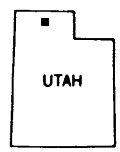
GEOLOGIC MAP OF THE HOWELL QUADRANGLE, BOX ELDER COUNTY, UTAH

By Teresa E. Jordan, Richard W. Allmendinger, and Max D. Crittenden, Jr.



UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
MAP 107 **1988**

UTAH GEOLOGICAL AND MINERAL SURVEY

606 Black Hawk Way
Salt Lake City, Utah 84108-1280

THE UTAH GEOLOGICAL AND MINERAL SURVEY is one of eight divisions in the Utah Department of Natural Resources. The UGMS inventories the geologic resources of Utah (including metallic, nonmetallic, energy, and ground-water sources); identifies the state's geologic and topographic hazards (including seismic, landslide, mudflow, lake level fluctuations, rockfalls, adverse soil conditions, high ground water); maps geology and studies the rock formations and their structural habitat; and provides information to decisionmakers at local, state, and federal levels.

THE UGMS is organized into five programs. Administration provides support to the programs. The Economic Geology Program undertakes studies to map mining districts, to monitor the brines of the Great Salt Lake, to identify coal, geothermal, uranium, petroleum and industrial minerals resources, and to develop computerized resource data bases. The Applied Geology Program responds to requests from local and state governmental entities for site investigations of critical facilities, documents, responds to and seeks to understand geologic hazards, and compiles geologic hazards information. The Geologic Mapping Program maps the bedrock and surficial geology of the state at a regional scale by county and at a more detailed scale by quadrangle.

THE INFORMATION PROGRAM distributes publications, answers inquiries from the public, and manages the UGMS Library. The UGMS Library is open to the public and contains many reference works on Utah geology and many unpublished documents about Utah geology by UGMS staff and others. The UGMS has begun several computer data bases with information on mineral and energy resources, geologic hazards, and bibliographic references. Most files are not available by direct access but can be obtained through the library.

THE UGMS PUBLISHES the results of its investigations in the form of maps, reports, and compilations of data that are accessible to the public. For future information on UGMS publications, contact the UGMS sales office, 606 Black Hawk Way, Salt Lake City, Utah 84108-1280.

GEOLOGIC MAP OF THE HOWELL QUADRANGLE, BOX ELDER COUNTY, UTAH

By Teresa E. Jordan[1], Richard W. Allmendinger[1], and Max D. Crittenden, Jr.[2]

INTRODUCTION

The Howell quadrangle is located in northwestern Utah, north of the eastern arm of the Great Salt Lake and about 8 miles (13 km) south of the Idaho-Utah border (figure 1). Part of the western Blue Springs Hills is exposed within this quadrangle. The Blue Springs Hills are a north-trending, low-relief mountain range in the northeastern Basin and Range Province. In this range, marine sedimentary rocks of the late Paleozoic Oquirrh basin and clastic Mississippian rocks crop out; rocks older than Mississippian in age are not exposed at the surface. The rocks were folded and thrusted, probably during Mesozoic time. Cenozoic high- and low-angle faults have modified the Mesozoic(?) structures.

Stratigraphic and structural studies were undertaken in the Blue Springs Hills as part of a project to investigate the evolution of the Paleozoic Oquirrh basin and its effect on Mesozoic and Cenozoic deformation of northwestern Utah. The Howell quadrangle is one of a series of maps by the authors that describe stratigraphic and structural relations in the Blue Springs Hills and adjoining North Promontory and Promontory Mountains and West Hills. In combination with stratigraphic studies to the east (Beus, 1958; Oviatt, 1985), north (Platt, 1977; Allmendinger, 1983; Allmendinger and Platt, 1983; Murphy, 1983), west (Jordan, 1985) and southwest (Jordan, 1979; Jordan and Douglass, 1980; M.D. Crittenden, Jr., unpublished mapping), this work reveals rapid thickness changes at the margin of the Oquirrh basin. This area of rapid thickness change apparently localized overturned folds and thrust faults that are inferred on the basis of regional relations to be of probable Mesozoic age (figure 1). Further data are given by Allmendinger and Jordan (1981), Allmendinger and others (1984), and Jordan and others (1987).

The highest part of the quadrangle is located in the northeast, where the peaks exceed 5900 feet (1800 m) in elevation. The highlands in the eastern third of the quadrangle are heavily vegetated by sagebrush and other low shrubs. Exposure of bedrock is poor on north-facing slopes and moderate on south-facing slopes. The Blue Creek Valley trends northward through the center of the quadrangle and ranges upward in elevation from 4470 feet (1363 m). The western part of the quadrangle comprises the eastern slope of the North Promontory Mountains. Surficial deposits of Pleistocene Lake Bonneville occur in much of the lowlands, and when Lake Bonneville was filled to its greatest depth, all but the highest ridges in the Blue Spring Hills were submerged. The mountain ranges are utilized primarily for sheep and cattle grazing; the lowlands are tilled.

STRATIGRAPHY

Paleozoic strata exposed at the surface in the Blue Springs Hills are lithologically similar to strata elsewhere in the Oquirrh basin but were deposited in the shelf region along the northeast border of the basin (Jordan and Douglass, 1980). Cenozoic deposits are limited to Tertiary clastic deposits and fresh-water limestone and varied Quaternary deposits, including local sand and gravel accumulations. General descriptions of all of the mapped units accompany the geologic map (plate 2), but descriptions of some of them are amplified here.

[1] Cornell University
[2] U.S. Geological Survey

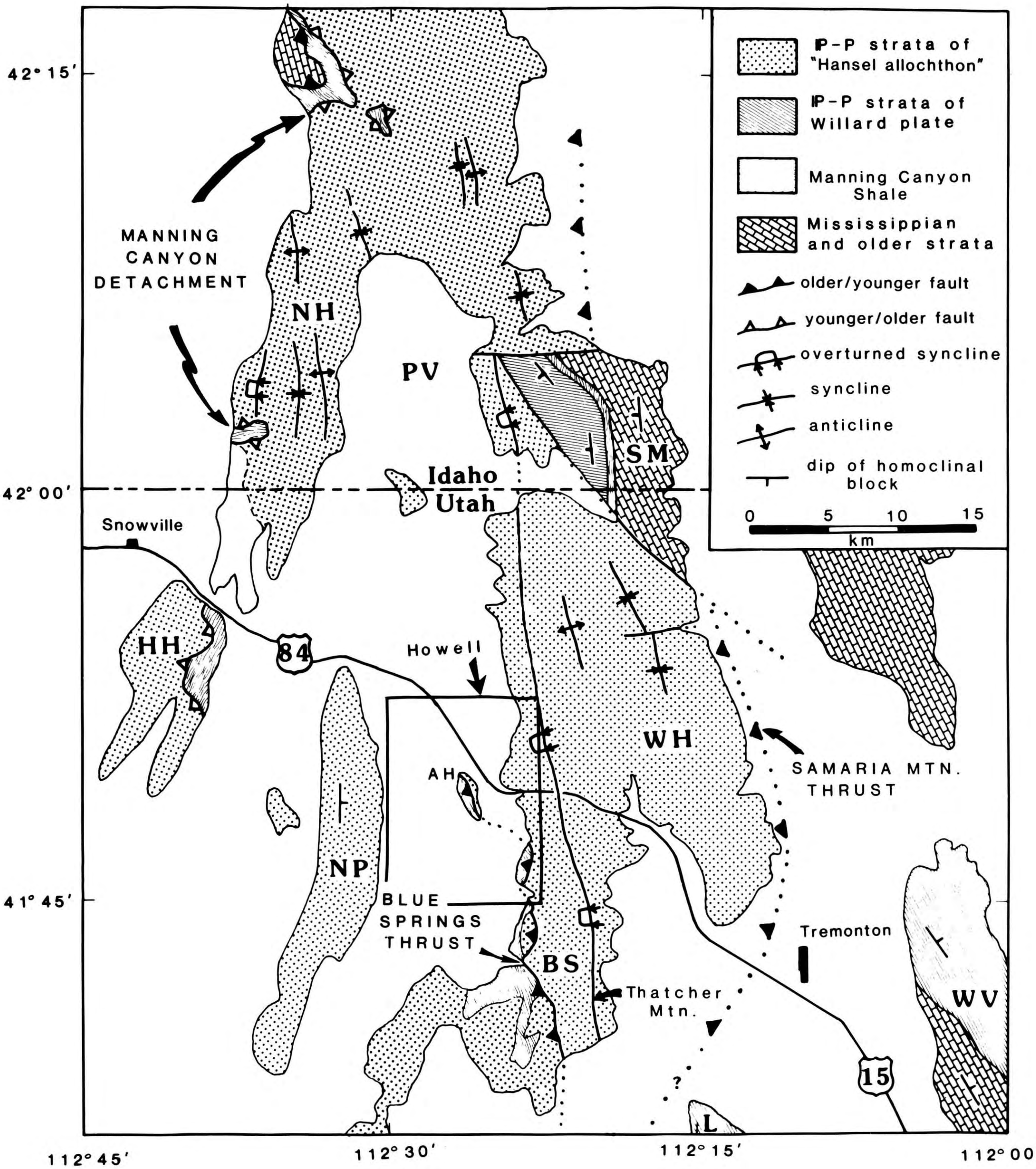


Figure 1. Regional geologic and geographic setting of the Howell quadrangle. "IP-P" in legend indicates Pennsylvanian and Permian age strata. NH = North Hansel Mountains, PV = Pocatello Valley, SM = Samaria Mountain, HH = Hansel Hills, NP = North Promontory Mountains, AH = Anderson Hill, WH = West Hills, BS = Blue Spring Hills, WV = Wellsville Mountain, and L = Little Mountain. Geologic framework adapted from Allmendinger and others (1984).

MANNING CANYON SHALE
(Mississippian and Pennsylvanian)

The Manning Canyon Shale is the stratigraphically lowest unit exposed in the Blue Springs Hills, although it rests structurally above Pennsylvanian and Permian units along the Blue Springs thrust fault. Its principal exposures in the Howell quadrangle are in sections 14 and 23 of T. 12 N., R. 5 W., in the southeast corner of the map, and on Anderson Hill in the center of the quadrangle.

The most prominent outcrops of the Manning Canyon Shale are of rounded weathering but bold quartzite composed of fine- to medium-grained sand. The quartzite is white on fresh surfaces but stains and weathers to dark brown. Locally, the quartzite is thin to medium bedded, with rare cross beds, but more commonly it weathers to very thick, featureless beds. Granule conglomerate is locally incorporated into the quartzite. Sand and granules consist dominantly of quartz, with minor detrital sandstone and chert clasts; siltstone clasts may be either detrital or intraclasts. Non-resistant, soil-covered areas between the quartzite exposures are inferred to be underlain by shale and minor limestone. Because exposure is poor and the unit is folded and faulted, it is difficult to determine the ratio of sandstone and quartzite to shale, but we estimate that the unit is approximately 20 to 30 percent sandstone and quartzite. This percentage of sandstone and quartzite is higher than in exposures in ranges that lie to the west and north of the Blue Springs Hills (e.g., M.D. Crittenden, Jr., unpublished mapping; Smith, 1982; Allmendinger, 1983).

The base of the Manning Canyon Shale is not exposed in the Blue Springs Hills and is inferred to be faulted (see cross sections). The top is gradational with the overlying Oquirrh Formation; in the Lampo Junction quadrangle to the south, we estimate a thickness of 490 feet (150 m) of interbedded sandstone and limestone that are here designated as the transitional member (Pmct) of the Manning Canyon Shale. The upper contact has been placed at the top of this transitional zone, above the uppermost dark-brown weathering sandstone. The minimum total thickness of the Manning Canyon Shale, measured from cross section C-C′, is 2400 feet (730 m), although a high degree of folding in the unit makes this value suspect.

The Manning Canyon Shale is widespread in much of northwest Utah. The type section is in the southern Oquirrh Mountains, where its age is latest Mississippian and Early Pennsylvanian (Gilluly, 1932). No fossils were found in the Manning Canyon Shale in the Howell quadrangle, but an earliest Pennsylvanian conodont assemblage was recovered from limestone beds in this unit in the adjacent Lampo Junction quadrangle (J.E. Repetski, 1985, written communication). Alteration of those conodonts indicates heating to temperatures exceeding 300°C (CAI of 5) (J.E. Repetski, 1985, written communication).

The Manning Canyon Shale is important for a variety of reasons. In much of western Utah it is considered to have potential as a source of organic matter for hydrocarbon accumulations. As the only major shale-bearing unit in the middle and upper Paleozoic sequence, it has played an important role in localizing deformation (Allmendinger and Jordan, 1981; Allmendinger and others, 1984) and has been widely affected by sub- to lower greenschist facies of metamorphism (Christensen, 1975). Surface exposures of the Manning Canyon Shale are important because springs are commonly associated with the unit.

OQUIRRH FORMATION
(Pennsylvanian and Permian)

The Oquirrh Formation or Group, the most widespread bedrock unit in Box Elder County north of the Great Salt Lake, exceeds 10,000 feet (3000 m) in thickness in the region. The type section of the Oquirrh Group is located in the Oquirrh Mountains, about 90 miles (145 km) south of the study area, where Tooker and Roberts (1970) described the formations that comprise the group. To the north and west of the Oquirrh Mountains and in the area described here, most of those formations have not been recognized nor have alternative formal formations been proposed. Instead, recent studies in ranges that neighbor the Blue Springs Hills have subdivided the Oquirrh into informal members (e.g., Allmendinger, 1983; Platt, 1977; Murphy, 1983; Jordan, 1985; Jordan and others, 1988); rules of nomenclature therefore require that the Oquirrh be considered a formation at those locations, rather than a group. A similar approach is utilized here. However, the Oquirrh Group of the southern Oquirrh Basin and the Oquirrh Formation of the northern and western Oquirrh Basin are equivalent rock-units. Figure 2 compares the members mapped in the Blue Springs Hills to those used in neighboring ranges.

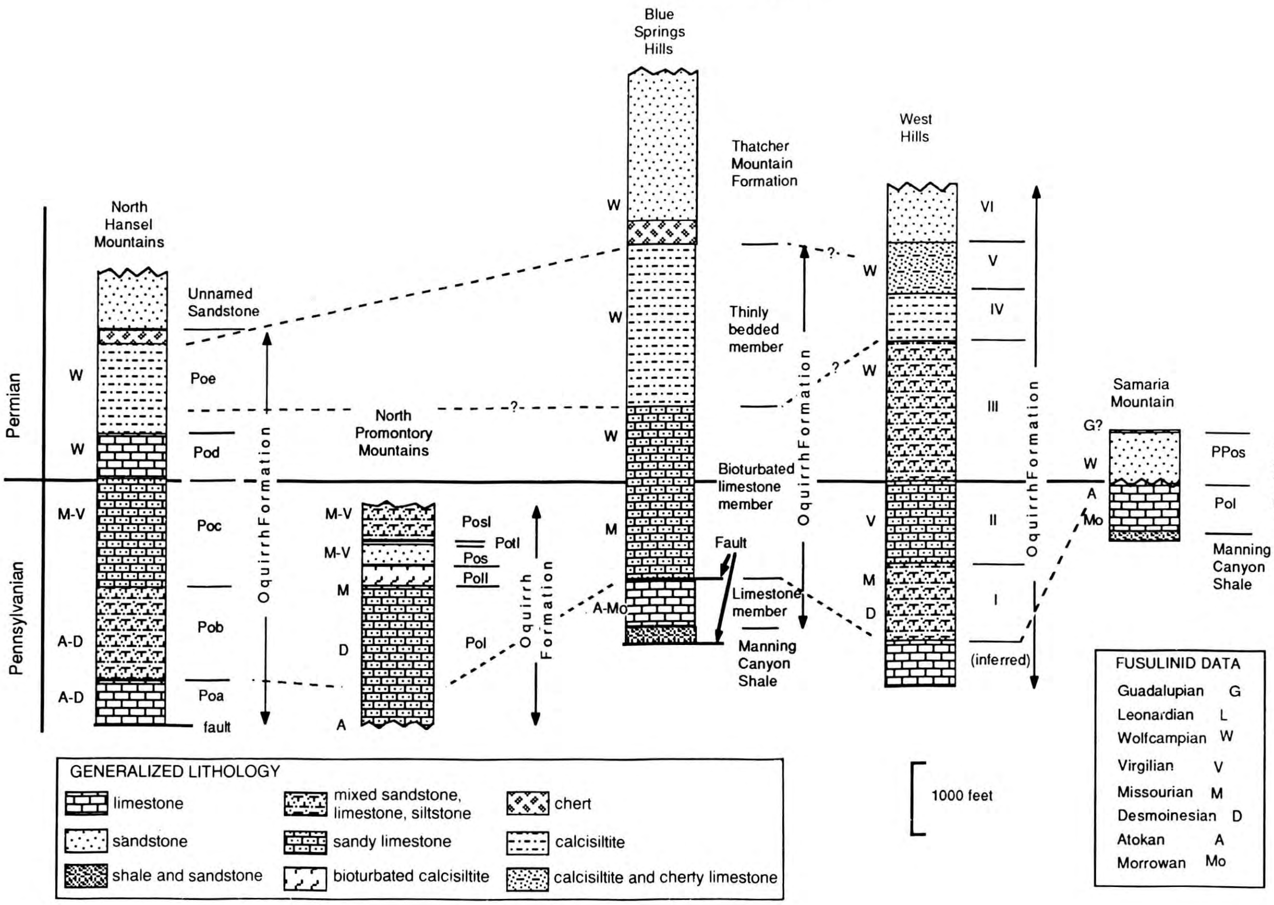
Limestone Member

Bold exposures of fossiliferous limestone are gradational above the Manning Canyon Shale. Fine-grained calcarenite predominates, but quartz sand is intermixed with lime sand locally and also forms calcareous sandstone and quartzite beds. Lamination, cross-bedding, and herringbone cross-laminae occur locally. Chert pebbles occur locally in coarse bioclastic deposits.

The upper contact of the limestone member may be preserved on Anderson Hill, but the exposure is very poor and details of the lithologic changes across the contact are not well known. Elsewhere the upper contact is faulted or eroded. The limestone member is exposed only in the upper plate of the Blue Springs thrust fault, in the eastern part of the map area, and as part of an overturned anticline at Anderson Hill. Its faulted thickness is estimated to be 1200 feet (370 m).

The limestone member is lithologically similar to the Lower Pennsylvanian (Morrowan) West Canyon Limestone of the Oquirrh Mountains which M. Gordon, Jr. and H.M. Duncan, (*in* Tooker and Roberts, 1970) designate as the lowest formation of the Oquirrh Group. Although several fossil collections from the limestone member in the Howell quadrangle were examined, no fusulinids were recognized (R.C. Douglass, 1984, written communication). Conodonts from lithologically similar strata in the adjacent Lampo Junction quadrangle were studied by J.E. Repetski (1985, written communication) who assigned an age of late Morrowan or Atokan (Early or Middle Pennsylvanian). We interpret the age of the limestone member to be Middle Pennsylvanian. Alteration of the conodonts indicates that temperatures exceeded about 200°C, based on CAI values of 4 to 6 (J.E. Repetski, 1985, written communication).

Figure 2. Comparison of the subdivisions mapped of the upper Paleozoic strata in the Howell quadrangle with the units recognized in adjacent ranges. Dashed lines suggest possible correlations of the lithostratigraphic units, whereas the fusulinid age data indicate age relations. The solid horizontal line indicates the estimated position of the Pennsylvanian-Permian boundary in each section. Sources of information are: North Hansel Mountains from Allmendinger (1983) and Allmendinger and Platt (1983); North Promontory Mountains from Jordan (1985); Blue Springs Hills from this report and Jordan and others (1988); West Hills from Murphy (1983) and Murphy and others (1985); Samaria Mountain from Platt (1977) and Allmendinger and Platt (1983).



Bioturbated limestone member

The mixed terrigenous detrital-grain (quartz and potassium feldspar) and calcite-grain arenites of this member are distinguished by the common preservation of burrows; non-bioturbated beds have parallel and cross lamination. The arenites are medium to thick bedded. Bioclastic beds are rare. The only location in the Blue Springs Hills where the bioturbated limestone member may be in stratigraphic contact with the underlying limestone member of the Oquirrh Formation is at Anderson Hill where the boundary is very poorly exposed. In the North Promontory Mountains to the west, similar strata are conformable upon limestones that are similar to the limestone member mapped in the Blue Springs Hills (figure 2) (Jordan, 1985).

The upper 300-foot (90-m) part of this member is characterized by laminated calcisiltite containing soft sediment folds, interbedded intraformational conglomerate and bioclastic calcarenite, and clean, well sorted, cherty calcarenite. The contact is placed at the uppermost clean, thick calcarenite.

The estimated thickness of the bioturbated limestone member is 5000 feet (1500 m), but due to probable structural thickening and thinning in the area, this value may be significantly in error. Fusulinid collections from the upper part of this member yield Wolfcampian ages (table 1). Collections from lower in the member in the adjacent quadrangles to the east and south indicate that it ranges in age from Missourian (Late Pennsylvanian) to Wolfcampian (Early Permian) (Jordan and others, 1987; D.M. Miller and others, unpublished mapping).

The bioturbated limestone member has some lithologic similarity to the Middle Pennsylvanian Butterfield Peaks Formation of the Oquirrh Mountains, particularly because of the interbedding of siliciclastic arenites and calcarenites. It bears little similarity to the Upper Pennsylvanian Bingham Mine Formation.

Thinly bedded member

The silicified siltstones and calcisiltites of this member are conformable on the bioturbated limestone member. They weather from tan to dark brown. Bedding is characteristically thin, but relatively thick bedding occurs low in the member. The upper part of the member includes some sandstone beds and rare coral-bearing beds that grade up into the overlying Thatcher Mountain Formation. Soft-sediment folds are present locally. In addition, this unit tends to accomodate deformation by layer parallel slip and by forming small-scale, tight folds, making estimation of its thickness difficult. Its thickness, estimated from cross sections, is about 7000 feet (2130 m) in the overturned limb of the Thatcher Mountain syncline (cross section B-B′).

Rare bioclastic beds contain fusulinids, solitary corals, and crinoid debris. Fusulinids of early to middle Wolfcampian age have been identified (table 1).

The thinly bedded member of the Oquirrh Formation in the Howell quadrangle is generally finer grained and more thinly bedded than the age-equivalent Curry Peak Formation (Swenson, 1975) of the Oquirrh Mountains. Bioturbation is also more characteristic of the Curry Peak Formation than it is of the thinly bedded member.

THATCHER MOUNTAIN FORMATION (Permian)

The Thatcher Mountain Formation is a thick series of sandstone and lesser dolomite and limestone that lies conformably on the Oquirrh Formation. It is the youngest unit in the region that predates the folds and thrust faults. Its type section is located at Thatcher Mountain in the southeastern Blue Spring Hills (Jordan and others, 1988). The Thatcher Mountain Formation crops out only along the northeastern limit of the Howell quadrangle.

The Thatcher Mountain Formation in the Howell quadrangle is characterized by sandstone, limestone, and chert. In ascending order, a (basal) chert-rich member, herein informally designated as the cherty member, and a sandstone and limestone (or dolomite) member are distinguished at the type section. In the Howell quadrangle only the lower member and lower part of the upper member occur. The cherty member is shown as a separate map unit because of its importance in recognizing the transition from the Oquirrh Formation into the Thatcher Mountain Formation.

Cherty member

The basal member of the Thatcher Mountain Formation is characterized by resistant and commonly boldly exposed 3- to 10-foot (1- to 3-m) beds of bluish-gray chert. The bluish-gray chert is nodular and anastomosing, comprising 50-70 percent of thick beds in which it replaced fine-grained sandstone. Interbedded black chert is thin to medium bedded and is associated with medium-gray weathering, fine-grained calcarenite and dolomite. Thickly bedded, fine-grained, brown-weathering sandstone with local laminations is interbedded with the chert-rich beds.

The lithologies in the cherty member of the Thatcher Mountain Formation are not markedly different than those of the underlying Oquirrh Formation. However, the thinly bedded siltstones of the thinly bedded member of the Oquirrh Formation are gradually replaced by more thickly bedded sandstones.

Upper member

The upper member of the Thatcher Mountain Formation is predominantly sandstone. The sandstone is largely very fine to fine grained but is locally medium to coarse grained. Cross beds, cross laminae, and parallel laminae are characteristic structures in the sandstone, although it is also commonly bioturbated and structureless. The sandstone is associated with cherty limestone (dolomite in the southern part of the map area) and laminated cherty siltstone. In natural exposures, the sandstone is the most obvious lithology, whereas in fresh exposures cherty siltstone is a major component of the Thatcher Mountain Formation. Gastropod and crinoid debris occurs locally with fusulinids in bioclastic horizons. Middle Wolfcampian fusulinids were recognized from strata near the base of the upper member of the Thatcher Mountain Formation (table 1). Attempts to improve the chronologic control on this unit with conodont collections have proven to be of little use, but alteration of conodonts found in the Blind Springs quadrangle to the east indicates that temperatures in the Thatcher Mountain Formation varied from 50°C to at least 110°C (CAI of 1.5 to 3) (J.E. Repetski, 1985, written communication).

SALT LAKE FORMATION (TERTIARY)

The poorly consolidated Salt Lake Formation is exposed only along the western margin of the Howell quadrangle where it forms a gently east-dipping pediment surface and is covered by a thin veneer of Quaternary deposits. No fossils were found in this unit in the quadrangle, but similar rocks were dated as Miocene and Pliocene elsewhere in Box Elder County (Williams and others, 1982).

The exposed thickness of the Salt Lake Formation is greatest on the northern, downdropped side of an east-trending fault at the section 14 - 23 boundary (T.13 N., R. 6 W.). Its exposed thickness is estimated to be several hundred feet. The thickness beneath the Blue Creek Valley is constrained by gravity data but cannot be estimated precisely. The gravity data show a -20 mgal anomaly in the southern part of the Blue Creek Valley (U.S. Geological Survey, unpublished compilation of gravity data). That anomaly is due to the combination of relatively thick unconsolidated Quaternary deposits and the thick Salt

Lake Formation beneath the valley. Assuming that approximately half of the anomaly is due to Quaternary deposits, the thickness of the Salt Lake Formation shown on cross section B-B′, where the anomaly is approximately -14 mgal, is estimated to be 2400 feet (730 m) (D.B. Snyder, 1986, personal communication).

QUATERNARY DEPOSITS

Two types of deposits are particularly widespread in the Howell quadrangle. The first type includes deposits of Pleistocene Lake Bonneville. Wave action in the lake caused widespread, partial reworking of poorly consolidated older units (unit Qla on the map). Along the western slope of Blue Creek Valley these deposits form a very thin veneer over the Salt Lake Formation: as mapped, areas included in unit Qla may include small areas of outcrop of the Salt Lake Formation. Gravel deposits related to relatively high-energy lakeshore activity mantle the bedrock ranges. Lacustrine silts and muds deposited in deeper parts of Lake Bonneville are widespread in the lowland areas of the Blue Creek Valley.

The second set of units was deposited by fluvial activity. Sand and silt deposits associated with active streams form shallow ribbons bordering the intrenched streams. More widespread fluvial deposits are found south of Howell, where the Blue Creek deposits and reworks silt and clay. Volumetrically, alluvial-fan deposits are most important, and here are divided into two groups by age. The older alluvial fans are crossed by both erosional and depositional features generated by younger shorelines of Lake Bonneville, and they are partly dissected by younger stream channels. In varying locations they are both cut by and overlap the Provo shoreline, suggesting that they formed during a time interval that spans the time of the Provo lake level. The younger set of alluvial fans has a morphology suggesting that they are active sites of deposition. They commonly head near or change shape at the Provo shoreline, suggesting that they post-date that feature. Locally, prominent shorelines can be traced across the younger fans, apparently because the younger fan deposits draped across the previously existing shoreline features. The younger fan deposits grade into the lacustrine deposits at lower elevations, suggesting that they began to form contemporaneously with the last stages of Lake Bonneville activity.

A mound-like landslide deposit (boundary of sections 11 and 14, T. 12 N., R. 5 W.) consists of soil and boulders comprised of a mixture of bedrock units that are exposed upslope, to the east.

The thickness of Quaternary deposits is not known from direct measurements. The gravity data and assumptions described above indicate that the Quaternary deposits may exceed 700 feet (200 m) thickness in the center of the Blue Creek Valley.

STRUCTURAL GEOLOGY

Folds and faults in the pre-Quaternary rocks of the Howell quadrangle are continuous with those described by Allmendinger and others (1984) and Jordan and others (1988) in other parts of the Blue Springs Hills and are similar to those described by Allmendinger and Platt (1983), Murphy (1983), and Jordan (1985) in the adjacent North Hansel - Samaria Mountains, West Hills and North Promontory Mountains, respectively (figure 1). These structures are divided into an early group, indicating east-west shortening, and a later group that indicates east-west extension.

EARLY FOLDS AND FAULTS

The principal structure exposed in the Howell quadrangle is the gently west-dipping Blue Springs thrust fault in the southeastern and central part of the map area. It places a complicated but upright section of the Manning Canyon Shale and limestone member of the Oquirrh above nearly vertical Pennsylvanian and Permian strata. The Blue Springs thrust was first identified by Doelling (1980) and described by Allmendinger and others (1984). The Howell quadrangle contains the northernmost recognized exposure of the thrust fault at Anderson Hill. Within this quadrangle the fault dips about 30° to the west. The structure of the upper plate is best displayed in hills in the southeast part of the map (sections 14 and 23, T.12 N., R. 5 W.). There the Manning Canyon Shale and Oquirrh limestone member of the upper plate are folded into a series of northeast- to northwest-trending minor folds that are truncated by the fault (cross section C-C′). The minor folds apparently mimic the form of the Thatcher Mountain syncline, with eastward-overturned limbs. The fault zone includes brecciated and thoroughly silicified limestone that weathers to large, brown, rounded outcrops.

The structure of Anderson Hill is best interpreted as representing the northern termination of the Blue Springs thrust, although poor exposure and complex faults make it difficult to interpret. Anderson Hill is divided into three segments by east-and northeast-trending faults. In the southern third of the hill, the Blue Springs thrust places the Manning Canyon Shale over both the limestone member and the bioturbated limestone member of the Oquirrh Formation, which are also separated by a thrust fault. In the middle third of the hill, the axis of an eastward-overturned anticline repeats the Oquirrh limestone member, which is apparently in stratigraphic contact with the overlying bioturbated limestone member (cross section B-B′). In the northern third, no major repeats or inversions of the stratigraphic sequence occur, although there is local evidence of faulting. We interpret the structure of Anderson Hill to indicate that the Blue Springs thrust formed by overtightening of an anticlinal hinge zone. Apparently the total shortening across the anticline and thrust fault varies along strike, increasing southward from Anderson Hill.

Gravity data show a slight (+2 mgal) anomaly that strikes northward between the western flank of the Blue Springs Hills and Anderson Hill (U.S. Geological Survey, unpublished compilation of gravity data). It may be caused by the wedge of overthickened Manning Canyon Shale that is inferred to exist in the core of the anticline to which the Blue Springs thrust is related (cross sections A-A′, B-B′, and C-C′).

TABLE 1.
Paleontological data for the Howell quadrangle

Map site/field number/ USGS number	Unit & faunal description	Fossil age	Date of report	Paleontologist	Location Latitude (north)	Longitude (west)
1 84T7b f14675	Oquirrh Formation Thinly bedded member. Fine calcareous sandstone with scattered fusulinids that show abrasion and some breakage. *Pseudofusulina* sp. confirms the Wolfcampian age, but is considered no younger than middle Wolfcampian.	middle Wolfcampian	10/2/84	R.C. Douglass and L. Jacobsen	41°48′5.8″	112°22′44″
2 84T8 f14676	Oquirrh Formation Bioturbated limestone member. Fine calcareous sandstone with scattered fusulinids and rare bryozoans. The fusulinids have the outer volutions crushed. They represent a *Schwagerina?* sp. or *Pseudofusulina?* sp. and indicate a Wolfcampian age (cannot be more precise with the available material).	Wolfcampian	10/2/84	R.C. Douglass and L. Jacobsen	41°50′25″	112°23′37″
3 84T9 f14677	Oquirrh Formation Thinly bedded member. Fine calcareous sandstone with scattered fusulinids. The fusulinids represent *Schwagerina*? sp. or *Pseudofusulina*? sp. and indicate a Wolfcampian age.	Wolfcampian	10/2/84	R.C. Douglass and L. Jacobsen	41°50′12″	112°23′50″
4 84T10 f14678	Oquirrh Formation Thinly bedded member. Fine calcareous sandstone with scattered bits of crinoidal and bryozoan material. The fusulinids include *Schwagerina* sp. and *Pseudofusulina*? sp. suggesting a Wolfcampian age.	Wolfcampian	10/2/84	R.C. Douglass and Jacobsen	41°50′5″	112°23′50″
5 84T15 f14680	Thatcher Mountain Formation Calcareous siltstone with crinoidal debris and fusulinids including *Schwagerina* sp., *Pseudofusulina* sp., and *Pseudoschwagerina* sp. suggesting a middle Wolfcampian age.	middle Wolfcampian	10/20/84	R.C. Douglass and L. Jacobsen	41°51′20″	112°22′53″

The second major exposed structure is a syncline referred to as the Thatcher Mountain syncline. The trace of its north-trending axial plane is located a short distance to the east of the eastern margin of the quadrangle and its overturned western limb controls the exposure of upper Paleozoic strata in the eastern part of the quadrangle (figure 1). The Thatcher Mountain syncline is a structure of regional extent (figure 1), as described by Allmendinger and others (1984) and Jordan and others (1988).

Within the Howell quadrangle, there is a major change along strike in the geometry of the Thatcher Mountain syncline. To the south of an east-striking high-angle fault in sections 26 and 27 (T. 13 N., R. 5 W.) the syncline is overturned to the east and the axial surface dips about 40° to 50° to the west, such that the Pennsylvanian and Permian strata in the lower plate of the Blue Springs thrust are in the western, overturned limb of the Thatcher Mountain syncline. In the block south of that fault, in the Thatcher Mountain quadrangle and southern part of the Howell quadrangle, the amplitude of the syncline is about 18,000 feet (5500 m), and there are many small-scale parasitic folds. To the north of the east-striking fault, the fold has an open, apparently upright form, with an amplitude of perhaps 4000 feet (1200 m), and intermediate-scale folds are important (cross section A-A′).

Another important structure, the Samaria thrust fault, is inferred to lie in the subsurface and to control the surficial structure. The eastward-transported Samaria thrust fault (Allmendinger and Platt, 1983) underlies much of the Pennsylvanian and Permian bedrock north of the Great Salt Lake, but it is only exposed in local structural windows where it has been referred to as the Manning Canyon detachment (figure 1) (Allmendinger and Jordan, 1981; Allmendinger and others, 1984). The upper plate of that fault has been referred to as the Hansel plate (figure 1) (Allmendinger and Jordan, 1981; Allmendinger and others, 1984).

Regionally the Samaria thrust fault is localized within or at the base of the Manning Canyon Shale and carries the Oquirrh Formation and overlying units eastward. Its trace is thought to separate units typical of those that form the Blue Springs Hills from stratigraphically distinct sequences to the east, in the upper plate of the Willard thrust. The strata of the Willard plate include upper Precambrian to Permian strata, but the upper Paleozoic rocks are considerably thinner than those of the Blue Springs Hills and locally the Manning Canyon Shale is absent (Oviatt, 1985).

The Thatcher Mountain syncline and Blue Springs thrust are both thought to be directly related to the Samaria thrust fault. The Blue Springs thrust and Thatcher Mountain syncline parallel one another and are perpendicular to the inferred direction of translation of the Samaria thrust, and most plausibly formed due to shortening in the upper plate of that fault. Based on structural geometry and regional relations, Allmendinger and others (1984) suggested that a minimum of 9 miles (15 km) of east-west shortening was produced by the Samaria thrust fault and that the shortening probably occurred before the Late Cretaceous. However, the direct evidence in the Blue Springs Hills for the age of deformation requires only that it was post-Early Permian and pre-late Tertiary.

At least one east-striking high-angle fault is inferred to have been active when the thrusts and folds were formed. The nature of the east-trending fault (sections 26 and 27, T. 13 N., R. 5 W.) that separates the two domains of the Thatcher Mountain syncline is not well known. Based on its limited map pattern and lack of disruption of structural trends adjacent to it, we consider it to be a high-angle fault. It is an important feature because the fold geometry to the south accommodated much more shortening than that to the north. Although there is a slight down-to-the-south offset implied by the stratigraphic contrast across the fault, it may be more accurate to view this fault as having largely strike-slip motion with a lateral displacement accommodating less shortening to the north than to the south. This fault must have been active during the time that the north-trending folds and thrust faults formed. It not only can be mapped in sections 26 and 27 (T. 13 N., R. 5 W.) but projects westward near the northen end of Anderson Hill, where it is approximately coincident with the northward decrease in shortening expressed in the termination of the Blue Springs thrust at Anderson Hill. The east-striking fault that separates the southern and central segments of Anderson Hill may also have been active at the time that the Blue Springs thrust and Thatcher Mountain syncline formed.

YOUNGER FAULTS

High-angle and low-angle normal faults cut the folds and thrust faults. Most normal faults that are exposed in the bedrock of the Howell quadrangle strike to the east or north, but locally faults with northwest and northeast strikes occur. The faults are recognized on the basis of offset stratigraphic contacts, fold axes and thrust faults; other examples are expressed in landforms, such as aligned notches in ridges, and as lineaments on airphotos that reflect vegetation variations. The nearly straight traces of these faults suggest that many of them are steeply-dipping at the surface. Evidence within the Howell quadrangle is insufficient to prove whether or not any of the east-striking faults in the upper plate of the Blue Springs thrust pre-date the thrust. It is clear, however, that some of the east-, northeast-, and northwest-striking faults post-date the thrust.

The east-trending fault in sections 26 and 27 (T. 13 N., R. 5 W.) that was active during the earlier deformation is inferred to have been reactivated during the younger phase of faulting. This is based on the map relations: a north-northeast-striking fault (sections 14 and 23) that terminates against the east-striking fault in sections 26 and 27 cuts several east-striking faults that offset fold axes.

An east-trending fault in the northwest part of the quadrangle cuts the Miocene and Pliocene Salt Lake Formation (sections 13 and 14, T. 13 N., R. 6 W.). This fault is continuous with a fault mapped in the adjacent North Promontory Range (Jordan, 1985) that places the Salt Lake Formation against the Oquirrh Formation, dropping the north block downward. In the Bulls Pass quadrangle it is unclear whether or not this fault cuts the Quaternary units. However, there is more evidence in the Bulls Pass quadrangle that faults cut older Quaternary alluvial fans to the south than to the north of this east-trending fault, suggesting that motion is hinged across this east-trending fault and thus that there has been movement on this fault during the Quaternary. In the Howell quadrangle, the south side of the fault exposes both the Salt Lake Formation and a thin veneer of deposits that were reworked by Lake Bonneville but overlie the Salt Lake Formation. No evidence of faulting in the Quaternary deposits is known where the fault trace projects through cultivated fields. An attempt to correlate shorelines of Lake Bonneville to the north and south of the fault suggests that the erosional scarp attributed to the Provo level is about 10 feet (3 m) lower north of the fault than it is to the south. However, because different lithologies in the Salt Lake Formation are exposed across the fault, the Provo level may not be equally expressed across it, and the shoreline correlation may be in error. This question merits study of the Quaternary deposits and geomorphology beyond the scope of the present regional mapping project. A north-northwest-trending scarp in section 24 between alluvial-fan deposits and Lake Bonneville sediments is suggestive of young faulting with down-to-the-east motion. It is sub-parallel with a set of faults located nearby (Bulls Pass quadrangle) that place the Salt Lake Formation against the Oquirrh Formation (Jordan, 1985).

No major north-trending faults are inferred to separate the Blue Creek Valley from bedrock exposures of the North Promontory Range. The morphology of the west side of the valley and east side of the North Promontory Mountains suggests that a gently east-dipping pediment surface cut in the Salt Lake Formation lies at a shallow depth beneath the Quaternary deposits. This is corroborated by the recognition of well-developed soil horizons on the western side of the valley, indicating long-term stability (C.G. Oviatt, 1985, personal communication). Pre-Bonneville soils are well exposed at the boundary of sections 19 and 30, T. 13 N., R. 5 W.

A north-northeast-striking fault in the bedrock in the northeast part of the map area has an estimated 8000 feet (2440 m) of down-to-the-east displacement (cross section A-A′). It is not known whether it dips to the east or west, but the relatively straight map trace suggests that it is nearly vertical at the surface. It apparently terminates to the south against the east-trending fault in sections 26 and 27 (T. 13 N., R. 5 W.) (discussed above).

Major north-trending faults that apparently separate the Blue Creek Valley from the Blue Springs Hills and Anderson Hill are obscured by Quaternary deposits. As discussed above, a north-striking gravity anomaly (maximum -20 mgal) beneath the Blue Creek Valley indicates that there is a significant thickness of Quaternary deposits and the Salt Lake Formation deposited on the downdropped fault block. In combination with the relative stratigraphic positions of the bedrock of Anderson Hill and the Oquirrh Formation exposed 4 miles to the west in the North Promontory Mountains (Jordan, 1985), these data indicate as much as 7000 feet (2100 m) of down-to-the-west displacement (cross section B-B′). The trace of the fault is constrained only by the gravity data (U.S. Geological Survey, unpublished compilation of gravity data). There is no evidence that these faults have been active during deposition of the younger Quaternary horizons.

The distribution of units on the east side of Anderson Hill suggests that there is a moderately west-dipping normal fault with about 4000 feet (1220 m) of offset (cross section B-B′). This interpretation is based on the occurrence of the Manning Canyon Shale to the east of exposures of the bioturbated limestone member of the Oquirrh Formation, where attitudes in the Oquirrh Formation suggest that it is part of the west limb of the Thatcher Mountain syncline. That moderately dipping detachment might be continuous with the north-northeast-striking fault that separates the Manning Canyon Shale on the north part of Anderson Hill from the limestone member of the Oquirrh Formation in the center of Anderson Hill.

ECONOMIC DEPOSITS

Sand and gravel are the principal resources of the Howell quadrangle. They have been exploited for many years within the quadrangle, and there is a potential for continued exploitation (Utah State Highway Department, 1965). Principal regions with sand and gravel potential (indicated as Qlg on the map) are: the west and east sides of Anderson Hill, and the northeast side of the Blue Creek Valley (section 34, T. 13 N., R. 5 W.; NW¼ section 22, T. 13 N., R. 5 W.; sections 10 and 11, T. 12 N., R. 5 W.). On the west side of Anderson Hill rounded gravel composed of sandy limestone and sandstone is well sorted, occurring locally in foreset beach deposits at the Provo level. Well sorted gravel on the east side of Anderson Hill formed in a spit related to the Provo shoreline. Sorted sand and gravel that accumulated above the Provo level has been locally exploited at the other sites noted.

There is no evidence of mining activity in the Howell area of the Blue Springs Hills (Doelling 1980). The limestones of the Oquirrh Group are generally quite impure, and thus not likely to be of economic value.

The oil and gas resource potential of the area has not been extensively assessed. Exploration in the vicinity of the Howell quadrangle includes two test wells in Whites Valley, about 2 miles (3 km) east of the Howell quadrangle, to depths of 2013 and 7321 feet (614 and 2232 m), with no reported oil or gas shows (J. Campbell, *in* Doelling, 1980). Five miles (8 km) to the south, in the Lampo Junction quadrangle, a test well was abandoned at 8966 feet (2733 m). Heavy oil has been produced from the Pliocene basalt off the south end of the Promontory Mountains by Amoco.

The recognition of the Thatcher Mountain syncline and Blue Springs thrust at the surface and Samaria thrust in the subsurface should have an impact on assessments of hydrocarbon potential and on exploration strategies in the quadrangle. The facies changes responsible for the anomolous abundance of quartzites in the Manning Canyon Shale may be important in assessing the source-rock potential of that unit. The elevated paleotemperatures in the Manning Canyon Shale and limestone member of the Oquirrh Formation (D. M. Miller and others, unpublished mapping) may be related to either the Blue Springs thrust or Samaria thrust. The impact of the thermal history on source-rock potential and timing of hydrocarbon migration must be assessed in light of the structural geometry and facies changes. In addition, the recognition of an east-trending fault that was active during the compressional deformation may be important in exploring for structural traps.

GEOLOGIC HAZARDS

An earthquake of magnitude 6.0 occurred about 10 miles (16 km) north of the Howell quadrangle in 1975. It was caused by slip along a west-dipping fault beneath the Pocatello Valley that caused no surface rupture (Arabasz and others, 1981). In the same region, Pleistocene or Holocene faulting is documented along the eastern border of the Pocatello Valley (Platt, 1975). Similarly, a 6.6 magnitude earthquake occurred in the Hansel Valley in 1934, about 12 miles (19 km) west of the Howell quadrangle (Anderson and Miller, 1979).

The western flank of the North Promontory Mountains has a particularly abrupt topographic expression, and Jordan (1985) mapped normal faults cutting the older of two Quaternary alluvial fan units along that mountain front. There is no equally direct evidence of Quaternary faulting along the eastern flank of the North Promontory Mountains in the Bulls Pass quadrangle (Jordan, 1985). However, as discussed above, relations in the northwestern part of the Howell quadrangle indicate the possibility of Quaternary faulting along the west side of the Blue Spring Valley.

The regional history of seismic activity and evidence of Quaternary faulting in the North Promontory Mountains raises the possibility of moderate to large earthquakes in the vicinity of the Howell quadrangle. Liquefaction features have not been described within the quadrangle but could result from ground motion during an earthquake in areas of shallow ground water.

A landslide deposit has been recognized at only one location (boundary of sections 11 and 14, T. 12 N., R. 5 W.) within the Howell quadrangle, in a zone where the bedrock consists of the Manning Canyon Shale. They are to be anticipated during times of high rainfall (e.g., the winter of 1984) in sites where the Manning Canyon Shale is exposed.The relative paucity of landslides may be related to the fact that the regions exposing Manning Canyon Shale are in the lower elevations of the hills. More abundant landslides in the Manning Canyon Shale have been recognized farther south in the Blue Springs Hills (D. M. Miller and others, unpublished mapping), where relief is greater.

Unstable ground resulting in caved areas, apparently due to high volumes of ground-water flow, has been reported locally in adjacent quadrangles.

ACKNOWLEDGMENTS

Examination of fusulinid collections by R.C. Douglass in the Howell quadrangle and adjacent areas has been vital to understanding the age relations. We are grateful to D.M. Miller, J.D. Schneyer, L.B. Platt, B.E. Murphy, and C.G. Oviatt for discussions and cooperation during the field work. D.B. Snyder's advice regarding interpretation of the gravity data is gratefully acknowledged. Financial support by the National Science Foundation (EAR 80-18758 and EAR 82-18617) for Jordan and Allmendinger was instrumental. The U.S. Geological Survey provided base materials and support for Jordan and Crittenden, Lehi Hintze, Paul Stone, D.M. Miller, Don Currey, Bryce Tripp, and Gary Christenson made constructive suggestions for the manuscript and illustrations.

REFERENCES

Allmendinger, R.W., 1983, Geologic map of the North Hansel Mountains, Idaho and Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1643, scale 1:24,000.

Allmendinger, R.W., and Jordan, T.E., 1981, Mesozoic evolution, hinterland of the Sevier orogenic belt: Geology, v. 9, p. 308-313.

Allmendinger, R.W., Miller, D.M., and Jordan, T.E., 1984, Known and inferred Mesozoic deformation in the hinterland of the Sevier belt, northwest Utah, *in* Kerns, G.J., and Kerns, R.L., eds., Geology of Northwest Utah, Southern Idaho, and Northeast Nevada: Utah Geological Association Publication 13, p. 21-34.

Allmendinger, R.W. and Platt, L.B., 1983, Stratigraphic variation and low-angle faulting in the North Hansel Mountains and Samaria Mountain, southern Idaho, *in* Miller, D.M., Todd, V.R., and Howard, K.A., eds., Tectonic and Stratigraphic Studies in the Eastern Great Basin: Geological Society of America Memoir 157, p. 149-163.

Anderson, L.W., and Miller, D.G., 1979, Quaternary fault map of Utah: Fugro, Inc., (Long Beach, California), scale 1:500,000.

Arabasz, W.J., Richins, W.D., and Langer, C.J., 1981, The Pocatello Valley (Idaho-Utah border) earthquake sequence of March to April 1975: Bulletin Seismological Society America, v. 71, p. 803-826.

Beus, S.S., 1958, Geology of the northern part of Wellsville Mountain, northern Wasatch Range, Utah: M.S. thesis, Utah State University, Logan, Utah, 84 p.

Christensen, O.D., 1975, Metamorphism of the Manning Canyon and Chainman Formations: Ph.D. thesis, Stanford University, Stanford, California, 166 p.

Doelling, H.H., 1980, Geology and mineral resources of Box Elder County, Utah: Utah Geological and Mineral Survey Bulletin 115, 251 p.

Gilluly, J, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geological Survey Professional Paper 173, 171 p.

Jordan, T.E., 1979, Evolution of the Late Pennsylvanian-Early Permian western Oquirrh Basin, Utah: Ph.D. thesis, Stanford University, Stanford, California, 253 p.

Jordan, T.E., 1985, Geologic map of the Bulls Pass quadrangle, Box Elder County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-1491, scale 1:24,000.

Jordan, T.E., Crittenden, M.D., Jr., Allmendinger, R.W., and Schneyer, J.D., unpublished mapping of the Blind Springs quadrangle, Box Elder County, Utah.

Jordan, T.E., Crittenden, M.D., Jr., Allmendinger, R.W., and Miller, D.M., 1988, Geologic map of the Thatcher Mountain quadrangle, Box Elder County, Utah: Utah Geological and Mineral Survey Map 109, scale 1:24,000.

Jordan, T.E., and Douglass, R.C., 1980, Paleogeography and structural development of the Late Pennsylvanian to Early Permian Oquirrh Basin, northwestern Utah, *in* Fouch, T.E. and Magathan, E.R., eds., Paleozoic Paleogeography of the West-Central United States: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, West-Central United States Paleogeography Symposium 1, p. 217-238.

Miller, D.M., Jordan, T.E.,Crittenden, M.D., Jr., Schneyer, J.D., and Allmendinger, R.W., unpublished mapping, Lampo Junction quadrangle, Box Elder County, Utah.

Murphy, B., 1983, Geology of the Limekiln Knoll quadrangle, Utah, M.S. thesis, Bryn Mawr College, Bryn Mawr, Pennsylvania, 53 p.

Murphy, B.E., Beus, S.S., and Oviatt, C.G., 1985, Provisional geologic map of the Limekiln Knoll Quadrangle, Box Elder County, Utah: Utah Geological and Mineral Survey, Map 79, scale 1:24,000.

Oviatt, C.G., 1985, Preliminary notes on the Paleozoic stratigraphy and structural geology of the Honeyville quadrangle, northern Wellsville Mountain, Utah, *in* Kerns, G.J., and Kerns, R.L., eds., Orogenic Patterns and Stratigraphy of North-Central Utah and Southeastern Idaho: Utah Geological Association Publication 14, p. 47-54.

Platt, L.B., 1975, Recent faulting at Samaria Mountain, southeastern Idaho: Geological Society America Abstracts with Programs, v. 7, p. 1229-1230.

Platt, L.B., 1977, Geologic map of the Ireland Springs-Samaria area, southeastern Idaho and northern Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-890, scale 1:48,000.

Smith, J.F., 1982, Geologic map of the Strevell 15-minute quadrangle, Cassia County, Idaho: U.S. Geological Survey Miscellaneous Investigations Map I-1403, scale 1:62,500.

Swenson, A.J., 1975, Sedimentary and igneous rocks of the Bingham district: Society of Economic Geologists Guidebook, "Bingham Mining District", p. 21-39.

Tooker, E.W., and Roberts, R.J., 1970, Upper Paleozoic rocks in the Oquirrh Mountains and Bingham Mining District, Utah: U.S. Geological Survey Professional Paper 629-A, 76 p.

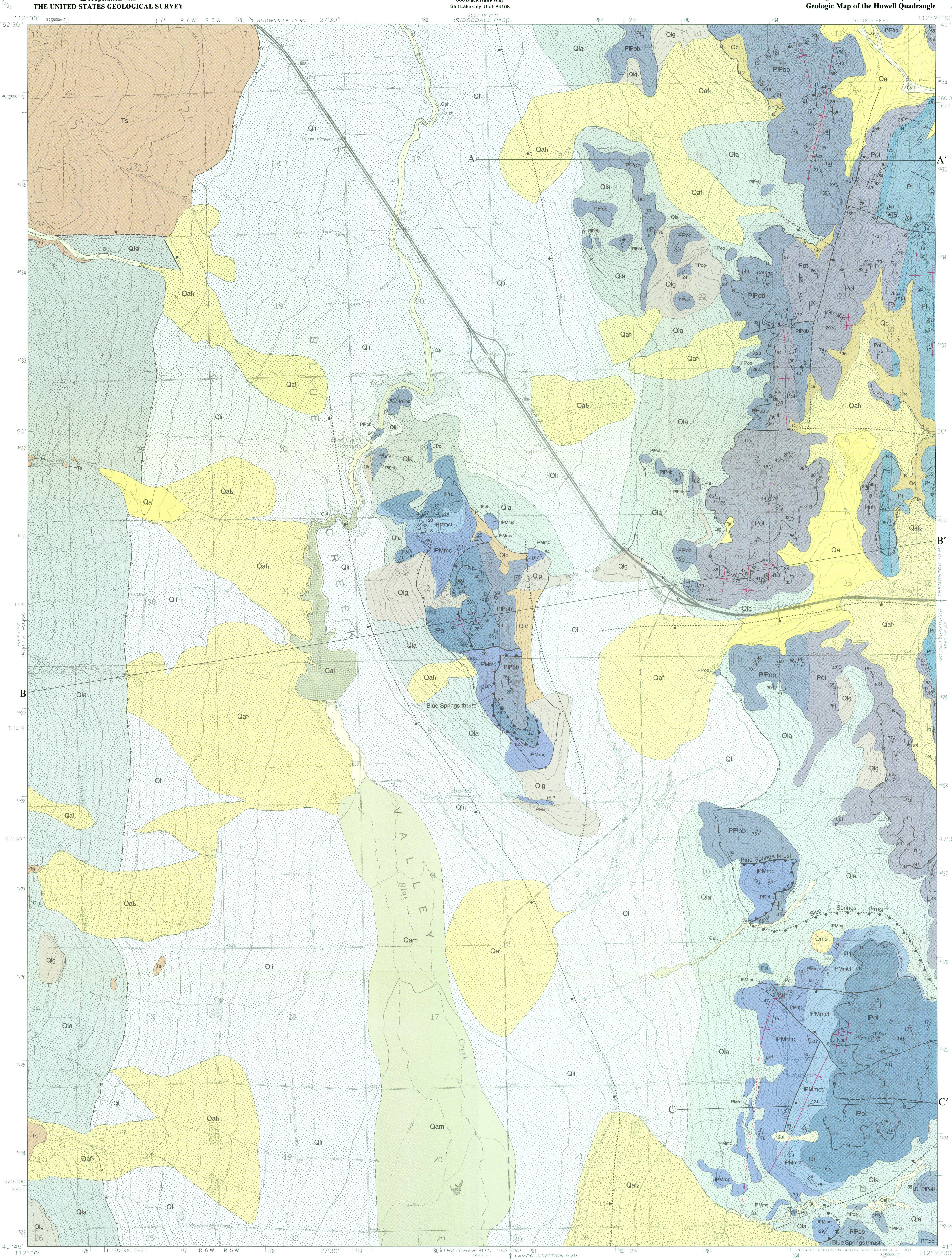
Utah State Highway Department, 1965, Materials inventory of Box Elder County, Utah: Utah State Highway Department, 17 p.

Williams, P.L., Covington, H.R., and Pierce, K.L., 1982, Cenozoic stratigraphy and tectonic evolution of the Raft River Basin, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic Geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 491-504.

UTAH GEOLOGICAL AND MINERAL SURVEY
UTAH DEPARTMENT OF NATURAL RESOURCES
in cooperation with
THE UNITED STATES GEOLOGICAL SURVEY

Published and sold by
UTAH GEOLOGICAL AND MINERAL SURVEY
Genevieve Atwood, Director
606 Black Hawk Way
Salt Lake City, Utah 84108

Plate 1
Utah Geological and Mineral Survey Map 107
Geologic Map of the Howell Quadrangle



Base map from U.S. Geological Survey,
Howell Quadrangle, 1968

SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

J.W. Parker, Cartographer

GN
MN
4.8°
1.4 mils
15°01'
266 mils

UTM GRID AND 1987 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

GEOLOGIC MAP OF THE HOWELL QUADRANGLE, BOX ELDER COUNTY, UTAH

by

Teresa E. Jordan[1], Richard W. Allmendinger[1], and Max D. Crittenden, Jr.[2]

[1]Cornell University, [2]U.S. Geological Survey

UTAH

QUADRANGLE LOCATION

1988

CORRELATION OF MAP UNITS

Qal, Qam, Qaf₁, Qlg, Qli, Qa, Qlc, Qla, Qc, Qms, Qaf₂ — Holocene, Pleistocene — QUATERNARY

Unconformity

Ts — TERTIARY

Unconformity

Pt, Ptc, Pot, PIPob — PERMIAN

Thrust fault

IPol, IPMmct, IPMmc — PENNSYLVANIAN, MISSISSIPPIAN

Thrust fault

Pzs — MIDDLE PALEOZOIC *

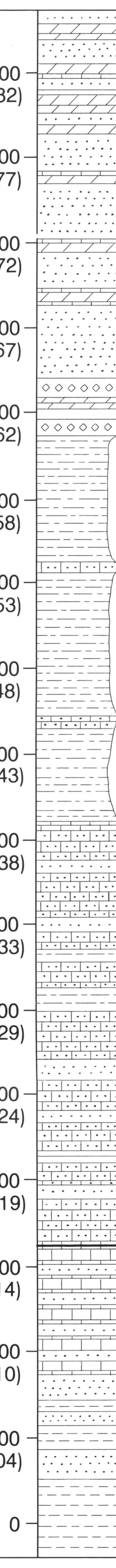
*On cross section only.

DESCRIPTION OF MAP AND CROSS SECTION UNITS

- **Qal** Alluvium—*Silt and sand in active streams and washes.*
- **Qam** Fine-grained alluvium—*Silt and clay in active streams and marshes.*
- **Qaf₁** Younger alluvial-fan deposits—*Sand, silt, and gravel in active alluvial fans.*
- **Qc** Colluvium—*Colluvium of sand and silt.*
- **Qms** Landslide deposits—*Boulders, gravel, and soil displaced downslope by gravity.*
- **Qli** Lacustrine silt—*Silt and clay deposited in Lake Bonneville, commonly calcareous and containing ostracode shells.*
- **Qlg** Lacustrine gravel—*Well-sorted and well-rounded, locally cross-bedded gravel and sand deposited along Lake Bonneville shorelines, including beach, delta, spit, and barrier deposits.*
- **Qla** Undifferentiated lacustrine and alluvial deposits—*Silt and sand of alluvial origin, in part reworked by Lake Bonneville.*
- **Qlc** Undifferentiated lacustrine and colluvial material—*Silt and sand of colluvial origin, in part reworked by Lake Bonneville.*
- **Qa** Older alluvium—*Older deposits of silt and sand, graded to higher lake levels and presently being incised and eroded.*
- **Qaf₂** Older alluvial-fan deposits—*Sand, silt, and gravel in alluvial fans that predate or are contemporaneous with Lake Bonneville deposits. Locally they may include deltaic deposits.*
- **Ts** Salt Lake Formation—*Tuffaceous to calcareous conglomerate and sandstone with local lacustrine limestone beds. Poorly resistant.*
- **Pt** Upper member of Thatcher Mountain Formation—*Thin- to thick-bedded, reddish-brown, fine- to coarse-grained sandstone, locally cross bedded, with interbedded limestone or dolomite.*
- **Ptc** Cherty member of Thatcher Mountain Formation—*Bluish-gray nodular and anastomosing chert replacing and interbedded with fine-grained sandstone, calcisiltite, and dolomite.*
- **Pot** Thinly bedded member of Oquirrh Formation—*Thinly bedded siltstone and calcisiltite with common dark-brown chert lenses.*
- **PIPob** Bioturbated limestone member of Oquirrh Formation—*Light- to medium-gray, silty and sandy limestone and brown, calcareous, very fine-grained sandstone. Bioturbated beds and laminated beds are medium to thickly interbedded.*
- **IPol** Limestone member of Oquirrh Formation—*Light- to medium-gray limestone and minor brown sandstone in bold exposures. Medium to thickly bedded, with local chert nodules.*
- **IPMmc** Manning Canyon Shale—*Medium- to coarse-grained sandstone and bold, dark-brown quartzite interbedded with non-resistant gray to black shale and minor fossiliferous limestone.*
- **IPMmct** Transitional member of Manning Canyon Shale—*Interbedded tan-weathering quartzite and gray-weathering medium- to thick-bedded bioclastic limestone.*
- **Pzs** Older sedimentary rocks—*Carbonate, sandstone, and shale typical of region. (Cross section only).*

UPPER PALEOZOIC STRATIGRAPHY

FORMATION	MEMBER	THICKNESS Feet (Meters)	LITHOLOGY	UNIT
Thatcher Mountain Formation	Upper member	17000 (5182), 16000 (4877), 15000 (4572), 14000 (4267)		Pt
	Cherty member	13000 (3962)		Ptc
Oquirrh Formation	Thinly bedded member	12000 (3658), 11000 (3353), 10000 (3048), 9000 (2743)		Pot
	Bioturbated limestone member	8000 (2438), 7000 (2133), 6000 (1829), 5000 (1524), 4000 (1219)		PIPob
	Limestone member	3000 (914)		IPol
	Transitional member	2000 (610)		IPMmct
Manning Canyon Shale		1000 (304), 0		IPMmc



MAP SYMBOLS

Contact — *Dashed where location approximate, dotted where covered.*

FAULTS

Dashed where approximate, dotted where covered.

High-angle normal fault — *Bar and ball on downthrown side.*

Low-angle normal fault — *Teeth on downthrown side where exposed.*

Thrust fault — *Teeth on upthrown side; queried where probable.*

STRIKE AND DIP OF BEDDING

17 Inclined · 75 Overturned · Vertical · Horizontal

Ball indicates that facing direction is determined from outcrop features.

TRACE OF AXIAL SURFACE OF FOLD

Anticline

Syncline

Overturned fold

Direction of plunge indicated.

Plunge and form of small-scale fold

22

STRIKE AND DIP OF FOLIATION

* 1

LOCATION OF PALEONTOLOGICAL SAMPLE

GEOMORPHOLOGICAL FEATURES

—B——B——B—

Trace of Bonneville shoreline

—P——P——P—

Trace of Provo shoreline

(Also serve as unit contacts locally)