slip episodes with opposite slip directions*
- Folds - *dashed where approximately located or inferred; dotted where concealed; arrow shows plunge direction where known*
  - Anticline
  - Overturned Anticline
  - Synformal (inverted) Anticline
  - Syncline
  - Overturned Syncline
  - Antiformal (inverted) Syncline
  - Monocline - *showing anticlinal bend, A; showing synclinal bend, S*
- Strike and Dip of Bedding - *in structurally complex areas ball used when top of bedding is known*
  - Inclined; *symbol on right used where top of bed can be distinguished*
  - Overturned; *symbol on right used where top of bed can be distinguished*
  - Vertical
- Strike and Dip of Cleavage
- Dry Hole
- Ancient Shoreline
- "D" marker of Gypsum Spring Member of Twin Creek Limestone
- Gravel Quarry
- Line of Cross Section
- Line of Measured Section - *dashes shown where offset*
- Drill hole on cross section showing bore-path deviation and dip from dipmeter survey

INDEX MAP



CORRELATION OF MAP UNITS
(*indicates exposure in the Bear Lake South quadrangle)

- Qal*, Qaf₁*, Qdma*, Qlsg₁*, Qmc*, Qmt*, Qms*, Qa*, Qd₁*, Qlf*, Qlsg₂*, Qaf₂, Qd₂* — Holocene, Pleistocene — Quaternary
- unconformity
- Tbf, Tbb, Tbd — Oligocene — Tertiary
- Tw*, Twl*, Twq — Eocene
- regional angular unconformity
- Jp, Jtgc, Jtl, Jtw, Jtb, Jtr*, Jts* — Middle — Jurassic
- J2 unconformity
- Jtg*
- J1 unconformity
- Jn* — Lower
- J0 unconformity
- Ŧaw*, Ŧh* — Upper — Triassic
- unconformity
- Ŧti*, Ŧtp*, Ŧal* — Lower
- Intervening section missing in quadrangle due to displacement on Willard and Bear Lake faults.
- Ꞓgc* — Middle, Lower — Cambrian

STRATIGRAPHIC COLUMN
(*indicates exposure in the Bear Lake South quadrangle)

Time Stratigraphic Units		Formation and Members		Symbol	Thickness feet (meters)	Lithology
Quaternary		Surficial deposits		Q*	0-50 (0-15)	unconformity
Tertiary	Olig.	Basalt of Black Mountain		Tbf, Tbb, Tbd	0-40 (0-12)	
	Eocene	Wasatch Formation	Main body	Tw*	0-700 (0-210)	
			Limestone member	Twl*	0-400 (0-120)	oncolites in limestone
			Quartzite Conglomerate Member	Twq	0-100 (0-30)	regional angular unconformity
Jurassic	Middle	Preuss Redbeds		Jp	0-200 (0-60)	salt zone in wells
		Twin Creek Limestone	Giraffe Creek Member	Jtgc	300 (100)	
			Leeds Creek Member	Jtl	1550 (475)	
			Watton Canyon Member	Jtw	800 (245)	
			Boundary Ridge Member	Jtb	265-300 (80-90)	oolitic
			Rich Member	Jtr*	550-730 (165-220)	
			Sliderock Member	Jts*	250-500 (75-150)	J2 unconformity
			Gypsum Spring Member	Jtg*	350 (105)	"D" marker; anhydrite zone in wells; J1 unconformity
	Lower	Nugget Sandstone		Jn*	1300 (400)	J0 unconformity ?
Triassic	Upper	Ankareh Formation	Wood Shale Tongue	Ŧaw*	400-570 (120-175)	
		Higham Grit		Ŧh*	135 (41)	unconformity
	Lower	Thaynes Formation	Timothy Sandstone	Ŧti*	125 (38)	
			Portneuf Limestone	Ŧtp*	65 (20)	chert
		Ankareh Formation	Lanes Tongue	Ŧal*	508-580 (155-175)	Base not exposed
Intervening Lower Triassic through Cambrian rocks not exposed in quadrangles. See cross sections.						Top not exposed
Cambrian	Middle, Lower	Geertsen Canyon Quartzite		Ꞓgc*	1200+ (365+)	Base not exposed

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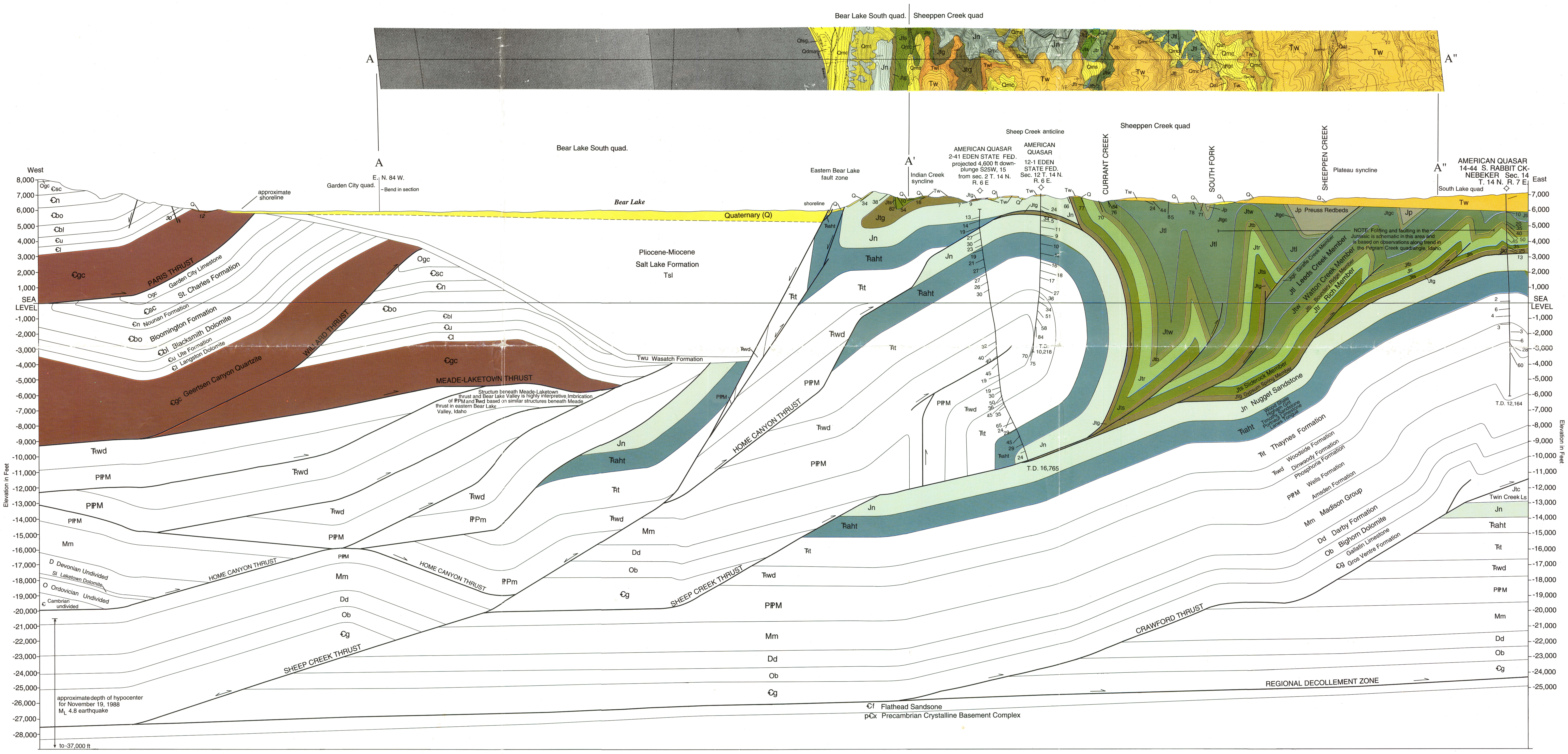

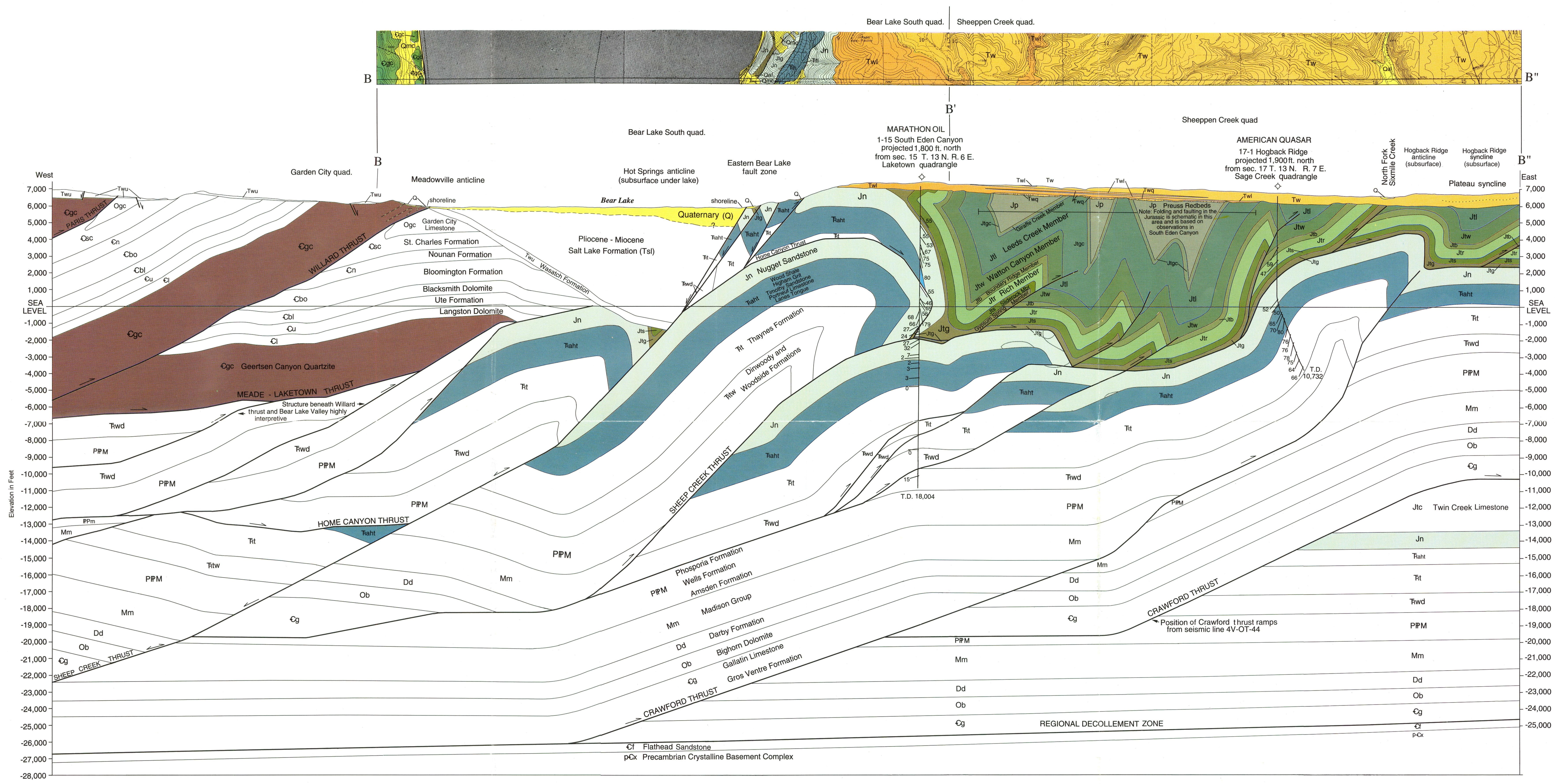

SCALE 1:48,000

1 ½ 0 1 MILE

1000 0 1000 3000 5000 7000 FEET

1 .5 0 1 KILOMETER