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GEOLOGY OF THE COVE FORT-SULPHURDALE KGRA

by

J. N. Moore and S. M. Samberg

with Bibliographic Annotations and

Petrographic Descriptions by Bruce Sibbett

May, 1979

Work performed under Contract No. EG-78-C-07-1701

EARTH SCIENCE LABORATORY
University of Utah Research Institute
Salt Lake City, Utah

Prepared for

U.S. Department of Energy

Division of Geothermal Energy

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ABSTRACT

The Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) is located on the northwestern margin of the Marysvale volcanic field in southwestern Utah. The geology of the KGRA is dominated by lava flows and ash-flow tuffs of late Oligocene to mid-Miocene age that were deposited on faulted sedimentary rocks of Paleozoic to Mesozoic age. The rocks of the Cove Fort-Sulphurdale area were metamorphosed and mineralized by stocks of quartz monzonite and latite porphyry during the lower Miocene. An unrelated hydrothermal event produced small fluorite deposits near Cove Fort. Quaternary volcanic activity produced extensive andesitic basalt flows along the western margin of the KGRA.

The geothermal system of the Cove Fort-Sulphurdale KGRA is structurally controlled by normal faults. The principle structures include: north-northwest and northeast-trending steeply dipping faults and low-angle west-dipping faults. The low-angle faults bound large-scale gravitational glide blocks in the central part of the Cove Fort-Sulphurdale area. High-angle faults control fluid flow within the geothermal reservoir, while the gravitational glide blocks provide an impermeable cap for the geothermal system in the central part of the field.

Surficial activity occurring to the north and south of the glide blocks is characterized by the evolution of hydrogen sulfide and deposition of native sulphur. Intense acid alteration of the alluvium, resulting from downward migration of sulphuric acid, has left porous siliceous residues that retain many of the original sedimentary structures. The acid-altered areas are concentrated along mineralized, steeply dipping faults. It is suggested that the intense low magnitude earthquake activity in the Cove Fort area reflects reactivation of older faults.

This report includes detailed logs of Union Oil Company drill holes Forminco #1, Utah State 42-7, and Utah State 31-33.

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INTRODUCTION

The Cove Fort-Sulphurdale Known Geothermal Resource Area (KGRA) is centered near the junction of the Pavant Range and the Tushar Mountains in south central Utah (Figure 1). The area lies approximately midway between the Monroe-Joseph Hot Springs and the Roosevelt Hot Springs geothermal areas.

The active hydrothermal system in the Cove Fort-Sulphurdale area has produced intense alteration of the alluvium as well as deposition of sulphur and minor sulfides. Small but commercial deposits of sulphur have been mined at Sulphurdale (Mount, 1964).

In 1975, Union Oil Company initiated an exploration program in the Cove Fort-Sulphurdale KGRA to test the geothermal potential of the area. This program included the drilling of three deep holes and 14 shallow thermal gradient holes, and preparation of detailed resistivity profiles (Union Oil Company, 1978b-d). These studies, as well as the work of King (1953), Rodriguez (1960), and Callaghan (1973), pointed out the need for a better understanding of the structural evolution and subsurface geology of the geothermal field. Consequently, detailed geologic and geophysical studies were initiated as part of the Industry Coupled Case Study Program of the Department of Energy, Division of Geothermal Energy. This report describes the geology of the Cove Fort-Sulphurdale KGRA and provides detailed lithologic logs of the Union Oil Company exploration wells.

Our studies have outlined a far more complex picture of hydrothermal alteration and structural deformation in the Cove Fort area than had previously been described. Evidence now indicates that the altered rocks and

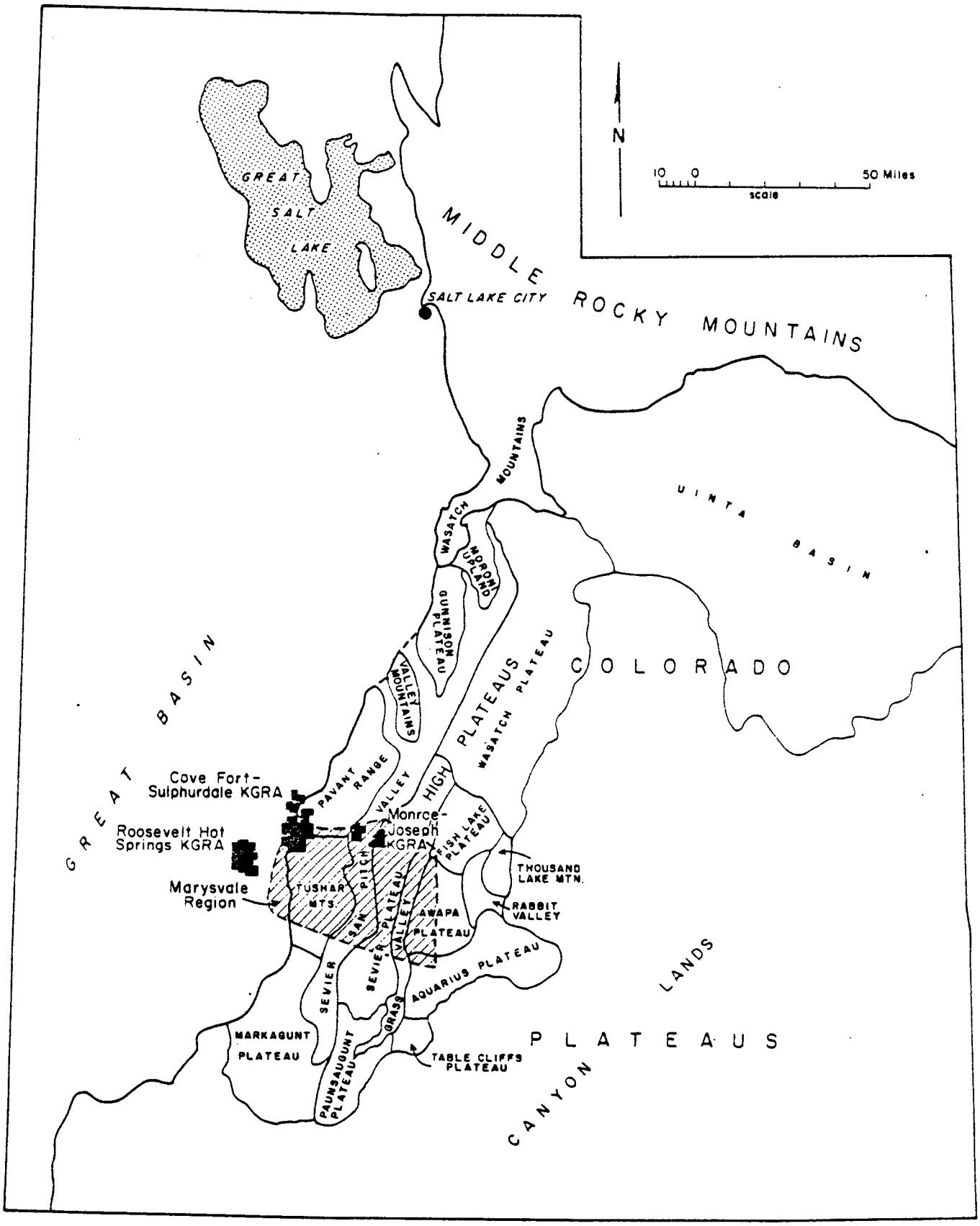

Figure 1. Map of Utah illustrating the location of the Cove Fort-Sulphurdale KGRA, the adjacent geothermal resource areas, and the divisions of the High Plateaus. The approximate outline of the Marysvale region is shown by the ruled pattern (modified from Callaghan, 1973).

related surficial sulphur deposits of the district overlie a deeply buried, unrelated intrusive system of mid-Tertiary age which is largely obscured by younger volcanic rocks and alluvium. Union Oil Company drill holes near Sulphurdale and Cove Fort (App. I-III) provide insight into the deeper buried portions of this system. Another hydrothermal system, between the other two systems in age, deposited fluorite in brecciated Paleozoic limestones of the southwestern Pavant Range. The three hydrothermal systems of the Cove Fort-Sulphurdale area differ in style as well as in intensity, and their geological and geochemical characteristics are the major themes of this paper.

GEOLOGIC SETTING

The Cove Fort-Sulphurdale geothermal resource area spans the northwestern margin of the Marysvale volcanic field (Fig. 1). It is bounded to the east and south by Tertiary volcanics, to the west by the Cove Fort basalt field, and to the north by Paleozoic and Mesozoic sedimentary rocks. The zones of intensely altered rocks related to the presently active hydrothermal system lie almost entirely within the Marysvale volcanic field and are included in the present study area (Plate 1).

The Marysvale volcanic field lies near the eastern edge of a broad belt of intrusive rocks and widely distributed mineral deposits (Callaghan 1973, Rowley and others, 1968). The belt extends from the boundary of the Colorado Plateau east of Marysvale, Utah through Pioche, Nevada and is commonly referred to as the Pioche-Beaver-Tushar belt (Callaghan, 1973). The evolution of the Marysvale volcanic field has been studied by many workers including Callaghan (1939, 1973), Molloy and Kerr (1962), Anderson and Rowley (1975), Cunningham and Steven (1977), and Steven and others (1977). The latter

summarized the stratigraphic relationships within the northern half of the Marysvale volcanic field. Although the basic stratigraphic framework has been outlined, the detailed geologic relationships in many portions of the volcanic field have not yet been mapped.

The stratigraphic and structural relationships on the northwestern margin of the Marysvale volcanic field have been described by Steven and Cunningham (1979) and Steven (1978). These studies have led to substantial revisions in the geologic relationships presented by many of the earlier investigations [e.g. Crosby (1959), Rodriguez (1960), Callaghan and Parker (1961a), Callaghan (1973), Caskey and Shuey (1975) and Union Oil Company (1978a)]. While our field investigations support the relationships presented by Steven and Cunningham (1979), this study provides further insight into the volcanic stratigraphy and hydrothermal activity of this portion of the volcanic field. The geology to the west of the Pavant Range has been mapped by Zimmerman (1961).

The Cove Fort area is underlain at depth by thick accumulations of Paleozoic and Mesozoic sedimentary rocks in the southern Pavant Range (Maxey, 1946; Lautenschlager, 1952; Crosby, 1959; Hintze, 1973). These rocks are part of a broad belt that was folded and faulted during the Sevier Orogeny (Crosby, 1959; Armstrong, 1968). Near Cove Fort, the sedimentary rocks consist primarily of Paleozoic carbonates and sandstones, and Mesozoic redbeds (Crosby, 1959). Following deformation, erosion of the thrust sheets led to the formation of the Price River Conglomerate during the late Cretaceous and early Tertiary (Crosby, 1959). Within the mapped area, the conglomerate overlies the Pennsylvanian Oquirrh Formation or the Permian Coconino Sandstone. The

conglomerate is coarsely fragmental near its base but becomes finer-grained upward and laterally to the south.

Volcanism began in the Marysvale volcanic field approximately 30 my ago and continued into the lower Miocene, producing intermediate-composition lava flows, breccias, and ash-flow tuffs from numerous local vent centers (Steven and others, 1977). Concurrently, widespread ash-flow tuffs derived from sources within the Basin and Range Province lapped up along the margins of the developing stratovolcanic complex (Mackin, 1963; Caskey and Shuey, 1975; Anderson and Rowley, 1975; Steven and others, 1977). The final stages of intermediate-composition volcanism were accompanied by emplacement of widely distributed hypabyssal quartz monzonite intrusions in the lower portions of the volcanic complex. Intense hydrothermal alteration and minor base metal mineralization were associated with these intrusions in many parts of the volcanic field.

Rhyolitic ash-flow tuffs and lava flows were erupted from volcanic centers in the Marysvale volcanic field between 21 and 17 my ago (Bassett and others, 1963; Cunningham and Steven, 1977; Carmony 1977). The voluminous ash-flow tuffs spread outward from a large collapse caldera in the central Tushar Mountains, accumulating in adjacent depressions within the older stratovolcanic complex (Steven and others, 1977). A smaller vent center was simultaneously active in the Antelope Range to the east and in the adjacent portions of the Tushar Mountains (Cunningham and Steven, 1977).

Extensive Basin and Range faulting began after deposition of the rhyolitic volcanics and is responsible for many of the present topographic

features. Faulting continued throughout the Cenozoic and the area is still seismically active (Smith and Sbar, 1974; Olson and Smith, 1976).

Locally derived alluvial deposits of the Sevier River Formation and thin, interbedded basalt flows accumulated in depressions after deposition of the rhyolitic volcanics. Although the Sevier River Formation is poorly represented in the study area, thick sections occur in the Clear Creek downwarp located east of Cove Fort (Callaghan and Parker, 1961a). Steven and others (1977) have dated a volcanic ash near the base of the formation at 13.8 ±1.7 my and another ash near the top of the formation at 6.9 ±1.3 my using fission track techniques on included zircon. The Sevier River Formation in the Clear Creek downwarp is displaced by north- and northeast-trending Basin and Range faults.

The Cove Fort-Sulphurdale geothermal field is bordered on the west by the late Cenozoic Cove Fort basalt field (Condie and Barskey, 1972). The lava flows did not, however, extend into the Pavant Range or Tushar Mountains. The chemistry and petrographic descriptions of the lava flows are provided by Clark (1977).

VOLCANIC STRATIGRAPHY

The volcanic rocks of the Cove Fort-Sulphurdale area define a relatively simple stratigraphic succession (Plate 1). The oldest rocks, exposed principally in the southern portion of the Pavant Range, include intermediate-composition lava flows and breccias erupted about 30 my ago from a local volcano (Steven and others, 1978). Younger ash-flow tuff sheets derived from volcanic centers within the Marysvale volcanic field and in the Basin and

Range to the west have accumulated on the margins of this upper Oligocene volcano, locally lapping up and wedging out against it. Portions of the thin edges of the ash-flow sheets are now preserved in downdropped fault blocks south of Cove Fort. In adjacent areas, the ash-flow tuffs intertongue with vent and alluvial facies volcanics of the Marysvale volcanic field (Steven and others, 1977; Cunningham and others, 1978).

Bullion Canyon Volcanics

Steven and others (1977) have assigned the locally derived Oligocene volcanic rocks and intrusives of intermediate composition to the Bullion Canyon Volcanics. On the distal edge of the Marysvale volcanic field in the study area, the Bullion Canyon Volcanics include lava flows, flow breccias, ash-flow tuffs, and subordinant hypabyssal intrusives. In the portion of the volcanic field we have studied, the lava flows are restricted to the lower part of the Bullion Canyon Volcanics. Elsewhere in the volcanic field, lava flows of similar composition belonging to the upper and lower portions of the Bullion Canyon Volcanics are separated by the distinctive and widespread Three Creeks Tuff Member (Steven and others, 1977; Cunningham and others, 1978). The Bullion Canyon Formation is overlain by the regional Osiris Tuff in the Cove Fort area.

Lower Member--The rocks of the lower part of the Bullion Canyon Volcanics include dacite lava flows and flow breccias that are interlayered with a locally thick, crystal-rich ash-flow tuff. The lava flows predominate in the southern Pavant Range, but deep drilling in the northern Tushar Mountains (App. I, II; Plate 1) indicates that the ash-flow tuff becomes increasingly important to the south. We follow Steven (personal comm., 1979) in assigning

this ash-flow tuff to the Needles Range Formation. Caskey and Shuey (1975) have mapped the Needles Range Formation near Highway 15 northwest of Cove Fort.

The lava flows in the southern Pavant Range overlie the Price River Conglomerate or the Coconino Sandstone and partly underlie the Needles Range Formation. Here Caskey and Shuey (1975) have mapped a thick plagioclase-hornblende-bearing lava flow which they termed the Sulphur Peak Member of the Bullion Canyon Volcanics. The flow is several hundred meters thick in the Sulphur Peak area, located just east of our study area. Our mapping suggests that the Sulphur Peak Member is correlative with the basal lava flows mapped north of Cove Fort.

The dacite flows consist of 15-30% phenocrysts in a glassy to cryptocrystalline matrix. Plagioclase and hornblende account for nearly 80% of the phenocrysts in the samples studied. The average phenocryst abundances of the lava flows from the Cove Fort area are 15% andesine, 5% hornblende, 2% each of biotite and magnetite. Minor amounts of pyroxene occur in some of the lava flows.

The regionally extensive Needles Range Formation, derived from a source area in the Basin and Range (Mackin, 1963), contains approximately 40 percent phenocrysts in a welded matrix of devitrified glass shards and flattened pumice. The phenocrysts consist largely of plagioclase, hornblende and minor biotite. In contrast to the overlying densely welded and crystal-rich Three Creeks Tuff Member, the Needles Range Formation is finer grained and commonly contains abundant pumice fragments; near Cove Fort, it has a minimum thickness of approximately 120 m (App. II).

Propylitic alteration of the lower part of the Bullion Canyon Volcanics has produced epidote, sericite, clays, calcite after plagioclase and magnetite, and chlorite and biotite after amphibole. Where alteration is intense, aggregates of magnetite record the original distribution and form of the amphibole phenocrysts. Alteration of the matrix of the lava flows has produced aggregates of clays and quartz.

Caskey and Shuey (1975) believe that one of the vent areas for the lava flows was located at Sulphur Peak. Our mapping suggests that additional vent areas were centered in the northern Tushar Mountains approximately 2 km southeast of Cove Fort and immediately east of Utah State 31-33 (Plate 1). In the latter area, an andesitic intrusive contains about 35% phenocrysts in a devitrified matrix. The phenocryst content of the intrusive is approximately 28% andesine, 3% hornblende, 2% augite, and 2% of magnetite, biotite, rutile, apatite, and zircon. The compositional similarities between this intrusive phase and the dacite lava flows have led us to interpret the intrusive as a feeder for some of the flows.

Three Creeks Tuff Member--The lower parts of the Bullion Canyon Volcanics are overlain by the crystal-rich Three Creeks Tuff Member (the Clear Creek Tuff of Caskey and Shuey, 1975; Steven and others, 1977) in the Pavant Range and Tushar Mountains. This tuff is widely distributed throughout the northern portion of the volcanic field and forms, in the south-central Pavant Range, a thick compound cooling unit. Caskey and Shuey (1975) proposed a three-fold division of the Three Creeks Tuff Member and informally separated the densely welded upper and lower portions of the ash-flow tuff from a poorly welded central portion. Subsequently, Steven and others (1977) and Steven (1978)

mapped parts of the source caldera in the southern Pavant Range. In its source area, the Three Creeks Tuff Member has a thickness of over 500 m (Steven and others, 1977).

In the southwestern Pavant Range and northwestern Tushar Mountains, densely welded Three Creeks Tuff accumulated on the margins of the upper Oligocene volcanic complex, forming thick deposits in the Cove Fort-Sulphurdale area. The ash-flow tuff forms extensive outcrops along the northwestern and southern edges of the mapped area and, near Sulphurdale, has a minimum thickness of almost 400 m in Utah State 42-7 (c.f., App. I, Plate 1). We follow Caskey and Shuey (1975) in assigning this densely welded portion of the Three Creeks Tuff Member to the lower part of the compound cooling unit. However, at several places near Sulphurdale and in the area north of Cove Fort we have observed local partings and minor variations in welding which reflect compound cooling of the lower part of the Three Creeks Tuff Member also.

The Three Creeks Tuff Member contains approximately 45% phenocrysts in a densely welded groundmass of devitrified glass shards. Steven and others (1977) give the following average mode: andesine 30%, kaersutitic amphibole 12%, quartz 2%, and minor amounts of biotite, opaques, sanidine, apatite, sphene, zircon, and pyroxene. The biotite often forms large (up to several mm) euhedral plates which are conspicuous in hand specimen. The Three Creeks Tuff has a K-Ar age of 27 my (Caskey and Shuey, 1975; Steven and others, 1977).

Red Tuff--A simple cooling unit that we have informally designated as the Red Tuff [tuff of Albinus Canyon of Steven and Cunningham (1979)] overlies the

Three Creeks Tuff Member in the Cove Fort area. The Red Tuff contains 2-5% potassium feldspar, 0-5% andesine, 1-2% quartz, and trace amounts of opaque minerals, apatite, and zircon in a matrix of densely welded glass shards. Although the source area has not yet been identified, Steven (personal comm., 1978) suggests that the vent may be located to the east of Cove Fort.

White Tuff--The upper portions of the volcanic section in the northwestern portion of the Tushar Mountains is dominated by a crystal-poor ash-flow tuff that we have informally designated as the White Tuff [zeolitic tuff of Steven and Cunningham (1979)]. Although the tuff is more than 180 m thick southeast of Cove Fort, it is not present in the volcanic section of the northern Tushar Mountains east of the study area (Steven, 1978).

The White Tuff contains approximately 3% phenocrysts in a poorly welded matrix of glass shards and pumice. The phenocrysts include 1% oligoclase, 1% potassium feldspar, 0.5% each of quartz and biotite, and trace amounts of opaque minerals, apatite, and zircon. The plagioclase phenocrysts exhibit combined simple and polysynthetic twinning characterized by unequal development of the polysynthetic twins with respect to the simple twin plane.

The circulation of water through the ash-flow tuff has produced widespread zeolitization of the matrix (Steven and Cunningham, 1979), imparting a pink hue to the rock. In contrast to the White Tuff, the younger, poorly welded Joe Lott Tuff Member of the Mount Belknap Volcanics has not been diagenetically altered.

The upper portion of the White Tuff was eroded before deposition of the overlying Osiris Tuff 22 my ago (Fleck and others, 1975). Tuffaceous sediments representing the upper reworked portions of the White Tuff occur at several localities within the northern Tushar Mountains. These sedimentary deposits are less than several meters thick.

Latite Porphyry and Quartz Monzonite Intrusives--During the mid-Tertiary, the volcanic and sedimentary rocks of the Cove Fort-Sulphurdale area were altered and intruded by dikes and stocks of latite porphyry and quartz monzonite. The intrusion of the latite porphyry into the lower portions of the volcanic sequence was accompanied throughout the area by the formation of domes and lava flows. In the southeastern portion of the mapped area along cross section A-A' (Plate 2), lava flows related to one of the vent areas are preserved beneath the Osiris Tuff. At this locality the lava flows overlie fine-grained latite porphyry of a dome interior.

The latite porphyry is characterized by phenocrysts and aggregates of pyroxene, labradorite, and an altered mafic mineral pseudomorphosed by fine-grained aggregates of phlogopite and talc. The habit of this altered mineral suggests that it may have been olivine. The pyroxene-labradorite aggregates consist of approximately 50% labradorite, 25% clinopyroxene, 15% altered olivine(?), 9% opaque minerals, and 1% apatite. In contrast to the relative abundances of phenocrysts in the latite porphyry, the aggregates have a significantly greater clinopyroxene-to-plagioclase ratio than the latite porphyry. We suggest that the pyroxene-labradorite aggregates represent the early crystallized portion of a zoned magma chamber located in the north-

western Tushar Mountains. The remaining residual melt is represented by the phenocryst and matrix content of the latite porphry.

Contact effects around the margins of these latite intrusions are generally only weakly developed. However, a zone of baked and glassy White Tuff occurs along the margin of a small stock 2.7 km northeast of Sulphurdale. Hence the White Tuff provides a lower age for this intrusive event.

Utah State 42-7 penetrated thin dikes of quartz monzonite and metamorphosed siliceous dolomites (App. I). The widespread sulfide and base metal mineralization and contact metamorphism discussed below are most likely related to this intrusive event, and specific aspects of the alteration are described. Small base metal and alunite deposits associated with 23 my-old quartz monzonite intrusions are widely distributed throughout the Marysvale volcanic field (Callaghan and Parker, 1961a-c and 1962; Steven and others, 1977). The Tertiary intrusive system centered near Cove Fort is probably contemporaneous with these intrusive bodies.

The quartz monzonite dikes consist of approximately 40% orthoclase, 35% andesine, 11% quartz, 10% augite, and 1% each opaque minerals, apatite, and zircon. The average grain size is approximately 0.4 mm although some of the plagioclase grains are slightly larger than 1 mm. Alteration of the dikes has produced minor amounts of sericite, clays, epidote, calcite, and actinolite.

Osiris Tuff

The Osiris Tuff is a distinctive, regionally extensive compound cooling unit that spread across the southwestern High Plateaus of Utah from a source area in the Marysvale volcanic field (Anderson and Rowley, 1975). In the Cove

Fort-Sulphurdale area the Osiris Tuff accumulated on an irregular topographic surface that developed after intrusion of the latite porphyry dikes and stocks. In different places the Osiris Tuff overlies the Three Creeks Tuff Member, the White Tuff and associated tuffaceous sediments, lower Bullion Canyon Volcanics, local lava flows associated with the intrusives, and the intrusives themselves. The Osiris Tuff was not affected by base metal mineralization in the study area and thus provides an upper age limit to this mid-Tertiary event. Fleck and others (1975) have established the age of the Osiris Tuff as 22.4 ±0.4 my.

The Osiris Tuff contains approximately 30% phenocrysts in a matrix of densly welded devitrified glass shards and sparse, flattened pumice. Anderson and Rowley (1975) report an average composition of 14.3% plagioclase, 3.9% potassium feldspar, 0.1% quartz, 1.3% biotite, 0.7% pyroxene, 0.8% magnetite, and a trace of amphibole. Samples from the Cove Fort-Sulphurdale area are characterized by a conspicuous parallelism of the plagioclase phenocrysts in a dark gray matrix. In the central portion of the study area, the upper poorly welded zone is preserved under the Joe Lott Tuff Member of the Mount Belknap Volcanics. Here the Osiris Tuff contains a slightly lower phenocryst content in a light gray matrix characterized by minor vapor phase crystallization.

Joe Lott Tuff Member of the Mount Belknap Volcanics

The Joe Lott Tuff Member of the Mount Belknap Volcanics (Steven and others, 1977) was erupted from the Mount Belknap Caldera about 19 my ago (Cunningham and Steven, 1977). This rhyolitic ash-flow tuff (Callaghan, 1939) spread radially outward from its source in the central Tushar Mountains, accumulating in the topographic lows on the Bullion Canyon Volcanic complex

(Steven and others, 1977). The Joe Lott Tuff Member forms steep canyon walls in the Clear Creek drainage basin along the northern margin of the Tushar Mountains where it reaches thicknesses of greater than 245 m (Callaghan and Parker, 1961a). In the Cove Fort-Sulphurdale area, the tuff is restricted to several small exposures in downfaulted blocks where it is overlain by conglomerate and basalt flows of the Sevier River Formation.

The Joe Lott Tuff Member in the northern portion of the Tushar Mountains is a white, pumice-rich unit characterized by vapor phase crystallization. The tuff contains approximately 1% broken phenocrysts of quartz, sanidine, plagioclase, and minor biotite. In the Cove Fort area, the matrix consists of poorly welded devitrified glass shards and pumice fragments.

STRUCTURAL DEFORMATION

As illustrated in Plate 1, the rocks of the northern Tushar Mountains and southern Pavant Range have been extensively disrupted by normal faults. We recognize north-northeast- and north-trending, steeply dipping faults and low-angle west-dipping faults in the Cove Fort-Sulphurdale area. Our mapping suggests that normal faulting intensified after deposition of the Joe Lott Tuff Member in the mid-Miocene and has continued throughout the remainder of the Cenozoic. Steven and others (1977) have assigned these mid-Miocene faults to the initial phase of Basin and Range activity in the Marysvale volcanic field.

North-trending faults of probable mid-Miocene age form the major range front faults in the Cove Fort-Sulphurdale area and several narrow horst and grabens north of Sulphurdale (see for example Plate 2, section A-A'). The

northeast-trending fault that bounds the southwestern Pavant Range has localized the fluorite deposits and several of the small sulphur occurrences near Cove Fort. There is as well a spatial, although perhaps not causal, relationship between the location of the basaltic vents and the projection of this fault southwestward into the Cove Fort basalt field. Faulting in the Cove Fort basalt field (Clark, 1977) may represent renewed activity along this structural trend.

The northwestern Tushar Mountains are dominated by a family of low-angle faults (denudation faults of Armstrong, 1972) which postdate many of the high-angle, mid-Miocene structures. These faults can be traced from the northern edge of the Tushar Mountains to Sulphurdale. The denudation faults bound gravitational glide blocks that have moved to the northwest. Cross section A-A' (Plate 2) illustrates the geometry of the glide blocks and denudation faults along an east-west section near Sulphurdale. The basal decollement has a dip of 30° to the northwest. The upper denudation faults must, as shown, merge with the basal decollement because of the slightly steeper dips of the upper glide planes. Stratigraphic relationships suggest that the basal decollement in Utah State 42-7 (Plate 2, section A-A') is located at the base of the volcanic section.

The youngest faults in the Cove Fort-Sulphurdale area include a family of northwest- to northeast-trending structures. Many of these faults are associated with recent scarps in the Quaternary alluvial fans. Recent studies by Olson and Smith (1976) demonstrate that the Cove Fort area continues to be seismically active and indicate that earthquake activity is concentrated 3 km northeast of Cove Fort at depths of less than 5 km.

TERTIARY MINERALIZATION AND ALTERATION

Intrusion of quartz monzonite and latite porphyry dikes and stocks during the mid-Tertiary was accompanied by the development of a broad, hydrothermally altered envelope and contact metamorphism of the adjacent sedimentary and volcanic rocks. The hydrothermal effects include widespread propylitic alteration of the volcanic rocks and introduction of pyrite and base metal sulfides.

The outer portions of the hydrothermally altered envelope are characterized by quartz-pyrite veins. In the northwestern Tushar Mountains, pyrite is locally accompanied by galena, sphalerite, pyrrhotite, bornite, and chalcopyrite. The distribution of the sulfide phases in the Union Oil Company drill holes is illustrated in Appendicies I-III. The mineralization in these drill holes is fracture controlled and dominated by pyrite.

Utah State 42-7 provides a nearly complete section of the contact metamorphic aureole related to mid-Tertiary quartz monzonite intrusion. The bulk of the metamorphic aureole consists of Paleozoic siliceous dolomites and limestones. The progressive metamorphism of the siliceous dolomites produced talc in the outer low-temperature portions of the aureole and forsterite in the inner high-temperature portions where it has been serpentinized through most of its extent. The grade of metamorphism increases with depth in Utah State 42-7.

Skarn assemblages containing various proportions of grossularite, diopside, epidote, potassium feldspar, and quartz occur between 2158 and 2176 m in Utah State 42-7. These assemblages are volumetrically minor,

constituting less than one percent of the chip samples. The skarn assemblages are spatially associated with dikes of quartz monzonite, suggesting that the calc-silicate minerals probably formed by metasomatic exchange between carbonate beds and the quartz monzonite dikes.

For the siliceous dolomites, the metamorphic changes suggest the following sequence of equilibria (c.f., Moore and Kerrick, 1976):

$$3 \text{ Dolomite} + 4 \text{ quartz} + H_2O = \text{talc} + 3 \text{ calcite} + 3CO_2$$

$$2 \text{ talc} + 3 \text{ calcite} = \text{tremolite} + \text{dolomite} + H_2O + CO_2$$

$$\text{tremolite} + 11 \text{ dolomite} = 8 \text{ forsterite} + 13 \text{ calcite} + 9CO_2 + H_2O$$

In spite of the absence of tremolite in the rocks studied, the stability field of tremolite has been firmly established by field and experimental studies to lie between that of talc and forsterite (Skippen, 1974; Slaughter and others, 1975). The absence of tremolite in our assemblages most likely reflects the lack of suitable bulk compositions preserved within the appropriate temperature range.

The contact metamorphism and mineralization probably is only incidently related to the small, high-level bodies of latite porphyry scattered throughout the northern Tushar Mountains as our observations indicate that metamorphic effects related to the latite porphyry dikes and stocks are weak and only locally developed. More likely the intense metamorphic effects are related to a large, mineralized quartz monzonite stock at depth in the northern Tushar Mountains. Figure 2 illustrates the general geologic relationships between the postulated quartz monzonite intrusive and the contact metamorphic aureole. The outer position of the metamorphic aureole is marked by the presence of

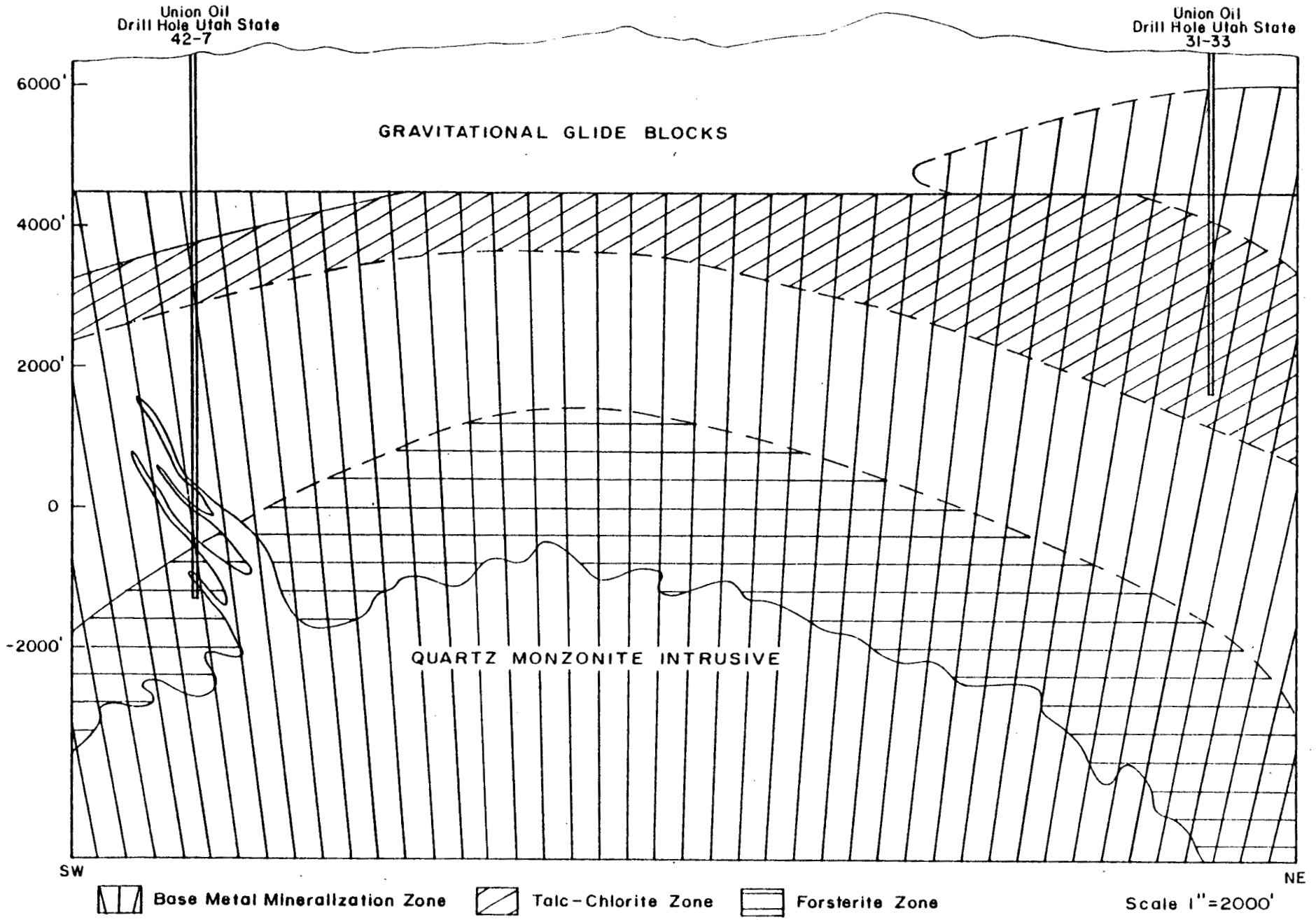

Figure 2: Generalized cross section of the northwestern Tushar Mountains illustrating the relationships between contact metamorphism, base metal mineralization and quartz-monzonite intrusion. The gravitational glide block has moved to the northwest. The spatial relationships between the zones of contact metamorphism and the quartz monzonite are based on the studies of Moore and Kerrick (1976).

talc in Utah State 42-7 and by weakly metamorphosed siltstones in Utah State 31-33 characterized by the low-grade metamorphic assemblage calcite-biotite-white mica-quartz-chlorite (Turner, 1968). Because the siltstones do not extend into the upper part of Utah State 31-33 (c.f., App. II), the outer edge of the metamorphic aureole as defined by chlorite-free rocks cannot be accurately located.

Two small fluorite deposits are located near Cove Fort along the northeast-trending Basin and Range fault in the southwestern Pavant Range (Fig. 3). The fluorite occurs in the Rain Bow and Black Mine areas in brecciated carbonate rocks of the Oquirrh Formation. Approximately 210 tons of ore were produced from the Rain Bow mine, and drilling has outlined an additional 20,000 tons of ore (Bullock, 1976).

At the Rain Bow deposit, fluorite is accompanied by silicified carbonates, minor sulphur, and locally intense acid alteration. Textural evidence clearly indicates that the sulphur deposition and acid alteration postdate the fluorite within this deposit and are probably contemporaneous with the other native sulphur deposits throughout the geothermal field.

Several lines of evidence suggest that deposition of fluorite was not related to the mid-Tertiary hydrothermal events. This conclusion is based primarily on the following observations: 1) the absence of fluorite in widespread carbonate rocks affected by mid-Tertiary hydrothermal alteration, in spite of the low solubility of fluorite in such environments (Moore and Kerrick, 1976), 2) the occurrence of fluorite in areas peripheral to the mid-Tertiary intrusions, and 3) the deposition of fluorite in tensional zones within structures of probable Basin and Range (post-intrusion) age. On the

other hand, 1) the absence of fluorite in nearly all areas presently associated with active hydrothermal alteration, 2) the substantial differences in hydrothermal environments between fluorite and sulphur deposition, and 3) the clearly younger age of the sulphur all suggest that the fluorite is not related to active hydrothermal alteration.

Fluorite occurrences are widespread throughout the Marysvale volcanic field. Our reconnaissance work suggests that most of these occurrences are related to the 17-21 million year old period of rhyolitic volcanism. Based on the observations and relationships described above, a genetic relationship between fluorite and rhyolitic volcanism is likely but cannot be definitely documented.

Samples of the hydrothermal fluids related to fluorite deposition are preserved as two-phase fluid inclusions within the fluorite. The volume of the vapor phase in these inclusions ranges from approximately 5-45%. These observations, as well as the absence of secondary daughter minerals, suggest that the fluorite was deposited by a boiling fluid of relatively low salinity. A simple reconstruction of the sedimentary and volcanic section in the area of the fluorite deposits suggests that the mineral deposition occurred at depths of at least 300 m.

THE COVE FORT-SULPHURDALE GEOTHERMAL SYSTEM

The youngest (and still active) hydrothermal event to effect the Cove Fort-Sulphurdale KGRA has produced surficial and subsurface alteration in an area covering a minimum of 47 sq. km. The surficial alteration of the alluvium and Price River Conglomerate near Cove Fort (Fig. 3) and at

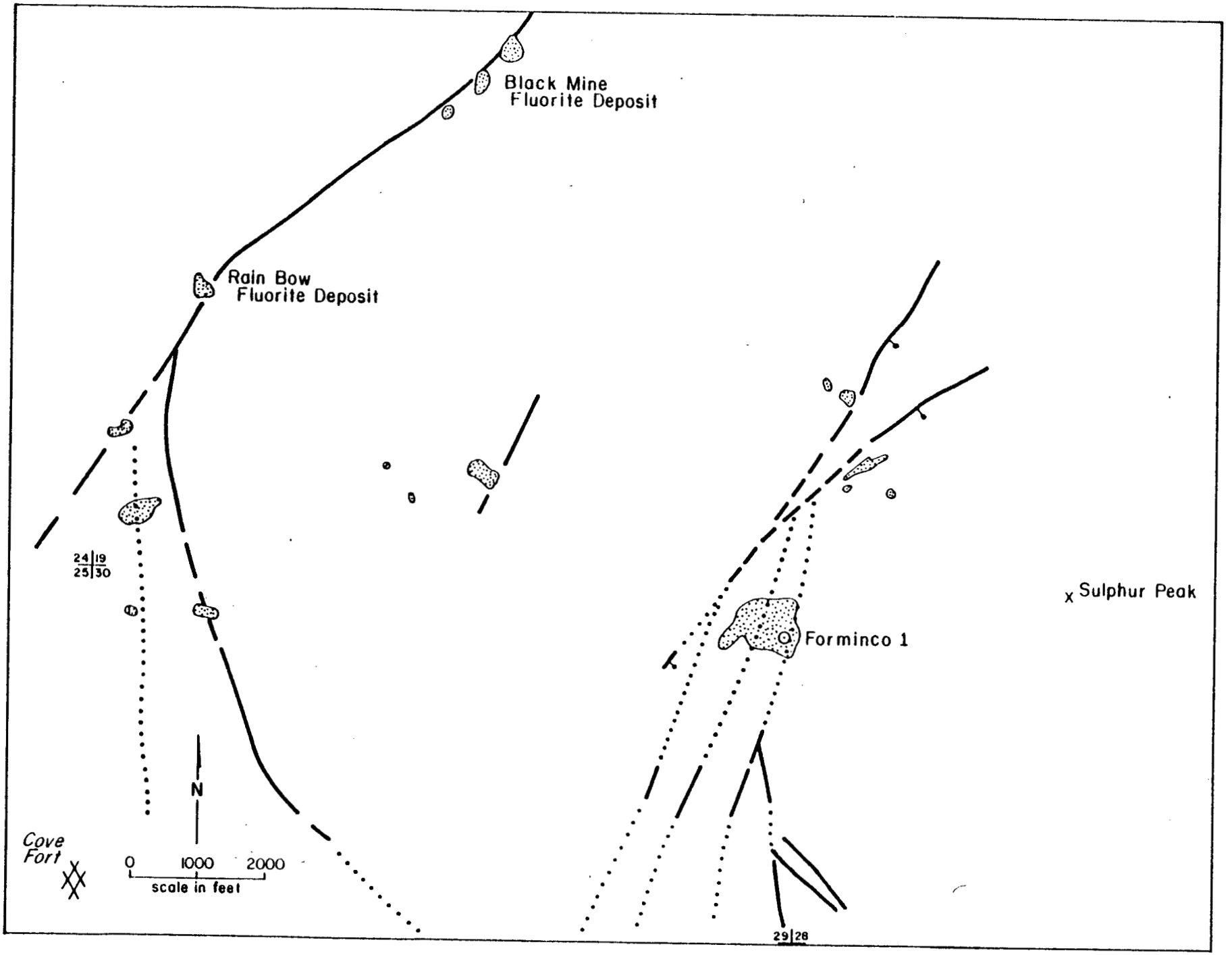

Figure 3. Map of the Cove Fort area illustrating the distribution of acid-altered areas, fluorite deposits and major fault zones. Altered areas are stippled.

Sulphurdale has been accompanied by the formation of native sulphur deposits. This alteration has left porous residues of silica and clays within which many of the original sedimentary textures and structures are preserved.

Although the existence of a hot water system (in the sense of White and others, 1971) in the Cove Fort-Sulphurdale area has been confirmed by deep drilling, many of the surficial features typical of other geothermal fields are not present, such as hot springs and deposits of siliceous and calcareous sinter. Instead, the altered areas produce hydrogen sulfide. White and others (1971) suggest that the differences in the surface manifestations of hot water systems can be explained in terms of relative depths of the water table. Where the water table is depressed, as in the Cove Fort-Sulphurdale area (approximately 400 m, Union Oil Company, 1978c), the surface features reflect degassing and boiling of the water table at depth.

Hydrogen sulfide is presently evolving from some of the altered areas near Cove Fort, also from the central portions of the Sulphurdale deposit where it escapes through small pools of standing water, probably of meteoric origin. The water has a pH of about 1. In contrast, surface water is not presently associated with any of the altered areas near Cove Fort. The release of hydrogen sulfide from the hydrothermal fluids has been considered by Schoen and others (1974) to explain the origin of the intense alteration ("acid altered areas" of Schoen and Ehrlich, 1968) and sulphur deposition at Steamboat Springs, Nevada. They concluded that siliceous residues of pre-existing rocks form above the water table by continuous downward migration of sulphuric acid dissolved in rain water and condensed water vapor. According to their model, the oxidation under surface conditions of hydrogen sulfide

derived from the geothermal fluids can lead directly to the formation and precipitation of native sulphur. Further oxidation by bacterial action leads to the formation of sulphuric acid. The downward-migrating acid waters produce, below the zone of intense acid leaching, assemblages dominated by clay minerals. The overall effect of these mineral reactions is to decrease the near-surface permeability by sealing the fracture zones.

The sulphur deposits of the Cove Fort-Sulphurdale area contain variable amounts of gypsum, sulphur, pyrite, and marcasite (Rodriguez, 1960). These minerals form a sequence of assemblages which diminishes with depth. Rodriguez (1960) recognized an upper envelope of secondary gypsum followed downward by successive envelopes of gypsum + sulphur, sulphur, sulphur + pyrite + marcasite, and pyrite + marcasite. Excavation in the largest of the deposits located at Sulphurdale has uncovered iron sulfides approximately 10 feet below the surface (Callaghan, 1973). In some of the smaller occurrences near Cove Fort, the replacement of sulphur by gypsum has been complete and no primary sulphur remains. The gypsum forms large tabular crystals up to several centimeters long and smaller delicate, radiating clusters. Locally, gypsum replaces limestone pebbles within the Price River Conglomerate (Rodriguez, 1960). The model proposed by Schoen and others (1974) provides an explanation, consistent with our observations, for the intense alteration and the declining surficial activity in some of the altered areas near Cove Fort.

The distribution of altered areas and fault zones near Cove Fort is illustrated in Figure 3. The altered areas are located east of Cove Fort and along the north- and northeast-trending faults in the southwestern Pavant Range. Our investigations indicate that the acid-altered areas are localized

along silicified fault zones and we suggest that the recent earthquake activity in the Cove Fort area reflects reactivation of these north- and northeast-trending faults.

The general structural relationships at Sulphurdale are similar to those east of Cove Fort. The Sulphurdale deposit lies on the southern edge of the denudation faults in the northern Tushar Mountains. It is bounded on the east by a locally silicified fault zone, and other silicified faults, located southeast of the deposit, project into the Sulphurdale area.

The areas of intense alteration northeast of Cove Fort lie along the northeast-trending Basin and Range fault. Many of these altered areas are spatially associated with the Tertiary fluorite deposits. It appears likely that it is the brittle behavior of these mineralized fault zones during recent tectonic activity that allows escape of hydrogen sulfide from the geothermal fluids.

Surficial alteration does not occur in the northwestern portion of the Tushar Mountains between Cove Creek and Sulphurdale, however, Utah State 31-33 encountered hydrogen sulfide at a depth of 412 m (c.f., Union Oil Company, 1978d). This area, in contrast to the southern Pavant Range and the area near Sulphurdale is characterized by thick accumulations of ash-flow tuffs and gravitational glide blocks that apparently act as an impermeable cap to this portion of the geothermal system (c.f., Nielson and others, 1978).

The relationship between low-angle faulting and the temperature distribution in the upper parts of the geothermal reservoir is illustrated in Figure 4. The low-angle fault that crosses Utah State 42-7 at 610 m separates

a nearly isothermal portion of the reservoir below from an upper zone characterized by a steep thermal gradient. The temperature distribution below the denudation fault suggests that heat transfer occurs primarily by convection of the thermal fluids through a fractured reservoir. A high fracture density in Utah State 42-7 is indicated by numerous intervals of lost circulation and no sample return in the test well (Appendix I). The drilling records of Forminco 1 and Utah State 31-33 also indicate a high fracture density in the geothermal field east of Cove Fort.

The rapid temperature loss above the denudation fault (Fig. 4) may reflect heat loss both by conduction and the influx of cold meteoric water. This interpretation is supported by the abundance of cold springs throughout the northern Tushar Mountains.

The subsurface activity in the northern portion of the Tushar Mountains has resulted in the deposition of anhydrite-bearing veins and open space fillings below the water table. These veins occur throughout the lower explored portions of the geothermal system. The anhydrite occurs as coarse euhedral blades often coated with calcite; both the carbonate coatings and habit contrast with the surficial secondary occurrences of gypsum formed by oxidation of native sulphur.

The heat source for the active Cove Fort-Sulphurdale geothermal system has been assumed by most workers to be related to recent basaltic volcanism (Callaghan, 1973; Steven and others, 1977) and seismic studies by Olson and Smith (1976) support this hypothesis. The concentration of hydrothermal

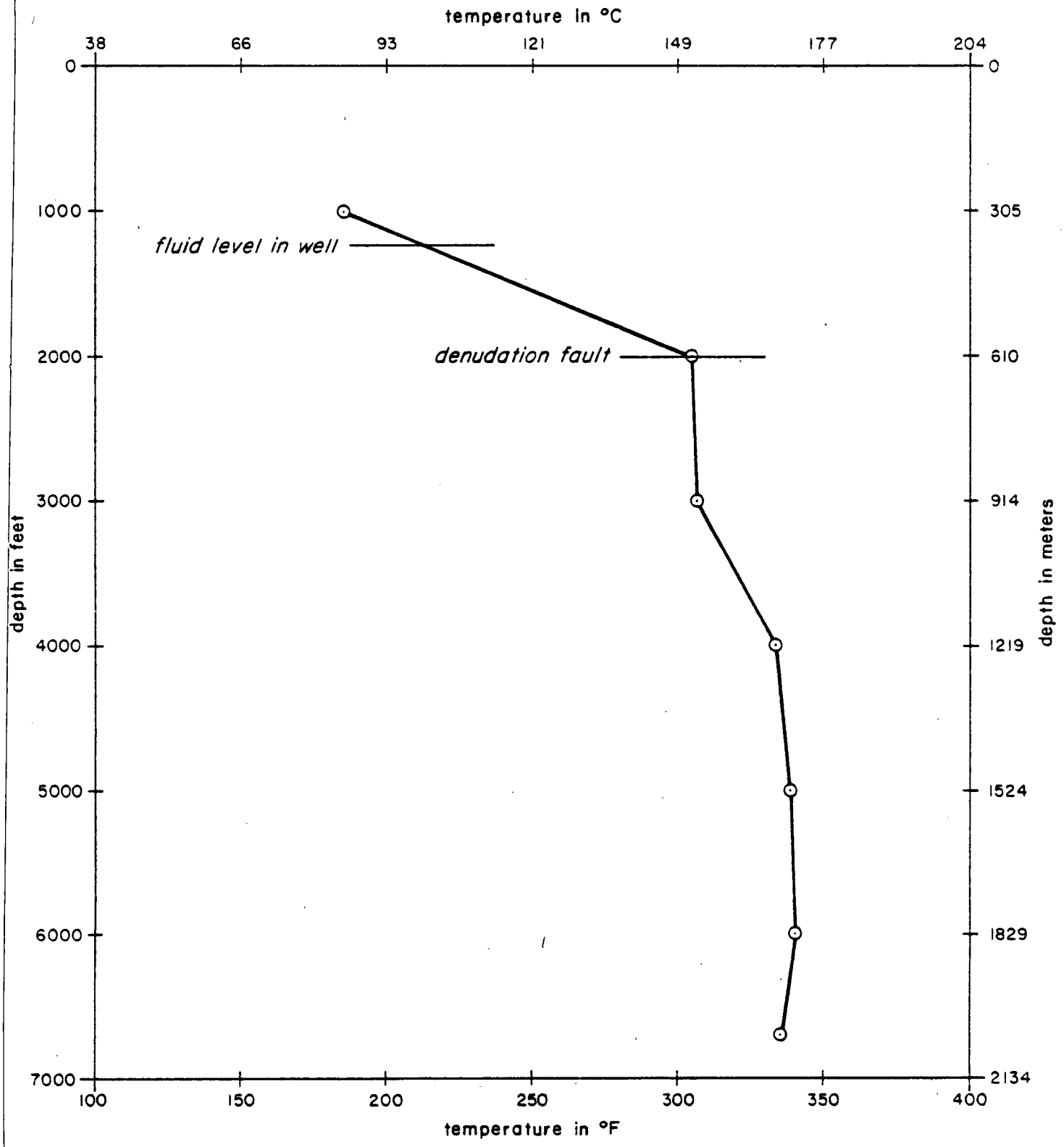

Figure 4. Temperature distribution in Union Oil drill hole Utah State 42-7 modified from (Union Oil Co. 1978d)

alteration and seismicity north and northeast of Cove Fort cannot be demonstrably related to basaltic volcanism and available geological and geophysical data do not allow resolution of this problem at the present time.

CONCLUSIONS

The geometry of the Cove Fort-Sulphurdale geothermal reservoir reflects the extensive faulting, volcanism, and intrusion that has occurred in the Pavant Range and Tushar Mountains primarily since the mid-Tertiary. Figure 5 summarizes the major geologic events that have affected this area. North of Cove Fort, faults related to the Sevier Orogeny may become increasingly important control factors. The reservoir consists of Paleozoic and Mesozoic sedimentary rocks as well as Tertiary intrusive and volcanic rocks. The migration of thermal fluids through the reservoir is controlled primarily by high-angle faults of Cenozoic age.

The central part of the geothermal field in the Cove Fort-Sulphurdale area is dominated by low-angle faults that bound gravitational glide blocks which act as an impermeable cap to the upper portions of the geothermal system in the northwestern Tushar Mountains. Surficial alteration related to the geothermal system is concentrated along steeply dipping faults to the north and south of the glide blocks and is characterized by the evolution of hydrogen sulfide at a water table located about 400 m (Union Oil Company, 1978c). The hydrogen sulfide is associated with areas of intense acid leaching and small native sulphur deposits.

The dimensions of the geothermal reservoir and the base temperatures have not yet been established. Nevertheless, hot water wells and intense

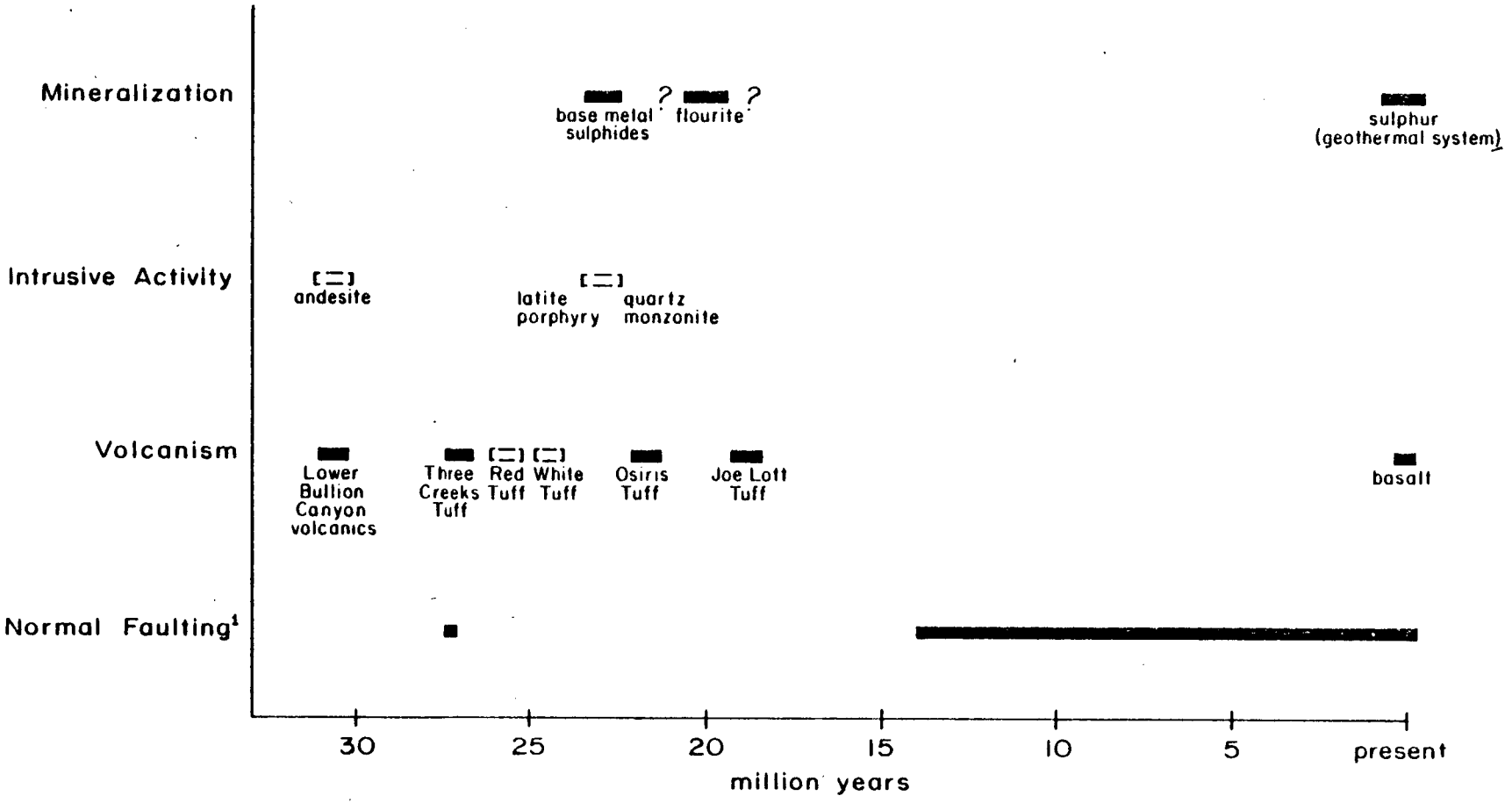

Figure 5. Summary diagram of the geologic events in the Cove Fort-Sulphurdale KGRA since the late Oligocene

seismicity 8 km north of Cove Fort in Dog Valley (Olson and Smith, 1976) suggest that the geothermal system may be significantly larger than the area characterized by surficial alteration and high thermal gradients (Union Oil Company 1978a).

ACKNOWLEDGEMENTS

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APPENDIX I

Union Oil Company drill hole Utah State 42-7 was collared in alluvium approximately 1066 m northeast of Sulphurdale in T26S, R6W, section 7. The alluvium overlies Bullion Canyon Volcanics and the Needles Range Formation which extend from 60 to 2040 feet (18 to 622 m). The volcanics consist of thick accumulations of the Three Creeks Tuff Member of the Bullion Canyon Volcanics, Needles Range Formation and minor lava flows and breccias of the lower member of the Bullion Canyon Volcanics. The basal portion of the volcanic section is in fault contact with quartzitic sandstones of the Coconino Sandstone. This fault is interpreted as the basal glide plane to the gravitational slide blocks of the northwestern portion of the Tushar Mountains. Although the Price River Conglomerate is found elsewhere in the Cove Fort-Sulphurdale area, this unit is not present in drill hole Utah State 42-7.

The Coconino Sandstone overlies thermally metamorphosed Paleozoic sedimentary rocks consisting primarily of recrystallized and locally graphitic limestones and lesser amounts of siliceous dolomites and quartzites. The metamorphism of siliceous dolomites has produced talc near the top of the section (at 2820 feet; 800 m) and forsterite marble near the base; the latter interval is entirely serpentinized (7100-7730 feet; 2164-2356 m).

Dikes of quartz monzonite associated with the mid-Tertiary hydrothermal event are intersected by the hole at 6180'-6220' (1884-1896 m), 6490'-6540' (1978-1993 m), 6960'-7100' (2121-2164 m), and 7530'-7540' (2295-2298 m). Metasomatic exchange between the carbonate rocks and the quartz monzonite has

produced skarns adjacent to some of the dikes. The skarn assemblages contain grossularite, diopside, epidote, potassium feldspar, and quartz.

Pyrite is widely distributed throughout the drill hole and in places is associated with minor amounts of pyrrhotite, bornite, chalcopyrite, galena, and sphalerite. At 3360 feet (1024 m) the mineralization is associated with intense quartz veining. Minor amounts of anhydrite coated with calcite are common below 2800 feet (853 m) and constitute approximately 45 percent of the sample at 6080 feet (1853 m).

APPENDIX II

Union Oil Company drill hole Utah State 31-33 was collared in alluvium on the northern edge of the Tushar Mountains approximately 3.5 km east of Cove Fort in T25S, R6W, section 32. The upper portion of the drill hole consists of Bullion Canyon Volcanics that extend from 52-1000 feet (16-305 m). At this locality, a thick accumulation of Needles Range Formation is interbedded with dacite lava flows. Sills of andesite porphyry intrude the volcanics near the base of the section and near the top of the drill hole. The lava flows are part of the lower member of the Bullion Canyon Volcanics. The volcanic rocks are in fault contact with the underlying argillaceous sandstones of the Price River Conglomerate. The fault is interpreted as one of a family of denudation structures related to gravitational glide blocks in the northern Tushar Mountains. A second glide plane is believed to cross the drill hole about 2000 feet (610 m). The Price River Conglomerate unconformably overlies fine- to medium-grained dolomites of Paleozoic age. Near the base of the drill hole, pre-volcanic thrust faulting has juxtaposed Triassic siltstones and limestones against the Paleozoic dolomites.

The rocks of Utah State 31-33 have been affected by minor base metal and sulfide mineralization as well as low-grade metamorphism. The mineralization is dominated by pyrite and is fracture controlled. Between 1390 and 1400 feet (424-427 m), significant amounts of galena, sphalerite, and chalcopyrite accompany the pyrite. Metamorphism has produced minor amounts of chlorite in the calcareous siltstones throughout the lower portion of the drill hole.

APPENDIX III

Union Oil Company drill hole Forminco #1 is located approximately 3 km east of Cove Fort in a small alluvial-covered basin in the southern end of the Pavant Range. Beneath the alluvium, the drill hole penetrated volcanic rocks from 55 to 240 feet (17 to 73 m). The volcanic rocks are bleached and contain gypsum, pyrite, and minor native sulphur to a depth of 105 feet (32 m). We believe that this alteration is related to the presently active hydrothermal system in the Cove Fort-Sulphurdale area. Petrographic examination of the chip samples indicates that the volcanic section consists primarily of lava flows belonging to the lower part of the Bullion Canyon Volcanics. Although lesser amounts of ash-flow tuff also occur in the drill hole, the volcanic rocks are not differentiated on the accompanying log because of the intense alteration and poor sample recovery in this interval. The volcanic rocks are in fault contact with the underlying Coconino Sandstone which overlies in turn a blue-gray limestone of the Pakoon Formation. Below 720 feet (219 m) many sample intervals returned few cuttings because of lost circulation; from 720-1000 feet (219-305 m) there were no returns. The bottom of the drill hole is in brown-gray friable and coarsely crystalline dolomite. Both the dolomite and limestone are probably of mid-Paleozoic age.

In Forminco #1, in contrast to Utah State 42-7 and 31-33, pyrite was the only sulfide found. Near the top of the hole, pyrite is associated with the acid-altered rocks. Quartz-pyrite veins occur sporadically between 240 and 740 feet (73-226 m) in the Coconino sandstones and underlying limestones but are absent from the dolomites at the base of the drill hole. The association of the pyrite with quartz veins leads us to believe that this mineralization is related to the early mid-Tertiary hydrothermal event.

ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF THE COVE FORT KGRA AND VICINITY

Bruce Sibbett

Anderson, J.J., and Rowley, P.D., 1975, Cenozoic stratigraphy of southwestern High Plateaus of Utah in Cenozoic Geology of Southwestern High Plateaus of Utah: Geol. Soc. Amer. Spec. Paper 160, 88p.

Armstrong, R.L., 1968, Sevier orogenic belt in Nevada and Utah: Geol. Soc. Amer. Bull., v. 79, p. 429-458.

_____1972, Low angle (denudation) faults, hinterland of the Sevier Orogenic belt, eastern Nevada and western Utah; Geol. Soc. Am. Bull., v. 83, p. 1729-1754.

Bassett, W.A., Kerr, P.F., Schaeffer, O.A., and Stoenner, R.W., 1963, Potassium-argon dating of the late Tertiary volcanic rocks and mineralization of Marysvale, Utah: Geol. Soc. Amer. Bull., v. 74, p. 213-220.

Best, M.G., Shuey, R.T., Caskey, C.F., and Grant, S.K., 1973, Stratigraphic relations of members of the Needles Range Formation at type localities in southwestern Utah: Geol. Soc. Amer. Bull., v. 84, p. 3269-3278.

The paper contains a map and description of the Needles Range Formation in the northern Needles Range, by Wah Wah Springs, and to the northwest of Lund, Utah. Each tuff member is described and modal percentages given for each location.

Brumbaugh, W.D., and Cook, K.L., 1977, Gravity survey of the Cove Fort-Sulphurdale KGRA and the North Mineral Mountains area, Millard and Beaver Counties, Utah: ERDA Technical Report, 77-4, contract EY-76-S-07-1601, 131 p.

This study surveyed the northern end of the Mineral Mountains from approximately 38°31' latitude to the north edge of the KGRA. Data were collected from 671 gravity stations over an area of 1300 km^2 and are presented as a Bouguer gravity anomaly map and an isometric, three-dimensional gravity anomaly surface. Depth to bedrock and structural interpretations are presented.

Bullock, K.C., 1976, Fluorite occurrences in Utah: Utah Geol. Mineral Survey Bull. 110, p. 58-60.

The paper describes the sulphur and fluorite mineralization in the Cove Fort area. The largest occurrence is at the Rain Bow (Forminco) mine, located 2-1/2 miles north of Cove Fort, in faulted Callville limestone.

Callaghan, Eugene, 1939, Volcanic sequence in the Marysvale region in southwest-central Utah: Amer. Geophys. Union Trans. Ann. Mtg., pt. 3, p. 438-452.

_____1973, Mineral resources of Piute County, Utah, and adjoining area: Utah Geol. Mineral Survey Bull. 102, p. 120-128.

All of the known sulphur and fluorite occurrences in the Cove Fort area are briefly described. Production figures are given, and detailed maps and sections of the major deposits are included. A geologic map, at one inch to the mile, covers an area extending eight miles to the north, east, and south of Cove Fort.

Callaghan, E., and Parker, R.L., 1961a, Geology of the Sevier quadrangle, Utah: U.S.G.S. Geologic Quadrangle Map GQ-156.

_____1961b, Geological map of part of the Beaver quadrangle, Utah: U.S.G.S. Mineral Investigation Field Studies Map MF-202.

The map covers the eastern part of the quadrangle at a scale of 1:62,500. The mapped area extends from Wildcat Creek south to the South Fork of North Creek. A brief account of the geology and mineral deposits is included.

_____1961c, Geology of the Monroe quadrangle, Utah: U.S.G.S. Geologic Quadrangle Map GQ-155.

_____1962, Geology of the Delano Peak quadrangle, Utah: U.S.G.S. Geologic Quadrangle Map GQ-153.

Carmony, J.R., 1977, Stratigraphy and geochemistry of the Mount Belknap series, Tushar Mountains, Utah: Penn. State Univ., unpub M.S. thesis, 153 p.

Caskey, C.F., and Shuey, R.T., 1975, Mid-Tertiary volcanic stratigraphy, Sevier-Cove Fort area, Central Utah: Utah Geology, v. 2, no. 1, p. 17-25.

The paper covers the area from U.S. Interstate 15 east into Beaver Co. 12 kilometers, and from just south of Interstate 70 to 12 kilometers north this paper provides paleo-magnetic data and a geologic sketch map with sample sites. Hand sample descriptions are given for the units, but the petrographic relationships are not described in detail.

Clark, E. E., 1977, Late Cenozoic volcanic and tectonic activity along the eastern margin of the Great Basin, in the proximity of Cove Fort, Utah: Brigham Young Univ. Geology Studies, v. 24, pt. 1, p. 87-114.

This paper discusses the petrography and tectonic activity of the Cove Fort basaltic field (southern half of the Black Rock Desert). The geochemical compositions for 20 samples are listed. The geologic map is at a scale of 1:125,000 and extends from Interstate 15 to Black Rock on the Union Pacific railroad line to the west.

Condie, K.C., and Barsky, C.K., 1972, Origin of Quaternary basalts from the Black Rock Desert Region, Utah: Geol. Soc. Amer. Bull., v. 83, p. 333-352.

The individual volcanic fields are briefly described. The geochemical variations are discussed, and the geochemical trends of the eruptions are used to interpret the magmatic evolution. The geologic map is a small-scale reference map.

Crosby, G.W., 1959, Geology of the South Pavant Range, Millard and Sevier Counties, Utah: Brigham Young Univ. Geology Studies, v. 6, no. 3, 59 p.

The focus of the paper is on the sedimentary rocks ranging from Cambrian to Quaternary and it includes a brief discussion of Miocene? volcanics. A stratigraphic column and a geologic map with a scale of 1 inch to 4693 feet are included.

Cunningham, C.G., and Steven, T.A., 1977, Mount Belknap and Red Hills Calderas and associated rocks, Marysvale volcanic field, west-central Utah: U.S.G.S. Open-File Report 77-568, 40 p.

The Mount Belknap volcanic units and the Red Hills units are described and a small scale geologic map of the Mount Belknap Caldera is included. The chemical breakdown of 11 samples is also listed.

Cunningham, C.G., Steven, T.A. and Naeser, C.W., 1978, Structural and mineralogical analysis of the Deer Trail Mountain-Alunite Ridge mining area, Utah: U.S.G.S. Open-File Report 78-314, 1 plate.

Dasch, M.D., 1964, Fluorine, in Mineral and water resources of Utah: Utah Geol. Mineral Survey Bull. 73, p. 162-168 (reprinted 1969).

Fleck, R.J., Anderson, J.J., and Rowley, P.D., 1975, Chronology of mid-Tertiary volcanism in high plateaus region of Utah: in Cenozoic geology of southwestern high plateaus of Utah: Geol. Soc. Amer. Spec. Paper 160, 88 p.

Haugh, G.R., 1978, Late Cenozoic, cauldron-related silicic volcanism in the Twin Peaks area, Millard County, Utah: Brigham Young Univ., unpub. M.S. thesis, 53 p.

The study area is located about 12 km northwest of Cove Fort. The geologic map is at a scale of 1:95040. The thesis defines the volcanic units and relates their occurrence to a cauldron. Petrographic descriptions of the units, their petrochemistry, and trace element model distributions are discussed.

Hintze, Lehi F., 1973, Geologic history of Utah: Brigham Young Univ. Geology Studies, v. 20, pt. 3, 181 p.

This paper provides a brief review of the geologic history of Utah. Stratigraphic columns for 46 locations within the state are given including the Cove Fort, northern Pavant Range, and Marysvale areas.

Hoover, J.D., 1974, Periodic Quaternary volcanism in the Black Rock Desert, Utah: Brigham Young Univ. Geology Studies, v. 21, pt. 1, p. 3-72.

The paper describes the individual volcanic fields and eruptive events in eastern Millard County. The geochronology for 20 samples is given, the structure is discussed, and petrography and petrochemistry of the Quaternary basalt flows are described.

King, C.R., 1953, Cove Creek sulphur: Mining Engineering, p. 375-387.

Lautenschlager, Herman K., 1952, The Geology of the central part of the Pavant Range, Utah: Ohio State Univ. unpub. M.S. thesis.

The thesis describes the sedimentary units and structures in the Pavant Range. Petrographic descriptions and photomicrographs are also given for two samples of Bullion Canyon Volcanics. A map at a scale of 1:31,000 is included.

Lee, W.T., 1906, The Cove Creek sulphur beds, Utah: U.S.G.S. Bulletin, v. 315, p. 485-490.

Lee reports that the sulphur deposits are along a zone of intense faulting and volcanic activity. The paper describes the character of the ore and discusses its origin. Large volumes of gas were reported to be escaping through vents in 1906. An analysis of the water in the sulphur beds is listed.

Molloy, M.W., and Kerr P.F., 1962, Tushar Uranium area, Marysvale, Utah: Geol. Soc. Amer. Bull., v. 73, p. 211-236.

Mackin, J.H., 1963, Reconnaissance stratigraphy of the Needles Range Formation: Intermtn. Assoc. Petroleum Geologists, 12th Ann. Field Conf., Southwestern Utah Guidebook, p. 71-78.

Maxey, G.B., 1946, Geology of part of the Pavant Range, Millard County, Utah: Amer. Jour. Sci., v. 244, p. 324-356.

The geology of the southern end of the Pavant Range is discussed. Early Paleozoic rocks are in thrust contact with Mesozoic and Permian rocks.

Mehnert, H.H., Rowley, P.D., and Lipman, P.W., 1978, K-Ar ages and geothermal implications of young rhyolites in West-Central Utah: Isochron/West, no. 21, p. 3-7.

This paper gives K-Ar dates for 14 samples from Thermo, Roosevelt, and Black Rock Desert areas. Mineral modes for the 14 samples are also listed.

Moore, J.N., and Kerrick, D.M., 1976, Mixed-volatile equilibria in calcareous rocks from the Alta aureole, Utah: Amer. Jour. Sci., v. 276, p. 502-524.

Mount, Priscilla, 1964, Sulfur, in Mineral and water resources of Utah: Utah Geol. Mineral Survey Bull. 73, p. 228-232.

Mount describes briefly the production of sulphur from Cove Creek and Sulphurdale between 1869 and 1906. There has been no significant output from these deposits since 1952. Types of sulphur deposits which follow a zone of faulting are discussed. A map of Utah's sulphur deposits is included.

Nielson, D.L., Sibbett, B.S., McKinney, D.B., Hulen, J.B., Moore, J.N., Samberg, S.M., 1978, Geology of the Roosevelt Hot Springs KGRA: Earth Science Lab, Univ. of Utah Research Inst., no. 12, Contract no. EG-78-C-07-1701, 120 p.

Olson, T.L., and Smith, R.B., 1976, Earthquake Surveys of the Roosevelt Hot Springs and the Cove Fort areas, Utah; Univ. Utah Dept. Geol. and Geophysics Rpt. v. 4, Grant no. GI-43741, 83 p.

Peterson, D.L., 1974, Principal facts for gravity stations in parts of Beaver, Iron, and Millard Counties, southwestern Utah: U.S.G.S. Open-File Report 74-298. 9 p.

The report contains station locations by longitude and latitude, and lists the type of station. The elevation, observed gravity, and free air correction are listed.

Rodriguez, E.L., 1960, Economic geology of the sulphur deposits at Sulphurdale, Utah: Univ. of Utah unpub. M.S. thesis, 74 p.

The geology of the Cove Fort and Sulphurdale area is described. The sulphur deposits are described in detail, and information from drill holes is given. Ore and gangue minerals are described. The sulphur deposits are attributed to thermal springs of sulfotaric nature. Ore reserves for the area are listed.

Rowley, P.D., Lipman, P.W., Mehnert, H.H., Lindsey, D.A., and Anderson, J.J., 1968, Blue Ribbon lineament, an east-trending structural zone within the Roche mineral belt of southwestern Utah and eastern Nevada: Jour. Research, U.S.G.S., v. 6, no. 2, p. 175-192.

Schoen, R., and Ehrlich, G.G., 1968, Bacterial origin of sulphuric acid in sulphurous hot springs: Proc. 23rd Int. Geol. Congress, v. 17, p. 171-178.

Schoen, R., White, D.E., and Hemley, J.J., 1974, Argillization by descending acid at Steamboat Springs, Nevada: Clays and Clay Minerals, v. 22, p. 1-22.

Skippen G., 1974, An experimental model for low pressure metamorphism of siliceous dolomitic marble: Amer. Jour. Sci., v. 274, p. 487-509.

Slaughter J., Kerrick, D.M., and Wall, V.J., 1975, Experimental and thermodynamic study of equilibria in the system $CaO-MgO-SiO_2-H_2O-CO_2$: Amer. Jour. Sci., v. 275, p. 143-162.

Smith, R.B., and Sbar, M.L., 1974, Contemporary tectonics and seismicity of the western United States with emphasis on the intermountain seismic belt: Geol. Soc. Amer. Bull., v. 85, p. 1205-1218.

Steven, T.A., 1978, Geologic Map of the Sevier SW Quadrangle, West-central Utah: U.S.G.S. Map MF-962.

Steven, T.A., and Cunningham, C.G., 1979, Clinoptilolite resources in the Tushar Mountains, west-central Utah: U.S.G.S. Open-File Report 79-535, 22 p.

Steven, T.A., Cunningham, C.G., Naeser, C.W., and Mehnert, H.H., 1977, Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysvale area, west-central Utah: U.S.G.S. Open-File Report 77-569, 45 p.

The paper describes the volcanic geology of the Marysvale area and includes lithologic, petrographic and mineral composition of the Bullion Canyon Series. The Mount Belknap Volcanics and the hydrothermal alteration and metallic and uranium mineralization are described. K-Ar age dates on 19 samples are listed. A geologic map is not included.

Steven, T.A., Rowley, P.D., and Cunningham, C.G., 1978, Geology of the Marysvale volcanic field, west-central Utah: Brigham Young Univ., v. 25, pt. 1, p. 67-70.

Turner, F.J., 1968, Metamorphic Petrology-Mineralogical and Field Aspects: McGraw Hill Inc., 403 p.

Union Oil Company, 1978a, Cove Fort-Sulphurdale Geothermal Unit Area, Millard and Beaver Co., Utah, Geologic Report.

_____1978b, Cove Fort-Sulphurdale Unit Well Forminco #1, Millard Co., Utah, technical report.

_____1978c, Cove Fort-Sulphurdale Unit Well #42-7, Beaver Co., Utah technical report.

_____1978d, Cove Fort-Sulphurdale Unit Well #31-33, Millard Co., Utah, technical report.

Welsh, J.E., 1972, Upper Paleozoic stratigraphy, Plateau-Basin and Range transition zone, central Utah: Utah Geol. Assoc. Publ. 2, p. 13-20.

This paper provides a description of the Mississippian, Pennsylvanian, and Permian stratigraphy including regional relationships in central Utah. It discusses the tectonics effecting distribution of late Paleozoic rocks and includes a state map, "Tectonic Elements of Different Ages that Effect Distribution of Upper Paleozoic Rocks." Base metal deposits and oil and gas resources with locations are listed.

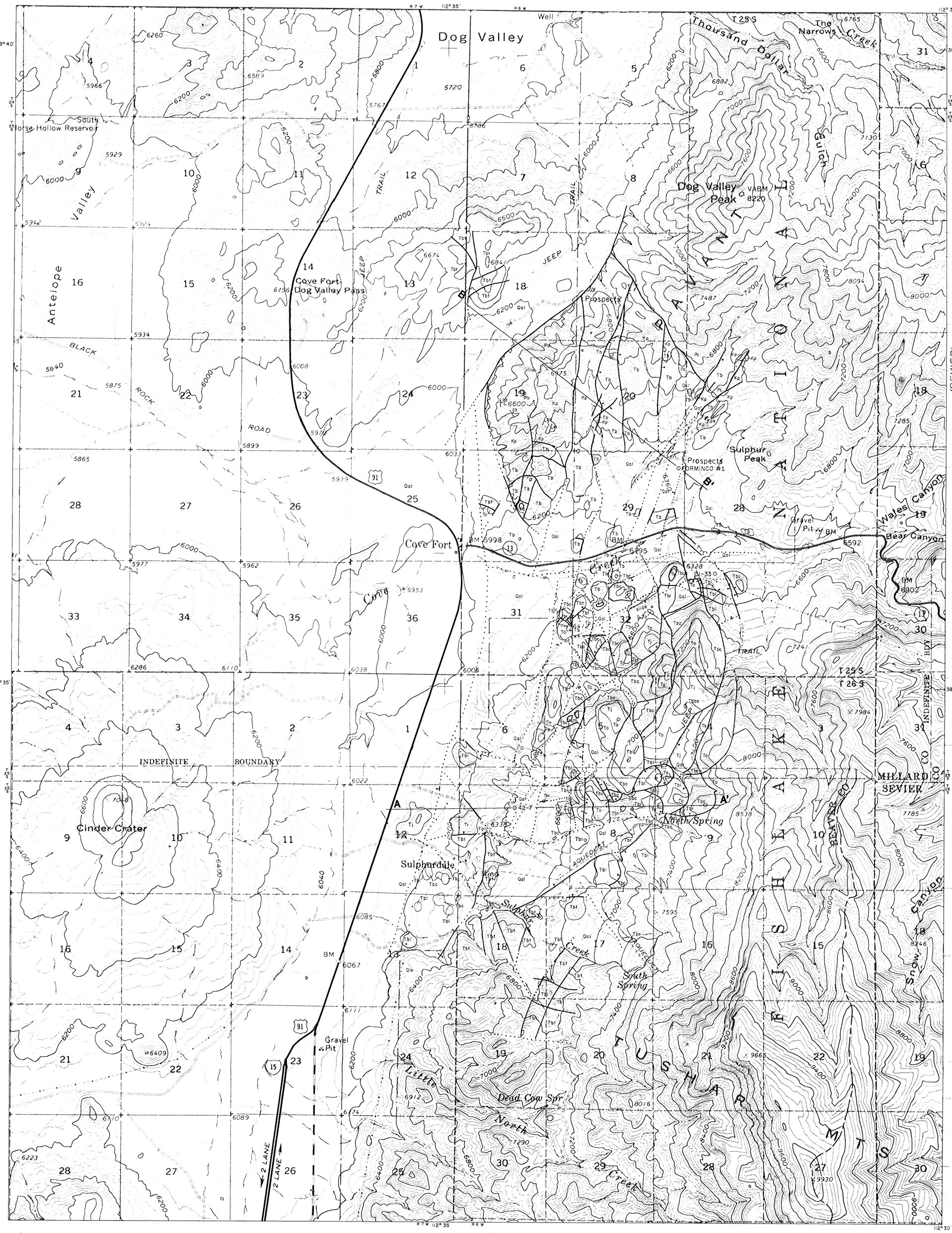
Willard, M.E., Callaghan, E., 1962, Geology of Marysvale quadrangle, Utah: U.S.G.S. Geologic Quadrangle Map GQ-154.

A brief discussion of lithologies, alteration, structure and mineral deposits accompany a 1:62,500 scale map.

White, D.E., Muffler, L.J.P., and Truesdell, A.H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems; Econ. Geol., v 66, p. 75-97.

Zimmerman, J.T., 1961, Geology of the Cove Creek area, Millard and Beaver Counties, Utah: Univ. of Utah unpub. M.S. thesis, 91 p.

The study area extends west from Interstate 15 about 8 miles and from the Millard Co. line north to Sec. 36, T24S. The Paleozoic and Cenozoic units are described in some detail with Tertiary and Quaternary igneous rocks extensively described. Petrographic descriptions are included and a map at a scale of 1:20,000 has good detail.



Correlation of Map Units - Cove Fort-Sulphurdale

Qal, Qls		Quaternary
unconformity		
Ts, Tbas	Pliocene and Miocene	Tertiary
unconformity		
Tj	Miocene	Tertiary
unconformity		
To	Miocene	Tertiary
unconformity		
Tbqm, Tbl		Tertiary
Tbc, Tbr, Tbt, Tb, Tbi	Miocene, Oligocene	Tertiary
unconformity		
Kp, Kps	Tertiary? and Upper Cretaceous	
unconformity		
TRu	Triassic	
Pc	Permian	
Pk, IPo	Pennsylvanian	

Qal Alluvial Deposits (Quaternary)

Qls Landslide Deposits (Quaternary)

Tbas Vesicular Basalt Flows

Ts Sevier River Formation
Partly consolidated fanglomerate deposits

Tj Joe Lott Tuff
Light gray poorly welded rhyolitic ash-flow tuff. Contains about 1% phenocrysts mainly of quartz, sanidine, plagioclase and traces of biotite. Minor vapor phase crystallization is common. Erupted from the Mount Belknap Caldera (Steven and others, 1977).

To Osiris Tuff
Densely welded gray to moderately welded light red-gray rhyodacitic ash-flow tuff containing about 30% phenocrysts (mainly plagioclase, pyroxene, biotite). Alignment of plagioclase phenocrysts is conspicuous. K-Ar age is 22.4 m.y. (Fleck and others, 1975).

Bullion Canyon Volcanics

Tbqm Quartz Monzonite
Medium-grained dikes consisting of orthoclase, andesine, quartz, augite. Dikes occur only in Union Oil Drill Hole 42-7. The relative age of the quartz monzonite with respect to the latite porphyry (Tbl) is not known.

Tbl Latite Porphyry
Porphyritic gray dikes and stocks containing 30-40% phenocrysts of labradorite, clinopyroxene, and an altered mafic phase. Aggregates of clinopyroxene and labradorite are abundant. Includes extrusive equivalents and locally brecciated cap rocks.

Tbc White Tuff Member
Poorly welded pink ash-flow tuff containing about 3% phenocrysts (mainly oligoclase, sanidine, quartz, and biotite). Secondary devitrification of matrix is ubiquitous.

Tbr Red Tuff Member
Densely welded red ash-flow containing about 3% phenocrysts (mainly sanidine, andesine, and quartz).

Tbt Three Creeks Tuff Member
Densely welded red to moderately welded gray latitic ash-flow tuff containing about 45% phenocrysts (mainly andesine, kaersutitic amphibole, and biotite). Displays conspicuous compound cooling characteristics in the mapped area. Erupted from the Three Creeks Caldera at 27 m.y. (Steven and others, 1977).

Tb Lower Bullion Canyon Volcanics
Tbi Largely porphyritic and variably propylitized dacite lava flows and breccias contining about 30% phenocrysts of andesine, hornblende, and biotite. Includes porphyritic plagioclase, hornblende, pyroxene dikes (Tbi).

Tn Needles Range Formation
Moderately welded ash-flow tuff containing about 40% phenocrysts of plagioclase, hornblende and biotite. K-Ar age is 30.6 m.y. (Caskey and Shuey, 1975). Locally interlayered with lower Bullion Canyon Volcanics.

Kp Price River Conglomerate
Kps Largely boulder conglomerate containing clasts of limestone and quartzite. Includes sandstones and shale (Kps).

TRu Siltstone and Limestone
Undifferentiated siltstone and limestone of probable Triassic age.

Pc Coconino Sandstone
Buff-colored quartzitic sandstone.

IPo Oquirrh Formation
Largely blue-gray limestone with interbedded sandstone, shale, and dolomite.

Pk Pakoon Limestone
Limestone containing beds of sandy limestone and buff quartzitic sandstone at base.

Contact, dotted where covered.

Fault, dotted where covered; ball and bar on downthrown side.

Strike and dip of sedimentary layering or compaction foliation.

Geothermal well.

SCALE 1:24,000

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

Geology by J. N. Moore and S. M. Samberg, 1978, under Department of Energy contract DE-AC07-78ET 28392.

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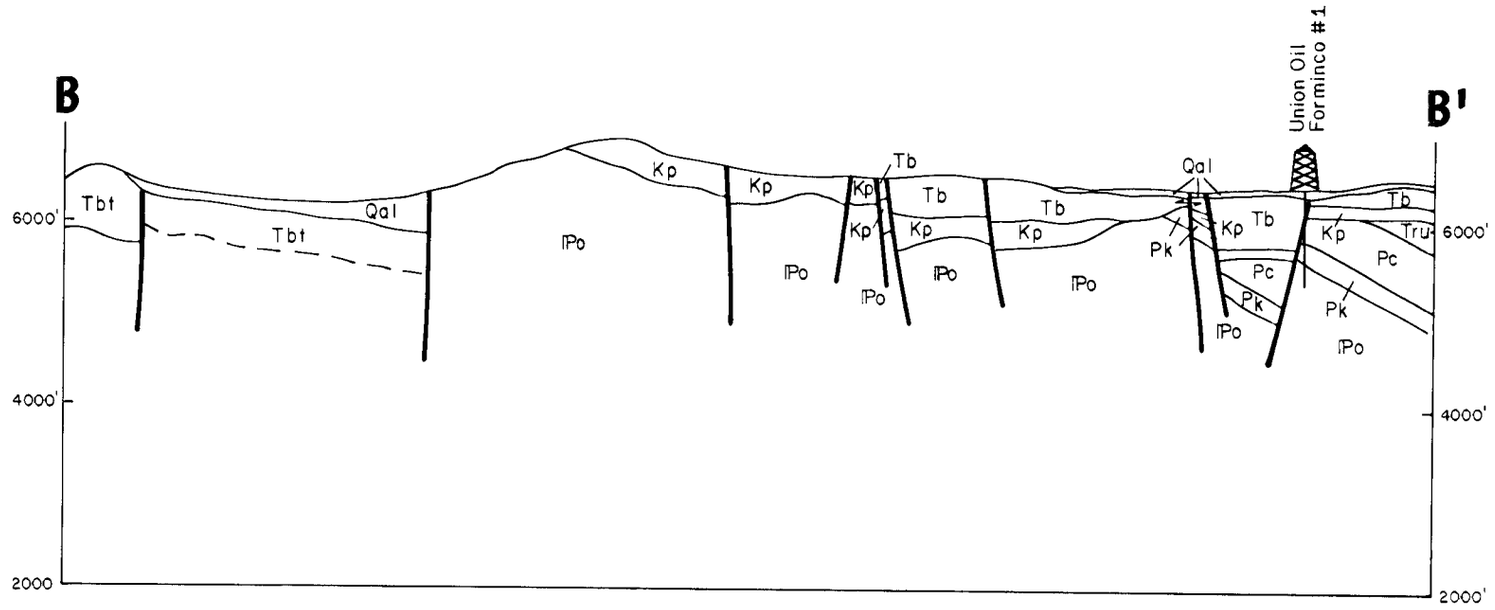
GEOLOGIC MAP OF THE COVE FORT-SULPHURDALE KGRA BEAVER AND MILLARD COUNTIES, UTAH

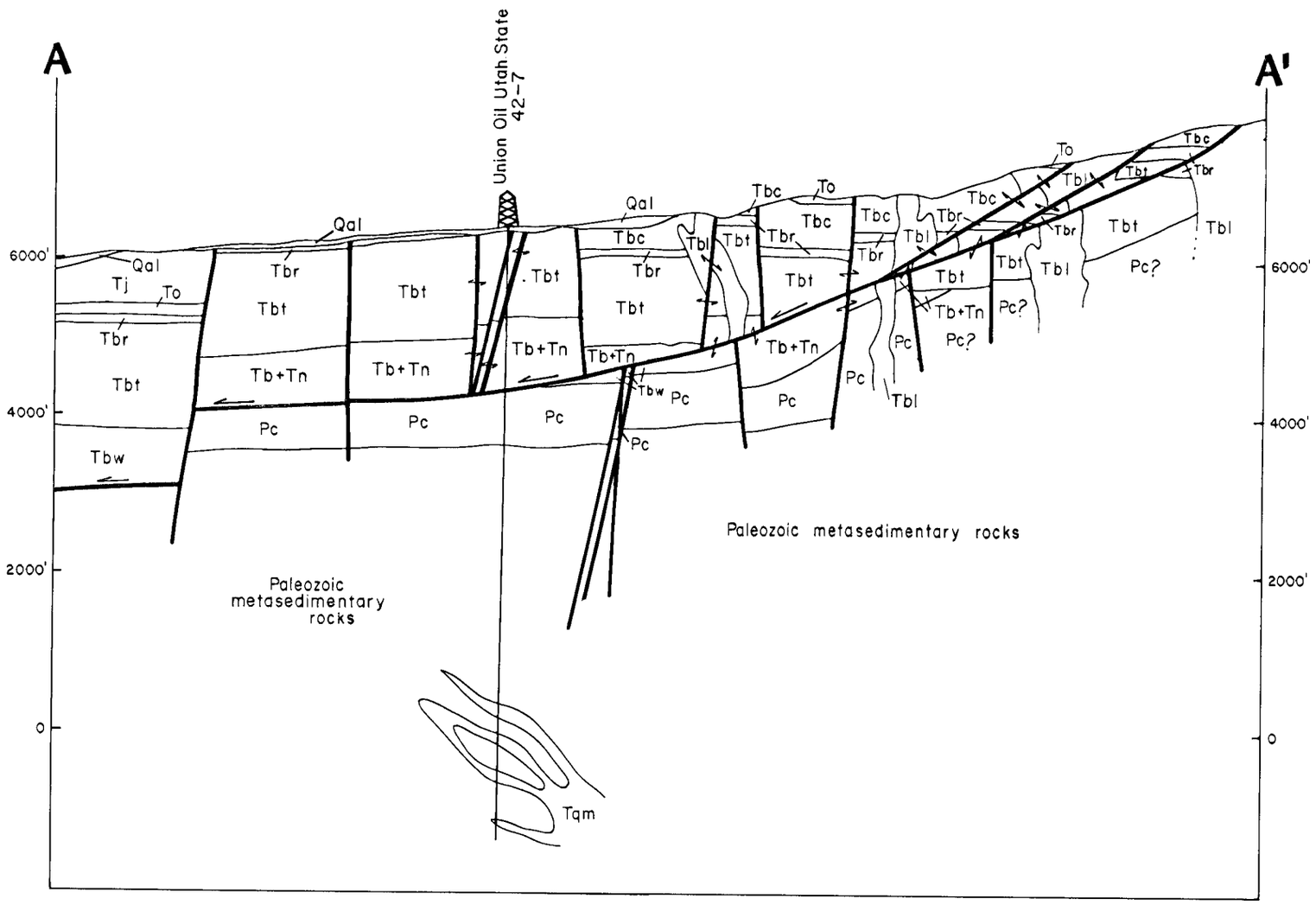
Geology by
Joseph N. Moore and Susan M. Samberg
1979

Plate I

APPROXIMATE MEAN DECLINATION, 1958

MAP LOCATION





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SCALE 1:24,000

1 1/2 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

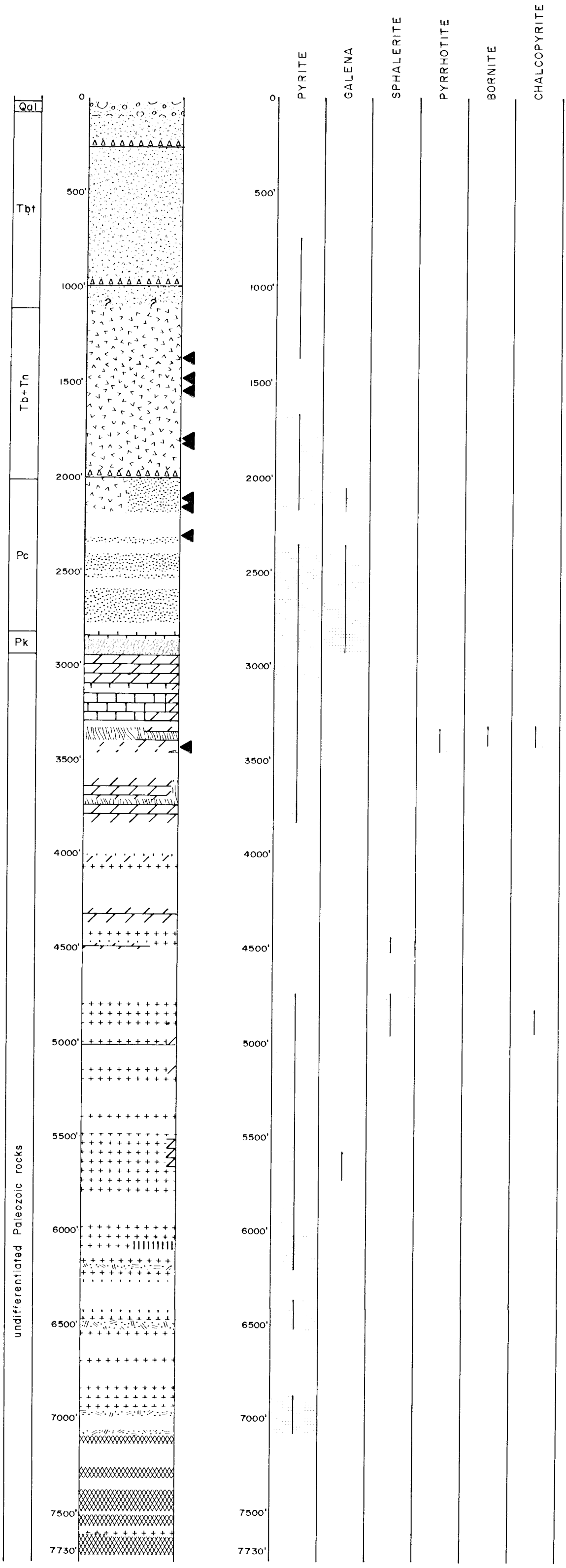
1 .5 0 1 KILOMETER

no vertical exaggeration

Geology by J. N. Moore and S. M. Samberg, 1978, under Department of Energy contract DE-AC07-78ET 28392

CROSS SECTIONS OF THE COVE FORT-SULPHURDALE KGRA BEAVER AND MILLARD COUNTIES, UTAH

Joseph N. Moore and Susan M. Samberg
1979



Refer to stratigraphic column for description of lithologies

alluvium (Qal)

Bullion Canyon Volcanics

quartz-monzonite

Three Creeks ash-flow tuff (Tbt)

Needles Range Formation (Tn)
Bullion Canyon volcanics (Tb)

Coconino Sandstone (Pc)

Pakoon Limestone (Pk)

limestone

sandstone

Blank spaces in column indicate no returns

◀ Arrows to right of column indicate lost circulation

Distribution of quartz-pyrite veins. Pyrite typically comprises less than 1% of the vein.

Undifferentiated Paleozic Rocks

dolomite

limestone

quartzite

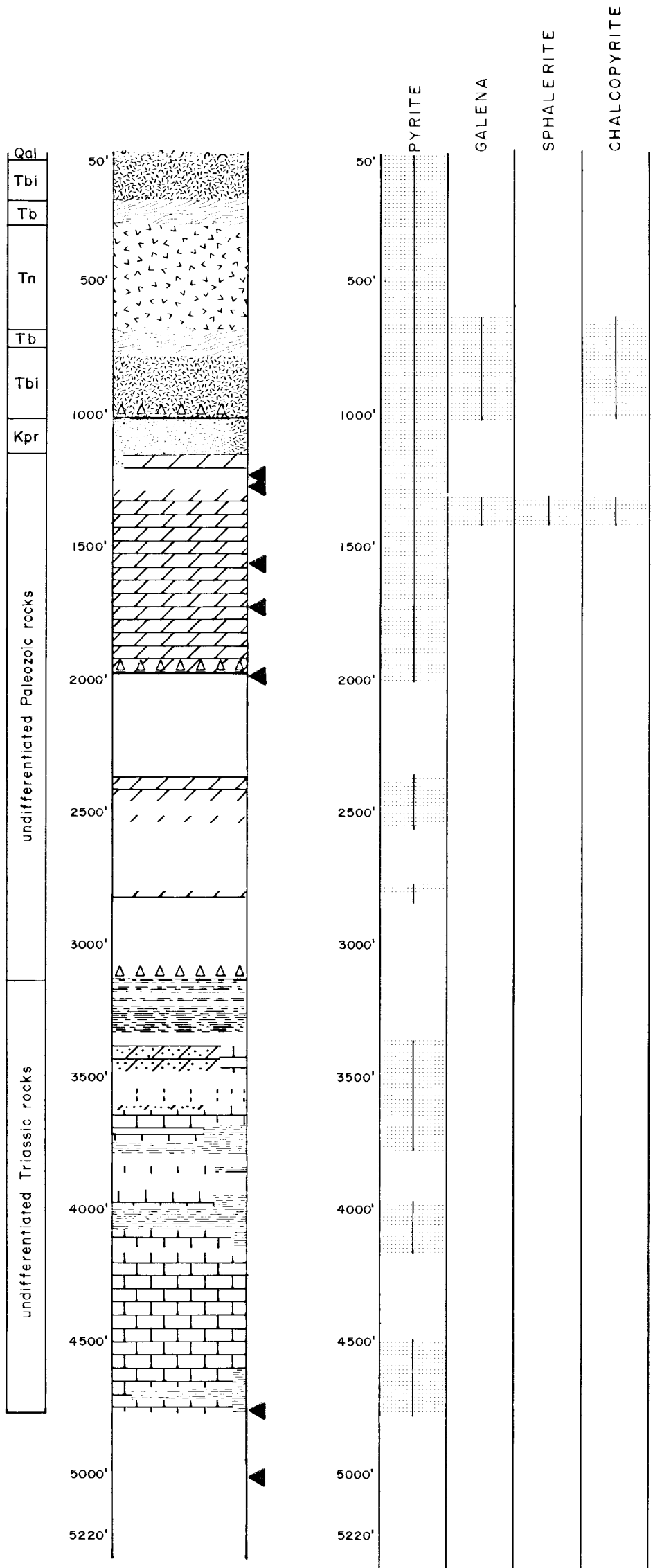
marble

serpentine marble

anhydrite mineralization

APPENDIX I

Union Oil Drill Hole Utah State 42-7 sulfide distribution



Refer to stratigraphic column for description of lithologies

alluvium (Qal)

Bullion Canyon Volcanics

andesite intrusive (Tbi)

Bullion Canyon lava flows (Tb)

Needles Range Formation (Tn)

Price River Conglomerate (Kpr)

Undifferentiated Triassic Rocks

dolomite

siltstone

limestone

undifferentiate Paleozoic rocks

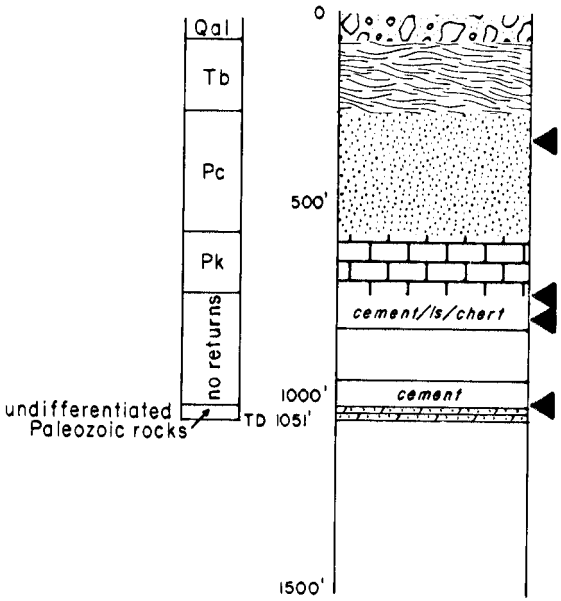
Blank spaces in column indicate no returns.

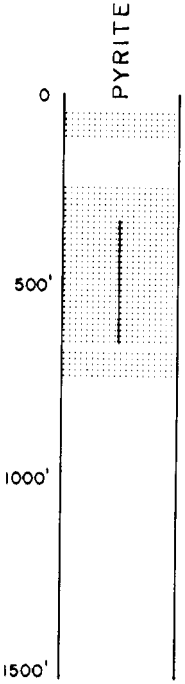
◀ Arrows to right of column indicate lost circulation

Distribution of quartz-pyrite veins. Pyrite typically comprises less than 1% of the vein.

APPENDIX II

Union Oil Drill Hole Utah State 31-33 sulfide distribution





Distribution of quartz-pyrite veins. Pyrite typically comprises less than 1% of the vein.

Refer to stratigraphic column for description of lithologies.

- alluvium (Qal)
- Bullion Canyon Volcanics; undiffertiated (Tb)
- Coconino Sandstone (Pc)
- Pakoon Limestone (Pk)
- undifferentiated Paleozoic rocks

Blank spaces in column indicate no returns.

◀ Arrows to right of column indicate lost circulation

APPENDIX III

Union Oil Drill Hole Forminco #1 sulfide distribution