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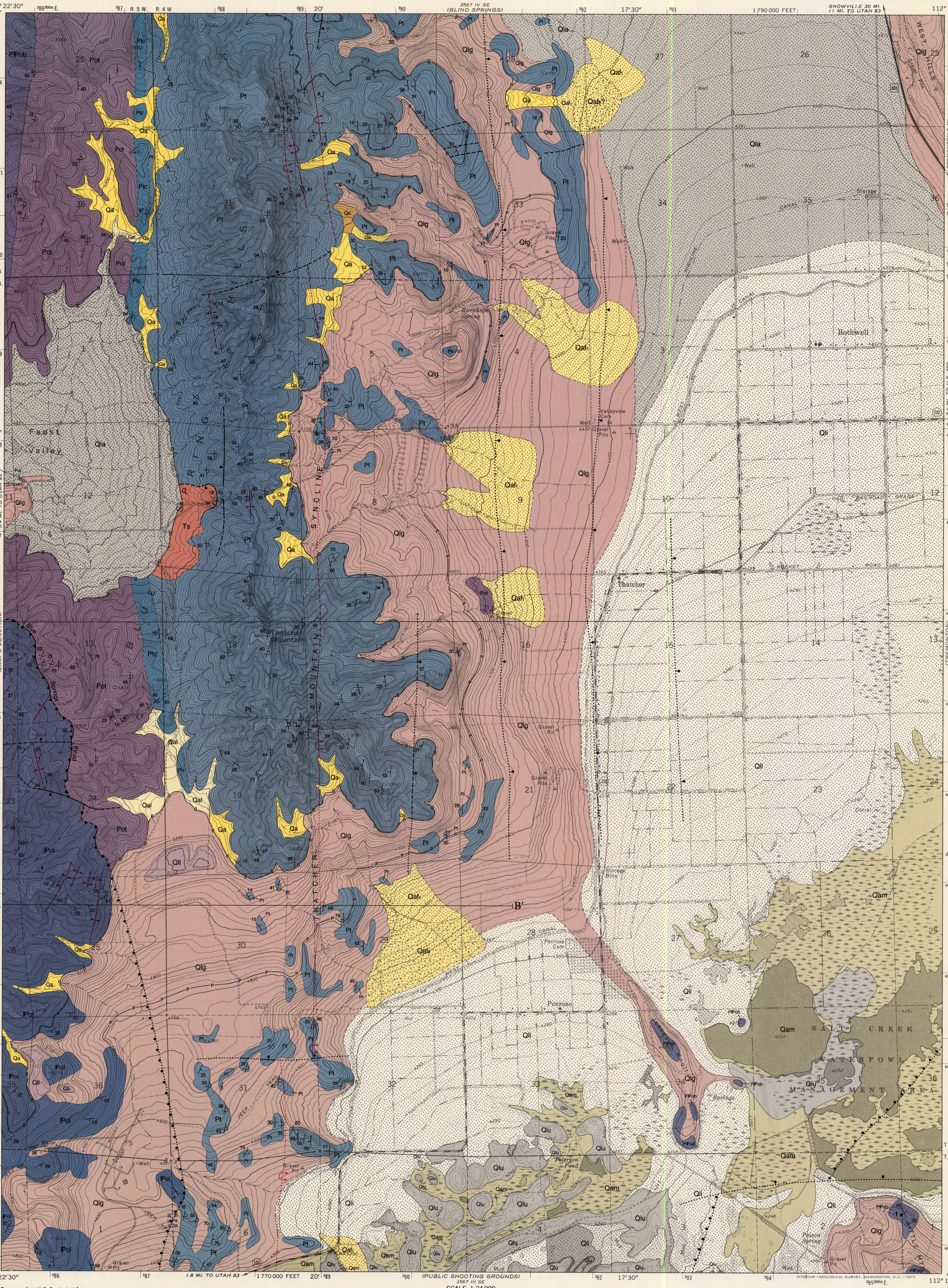
Plate 1
Utah Geological and Mineral Survey Map 109
Geologic Map of the Thatcher Mountain Quadrangle



Base map from U.S. Geological Survey, Thatcher Mountain Quadrangle, 1972

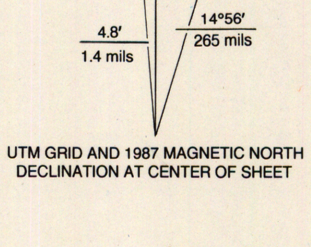
J. Parker, Cartographer

(THATCHER MTN. SW) 3567 III SW

(BEAR RIVER CITY) 3567 II SW

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

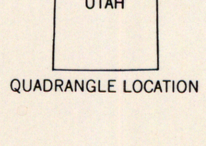


UTM GRID AND 1987 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

GEOLOGIC MAP OF THE THATCHER MOUNTAIN QUADRANGLE, BOX ELDER COUNTY, UTAH

by
Teresa E. Jordan[1], Max D. Crittenden, Jr.[2], Richard W. Allmendinger[2], and David M. Miller[2]
[1]Cornell University, [2]U.S. Geological Survey

1988



QUADRANGLE LOCATION

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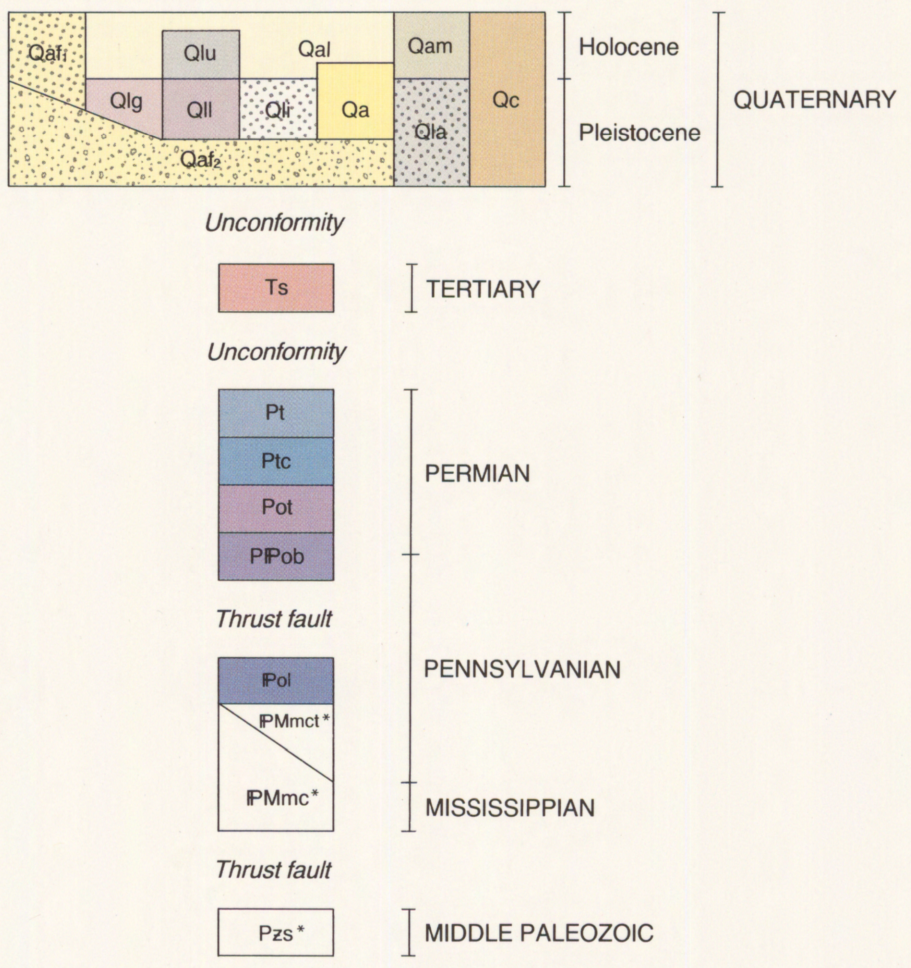
CORRELATION OF MAP UNITS

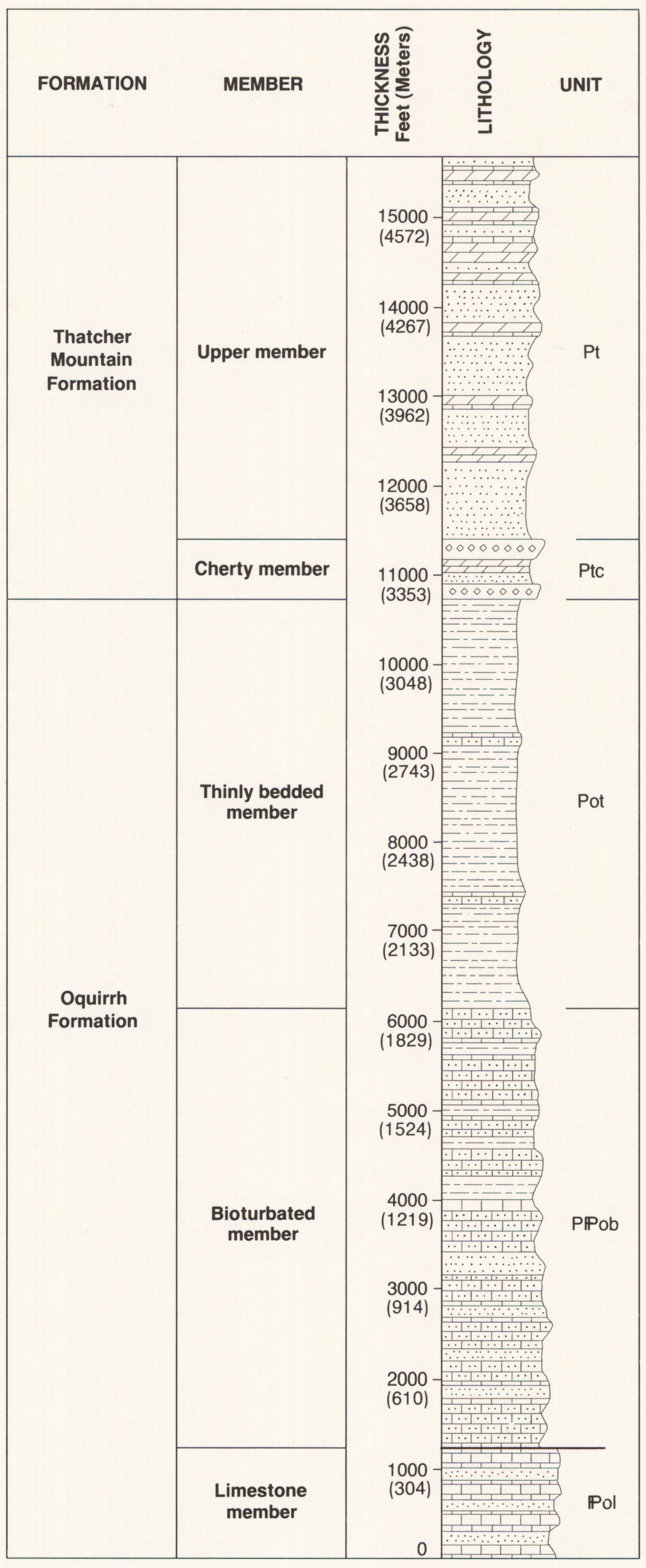


*On cross section only.

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.*
- **Qlu** Mixed and undifferentiated lacustrine and overbank fluvial sand and silt—*Sand and silt in local ridges.*
- **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.*
- **Qll** Lagoon deposits—*Well-sorted sand and silt deposited in quiet water behind barrier beaches and spits of Lake Bonneville shorelines.*
- **Qla** Undifferentiated lacustrine and alluvial deposits—*Silt and sand of alluvial 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. (Cross section only.)*
- **IPMmct** Transitional member of Manning Canyon Shale—*Interbedded tan-weathering quartzite and gray-weathering medium- to thick-bedded bioclastic limestone. (Cross section only.)*
- **Pzs** Older sedimentary rocks—*Carbonate, sandstone, and shale typical of region. (Cross section only).*

UPPER PALEOZOIC STRATIGRAPHY



MAP SYMBOLS

Contact — *Dashed where location approximate.*

FAULTS

Dashed where approximate, dotted where covered.

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

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

Thrust fault — *Teeth on upthrown side; dip indicated.*

STRIKE AND DIP OF BEDDING

Inclined — Overturned — Vertical

Ball indicates that facing direction is determined from outcrop features.

TRACE OF AXIAL SURFACE OF FOLD

Anticline

Syncline

Overturned fold

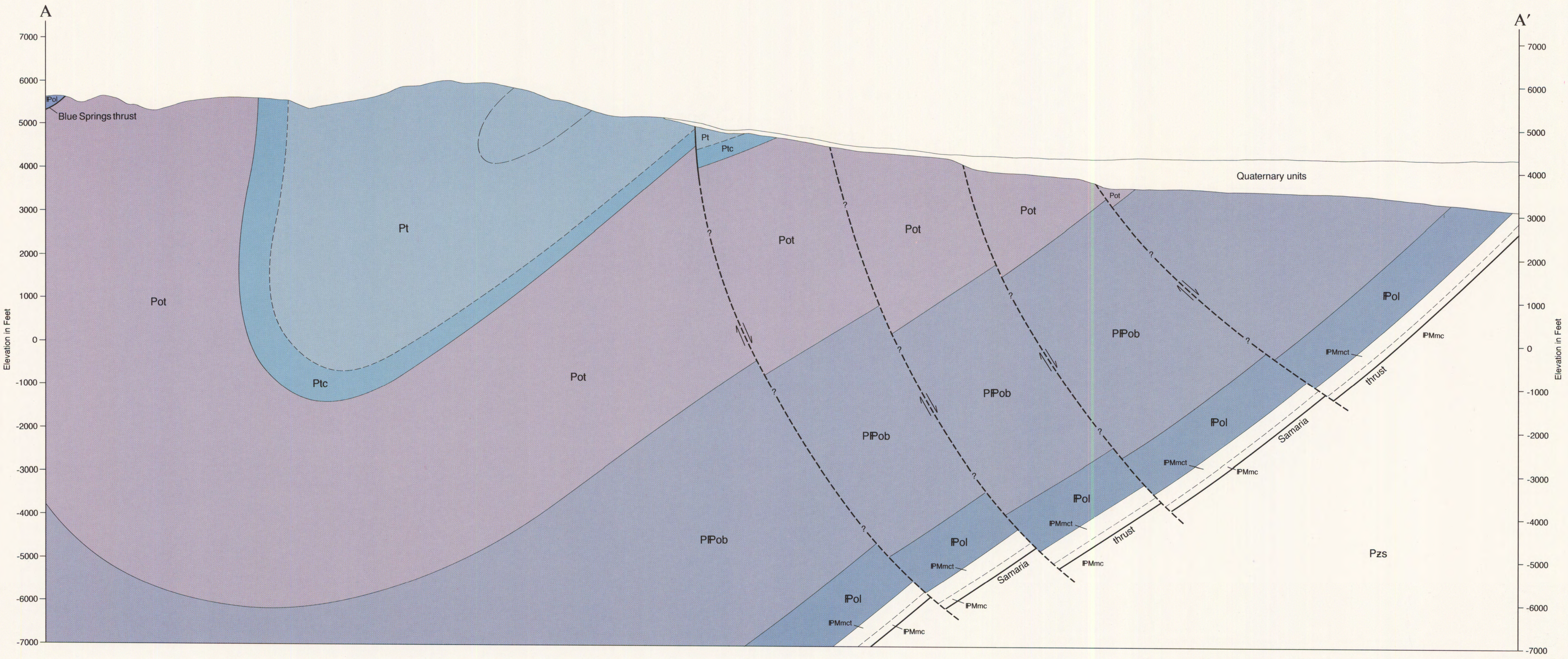
LOCATION OF PALEONTOLOGICAL SAMPLE

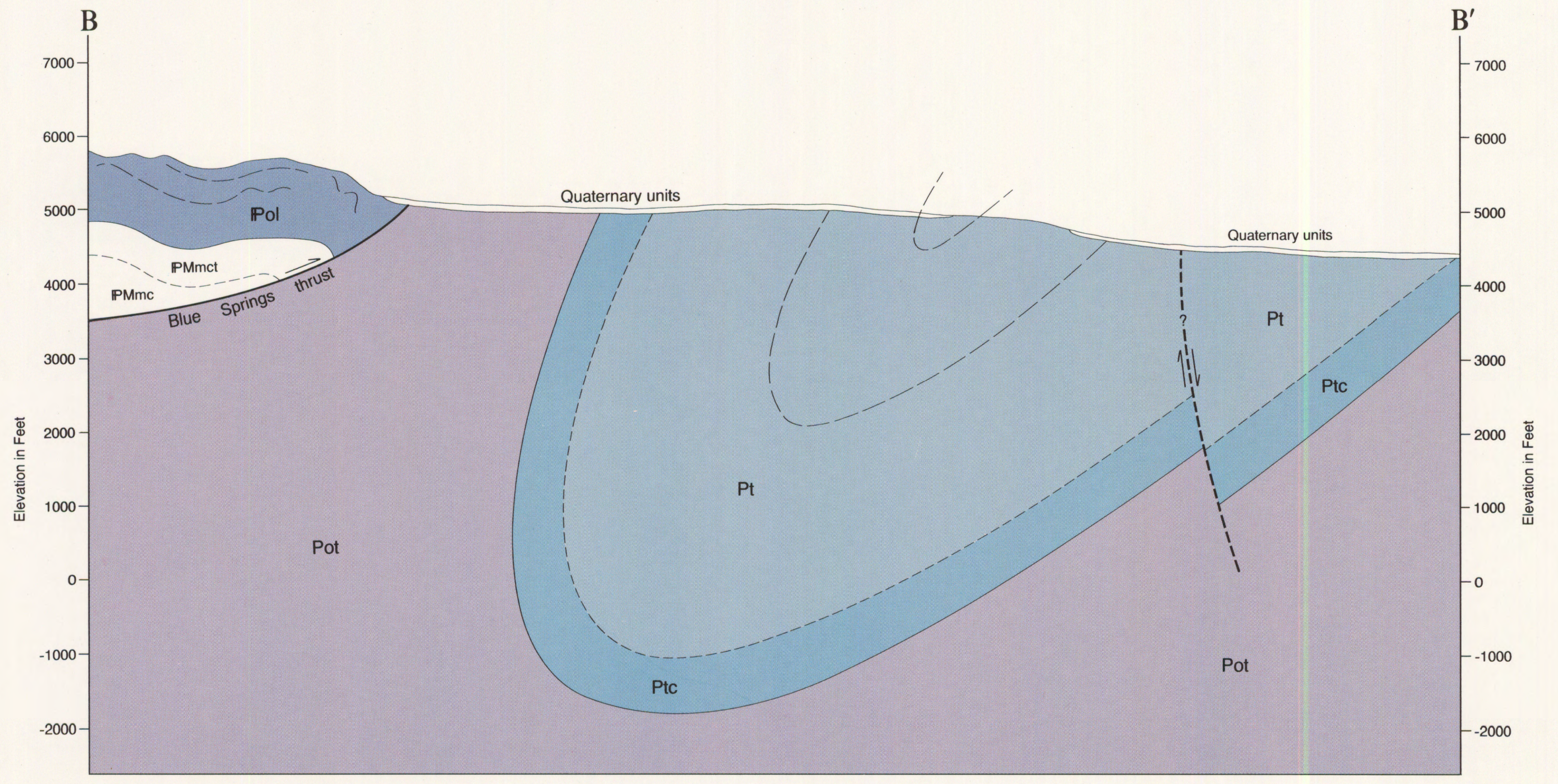
GEOMORPHOLOGICAL FEATURES

Trace of Bonneville shoreline

Trace of Provo shoreline

(Also serve as unit contacts locally)





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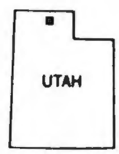
By Teresa E. Jordan, Max D. Crittenden, Jr., Richard W. Allmendinger, and David M. Miller



UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
MAP 109 **1988**

UTAH GEOLOGICAL AND MINERAL SURVEY

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

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GEOLOGIC MAP OF THE THATCHER MOUNTAIN QUADRANGLE, BOX ELDER COUNTY, UTAH

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

INTRODUCTION

THE Thatcher Mountain quadrangle is located in northwestern Utah, to the north of the eastern arm of the Great Salt Lake, about 18 miles (28 km) south of the Idaho-Utah border (figure 1). Part of the eastern Blue Springs Hills is located 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, sedimentary rocks of the late Paleozoic Oquirrh basin and immediately overlying strata crop out; older rocks are not exposed at the surface. The rocks were folded and thrusted, probably during Mesozoic time, and 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 the Paleozoic Oquirrh basin and its effect on Mesozoic and Cenozoic deformation of northwestern Utah. The Thatcher Mountain quadrangle is one of a series of maps by the authors that describe stratigraphic and structural relations in the Blue Springs Hills. This work, in combination with stratigraphic studies to the east ([Wellsville Mountain] Beus, 1958; Oviatt, 1985), north ([North Hansel and Samaria Mountains] Platt, 1977; Allmendinger, 1983; Allmendinger and Platt, 1983; [West Hills] Murphy, 1983), west ([North Promontory Mountains] Jordan, 1985; [Hansel Hills] T.E. Jordan, unpublished mapping) and south ([Promontory Mountains] Jordan and Douglass, 1980; M.D. Crittenden, Jr., unpublished mapping), reveals rapid thickness changes at the margin of the Oquirrh basin. This area of rapid thickness change apparently localized younger overturned folds and thrust faults (figure 1). The structures are inferred on the basis of regional relations to be of Mesozoic age. Further data are given by Allmendinger and Jordan (1981), Allmendinger and others (1984), and Jordan and others (1988).

Thatcher Mountain, located in the southeastern Blue Springs Hills, is, at 6240 feet (1900 m), the highest point in the quadrangle. The highlands are heavily vegetated by sagebrush and other low shrubs. Exposure of bedrock is poor on north-facing slopes and moderate on south-facing slopes. To the east the lowlands range upward in elevation from 4230 feet (1290 m), consisting of poorly drained marshes in lower parts. Surficial deposits of Pleistocene Lake Bonneville cover much of the lowlands. The mountain range is utilized primarily for sheep and cattle grazing; the lowlands are tilled.

STRATIGRAPHY

Pennsylvanian and Permian strata in the Blue Springs Hills are similar in general composition to those found elsewhere in the Oquirrh basin. The lithologic differences that exist indicate that they were deposited in the shelf region along the northeast border of the basin (Jordan and Douglass, 1980). Cenozoic deposits are limited to Tertiary conglomerate and sandstone with minor volcanic ash and varied Quaternary deposits, including significant sand and gravel accumulations. Detailed descriptions and discussions of problematical aspects of some of the stratigraphic units that occur in the Thatcher Mountain quadrangle are given here. In particular, a new formation within the Permian section is named.

[1] Cornell University
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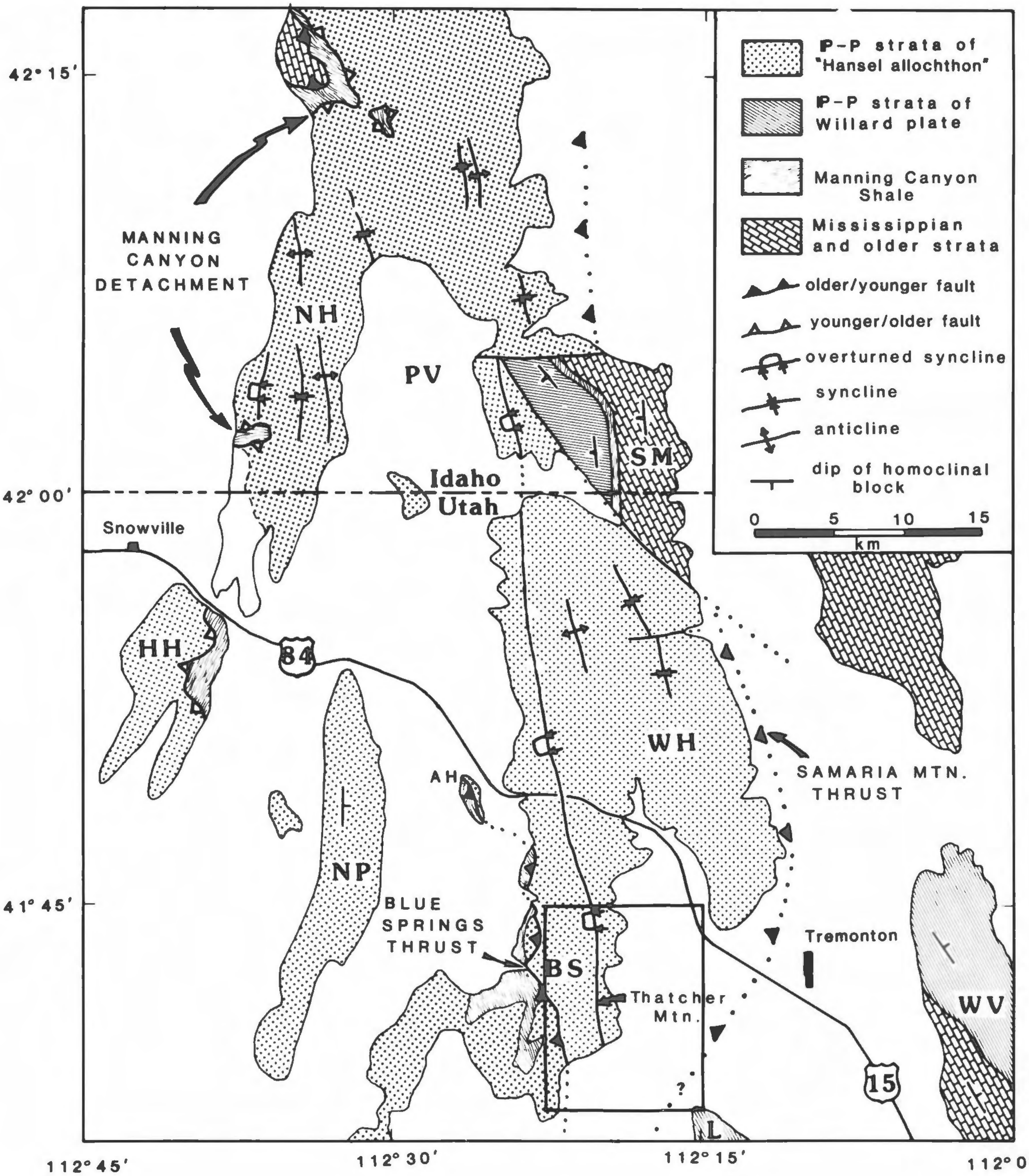

Figure 1. Regional geologic and geographic setting of the Thatcher Mountain quadrangle. "P-P" in legend indicates Pennsylvanian and Permian age strata. NH = North Hansel Mountains, PV = Pocatello Valley, SM = Samaria Mountain, HH = Hansel Hills, NP = North Promontory Mountains, WH = West Hills, BS =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

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, reaches 10,000 feet (3000 m) in thickness elsewhere in the region and is the oldest unit exposed in the Thatcher Mountain quadrangle. The type section of the Oquirrh Group is located in the Oquirrh Mountains, about 70 miles (100 km) south of the study area, where Tooker and Roberts (1970) described the formations that comprise the group. Although there are general similarities between the vertical succession of lithologies in the stratotype and the sequence in the Blue Springs Hills, there are major differences, especially in the Upper Pennsylvanian and Permian strata. The similarities and differences are discussed below. Because of those differences, recent studies in ranges that neighbor the Blue Springs Hills have subdivided the Oquirrh into informal members rather than formal formations (e.g., Allmendinger, 1983; Platt, 1977; Murphy, 1983; Jordan, 1985; Jordan and others, 1988). A similar approach is utilized here. Because nomenclatural convention necessitates that a group consist of formally named formations, and those are not mapped in this region, the Oquirrh is here considered to be of formational rank. Figure 2 compares the members mapped in the Blue Springs Hills to those used in neighboring ranges.

Limestone member

Bold exposures of texturally variable limestone and interbedded sandstone are gradational above the Manning Canyon Shale in the adjacent Lampo Junction quadrangle (D.M. Miller and others, unpublished mapping). The base of the Oquirrh Formation is defined there as the top of the uppermost, interbedded, laminated, brown sandstone or quartzite bed. 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.

The limestone member is exposed only in the upper plate of the Blue Springs thrust fault, in the southwestern part of the

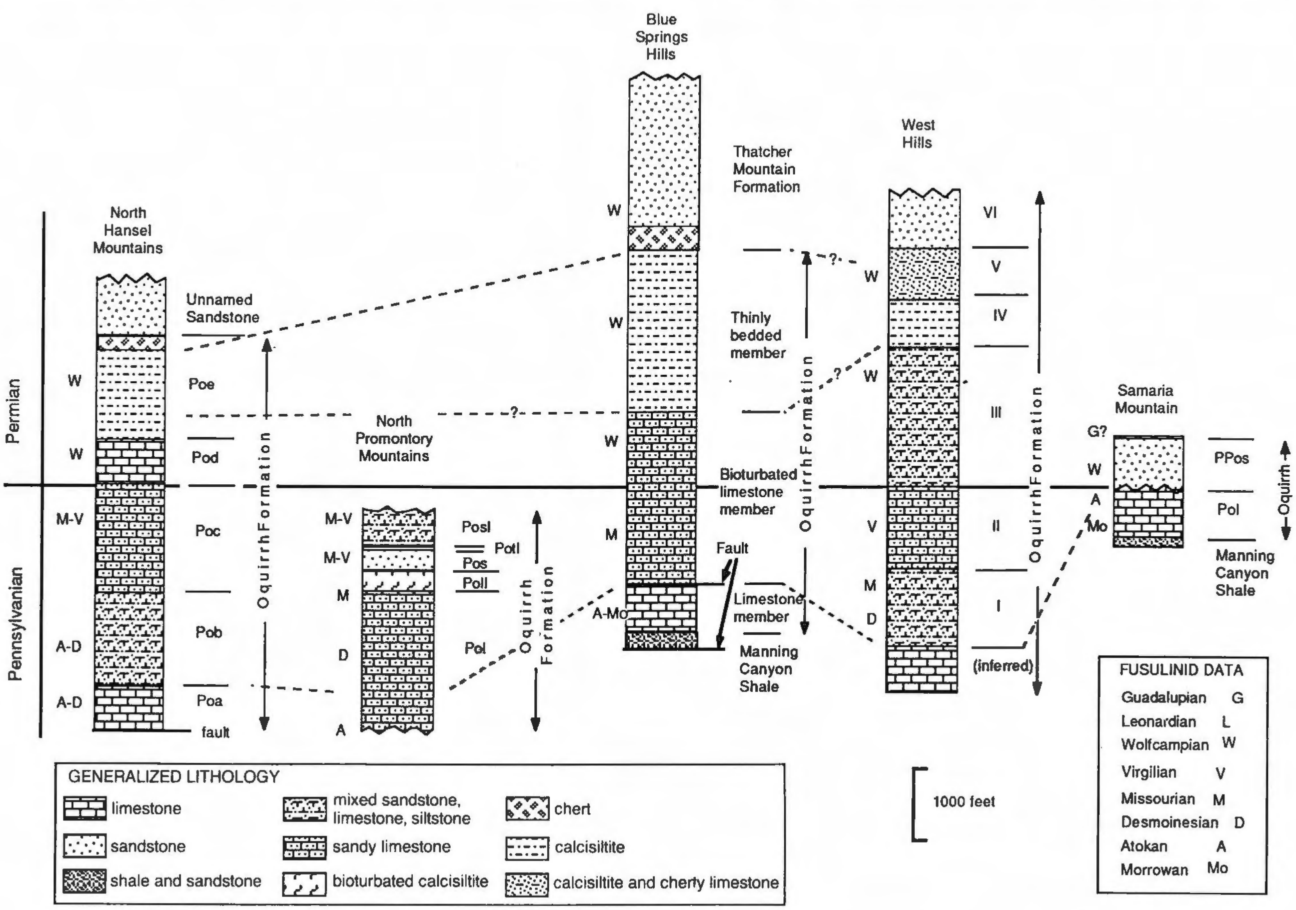

Figure 2. Comparison of the subdivisions mapped of the upper Paleozoic strata in the Thatcher Mountain quadrangle with the units recognized in adjacent ranges. Dashed lines suggest possible correlations of the lithostratigraphic units, whereas the fusulinid age data indicate age relations. The solid 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).

map area. Its eroded thickness is estimated to be 1200 feet (360 m). Conodonts from lithologically similar strata in the adjacent Lampo Junction quadrangle were studied by J. E. Repetski (written communication, 1985), who assigned them an age of late Morrowan or Atokan (Early or Middle Pennsylvanian). We consider the age of the limestone member to be Early and Middle Pennsylvanian.

Bioturbated limestone member

The mixed terrigenous detrital-grain (quartz and potassium feldspar) and calcite-grain arenites of this member are characterized by the common preservation of burrows; non-bioturbated interbeds have parallel and local cross laminations. The arenites are medium to thick bedded. Rare bioclastic beds consist of clean limestone containing broken shell debris.

The bioturbated limestone member is exposed in two small areas in the Thatcher Mountain quadrangle: in the northwest corner of the area where the upper part crops out, and at Little Mountain in the southeast corner where exposures are probably from much lower in the unit. In the Blue Springs Hills this member is everywhere separated from the limestone member by a fault. In the North Promontory Mountains to the west, strata similar to the bioturbated limestone member are conformable upon the limestone member (Jordan, 1985). The upper contact of the bioturbated limestone member is mapped above the last bioclastic limestone bed, corresponding closely to the upper limit of beds with abundant "rice grain" trace fossils. The upper part of the member includes very thinly bedded calcareous and silicified siltstone like that of the overlying member. Slump folds and intraformational conglomerate are characteristic of the upper part of the member.

The estimated minimum thickness of the bioturbated limestone member in the Lampo Junction quadrangle is 5000 feet (1520 m); it may be as much as 8000 feet (2440 m) thick, depending on fault geometries that are not yet well known. Fusulinid collections from this member at Little Mountain and in the Lampo Junction quadrangle indicate that it ranges from Missourian (Late Pennsylvanian) to Wolfcampian (Early Permian) in age (table 1 and R.C. Douglass, 1982 and 1984, written communications).

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 lithologic 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 and pinkish gray to dark brown. Bedding is characteristically thin, but relatively thick bedding occurs low in the unit. The upper part of this member includes some medium-bedded sandstone that grades into the overlying Thatcher Mountain Formation. Soft-sediment folds are present locally. In addition, strata in this member tend to accommodate deformation by layer-parallel slip and by forming small-scale, tight folds. Its minimum cross sectional thickness in the overturned limb of the Thatcher Mountain syncline is about 4500 feet (1370 m).

There are very few bioclastic beds in this member. Fusulinids of Wolfcampian age have been identified (R.C. Douglass, 1984, written communication) in this member in the Howell quadrangle (Jordan and others, 1988).

The thinly bedded member of the Oquirrh Formation in the Thatcher Mountain 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)

We here propose the name Thatcher Mountain Formation for a thick sequence of sandstone and lesser dolomite and limestone that is conformable on the Oquirrh Formation. It is the youngest unit in the region that predates the folds and thrust faults. Its type section is on Thatcher Mountain, from which the name is derived, in the overturned limb of the Thatcher Mountain syncline.

Similar rocks have been assigned to various formal and informal units elsewhere in the region. Murphy (1983) and Murphy and others (1985) mapped similar strata in the West Hills as an informal member of the Oquirrh Formation, whereas Allmendinger (1983) mapped them as his post-Oquirrh unnamed sandstone unit in the North Hansel Mountains. Doelling (1980) tentatively assigned rocks lithologically equivalent to the Thatcher Mountain Formation in the Blue Springs Hills to the Diamond Creek Sandstone (a unit defined in the southern Wasatch Mountains by Baker and Williams, 1940). The Oquirrh Group, as defined by Tooker and Roberts (1970) in the Oquirrh Mountains, does not include lithologically similar strata.

Table 1. Paleontological data for the Thatcher Mountain quadrangle

Map site	Field number	USGS number	Unit & Faunal description	Fossil age	Date of report	Paleon-tologist	Location Latitude (north)	Location Longitude (west)
1	8f58	f14026	Oquirrh Formation bioturbated limestone member. This sandy limestone contains a flood of fusulinids, most partly silicified and many totally silicified. They represent *Triticites* sp. of Late Pennsylvanian age.	Late Pennsyl-vanian	7/13/78	R.C. Douglas	41°58'15"	112°25'40"

The Thatcher Mountain Formation is divided into two informal members: a thin basal member (cherty member) and thick upper member. A consistent vertical sequence of lithologies in the upper unit was of benefit in mapping the major folds in the region.

Type section

The greater part of the unit type section of the Thatcher Mountain Formation is located on the western slope of Thatcher Mountain. The lower boundary is in the SE¼ of the NE¼ of section 13, T.11 N., R. 5 W. The type section continues to the east toward the summit of Thatcher Mountain and continues to the axis of the Thatcher Mountain syncline in the SW¼ of the NE¼ of section 17, T.11 N., R. 4 W. Access is simplest by driving south from Faust Valley along ranch roads but the section can also be reached on foot from the north, beginning at the road cut over the ridgeline, from the east, beginning at the gravel pit west of the village of Thatcher, or from the south.

Beds throughout the type section are steeply inclined, ranging from about 70° dips to the east to about 35° dips to the west, in the overturned limb of the large Thatcher Mountain syncline. We have selected this section as the type section despite its being overturned (and perhaps structurally thickened) because it preserves both the lower contact and a maximum part of the upper member of the formation. Sections in the upright limb of the syncline, both within and north of the Thatcher Mountain quadrangle, either do not expose the lower boundary of the formation or expose less of the upper part of the formation. A reference section can be obtained by continuing eastward from the synclinal axis or on many other parallel ridges in the gently dipping, upright, eastern limb of the syncline. Nowhere in the Blue Springs Hills is the upper boundary of the Thatcher Mountain Formation preserved. Instead, the unit is everywhere overlain unconformably by Cenozoic strata.

Description

The Thatcher Mountain Formation is composed of sandstone, dolomite, and chert. In ascending order, a chert-rich basal member is overlain by a lower sandstone-rich and upper dolomite-rich part of the upper member. Figure 2 and the schematic column on plate 2 illustrate the lithologies of the Thatcher Mountain Formation, which is estimated from cross section A-A′ to be 5000 feet (1520 m) thick at the type section. An estimation that exposures at the base of the east side of Thatcher Mountain represent a stratigraphic level near the base of the upper member implies that the formation is only 3000 feet (910 m) thick in the upright limb of the Thatcher Mountain syncline. This difference in thickness is probably due to structural thickening.

The lower boundary of the Thatcher Mountain Formation is marked by the first appearance of resistant and commonly boldly exposed 3- to 10-foot-thick (1- to 3-m) beds with a network of bluish-gray chert. The lithologies in the lower member of the Thatcher Mountain Formation are not markedly different than those of the underlying Oquirrh Formation, although the thinly bedded siltstones of the thinly bedded member of the Oquirrh are gradually replaced by more thickly bedded sandstones. Dolomite occurs in the Thatcher Mountain Formation but has not been recognized in the upper member of the Oquirrh Formation.

Cherty member

The lower member (here informally termed the cherty member) of the Thatcher Mountain Formation is 700 feet (210 m) thick and is characterized by bluish-gray and black chert. The bluish-gray chert is nodular and anastomosing; it comprises 50-70 percent of thick beds in which it replaces fine-grained sandstone. The black chert is thin to medium bedded and is associated with medium-gray-weathering calcisiltite and dolomite. Thickly bedded, fine-grained, brown-weathering sandstone with local laminations is interbedded with the chert-rich beds. The top of the cherty member is gradational into the overlying upper member of the formation.

Upper member

The upper member of the Thatcher Mountain Formation consists of two lithologically distinct parts. Its incomplete thickness is about 4300 feet (1300 m). The lower part is predominantly sandstone that is largely very fine to fine grained but is locally medium to coarse grained. The sandstone typically contains cross beds, cross laminae, and parallel laminae, although it is also commonly bioturbated and structureless. Dolomite cement is common. The sandstone is associated with laminated cherty siltstone and thin- to medium-bedded, very fine calcarenite (similar to the thinly bedded member of the Oquirrh Formation), thick-bedded dolomite, laminated black chert, and very cherty dolomite. In natural exposures, the sandstone is the most obvious lithology, whereas in artificial exposures, such as the road cut on the Faust Valley road, the cherty siltstone is also seen to be abundant. Comminuted and commonly silicified brachipod, gastropod, scaphopod, and crinoid debris occurs in local bioclastic horizons. This fossil debris has not proven useful for age determinations.

The upper part of the upper member consists of interbedded dolomite and sandstone. The abundance of dolomite increases gradually upward to comprise approximately 50 percent of the upper part of the upper member. The medium- to thick-bedded dolomite varies texturally from fine grained and laminated to coarse grained and thickly bedded. Locally, quartz sand is intermixed in the dolomite. Gray to black chert stringers and vugs filled with milky quartz occur locally. The interbedded sandstone, which locally fills shallow channels in the dolomite, is fine to coarse grained and commonly cemented by dolomite. Tabular cross beds suggest southwest-directed sediment transport (Jordan, 1979, figure 26). Limestone occurs locally in the member, as do silicified fossils.

Facies changes

The Thatcher Mountain Formation can be traced northward along the axis of the Thatcher Mountain syncline into the adjacent Blind Springs quadrangle. The lithologies vary gradually along strike. The most noteworthy change is that limestone gradually replaces dolomite as an important component both as discreet interbeds and as cement in the sandstones. Where the basal cherty member is poorly exposed, this lithologic variation causes greater difficulty in distinguishing the Thatcher Mountain Formation from the Oquirrh Formation. Therefore, to the north more reliance must be placed on the presence of cross-bedded sandstones in the Thatcher Mountain Formation to distinguish it from the Oquirrh Formation. Fossils are better preserved in the limestone than in the stratigraphically equivalent dolomite, so that age determinations can be made for the Thatcher Mountain Formation north of the Thatcher Mountain quadrangle. We infer that the dolomite of the type section was formed during diagenesis and that the depositional environment of the strata may not have varied greatly from north to south.

Age

No fossil age determinations have been made for the Thatcher Mountain Formation at the type section nor elsewhere within the Thatcher Mountain quadrangle, although samples of poorly preserved fossils have been examined by several paleontologists. However, in the Blind Springs quadrangle along strike to the north and the Howell quadrangle to the northwest, middle Wolfcampian fusulinids have been recognized (R.C. Douglass, written communication, 1984) from strata in the lower one-third of the formation. The age of the formation is here regarded as Early Permian.

Regional extent

Strata that are lithologically equivalent to the Thatcher Mountain Formation are common throughout much of northwest Utah. The lack of formally accepted stratigraphic terminology for these rocks has tended to understate their importance. Figure 2 compares sections from several nearby mountain ranges with the type-Thatcher Mountain Formation.

In the North Hansel Mountains (Idaho), Allmendinger (1983) mapped a unit (Ps, unnamed sandstone on figure 2) composed of sandstone and dolomite, above a resistant chert, limestone, and sandstone unit (top of Poe) that he mapped as the uppermost part of the Oquirrh Formation. Allmendinger's sandstone unit (Ps) is overlain unconformably by Cenozoic deposits; its minimum thickness is 1640 feet (500 m) (figure 2). He suggested its partial(?) correlation with the Hudspeth Cutoff Sandstone, which Cramer (1971) named in the Sublett Mountains. We here correlate Allmendinger's chert, limestone, and sandstone unit at the top of Poe with the (basal) cherty member of the Thatcher Mountain Formation and the overlying sandstone unit (Ps) with the upper member of the Thatcher Mountain.

In the Limekiln Knoll quadrangle in the West Hills, Murphy (1983) and Murphy and others (1985) mapped six informal members of the Oquirrh Formation (figure 2). The uppermost member (VI) consists of interbedded limestone and cross-bedded sandstone, in association with blue-gray chert. The member is about 1640 feet (500 m) thick, but its top is not preserved. Preliminary mapping in the Blind Springs quadrangle (T.E. Jordan, M.D. Crittenden, Jr., R.W. Allmendinger and J. Schneyer, unpublished mapping), which separates the Thatcher Mountain and Limekiln Knoll quadrangles, suggests that member VI and perhaps the upper, limestone-bearing, part of member V are approximately stratigraphically correlative with the Thatcher Mountain Formation.

In both the North Hansel Mountains and West Hills, late Wolfcampian fusulinids were identified by R.C. Douglass in the unit underlying that which is lithologically most similar to the Thatcher Mountain Formation (Allmendinger, 1983; Murphy, 1983). In contrast, the most direct age constraint on the Thatcher Mountain Formation where exposed in the Thatcher Mountain syncline comes from a fusulinid collection from near the base of the unit that is not younger than middle Wolfcampian (R.C. Douglass, written communication, 1984). Attempts to refine the age of the unit with conodont information have thus far proven futile (J.E. Repetski, 1985, written communication). We tentatively suggest that the Thatcher Mountain Formation may be a time-transgressive unit younger to the north.

Permian units overlying rocks that are typical of the Oquirrh Formation (or Group) have not been recognized in ranges immediately to the east (Beus, 1958; Oviatt, 1985), southwest (M.D. Crittenden, Jr., unpublished mapping; Jordan and Douglass, 1980) or west of the Blue Springs Hills (Jordan, 1985; T.E. Jordan, unpublished mapping). On the western side of the Great Salt Lake, however, a widespread sequence of Permian sandstone and dolomite overlies a particularly chert-rich horizon; it may be equivalent to the Thatcher Mountain Formation. In those areas a variety of informal terms and tentative stratigraphic names have been applied (e.g., unnamed sandstone unit in the Grassy Mountains (Doelling, 1964), Loray(?) Formation in the Terrace Mountains (Stifel, 1964), unnamed sandstone, limestone, and dolomite unit in the Newfoundland Mountains (Allmendinger and Jordan, 1984) (see also discussion by Bissell, 1967)). Recent stratigraphic studies in those areas have clarified the ages and identities of yet younger Permian strata (e.g., Wardlaw and others, 1979) but the upper mapping and age limit of the Oquirrh is still poorly defined.

South of the Great Salt Lake, the lithologies that occur in the type sections of the Wolfcampian Diamond Creek Sandstone and Kirkman Formation of the southern Wasatch Mountains (Baker and Williams, 1940) are similar to those of the Thatcher Mountain Formation.

SALT LAKE FORMATION (TERTIARY)

The poorly consolidated Salt Lake Formation is exposed only by virtue of the graded road cut on the crest of the Faust Valley Road. Clasts in the conglomerate there range up to boulder size and occur in a micaceous matrix. At that location, the base of the unit is not exposed and its top is faulted against Permian strata. Its minimum thickness is estimated to be 330 feet (100 m). No fossils were found in this unit in the Blue Springs Hills, but it is radiometrically dated as Miocene and Pliocene in age elsewhere in Box Elder County (Williams and others, 1982).

QUATERNARY DEPOSITS

Quaternary units consist of materials deposited in or reworked by Pleistocene Lake Bonneville, and fluvial deposits, which are predominantly alluvial-fan and mud deposits. 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. One of the younger lake-related units in the quadrangle, denoted as mixed lacustrine and overbank fluvial sand and silt (Qms), forms low ridges and buttes in the southern part of the map area. This material was probably deposited in levees along streams draining into the lake at the Gilbert level (Miller, 1980). Carbonate material (snail shells) at the base of these ridges has been dated as 10,950±150 years old (Miller, 1980). Low-energy fluvial action has reworked and deposited clay and silt over the lake deposits in the lowest parts of the quadrangle. Regional distribution and correlations of these units are discussed by Miller (1980).

The thickness of Quaternary deposits can be estimated from gravity data. The valley east of the Blue Springs Hills and north of Little Mountain contains an approximately -10 mgal gravity anomaly centered on the eastern border of the quadrangle (U.S. Geological Survey, unpublished gravity compilation). We assume that this gravity low is due to unconsolidated Quaternary and Tertiary sediments that fill a low zone in the bedrock. The magnitude of the anomaly suggests that there are approximately 1000 feet (300 m) of Quaternary deposits (cross section A-A')(D.B. Snyder, 1986, personal communication).

STRUCTURAL GEOLOGY

Folds and faults in the pre-Quaternary rocks of the Thatcher Mountain quadrangle are continuous with those described by Allmendinger and others (1984) 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. These structures are divided into an early group, caused by east-west shortening, and a later group that indicates east-west extension.

EARLY FOLDS AND FAULTS

The principal structure exposed in the Thatcher Mountain quadrangle is an eastward-overturned syncline, the Thatcher Mountain syncline, whose north-trending axis extends from the southern to northern boundaries of the quadrangle. It is the primary control on the distribution of bedrock units in the quadrangle. Its wavelength is at least 8 miles (12.7 km) and its amplitude is about 18,000 feet (5500 m). The axial surface dips westward about 40° to 50°. Most of the section in the western limb of the syncline consists of inverted strata that strike to the north and dip dominantly westward with inclinations of 45° to 90°. Small-scale parasitic folds are common in this limb, causing local complications in bed geometry and marked thickening of the section. In the axial region of the fold, intermediate-scale folds (wavelength about 100 to 200 feet) having box-like geometries commonly parallel the trend of the main syncline. Although usually poorly exposed, the synclinal axis can be located by examining facing directions in cross-bedded sandstones of the middle part of the Thatcher Mountain Formation, and by detailed mapping of the lithologic sequence within the Thatcher Mountain Formation. The eastern limb of the fold is upright and dips moderately (35°-40°) to the west. It contains much less small-scale folding than observed on the western limb or near the axis, but in areas of good exposure (e.g., near a gravel pit 0.5 miles west of the village of Thatcher) bedding-plane slip and small-scale thrust faults are evident. Gently to moderately west-dipping cleavage was observed rarely in the thinly bedded member of the Oquirrh Formation in the overturned limb of the syncline.

The west-dipping Blue Springs thrust fault crops out in the southwestern part of the map area, where it places a complicated but upright section composed of the limestone member of the Oquirrh Formation above Permian strata in the overturned limb of the Thatcher Mountain syncline. It was first identified by Doelling (1980) and described by Allmendinger and others (1984) (extent shown on figure 1). The Thatcher Mountain quadrangle contains the southernmost exposure of this structure. Within this quadrangle the fault dips about 35° westward. The Oquirrh limestone member of the upper plate is folded into a series of northeast- to northwest-trending minor folds that are truncated by the fault. The fault zone includes brecciated and silicified limestone that weathers to large, brown, rounded outcrops.

The west-dipping Samaria thrust fault (Allmendinger and Platt, 1983) is inferred to underlie the Thatcher Mountain Syncline and to intersect the earth's surface beneath the alluvial cover in the eastern lowlands of the quadrangle, separating the bedrock of Little Mountain from that of the Blue Springs Hills. The Samaria thrust is interpreted to be the frontal ramp zone of a regional fault across which the Pennsylvanian and Permian strata slipped eastward relative to the Mississippian and older units. Where those younger-over-older relations are exposed in local structural windows, the fault has been called the Manning Canyon detachment. The Samaria thrust fault/Manning Canyon detachment fault system is inferred to underlie much of the Pennsylvanian and Permian bedrock north of the Great Salt Lake (figure 1) (Allmendinger and Jordan, 1981; Allmendinger and others, 1984). The rocks above the fault surface have been referred to as the Hansel plate (figure 1) (Allmendinger and Jordan, 1981; Allmendinger and others, 1984).

The Samaria thrust is thought to separate units typical of those that form the Blue Springs Hills from stratigraphically distinct sequences to the east which occur in the upper plate of the Willard thrust. Upper Paleozoic rocks of the Willard plate comprise a considerably thinner sequence than that of the Blue Springs Hills, and the Manning Canyon Shale is locally absent (e.g., Oviatt, 1985). The sequence at Little Mountain, whose northeastern part occurs in the southeast corner of the Thatcher Mountain quadrangle, is tentatively considered to be part of the lower plate of the Samaria thrust. This interpretation is based on differing structural trends in Little Mountain, the apparent thinness of the upper Paleozoic sequence, and the apparent absence of the Manning Canyon Shale, although the zone of contact between the Oquirrh Formation and underlying strata is covered. Thus the trace of the Samaria thrust, now covered by Quaternary deposits, is interpreted to lie between strata exposed south of Thatcher Mountain and strata at Little Mountain.

The Thatcher Mountain syncline and the Samaria thrust fault parallel one another regionally and are thought to be genetically related. The fold is interpreted to represent shortening in the upper plate of the fault, perhaps caused by the fault passing eastward from a bedding-parallel position (west of the Blue Springs Hills) to a west-dipping attitude that cross-cuts the upper Paleozoic strata. The Blue Springs thrust, which is of more limited extent (figure 1) (Allmendinger and others, 1984; Jordan and others, 1988), represents faulting of an overtightened anticline that we presume was formed simultaneously with and parallel to the Thatcher Mountain syncline. Based on structural geometry and regional relations, Allmendinger and others (1984) suggested that the Samaria thrust fault produced a minimum of 9 miles (15 km) of east-west shortening, and that the shortening probably occurred before the Late Cretaceous. However, there is no direct evidence in the Blue Springs Hills for the age of deformation, except that it was post-Wolfcampian and pre-late Tertiary.

YOUNGER FAULTS

High-angle normal faults cut the folds and thrust faults. Most normal faults that are exposed in the bedrock of the Thatcher Mountain quadrangle trend east-west. Locally they are recognized because they offset fold axes and other 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 they are steeply inclined. Evidence within the Thatcher Mountain 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 that fault. Because it is clear that some of the east-striking faults post date the thrust, we infer that they are all younger than the structures described above.

The best exposed fault in the quadrangle is a normal fault exposed near the west end of the road cut on the Faust Valley road. It strikes approximately north and dips 54° to the west. The hanging wall is formed of east-dipping strata of the Salt Lake Formation, and the footwall consists of the Permian Thatcher Mountain Formation. The amount of offset on this fault is difficult to estimate, in part because the exposure is inadequate to indicate whether the Salt Lake Formation-Thatcher Mountain Formation contact along strike to the northwest and southwest is an erosional unconformity or a fault. If it is a fault, then its offset is probably at least a few hundred feet, given that the Salt Lake Formation is not recognized elsewhere in the quadrangle.

North-striking normal faults with probable large offsets are inferred to be present beneath Quaternary deposits. Such faults probably occur between separated bedrock remnants along the eastern flank of the Blue Springs Hills and geometrically similar faults probably separate the bedrock exposures from the broad plain of the eastern part of the map area. The north-striking faults are interpreted to have moderate to steep eastward dips and to down-drop the hanging wall blocks by hundreds of feet, based on four types of evidence. 1) In the north part of the map area, rocks exposed are typical of the Thatcher Mountain Formation for approximately 1 mile (1.6 km) east of an exposure of the west-dipping thinly bedded member of the Oquirrh Formation (section 16, T. 11 N., R.4 W.). This implies that the contact of the Oquirrh Formation and Thatcher Mountain Formation is repeated across faults (cross section A-A'). 2) Gravity data show that there is a straight, north-striking western boundary to a gravity anomaly (-10 mgal) that is centered under the valley to the east of the Blue Springs Hills (U.S. Geological Survey, unpublished compilation of gravity data). 3) The morphology of the eastern flank of the Blue Springs Hills is characterized by a set of north-trending topographic breaks, although these have been modified by lakeshore erosion and deposition. 4) The inferred faults in the Thatcher Mountain quadrangle occur along strike of mapped faults in the adjacent Blind Springs quadrangle (Jordan and others, unpublished mapping). There is no evidence that any of the north-trending normal faults cut the Quaternary lake deposits.

The north-striking faults on the east side of Thatcher Mountain either diminish in offset to the south or are cut by a set of east-striking faults between the latitudes of Penrose and the north side of Little Mountain. This interpretation is based on the nearly continuous bedrock exposures between Thatcher Mountain, Jesses Knoll, and Little Mountain. It is corroborated by gravity data which show a sharp east-striking gradient on the north side of Little Mountain (U.S. Geological Survey, unpublished compilation of gravity data).

ECONOMIC DEPOSITS

Sand and gravel are principal resources of the Thatcher Mountain quadrangle. They have been exploited for many years within the quadrangle, and there is a large potential for continued exploitation (Utah State Highway Department, 1965). There are three principal regions with sand and gravel deposits (indicated on the map as unit Qlg): the northeast corner of the quadrangle (the southwestern side of the West Hills), the southeast corner of the quadrangle, and the eastern and southern flanks of the Blue Springs Hills.

Rounded, well-sorted, gravel in the northeast area is composed of sandy limestone and sandstone, occurring locally in foreset beds; most gravel pits developed to date are in deposits below the Provo shoreline. Their position immediately adjacent to Interstate 84 makes them particularly important, and the deposits were utilized extensively in rebuilding the highway in 1984 and 1985.

Gravel deposits in the southeast, along the northwest margin of Little Mountain, are texturally and compositionally similar and all represent lake levels below the Provo shoreline. They have been exploited previously and large reserves still remain.

The deposits that flank the Blue Springs Hills cover broad areas and are associated with the Bonneville and Provo shorelines as well as with intermediate and lower shorelines. They are composed of clasts of sandstone, limestone, and dolomite. Barrier beaches that enclosed lagoons at and slightly below the Bonneville level are probably the best sorted deposits on the southern flank of the mountains.

A spit within Faust Valley and shoreline deposits associated with it are a local source of gravel. In general, tufa deposits that are locally associated with the Provo shoreline and lower shorelines may be detrimental to exploitation. Naturally fractured rock from the thinly bedded member of the Oquirrh Formation and from the Thatcher Mountain Formation provides small reserves of gravel along the Faust Valley road.

There is no evidence of mining activity in the Thatcher Mountain 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. Early drilling in the vicinity of the Thatcher Mountain quadrangle led to minor production of biogenic gas from depths of 250 to 350 feet (75-110 m)(J. Campbell, *in* Doelling, 1980), probably from unconsolidated deposits. Heavy oil has been produced from Pliocene basalt off the south end of the Promontory Mountains by Amoco. In 1931, Utah-Pennsylvanian Oil Co. drilled a test well to 4100 feet (1250 m) in NWNW section 3, T.10 N., R. 4 W., northwest of Little Mountain. The test was abandoned but a good gas show was reported at 3500 feet (1070 m) (J. Campbell *in* Doelling, 1980). A well drilled in 1963 (#1 Adams) by Gulf Oil Co. in the Engineer Hills in the Lampo Junction quadrangle, 4 miles to the west of the Thatcher Mountain quadrangle, had a weak oil show and a gas show but was abandoned at 8966 feet (2730 m) (J. Campbell *in* Doelling, 1980). Many wells have recently been drilled in the vicinity of the quadrangle, with varying success. The recognition of the Thatcher Mountain syncline, Blue Springs thrust, and Samaria thrust within the Thatcher Mountain quadrangle and Blue Springs Hills should have an impact on assessments of hydrocarbon potential and on exploration strategies in the quadrangle. Based on descriptions of the section that was drilled (J. Campbell *in* Doelling, 1980), the Engineer Hills test well is interpreted to have drilled through rocks in the upper plate of the Samaria thrust fault and entered those of the underlying Willard plate. In contrast, the Little Mountain test may have primarily penetrated the Willard plate rocks.

GEOLOGIC HAZARDS

Pleistocene or Holocene faulting (Platt, 1975) and a magnitude 6.0 earthquake without ground breakage in 1975 (Arabasz and others, 1981) about 25 miles (40 km) to the north of the Thatcher Mountain quadrangle in Pocatello Valley testify to the potential seismic risk in the Thatcher Mountain quadrangle. Similarly, an earthquake that measured 6.6 on the Richter scale occurred in the Hansel Valley in 1934, about 20 miles (36 km) west of the Thatcher Mountain quadrangle (Anderson and Miller, 1979). Faults that offset Quaternary units have been mapped on the eastern and western flanks of the North Promontory Mountains, a few miles to the west of the Thatcher Mountain quadrangle (Jordan, 1985; Jordan and others, 1988). This raises the possibility of moderate to large earthquakes in the vicinity of the Blue Springs Hills. Liquefaction features have not been described within the quadrangle but areas of shallow ground water in the southeast corner of the area may be susceptible due to ground motion during an earthquake.

Landslides have not been recognized within the Thatcher Mountain quadrangle, but are common during times of high rainfall (e.g., the winter of 1984) in areas where the Manning Canyon Shale is exposed, such as in the upper plate of the Blue Springs thrust immediately to the west of the Thatcher Mountain quadrangle boundary (D.M. Miller and others, unpublished mapping).

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

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