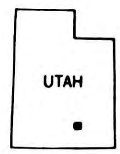
PROVISIONAL GEOLOGIC AND COAL RESOURCES MAP OF THE MT. ELLEN QUADRANGLE, GARFIELD COUNTY, UTAH

Loren B. Morton



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INTRODUCTION

The Mt. Ellen quadrangle lies on the northern end of the Henry Mountains in high, dissected, locally folded and faulted mesas and steep alpine topography. The highest point, Mt. Ellen, stands 11,506 feet (3,507 m) above sea level and is 19.9 miles (32 km) southwest of Hanksville and 16.2 miles (26 km) east of Capitol Reef National Park. More than 3,937 feet (1,200 m) of Jurassic, Cretaceous, Tertiary, and Quaternary rocks are exposed in the Mt. Ellen quadrangle. Jurassic and Cretaceous rocks have been upwarped and locally altered by Tertiary diorite porphyry intrusions.

STRATIGRAPHY

JURASSIC SYSTEM

Entrada Sandstone

The Entrada Sandstone is exposed in the northwestern corner of the quadrangle where it has been ruptured by the Dugout Creek and Cedar Creek laccoliths. The best exposures are in Slate Creek Canyon.

A complete section of Entrada Sandstone is not exposed in the quadrangle, but a partial section which was measured south of Dugout Creek is 164 feet (49.9 m) thick. The section is a pale red to very pale orange, very fine-grained sandstone with minor siltstone (Morton, 1983). The Entrada Sandstone here is calcite-cemented, contains minor gypsum, and is characteristic of Hunt's "earthy" facies (Hunt et al., 1953). Exposed units are very thin to massively bedded, weathering to ledges with minor slopes and rounded outcrops. No fossils were found in the Entrada Sandstone, however, an upper Jurassic age has been inferred by its stratigraphic position between the fossiliferous Carmel and Curtis formations (Baker, 1936, p. 58).

The basal contact of the formation is not exposed in the map area but is exposed to the east in Raggy Canyon. The upper contact with the greenish marine Curtis Formation is disconformable throughout most of the region (Hunt et al., 1953), although evidence of a disconformity was not seen in the locality where measured. This upper contact was mapped on a minor recessive zone that occurs at the boundary between the Entrada and Curtis Formations.

Curtis Formation

Outcrops of Curtis beds are limited to the northwest corner of the quadrangle. The formation is 28 feet (8.6 m) of light greenish grey, glauconitic, calcareous siltstone with minor greyish purple shale, measured south of Dugout Creek. Thinly laminated to thinly bedded and containing abundant oscillatory ripple marks, it forms a thin, sharp ledge which contrasts with the thick, rounded ledges of the underlying Entrada Sandstone and the slopes of the overlying Summerville Formation.

Gilluly and Reeside (1928, p. 79) found marine fossils in the Curtis Formation in exposures in the San Rafael Swell. These date the unit as middle Upper Jurassic. The upper contact with the Summerville Formation is gradational and conformable.

Summerville Formation

Some of the best exposures of the formation are found in Slate Creek Canyon. Throughout the study area the formation is a frequent host for the Tertiary age, diorite porphyry intrusions.

A complete section of the Summerville Formation was measured south of Dugout Creek (Morton, 1983). At this locality the formation is 194 feet (59 m) of pale reddish brown to light brownish grey siltstone, mudstone and shale interbedded with occasional hematitic gypsum. The clastic units in the formation contain abundant calcite as well as primary and secondary gypsum disseminated throughout.

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Age of the Summerville Formation was determined by Gilluly and Reeside (1928, p. 80) as Late Jurassic, based on the formation's stratigraphic position above the fossiliferous Curtis Formation and below the Morrison Formation. The basal contact with the Curtis Formation is gradational. The contact was mapped at the top of the ledge formed by the Curtis Formation. A minor glauconitic siltstone, similar to those of the Curtis Formation, appears 10 feet (3 m) from the basal contact of the Summerville Formation and may represent a remnant of the Curtis transgression.

The upper contact with the Salt Wash Member of the Morrison Formation is a prominent disconformity in the northern Henry Mountains region but is reported to be less evident to the south (Hunt et al., 1953) and was not apparent in the measured section (Morton, 1983). The upper contact was mapped on top of a massive, ledge forming, gypsum unit.

Morrison Formation

Baker, Dane, and Reeside (1936, p. 63) determined the age of the Morrison Formation as Upper Jurassic. It has two members.

Salt Wash Member: Hunt et al. (1953) reported that the Salt Wash Member in the Henry Mountains region is 150 to 475 feet (46 - 145 m) of lenticular claystone and shale with interfingering lenses of sandstone and conglomerate.

West of Pistol Ridge, the Salt Wash Member has been disrupted by high-angle faults, creating seven sandstone cliffs instead of the three cliffs seen south of Dugout Creek. South of Ragged Mountain, the Salt Wash Member is relatively undisturbed and has the best exposure of the member in the map area.

West of Ragged Mountain the member has been folded into a southward plunging anticline which is probably a result of a laccolithic intrusion into the Summerville Formation at depth. South of Granite Hole the Salt Wash Member is the roof of a major laccolith and has been disrupted by a tear fault of substantial displacement. Throughout the quadrangle the Salt Wash Member is a frequent roof for the laccolithic complex. A section measured south of Dugout Creek showed 387 feet (118 m) of very light grey to brownish grey sandstone and interbedded, subordinate, reddish and greenish bentonitic mudstone (Morton, 1983). Sandstones of the upper 151 feet (46 m) are dominated by medium-grained to granular quartz sands and, in the lower part of the member, by fine to very fine quartz sands with minor lenses of gravel. This upward coarsening trend may be evidence for uplift of the source area, possibly caused by the eastward migration of Nevadian orogenic highlands. Rip-up clasts of greenish claystone are common throughout sandstones in the member, while both sandstones and mudstones contain minor calcite and iron oxide. The Salt Wash Member contains cliff-forming, thick-bedded to massive sandstones and laminated to thin-bedded sandstones, siltstones, and mudstones that form minor ledges and prominent slopes. Lenses of crossbedded, gritty to pebbly sandstone occur in the massive cliff-forming units. The Salt Wash Member expresses itself as a series of cliffs and slopes.

Approximately 131 feet (40 m) from the basal contact a lens of loose sand was encountered and sampled. The sample was searched by Dr. J. K. Rigby Jr., of the University of Notre Dame, for mammal teeth. None were found although reptile teeth and turtle shell fragments occur. Hunt et al. described a distinct disconformity along the member's basal contact with the Summerville Formation at several localities in the Henry Mountain region (1953, p. 75). However, no disconformity was observed in the measured section (Morton, 1983).

Brushy Basin Member: The member is exposed in the northwest, southeast, and east-central portions of the map area. In the northwest corner of the quadrangle the Brushy Basin Member has been deformed by intense folding and faulting caused by the Dugout Creek and Cedar Creek laccoliths and the Pistol Ridge bysmalith. West of Slate Flat the member is a host for a minor laccolith. In the southeast corner of the quadrangle the Brushy Basin Member has been folded and faulted by the Ragged Mountain bysmalith. The Brushy Basin Member is a frequent host for the Tertiary age diorite porphyry laccoliths. At Granite Hole the member is host for a major laccolith.

A section of the Brushy Basin Member was measured in the Steele Butte quadrangle in the NE1/4, section 23, T. 31 S., R. 9 E. (Whitlock, 1983, appendix). There the member is 121 feet (37 m) of moderate red and pale greenish yellow mudstones and claystones. Minor, thin lenses of very fine-grained sandstones and siltstones are present. The member is laminated to thinly bedded and has a high bentonitic clay content. The lower 49 feet (15 m) of the member is dominated by the moderate red mudstones, while the upper 72 feet (22 m) is predominantly pale-greenish yellow mudstone. In this upper unit, approximately 56 feet (17 m) from the upper contact, a thin-bedded, very fine-grained, pyritic, quartzose sandstone occurs. This and the overall color of the upper unit indicate a change in the paleoenvironment to one of a reducing nature. The contact with the underlying Salt Wash Member is sharp, undulatory, and apparently conformable. This boundary was mapped at the break in slope formed by the rounded slopes of the Brushy Basin Member and the cliffs of the Salt Wash Member.

CRETACEOUS SYSTEM

Cedar Mountain Formation

The Cedar Mountain Formation consists of two members, the Buckhorn Conglomerate and an upper, unnamed shale member.

Buckhorn Conglomerate Member: A diagnostic feature of the member is the presence of light-grey to white quartzite pebbles. Outcrops of the member in the Mt. Ellen quadrangle are small, and rather isolated, and occur in three general localities: 1) west and north of Ragged Mountain, 2) southeast and north of Wickiup Ridge, and 3) west and southwest of Pistol Ridge. These outcrops are associated with those of the Jurassic system. The best exposures in the quadrangle occur between Slate Creek and Ragged Mountain, but the most accessible nearby exposures are found in the Steele Butte area to the west.

A section of the member which was measured 0.2 miles (0.3 km) north of the road in the SE1/4, NE1/4, section 23, T. 31 S., R. 9 E. (Whitlock, 1983, appendix) showed 54 feet (16.5 m) of brownish grey to yellowish brown sandstone and conglomerate. Sandstones, occurring mainly in the upper 25 feet (7.5 m) of the section, are thin bedded, fine grained, calcite cemented, and quartzose. This unit contains abundant iron oxide and is cross-laminated. The conglomerate, found in the lower 30 feet (9.0 m) of the section, is massively bedded and forms a cliff above the slopes of the Brushy Basin Member of the Morrison Formation. It is composed of chert, and light grey quartzite pebbles in a medium-grained quartz sand matrix. The pebbles range from 0.1 to 3.3 inches (3 to 85 mm) in diameter, and average 0.6 to 0.8 inches (15 - 20 mm) across. Minor lenses of medium-grained, calcareous, quartzose sandstone are present in the conglomerate.

Thickness and composition of the Buckhorn Conglomerate Member are extremely variable. A second section measured approximately 328 feet (100 m) to the southeast of the first one includes 25 feet (7.5 m) of very thin to laminated, fine-grained, calcareous, quartzose sandstone with frequent hematitic horizons that is equivalent to the conglomerate. Such variation may be attributed to a paleochannel running northeast-southwest, filled with a pebble lag gravel; and thin-bedded, finer grained sandstones on either side represent ancient levee deposits. Fossils are rare in the Buckhorn Conglomerate Member, and none were found in this study. Age of the formation is probably lower Albian (Peterson et al., 1980 p. 152).

Throughout this part of the Colorado Plateau a disconformity is present at the base of the Buckhorn Conglomerate (Stokes, 1944, p. 976), where channels have cut into the Brushy Basin Member. Contact with the overlying upper unnamed shale member appears conformable.

Upper Unnamed Shale Member: Exposures of this member are found in the same localities as the Buckhorn Conglomerate. The most accessible outcrops are found in the Steele Butte quadrangle to the west. A section which was measured 0.2 miles (0.3 km) north of the road in the SW1/4, NE1/4, section 23, T. 31 S., R. 9 E. (Whitlock, 1983, appendix) showed 26 feet (8.0 m) of interbedded, light-grey to brownish-grey carbonaceous shale and siltstone with minor laminated, fine-grained, quartzose sandstone. Carbonaceous shale in the lower 11 feet (3.5 m) is silty and iron sulfate is found along bedding planes. Fine-grained sandstone is restricted to this same interval. The upper 15 feet (4.5 m) of the member is mainly a carbonaceous shale with common macerated wood plant fragments. This upper unit also shows a coarsening upwards sequence as the section becomes predominantly a calcareous siltstone near the upper contact with the Dakota Sandstone. The entire member is thinly laminated to laminated and forms a slope.

Fossils have been collected at several localities in the upper unnamed member (Peterson et al., 1980, p. 152, 153), although none were found in this study. Age of the member has been discussed by Peterson et al. (1980, p. 152) and is considered to be middle to late Albian. The upper contact of this member with the Dakota Sandstone is reported to be disconformable in other areas (Peterson et al., 1980, p. 153), however, an unconformity was not observed.

Dakota Sandstone

Exposures of the Dakota Sandstone are found in the same localities as the two members of the Cedar Mountain Formation. The Dakota Sandstone generally forms a minor ledge. The most accessible exposures are found in the quadrangle to the west, where a section was measured (Morton, 1983).

A complete section is exposed in the N1/2 of section 23, T. 31 S., R. 9 E., 0.3 mile (0.5 km) west of exposures in the northwest part of the quadrangle (Whitlock, 1983, appendix). In this locality the Dakota Sandstone is more than 39 feet (12 m) of pale orange to greyish-yellow calcareous sandstone, with minor interbeds of siltstone in the lower 15 feet (4.5 m). The sandstone is composed of very fine- to medium-grained quartz sand, with minor kaolinite matrix and iron oxide cement. Gryphaeas and Ostreas are abundant throughout the formation. Layers of Ostreas oriented parallel to bedding occur 2.6 and 15 feet (0.8 and 4.5 m) from the base. The uppermost 2.3 feet (0.7 m) of the formation includes up to 50%, by volume, Gryphaeas in the sandstone. The formation is thinly laminated to thin bedded, but bedding is commonly strongly bioturbated.

Peterson et al.(1980, p. 154) reported that fossils found in the upper part of the Dakota Sandstone in the Henry Mountains area indicate that the formation is of late Cenomanian age. Upper contact of the formation with the overlying Tununk Shale Member of the Mancos Shale is sharp and conformable.

Mancos Shale

On the basis of paleontological studies, Maxfield (1976) and Peterson et al. (1980) both suggested that the members of the Mancos Shale in the Henry Mountains area are not entirely correlative with those of the Wasatch Plateau. The latter study indicated that both the Masuk Shale and Emery Sandstone of the Wasatch Plateau correlate with the Blue Gate Shale of the Henry Mountains region. As a result Smith (1983) renamed the "Emery Sandstone" of the Henry Mountain area the Muley Canyon Sandstone. The Masuk Shale Member retains its name since the type locality is in the Henry Mountain region.

Tununk Shale Member: The Tununk Shale is widely exposed across the quadrangle and is a common host for Tertiary laccoliths. Outcrops are commonly roof pendants or exposures immediately adjacent to the intrusions. Where it is not involved in the laccolithic complexes, the member weathers to incompetent slopes, with frequent landslides and mudflows.

A section measured in the Steele Butte quadrangle in sections 23, 14 and 15, T. 31 S., R. 9 E. found Tununk beds to be 440 feet (134 m) thick (Morton, 1983). There and across the Mt. Ellen quadrangle the member is medium bluish-grey, thinly laminated to laminated, silty shale with minor thinly bedded yellowish-orange, very fine-grained, quartzose sandstone. The shale is calcareous and gypsiferous. Bentonite is a common constituent of the shale and causes the member to weather with a "popcorn" surface texture and badland topography. Septarian and melikarian nodules were frequently found in the upper 66 feet (20 m) of the member, some as large as 24 inches (60 cm) in diameter. This section appears thin compared to those measured by other authors. This discrepancy may be related to errors in section measurement due to pediment gravel cover.

Peterson et al. (1980 p. 155) reported that fossils from the member in the Henry Mountain region indicate late Cenomanian to middle Turonian age. The contact with the overlying Ferron Sandstone Member is gradational and was mapped at a break in slope between the cliff-forming Ferron Sandstone and the slope of the Tununk Shale.

Ferron Sandstone Member: The Ferron Sandstone is widely exposed in bits and pieces in much of the quadrangle but is best exposed in the southwest corner of the map area between South Creek and The Horn. It is a frequent roof for the laccoliths and in some localities has undergone extensive folding and faulting.

A measured section of Ferron Sandstone west of South Creek Ridge shows 194 feet (59 m) of strata and consists of three units: a lower 48 feet (14.7 m) unit of interbedded sandstone, siltstone, and shale; a middle unit of 54 feet (16.5 m) of massive, cliff-forming, calcareous sandstone; and an upper unit of 53 feet (16.1 m) of interbedded carbonaceous shale, coal, and minor sandstone all capped by a calcareous, hematitic, fine-grained sandstone 8.2 feet (2.5 m) thick (Morton, 1983). The lower unit is characterized by a coarsening upward sequence, with siltstone interbeds confined to the lower part of the unit. Both siltstones and sandstones are very thin bedded, greyish orange, calcareous, and kaolinitic. Shale interbeds resemble those of the Tununk Shale. Trough cross-sets, climbing ripplemarks, hummocky stratification, and ball and pillow structures are common.

The middle unit consists of a greyish-orange, fine- to medium-grained, quartzose sandstone, with minor coaly and carbonaceous horizons. Crossbed sets are common throughout, with platy, hematitic, laminations in the upper part of the unit. Petrified wood was found in this middle unit between Bullfrog Creek and Steven's Narrows in the NW1/4, of section 19, T. 32 S., R. 10 E.

The upper unit is dominated by coal and carbonaceous shale. The carbonaceous interval is approximately 52 feet (16 m) thick and is interrupted twice by an olive-grey shale of possible marine origin. The upper 8.2 feet (2.5 m) of this unit is a light-grey, thin-bedded, fine-grained, quartzose sandstone with common hematitic concretions. This sandstone shows a coarsening upwards sequence and is gritty in the upper few centimeters. Northeast of Steven's Narrows, in the SE1/4 of section 12, T. 32 S., R. 9 E., pyritic concretions occur in this uppermost sandstone. These concretions are of the same size and texture as the hematitic concretions seen in the measured section and may be a product of hydrocarbon bleaching. Lower and middle units mentioned above correspond to the lower unit described by Peterson and others (1980, p. 155-159).

Fossils indicate the member is middle to upper Turonian in age (Peterson et al., 1980, p. 153 and 157). Hunt et al. (1953) reported that a disconformity is common at the contact with the overlying Blue Gate Shale. A conglomeratic sandstone at this upper contact in a section measured northeast of Steven's Narrows in the SE1/4 of section 12, T. 32 S., R. 9 E. (Smith, 1983, Appendix, unit 1 of Blue Gate Shale) may well represent the disconformity described by Hunt et al. This conglomeratic sandstone contains approximately 10% subangular chert and quartz pebbles 0.2 to 0.5 inches (6 - 12 mm) in diameter, 15% angular quartz granules, and it is calcareous and well indurated. Peterson et al. (1980, p. 159) suggested that this unconformity represents most of late Turonian and all of Coniacian time based on the absence of six ammonoid faunal zones.

Blue Gate Shale Member: The Blue Gate Shale forms strike valleys in the lower elevations along two belts: 1) from Bullfrog Creek across Steven's Narrows to South Creek, and 2) in the Blue Basin-Bull Creek area. In the higher areas of the quadrangle the member is a common host and is often exposed as roof pendants of the laccolithic complex (for example the outcrops west of South Summit Ridge).

A section measured northeast of Steven's Narrows in sections 12 and 14, T. 31 S., R. 9 E. (Smith, 1983, Appendix) found 1,525 feet (465 m) of medium bluish grey to olive grey, calcareous, gypsiferous shale with minor interbeds of siltstone and very fine-grained, calcareous, quartzose sandstone. Thickness of this section may be anomalously high because of difficulty in measurement and evaluation due to pediment gravel cover. The lower 108 feet (33 m) contain mainly a dark grey, calcareous shale that is very similar in appearance to the Tununk Shale Member. This resemblance creates difficulty in identifying the stratigraphic position of shaly roof pendants involved in the laccolithic complex. Higher in the section the shale is bentonitic and produces popcorn-textured soils and badland topography.

Minor interbeds of siltstone and sandstone generally form rounded shoulders, and gypsiferous shales produce thick, soft soils. The Blue Gate in the upper 171 feet (52 m) is interbedded yellowish-grey, very thin-bedded to laminated, very fine-grained, calcareous, quartzose sandstone and medium-grey, gypsiferous shale. The sandstone produces steeper slopes and contains macerated plant and wood fragments, ripple marks and crossbeds. Shale of this upper interval is bentonite-poor and highly gypsiferous with selenite crystals common on weathered surfaces.

Faunas from the Blue Gate Shale in other areas (Peterson et al., 1980, p. 159) indicate lower Santonian to lower Campanian age. The upper contact with the Muley Canyon Sandstone Member is gradational and was mapped at a break in slope at the base of the Muley Canyon Sandstone cliff.

Muley Canyon Sandstone Member: The Muley Canyon Member occurs in two localities in the quadrangle: 1) south of Steven's Narrows, where it forms a prominent cuesta, and 2) on Mt. Ellen Peak, where the member is isolated by intrusions. The Muley Canyon Sandstone Member in the quadrangle is approximately 354 feet (108 m) thick and is similar to outcrops described by Whitlock (1983) in the Steven's Narrows area. Muley Canyon coals in the quadrangle, south of Steven's Narrows, are discontinous and the upper sandstone unit less massive.

Fossils found thus far in the member are not diagnostic of age. Peterson et al. (1980, p. 159-162) concluded that it is early Campanian in age, on the basis of regional correlations and relationships to the overlying fossiliferous Masuk Shale. The contact of the Muley Canyon Sandstone with the overlying Masuk Shale is conformable and gradational. This upper boundary has been placed at different stratigraphic levels in different studies (Hunt et al., 1953; Doelling, 1972; Peterson et al., 1980; and Law, 1980). In this study, the contact was placed at the top of a continuous sandstone that overlies the middle carbonaceous unit of Whitlock (1983), following his usage. Carbonaceous mudstone and shale interfinger with abundant but discontinuous sandstone lenses above this contact.

Masuk Shale Member: Exposures of Masuk Shale are limited in the quadrangle and occur only south of Steven's Narrows, although intrusions on Mt. Ellen Peak may have invaded the member. Smith (1983) and Whitlock (1983) mapped subdivisions of the member in adjacent quadrangles. No such subdivisions were mapped here because only the lowest unit is exposed in the quadrangle. In the quadrangle to the west (Steele Butte), Whitlock (1983) separated the Masuk Shale into three units, the lowest of which is partly exposed in the Mt. Ellen quadrangle and is similar to outcrops he described near Steele Butte, 2.2 miles (3.5 km) west of the quadrangle in sections 28 and 33, T. 31 S., R. 9 E.

Peterson et al. (1980, p. 162) reported collections of gastropods, pelecypods, garpike scales, turtle shell fragments, and crocodilian teeth, which indicate a fresh to brackish water environment. Pollen collected from the overlying Tarantula Mesa Sandstone (Peterson et al.,1980, p. 162) indicate an early Campanian to early late Campanian age for the Masuk Shale Member.

TERTIARY SYSTEM

Tertiary igneous intrusions and breccias are the most widespread rocks in the quadrangle. Diorite porphyry comprises both the Mt. Ellen stock and its associated laccoliths. A shatter zone caused by and found at the periphery of the stock consists of a mixture of fragmented sedimentary rocks and diorite porphyry.

Diorite Porphyry

Composition of a typical sample of diorite porphyry consists of: 30% oligoclase, 15% hornblende, 5% magnetite, 4% apatite and titanite; and a 46% aphanitic groundmass predominantly of quartz, orthoclase, and albite or oligoclase (Hunt et al., 1953). A quartz-bearing diorite porphyry has also been reported in the central and southeastern portions of the stock (Hunt et al., 1953), but relative ages of the diorite or quartz-bearing diorite porphyries have not been established. K/Ar dating of samples of hornblende from a laccolith in the Henry Mountains yielded dates of 48 and 44 m.y. (Armstrong, 1969, p. 2084).

Hornblendite inclusions are common in the intrusive masses in the quadrangle and constitute approximately one to two percent of the igneous rocks. They are generally coarsely crystalline, angular, have sharp boundaries with the intrusive (Hunt et al., 1953), and are believed to be relicts of a Precambrian basement complex at depth (G. Hunt personal communication, 1983).

The diorite porphyry forms high ridges and peaks in the quadrangle. Diorite porphyry talus slopes, on the flanks of intrusions, make it difficult to distinquish outcrop from weathered debris. The prominent ridges are composed of predominantly in-place diorite porphyry with distal wedges of transported debris around their edges. Map contacts representing this relationship are shown with dashed lines (Morton, 1983).

Weathered outcrops of diorite porphyry display a variety of colors, ranging from red (iron oxide), to dark brown (desert varnish), to lighter shades of grey. The behavior of porphyry weathering is as unpredictable as the weathered color. In many areas the groundmass weathers first, leaving a granular soil of phenocrysts; elsewhere the phenocrysts weather first.

A minor laccolith with an anomalous aureole of contact metamorphism, hosted by the Brushy Basin Member of the Morrison Formation, was mapped west of Slate Flat. Alteration of the country rock, though not intense, is of a greater magnitude than seen elsewhere in the complex. The baked zone is two to three meters wide instead of only a few centimeters. Samples of the diorite porphyry contain abundant phenocrysts that were determined to be plagioclase partially altered to sericite like other examples reported by Hunt et al., (1953). Embayed and rounded quartz phenocrysts and secondary calcite also occur in the same sample.

The extraordinary aureole of thermal alteration around this body may be related to geometry. The intrusion in question has arched the overlying members of the Cedar Mountain Formation, and the Dakota Sandstone. Approximately 984 feet (300 m) north of the laccolith another intrusion has invaded the Tununk and Blue Gate Shales. These two intrusions may have "sandwiched" the Lower Cretaceous formations between them, increasing the amount of heat to which the sedimentary rocks were exposed, and thus increasing the intensity of metamorphism.

Shatter Zone

A shatter zone caused by the Mt. Ellen Stock consists of a mixture of fragmented sedimentary rocks and diorite porphyry. The zone of brecciation occurs at the stock's periphery and is as wide as 3,501 feet (1,067 m). Hunt et al. (1953) reported that the zone is predominantly diorite porphyry towards the stock and grades radially to a zone of predominantly sedimentary rocks. Thin basaltic sills and small irregular basaltic intrusions are associated with the diorite porphyry in the shatter zone and are apparently secondary (Hunt et al., 1953). Individual masses of sedimentary rocks are baked and irregularly oriented. Stratigraphic displacement of these sedimentary masses is not great (Hunt et al., 1953). The structure of the shatter zone is complex and was only given cursory attention in this study.

QUATERNARY SYSTEM

Five types of unconsolidated accumulations of Quaternary age have been mapped in the quadrangle (Morton, 1983): pediment gravels, colluvium, alluvium, landslide debris and talus.

Pediment Gravels

Two distinct episodes of deposition of pediment gravels were distinquished in the quadrangle. The oldest gravels were deposited on surfaces that are only gently sloping, inclined away from the Mt. Ellen complex. These older pediment-veneering gravels are found at relatively higher elevations than the younger series and have been dissected and beheaded by subsequent erosion. Exposures occur west of Birch Spring and southeast of Steven's Narrows and consist of cobbles and boulders of diorite porphyry, from the Mt. Ellen complex, that are somewhat rounded, and occur in a matrix of very fine- to fine-grained, light-brown sand. Thicknesses of the gravels vary: west of Birch Spring they are over 121 feet (37 m) thick, while those exposed southeast of Steven's Narrows are only up to 39 feet (12 m) thick. These older gravels correspond to the pediment gravel of Whitlock (1983), who has mapped them in lower, more distal distributions.

The younger pediment gravels were deposited during a later episode, after pediments and deposits of the older gravels had been dissected and pediments beheaded. The younger, lower gravel deposits have a composition similar to the older series and may well contain reworked materials of the older gravel. They have been deposited on relatively lower surfaces that are inclined away from the Mt. Ellen complex, and they tend to drape off of the igneous rocks to cover the Cretaceous and older sedimentary formations and to surround the pinnacle-like exposures of the older pediments.

The younger pediment gravels extend over a broad area of the quadrangle but are most evident in the southwest corner of the map area. There they form a belt that runs northwest - southeast, from west of McClellan Spring to Slate Creek. Another preserved remnant occurs at the head of a fan-like deposit at the eastern edge of the map, north of Crescent Creek. These gravel-veneered surfaces converge with other fans in the quadrangle to the east, some of which contain gold placer deposits (Hunt et al., 1953).

Younger pediment gravels between Box Spring and Slate Flat are similar to those found on the west side of the mountain but are in a different drainage. Areas east of these limited deposits, along the base of Ragged Mountain and south into the lower reaches of Slate Creek, have no pediment gravel development. This distribution suggests that the eastward-draining of Slate Creek may have captured an earlier system, which may have flowed southwestward from the Slate Flat area across Penellen Pass into Bullfrog Creek. These younger pediment gravels correspond to the alluvial terrace gravels of Whitlock (1983).

Colluvium

Colluvium consists of subangular cobbles and boulders of diorite porphyry in a sandy matrix, transported short distances by gravity, solifluction and frost action. Wedges of colluvium generally thicken distally from the igneous rock outcrops for a short distance then thin abruptly to distinct margins. The diorite porphyry-colluvium boundary was mapped along a break in slope formed at the transition from bedrock to transported debris. Colluvium-covered areas generally outline the perimeter of the intrusive complex.

Alluvium

Alluvium was deposited after the pediment gravels and contemporaneously with colluvium, landslide debris, and talus. Major streams in the quadrangle are margined with terraces and lined with sand and gravel of diorite porphyry clasts.

Landslide Debris

Landslides and associated debris were mapped near The Horn and north of Mt. Ellen Creek. The landslide debris consists of angular blocks of diorite porphyry, some as large as 39 feet (12 m) in diameter, floating in finer materials similar to colluvium. Surfaces of the debris slides are irregular and hummocky. The landslides may have been a product of the over-steepening of slopes by the downcutting of nearby streams, followed by the failure of shaly formations and subsequent debris flows. Such appears to be a reasonable explanation for the landslide seen near The Horn. More detailed work on the surficial deposits in the Bull Creek Basin area, in the northeastern corner of the quadrangle, has been done by Hohl (1980).

Talus

Talus occurs at the base of steep slopes throughout the quadrangle and is generally derived from the diorite porphyry. Talus usually consists of angular blocks from cobble to boulder sized, with little finer matrix.

STRUCTURAL GEOLOGY

General Statement

It was in the Henry Mountains that laccoliths were first identified and described by Gilbert (1877). Years later Hunt et al. (1953) resurveyed the region, refining Gilbert's work. The present study, through increased detail in mapping, has provided additional data on deformation of the sedimentary rocks by the intrusions. Four intrusions are discussed in detail below. Structures found in mapping suggest other intrusions at depth.

Intrusions

Mapping of members of the Cedar Mountain and Morrison Formations provided data on the nature of deformation of sedimentary rocks by laccoliths and bysmaliths. The stock and shatter zone, however, received only cursory attention in this study but has been described by Hunt et al. (1953). Four laccoliths and bysmaliths located in the western and southern parts of the complex received greater attention and include the South Creek and Dugout Creek laccoliths and the Ragged Mountain and Pistol Ridge bysmaliths. A short description of other minor intrusions follows. The remaining intrusions in the quadrangle have been described at length by Hunt et al. (1953).

Stocks

Hunt et al. (1953) described the Mt. Ellen stock as a discordant, vertical cylindrical mass composed of moderately homogeneous porphyry, rimmed by a shatter zone. An aerial magnetic survey (Affleck and Hunt, 1980) of the Henry Mountains has confirmed this interpretation. On a residual total magnetic intensity map a circular 169-gamma anomaly exists over the Mt. Ellen stock. From these data Affleck and Hunt suggested that the stock is cylindrical, steep sided, and probably widens at depth.

Several other magnetic anomalies occur in the Mt. Ellen complex, suggesting that other stock-like bodies also exist. One anomaly, mapped under North Summit Ridge, is circular in map view and has a magnitude of 89 gammas. This information supports field evidence of Hunt et al. (1953) that the North Summit Ridge intrusions are the result of upward and outward injections. A third circular anomaly of approximately 100 gammas magnitude occurs in the quadrangle under the northwest side of Wickiup Ridge. Once again, magnetic information supports field data collected by Hunt and others (Hunt et al., 1953, Affleck and Hunt, 1980) and infers a stock-like body under Wickiup Ridge.

Laccoliths

South Creek Laccolith: The South Creek laccolith holds up a prominent ridge that runs east-west in the southwestern part of the quadrangle. It is approximately 8,497 feet (2,590 m) long, and as wide as 8,005 feet (2,440 m), and divides the drainages of the north-flowing South Creek and the south-flowing Bullfrog Creek.

Gilbert (1877, p. 41) recognized the South Creek laccolith ("E" laccolith) and suggested that the Blue Gate Shale hosted the intrusion. Hunt et al. (1953) renamed the laccolith and concluded that the Tununk Shale was the original host.

Three new features around the South Creek laccolith were identified during the present study. They are: 1) linear oblique normal faults, 2) a low-angle reverse fault, and 3) a minor dike in front of the South Creek laccolith. Traces of the linear oblique normal faults trend northeast-southwest and are located on the south flank of the South Creek laccolith. Displacement along these faults is minor, juxtaposing different blocks of Ferron Sandstone. A central graben has been formed on the flank of the South Creek laccolith. Horsts to either side of the graben are marked by uplift of the carbonaceous zone of the upper Ferron Sandstone. Vertical displacement is minor, some 30 to 39 feet (9 - 12 m). Apparent horizontal displacement along the southernmost fault is some 689 feet (210 m).

The oblique normal faults indicate tension over the laccolith and occur along the south flank of the intrusion. Faults occur in a re-entrant, where Ferron Sandstone crops out between the South Creek laccolith and a laccolith to the southeast. This more southeastern laccolith trends northeast-southwest and will be referred to as the Bullfrog laccolith.

The oblique normal faults were produced as the Ferron Sandstone responded in a brittle manner to roof raising. It is likely that other radial faults existed over the crests of the South Creek and Bullfrog laccoliths. In fact, this style of faulting may have been common over many of the laccoliths in the complex, but cover beds in which these faults would have formed have been eroded away.

The trace of a low angle reverse fault trends north-south in front of the South Creek - Bullfrog laccoliths. The fault is best seen 1,198 feet (365 m) southwest of the Bullfrog laccolith. The Ferron Sandstone is overturned immediately in front of the laccolith, as much as 55 degrees, but is almost horizontal 591 feet (180 m) to the southwest (cross-section B-B'). The reverse fault is inclined towards the Bullfrog laccolith at a shallow angle and cuts the Tununk and Blue Gate Shales, and the Ferron Sandstone. Towards the intrusion, the dip of the fault may be shallower than depicted in the cross-section. Hunt et al. (1953) reported that many of the laccoliths climb in their hosts some 300 feet (100 m) in 1 mile (1.6 km). This type of discordance in the South Creek and Bullfrog laccoliths is much greater than previously recognized. The Ferron Sandstone roof has been ruptured and transported laterally as much as 1,247 feet (380 m). The low-angle reverse fault must have developed as the South Creek and Bullfrog laccoliths invaded the Tununk Shale. Continued intrusion, particularly of a lateral nature, overcame the internal strength of the Ferron Sandstone roof, rupturing it and carrying it and the intrusion to a higher interval in the Blue Gate Shale.

Further evidence for the existence of the low-angle reverse fault is a dike of diorite porphyry that crops out at the Head of the Bullfrog. The trend of the dike roughly parallels the fault and forms a series of low, rounded, westward-facing hills. Previous surveys have mapped this feature as an outcrop of the Blue Gate Shale. Slates, slate breccias, and highly weathered outcrops of diorite porphyry were identified along the Head of the Bullfrog, and a small outcrop of Blue Gate Shale trapped below the dike was mapped. This dike is here named the Head of Bullfrog dike. It is likely that the South Creek - Bullfrog laccoliths are its source. They both are composed of diorite porphyry that bears hornblende inclusions.

The low-angle reverse fault in front of the South Creek - Bullfrog laccoliths is a possible plane of weakness that allowed a portion of the porphyry in the laccoliths to flow discordantly through the Ferron Sandstone roof into the Blue Gate Shale (cross-section D-D'). It may extend northward in front of South Creek Ridge. Two Ferron Sandstone outcrops suggest this on the west end of South Creek Ridge as the section is repeated approximately 1,312 feet (400 m) southeast of Birch Spring. The northern outcrop is a roof pendant to the intrusion and consists of massive upper Ferron Sandstone. The southern outcrop is located at the floor of the intrusion and consists of carbonaceous shales and minor coal overlain by diorite porphyry.

Dugout Creek Laccolith: The Dugout Creek laccolith was first recognized by Gilbert (1877, p. 41, The Newberry Laccolith). Hunt et al. (1953) gave the laccolith its present name. The laccolith forms a prominent arch south of Dugout Creek and has invaded the Entrada Sandstone. Surface data, compared with the available subsurface data from the Exxon well 2,799 feet (853 m) to the north, indicate that the laccolith has raised its roof approximately 1,378 feet (420 m).

The Dugout Creek laccolith underlies the Sarvis Ridge laccolith located to the south and east which has invaded the Tununk Shale. The two laccoliths have created a broad dome more than 8,497 feet (2,590 m) long and 8,990 feet (2,740 m) wide. Arched strata along the eastern side of the complex dip eastward as much as 22 degrees. Dips are steepest along the western side, as much as 45 degrees, similar to the ideal model of laccoliths considered by Hunt.

An arch, principally formed in the Salt Wash Member of the Morrison Formation, occurs along the western margin of the Dugout Creek laccolith. A low-angle reverse fault was identified along this arch and another inferred near measured section no. 2 (Morton, 1983). The reverse fault has truncated the Summerville Formation and caused an offset of sandstone cliffs in the overlying Salt Wash Member. Displacement along this fault is minor, some 131 feet (40 m), but a distinct change in bed attitude occurs: the Salt Wash Member above the fault plane dips westward at 17 degrees, beds below dip at 25 degrees to the west. The fault plane, easily seen in the escarpment south of Dugout Creek, was mapped to the south along the western margin of the laccolith. There the fault scarp forms a minor cliff in sandstones of the Salt Wash Member but is obscure where the fault cuts claystones of the Brushy Basin Member farther south.

An inferred reverse fault is located 1,000 feet (305 m) to the west across the projected fault trace where beds of the inferred hanging wall dip 25 degrees west, while those of the footwall dip 17 degrees northwesterly. A minor cliff in the sandstones of the Salt Wash Member is seen to the south. Displacement along this fault must be less than that of its companion to the east. The inferred fault may extend quite a distance to the south, producing relationships like those in front of the South Creek laccolith, where a reverse fault has apparently provided a conduit for a dike-like arm of the porphyry to invade higher strata. If so, the diorite porphyry intrusion, hosted by the Tununk Shale just west of the quadrangle in the NE 1/4 of section 26, T. 31 S., R. 9 E., may have been fed from the Dugout Creek laccolith.

Another discordant feature was mapped around the Dugout Creek laccolith, where part of the Entrada Sandstone has been juxtaposed against the Summerville Formation along Dugout Creek near measured section no. 3 (Morton, 1983). At this locality the Entrada Sandstone, on the south side of Dugout Creek, occurs immediately on the roof of the intrusion, although the intrusion is hosted by the Summerville Formation on the north side of the creek. This discordance, possibly a high-angle fault, may likely have extended vertically into higher roof units. This zone of weakness may be the reason Dugout Creek became entrenched in the flank of the arched roof rocks rather than in the syncline to the north, between the Cedar Creek and Dugout Creek laccoliths.

The path of Dugout Creek is controlled in two other localities by structures created by the Dugout Creek complex. Along the eastern side of the intrusions, the creek makes an abrupt change in course to the north as it encounters eastward-dipping strata. Dugout Creek makes a second path change to the northwest as a fault is encountered near the junction of Pistol and Dugout Creeks.

In conclusion, low-angle reverse faults, dikes, and oblique normal faults occur in roofs of both the Dugout Creek and South Creek - Bullfrog laccoliths and suggest a more brittle response of the roof than previously thought. These faults reflect brittle responses caused by both the horizontal and the vertical components of the intrusion process. Such a reaction of the roof strata must have been influenced by overburden pressure and the rate of intrusion. Either factor alone could have produced the type of deformation identified, but both likely contributed.

Bysmaliths

Ragged Mountain Bysmalith: Ragged Mountain is a prominent butte approximately 6,000 feet (1,829 m) long and 4,500 feet (1,372 m) wide, located in the southeastern corner of the quadrangle. Gilbert (1877, p. 47) first described Ragged Mountain (Scrope Butte) as a laccolith. Hunt et al. (1953) recognized the intrusion as a bysmalith after discovering that its roof had been raised by faulting.

Hunt et al. (1953) suggested that the Ragged Mountain bysmalith was fed laterally from the Mt. Ellen stock and, initially, may have been a laccolith but ruptured its roof and underwent vertical intrusion. The initial host and conduit from the stock must have been located no higher than the Summerville Formation (Hunt et al., 1953).

A rim syncline, five radial oblique normal faults that displaced the rim syncline, and a high-angle fault peripheral to the intrusion have been differentiated in this study. Exposures of both members of the Cedar Mountain Formation and the Dakota Sandstone outline the rim syncline on the west side of Ragged Mountain. The Buckhorn Conglomerate Member is a key unit for mapping the relationship: west of Ragged Mountain it forms a ledge above the Brushy Basin Member of the Morrison Formation and dips eastward as much as 30 degrees. Farther east, upper Cedar Mountain beds and Dakota Sandstone dip westward at 50-70 degrees, forming an asymmetrical syncline that is steepest along its eastern limb. Dips decrease to the south, probably because the outcrops are closer to the axis of the rim syncline. The Tununk Shale crops out along the fold axis at the northwest corner of Ragged Mountain, while outcrops to the south expose progressively older rocks, indicating a northward-plunging syncline. Uplift of the southern part of the syncline supports the bysmalith model described by Hunt (greatest uplift occurs at distal end of the intrusion).

Radial oblique normal faults displace the rim syncline. The Buckhorn Conglomerate is a key horizon which displays these faults with offsets as much as 108 feet (33 m) vertically in a brittle response to vertical intrusion. Evidence supporting this idea is seen in the radial faults where the greatest displacements occur towards the southern end of the bysmalith which has undergone the greatest amount of uplift. Present topographic relief, combined with the radial disruption of the Dakota Sandstone, suggests that the intrusion may have invaded beds at least as high as the Tununk Shale and perhaps higher.

Evidence for a high-angle fault peripheral to the intrusion is seen along the west side of Ragged Mountain. One of the best exposures of the relationship is found at the southernmost outcrop of Dakota Sandstone, where the nearly horizontal beds are only 400 horizontal feet (122 m) from the intrusion. Outcrop patterns indicate a high-angle fault which runs north-south along the west side of Ragged Mountain, the south side may have the trace of this same fault turning east-west, somewhere in the outcrop of the Brushy Basin Member. This member forms a banded outcrop between the horizontal outcrops to the south and the vertical outcrops to the north of the Salt Wash Member of the Morrison Formation. Further study of the northern side of Ragged Mountain may locate another high-angle fault. If present, the Ragged Mountain bysmalith would be nearly circumscribed by high-angle faults. Such faulting and inferred faulting suggests that the Ragged Mountain bysmalith is more discordant than previously thought and that its bysmalithic behavior is well developed.

Genetically, the rim syncline, radial faults, and the peripheral high-angle fault are likely related. As the roof was lifted and folded a rim syncline formed, continued uplift initiated roof failure and radial normal faulting. Finally the disruption was consummated when a high-angle fault formed along the intrusion's perimeter as the magma moved upward into the overlying units.

Pistol Ridge Bysmalith: The western end of the Pistol Ridge bysmalith is shown in an escarpment approximately 6,699 feet (2,042 m) long, 1,499 feet (457 m) wide, and 499 feet (152 m) high in the northwest corner of the quadrangle. The bysmalith itself may extend eastward some 2.5 miles (4 km). Gilbert (1877, p. 42) named the feature the Shoulder laccolith, Hunt et al. (1953) renamed it the Pistol Ridge laccolith. The present Pistol Ridge differs from that of Hunt et al. (1953). Hunt's, which is in the present Star Flat, has been located on the bedrock geologic map. The Pistol Ridge intrusion crops out approximately 2,625 feet (800 m) west of this locality.

The Pistol Ridge intrusion is a bysmalith with a roof that has been raised by a fault along the western edge of the escarpment. Outcrops of Dakota Sandstone, and both members of the Cedar Mountain Formation, show beds inclined 39 degrees to the west approximately 49 feet (15 m) from the intrusion. The Summerville Formation is exposed along the roof of the bysmalith 1,304 feet (425 m) to the north. This indicates that outcrops of the Salt Wash Member along the bysmalith's roof are basal exposures. If the intrusion were concordant and if it had invaded the Summerville Formation as roof outcrops infer, then a spatial problem exists. These relationships are best explained by a fault that has displaced the roof strata some 899 feet (274 m) (see cross-section E-E').

Once again, Hunt's et al. (1953) model of bysmaliths in the Henry Mountains is exemplified by the Pistol Ridge bysmalith distal fault which dies out to the north where Salt Wash beds are steeply folded over the edge of the intrusion. Displacement along the fault also decreases to the south where the Dakota Sandstone and the Brushy Basin Member of the Morrison Formation are apparently juxtaposed. Farther east, the faulted contact is unclear where the Pistol Ridge bysmalith is crowded by other intrusions, apparently at higher stratigraphic intervals. The north-south orientation of the distal fault suggests that the axis of the intrusion is oriented more east-west than previously thought. Hunt et al. (1953) suggested that the bysmalith was injected in a northwesterly direction from the Mt. Ellen stock, 3.6 miles (5.8 km) to the southeast. Magnetic studies of Mt. Ellen (Affleck and Hunt, 1980, p. 110-111) suggest that an additional stock-like body may exist under North Summit Ridge, only 2.6 miles (4 km) to the east. Both the closer proximity of the North Summit Ridge "stock" and the north-south orientation of the bysmalith's distal fault suggest that the bysmalith may have been fed from the east rather than from the southeast. The overall topographic expression of the Pistol Ridge bysmalith suggests that it is lobate in form. Bedded roof rocks dip away from the intrusion on the north side of Cedar Creek and delineate the northern edge of the bysmalith. The southern edge, although unclear, suggests an east-west lineation of the intrusion and a possible lobate form.

Pistol Ridge bysmalith may be a transition between the rounded, distinctly discordant bysmaliths and lobate, dominantly concordant laccoliths. Pistol Ridge bysmalith, therefore, would be an incipient one that disrupted its roof by faulting the distal end and then stopped.

Other Intrusions

Laccolith West of Slate Flat: A minor laccolith invading the Brushy Basin Member of the Morrison Formation, it trends north-south and is approximately 4,000 feet (1,220 m) long and 2,000 feet (610 m) wide. The intrusion has created a dome in the overlying strata which plunge to the south. The structure is well outlined by the Dakota Sandstone.

At the southern toe of the laccolith the strata dip southward as much as 32 degrees, but 499 feet (152 m) to the north dips decrease to 10 degrees as the same units occur on the roof of the laccolith. The Buckhorn Conglomerate is the immediate roof and has undergone anomalous alteration as it was baked 7 to 10 feet (2 - 3 m) away from the intrusion contact. One thousand feet (305 m) farther north the Buckhorn Conglomerate is inclined some 27 degrees southwest immediately in front of a step-like ridge of diorite porphyry. An outcrop of the Brushy Basin Member of the Morrison Formation occurs immediately adjacent to the step-like ridge suggesting that the Buckhorn Conglomerate was the roof of the intrusion before erosion.

The step-like effect in the top of the laccolith has caused multiple folding of overlying strata. Similar step-like structural terraces were identified at the Wickiup Ridge laccolith by Hunt et al. (1953) in the northeastern corner of the quadrangle. It would suggest that the original shape of the intrusion may have been wedge-like and later altered by bulging of the intrusion.

North Summit Ridge Intrusions: The North Summit Ridge intrusions occur in a north-south belt in the northern part of the quadrangle and form a prominent ridge, including Mt. Ellen Peak, which is 11,506 feet (3,507 m) above sea level. Field work by Hunt et al. (1953) suggested that the North Summit Ridge intrusions were injected upwards and outward while magnetic anomalies (Affleck and Hunt, 1980) suggest that a stock-like body exists under the ridge. Synclinal folding of the Ferron Sandstone is therefore suggested for isolated outcrops north and east of Corral Point. The western limb of the southward-plunging syncline may be a result of laccolithic intrusion between Corral Point and Star Flat. Such a structural arrangement would infer that the shaly roof pendants found along North Summit Ridge are Tununk Shale. The sandstone roof pendants at the foot of Mt. Ellen Peak were identified as beds now included in the Muley Canyon Sandstone (Hunt et al., 1953). The same may be true of the minor exposures of sandstone approximately 4,495 feet (1,370 m) northwest of Blue Basin. If such is the case, the North Summit Ridge intrusions would appear anomalously thick and bulging at 2,904 feet (885 m) thick. Surface mapping of the South Creek laccolith suggests that the lateral intrusion is over 2,000 feet (610 m) thick. Thickness of the North Summit Ridge intrusions suggests that they have been fed directly from a nearby stock-like source.

STRUCTURES THAT INFER INTRUSIONS AT DEPTH

Faults West of the Pistol Ridge Bysmalith

Faults west of the Pistol Ridge bysmalith and north of Dugout Creek are apparently related to the Cedar Creek laccolith at depth. Hunt et al. (1953) described faulting in the NW1/4 of section 13 and the NE1/4 of section 14, T. 31 S., R. 9 E. roughly perpendicular to the Cedar Creek laccolith and west of the Pistol Ridge bysmalith. One faulted outcrop of the Salt Wash Member has also been rotated against a high-angle fault in the NE1/4, NW1/4 of section 13, T. 31 S., R. 9 E. All the faults mapped are high angle, most are nearly vertical, but two were found to be inclined to the west as little as 10 degrees (see cross-section E-E'). The westward inclination suggests they are normal faults, possibly formed during roof raising.

Surface mapping west of the Pistol Ridge bysmalith indicates that the Brushy Basin and Salt Wash Members of the Morrison Formation are exposed at approximately 7,398 feet (2,255 m) above sea level. Subsurface data from a well drilled by Exxon U.S.A., some 2,000 feet (610 m) southeast of cross-section E-E', places the top of the Carmel Formation approximately 5,722 feet (1,744 m) above sea level. Using measured and average thicknesses for the intervening units, it is apparent that nearly 400 feet (122 m) of section has been added at this locality.

The intrusion is likely hosted by the Entrada Sandstone which also hosted the Cedar Creek laccolith in the extreme northwest corner of the quadrangle, causing several faults. Evidence for the Entrada Sandstone as a host is that the Summerville Formation is faulted and intrusions are absent in outcrops in the canyon, only 2,800 feet (853 m) northwest of cross-section E-E'.

This evidence suggests that the Cedar Creek laccolith extends southward underneath the area in question and has caused numerous faults in the overlying strata. The Cedar Creek laccolith probably wedges out farther south toward the synclinal axis near Dugout Creek. Two explanations for the disruption of roof strata are offered: 1) if the Cedar Creek laccolith was emplaced first, then minimal overburden pressures and/or high rates of intrusion must have existed; 2) if the Pistol Ridge bysmalith was emplaced first, then the deformation may have been a response to reduced confining pressures as the Cedar Creek laccolith moved out from under the overlying bysmalith.

Structures West of South Creek Ridge

A monoclinal flexure, linear and perpendicular faults, and a minor syncline occur west of South Creek Ridge and have been caused by an intrusion at depth. The monocline forms two prominent cuestas on the Muley Canyon and Ferron Sandstones near Steven's Narrows. Surface mapping suggests that the monoclinal flexure of the Ferron Sandstone encloses a dome approximately 2,200 feet (671 m) high. Surface control suggests that the flexure-causing intrusion must be located at a moderate depth. From experience elsewhere in the quadrangle, a likely host for the intrusion is the Summerville Formation (cross-section A-A') which would encompass almost all structural closure. Linear normal faults minimally displace the monocline east, south, and northeast of Steven's Narrows. Five faults mapped east and south of Steven's Narrows trend northeast-southwest away from the Mt. Ellen stock and appear to be aligned. A series of *en echelon* faults may occur along this trend. The faults east of Steven's Narrows mark the boundary between the monocline and the plunging syncline. Both faults are down-thrown to the south and may occur over the southern lateral margin of the intrusion at depth. The three faults mapped south of Steven's Narrows form a graben in the Muley Canyon Sandstone cuesta but are difficult to follow both northeast and southwest. Due to the lack of displacement in the overlying Tarantula Mesa Sandstone, the system must die out within a short distance to the southwest. Such a loss of resolution in fault displacement and faulted strata passing horizontally into folded strata is found in other parts of the Henry Mountains Basin (Hunt et al., 1953).

The trace of another linear normal fault northeast of Steven's Narrows trends east-west and has displaced the coal outcrops of the upper Ferron Sandstone. Displacement is only 39 feet (12 m) vertically, but the fault has buried the coal on the down-dropped block to the south.

Perpendicular to this fault set is a normal fault trending northwest-southeast east of Steven's Narrows. The fault is down-thrown to the southwest and marks an abrupt change in attitudes in the Ferron Sandstone from nearly horizontal on the up-thrown block to a dip of 8 degrees southwest on the down-thrown block. Minor perpendicular faulting was identified elsewhere on the monocline but could not be mapped at this scale. These faults have displaced the coals of the upper Ferron Sandstone northeast of Steven's Narrows. All the above faults were likely produced in a manner similar to those associated with the Cedar Creek laccolith.

Subsurface Information

Data collected from three wells drilled in and adjacent to the quadrangle suggest the existence of major laccolith and sill-like bodies in Triassic and older formations. A well by Webb Resources in the NW 1/4, NW 1/4 of section 22, T. 31 S., R. 9 E., drilled through an igneous sill-like body, presumably of diorite porphyry, hosted by the Triassic Chinle Formation. Gamma-ray logs indicate that the sill is 180 feet (55 m) thick and has split the shales of the Chinle Formation approximately 98 feet (30 m) above the basal contact with the Shinarump Conglomerate. The intraformational nature of the sill coincides with general occurrences of laccoliths seen at the surface. The sill is 6.6 miles (10.6 km) from the Mt. Ellen stock and 6.0 miles (9.6 km) from the inferred stock under North Summit Ridge.

Information available from a well drilled by Exxon, U.S.A. west of the Pistol Ridge bysmalith and north of Dugout Creek indicates that the top of the Navajo Sandstone is located at 5,449 ft (1,661 m) above sea level, 3,320 feet (1,012 m) higher than in the Webb Resources well, some 14,255 feet (4,345 m) to the west. Such elevations of the Navajo Sandstone in the quadrangle produce a 13 degree regional dip to the west, strong evidence for the occurrence of intrusions in the pre-Navajo Sandstone formations.

A well drilled by Jake Hamon in the adjacent quadrangle to the east, in the SE 1/4, SE 1/4 of section 17, T. 32 S., R. 11 E., was spudded into an outcrop of a diorite porphyry dike invading the Navajo Sandstone. After 2,277 feet (694 m) the hole had still not penetrated the bottom of the intrusion and the site was abandoned. Gamma-ray logs indicate a "shaly" response between 4,659 and 4,980 feet (1,420 and 1,518 m) above sea level. This interval may well be a zone of pre-Navajo sedimentary rocks between two intrusions. The dike seen at the surface may be a vertical expression of a laccolith at depth.

In conclusion, subsurface data available strongly suggest the occurrence of substantial, if not massive, intrusions in Triassic age and possibly older formations. Data from wells on the west side of the quadrangle suggest that deep intrusions are sill-like and extend for several kilometers from known and inferred magma sources. This suggests that the broad structural dome over the Mt. Ellen region may not only be a result of a broad magma chamber at depth, as suggested by Affleck and Hunt (1980, p. 112), but may also be a product of broad multiple sill-like intrusions into the Triassic and older formations.

INTERPRETATIONS

Genesis of Intrusions

The Henry Mountains Basin is a great sand-shale province. Surface and subsurface data suggest that the majority of the laccoliths and bysmaliths in the Henry Mountains are confined, at least initially, to shaley formations. The shales thus appear less competent and apparently have less internal strengths, and could yield more readily to intrusive pressures. Also, water confined to particular layers would expand when in contact with an intrusion and the resulting pore fluid pressures would be an effective aid in roof raising and subsequent sill and laccolithic intrusion. Shales also would be more likely to undergo bedding-plane shear, necessary for the development of the marginal monoclinal flexures and flat roofs so commonly seen around the intrusions in the Henry Mountains (Johnson and Pollard, 1973). Clay-model experiments have shown that diapiric bodies tend to spread laterally when they encounter a strong overlying stratum (Ramberg, 1981, p. 267). The sand-shale sequence in the Henry Mountains Basin may certainly exemplify this model. Perhaps diapiric movement of the Mt. Ellen magmas was temporarily checked at each competent sandstone layer. Subsequent intrusion of sills and further laccolithic development could then have taken place in the immediately underlying incompetent or shaly formation.

Increasing magmatic pressures would eventually overcome the internal strength of the roof, and diapiric movement would continue upward until the next competent stratum was encountered, where the process would be repeated.

Intrusive Forms

The deep laccoliths appear to be more sill-like than those mapped at the surface. This may be due to two factors: higher confining pressures found at depth, and less viscous magma due to higher temperatures. Higher confining pressures would have certainly been present at greater depths and could have effectively checked diapiric movement and transformed such action, for a short time, to lateral motion and resulting development of sills and laccoliths. Higher magmatic temperatures would have caused the margins of the lateral intrusions to remain hotter, allowing continued injection of magma. The prolonged presence of high pore fluid pressures may also have allowed more lateral-type intrusion to cause a subsequent sill-like body. Higher magmatic temperatures, however, would have caused lower viscosities. This would be contrary to evidence presented by Hunt et al. (1953) who suggested magmas of the Henry Mountains must have been exceedingly viscous since they were able to float heavy hornblende inclusions. It is probable that the magmas were more viscous nearer the surface than at depth.

The shallow intrusions are more bulging. This shape may be related to two factors: 1) decreased overburden pressures, and 2) decreased magmatic temperatures. Decreased confining pressures would substantially reduce the amount of work necessary to lift and dome overlying strata. This could result in intrusive forms much more protruding than those seen at depth. Decreased magmatic temperatures would allow the margins of the intrusion to chill more rapidly, reducing the effectiveness of pore fluid pressures and possibly inhibiting the lateral invasion of strata. Lower temperatures of both the magma and shallower sediments would also cause viscosity to increase. It is likely that shapes of shallow intrusions may be a product of both reduced confining pressures and magmatic temperatures.

Brittle Deformation

Faulting identified around the laccoliths and bysmaliths may be the result of rapid rates of intrusion or minimal amounts of overburden pressure. Rapid rates of intrusion and high internal pressures are documented for the Mt. Ellen stock by the occurrence of a peripheral shatter zone. Linear normal oblique faults and low-angle reverse faults mapped around the laccoliths, and radial normal oblique and high-angle peripheral faults mapped around the bysmaliths, could have also been caused by relatively high internal pressures and rapid rates of intrusion.

Minimal amounts of overburden pressure present over the complex may have allowed the roof rocks to respond in a brittle manner as they were forced to enclose a greater volume. Brittle deformation around the laccoliths and bysmaliths is likely a product of both relatively rapid intrusion and decreased confining pressures.

Confining Pressures

Using measured and average stratigraphic thicknesses, approximate lithostatic pressures can be calculated for each shaly interval, in the Triassic to Cretaceous section, beginning with the Triassic Chinle Formation. The following assumptions were made: that the Tarantula Mesa Sandstone was the youngest stratum preserved in the Henry Mountains Basin; that lateral intrusions are intraformational, and emplaced near the middle of the shaly formations; that average wet densities for sandstones is 2.35 gm/cm^3 (2350 kg/m^3), and 2.40 gm/cm^3 (2400 kg/m^3) for shales; that density remains constant with depth; and that sandstones and conglomerates have equal densities.

Thicknesses (m) of the overlying sandstones and shales were totalled separately and then multiplied by their assumed densities (kg/m^3). The total mass per unit area (kg/m^2) was then multiplied by the acceleration of gravity to produce the assumed pressures present (N/m^2). Pressures were then converted to bars (1 bar = 100,000 N/m^2).

Using the assumptions listed above, the intrusion identified in the Webb Resources well, hosted by the Chinle Formation, would have experienced confining pressures of 451 bars. This sill-like intrusion lifted the eastern flank of the basin some 180 feet (55 m) at a distance of 6.0 to 6.6 miles (9.6 - 10.6 km) from a likely magma source. Intrusions in higher intervals may have experienced the following confining pressures: Carmel Formation - 356 bars, Summerville Formation - 304 bars, Brushy Basin Member of the Morrison Formation - 265 bars, Tununk Shale - 237 bars, Blue Gate Shale - 153 bars, Masuk Shale - 47 bars. These figures are best considered as minimum pressures present at the time of intrusion and likely vary due to uncertainty on stratigraphic cover and rock density.

All of the common hosts, except for the Brushy Basin Member of the Morrison Formation, are overlain by a stronger roof of sandstone. Little is known about the deep intrusions hosted by the Chinle and Carmel Formations in the quadrangle, and intrusions that must have invaded the Masuk Shale have been eroded away. Of the intrusions exposed in the quadrangle, most were emplaced in the Blue Gate and Tununk Shales. The deep intrusions, particularly those hosted by the Chinle Formation, have experienced confining pressures of over 450 bars and illustrate sill-like forms, while those of higher intervals and less confining pressures are much more bulging. Perhaps these relationships are products of decreased confining pressures combined with the presence of stronger overlying roofs.

ECONOMIC GEOLOGY

COAL

Coal occurs in the Ferron and Muley Canyon Sandstones, remnants of which are mostly restricted to the southwest corner of the quadrangle. Other outcrops in the quadrangle are badly broken, having been sandwiched between intrusions. No other coal exposures were observed. Ferron coal crops out on the monoclinal flexure east and northeast of Steven's Narrows. Coal at this locality is in lenticular beds and interfingers with carbonaceous shale. Thickness of the coal seams ranges up to 1.6 feet (0 - 0.5 m), with most outcrop sections only 4 to 8 inches (0.1 - 0.2 m) thick. The coals are black, hard to moderately hard, cleated north-south to northwest-southeast in intervals of 1 to 2 inches (2.5 - 5.0 cm) and cleats coated with abundant iron sulfates and occasional gypsum. The coal is 70-75 percent vitrain, and 25-30 percent fusain. Near faults the coal shows abundant slickensides. Carbonaceous shale forms the floor and roof for most of the coal seams.

Beds above and below the coal zone of the upper Ferron Sandstone dip to the west and southwest 11-22 degrees. Faults of two sets displace the coal zone (see Structures West of South Creek Ridge). An east-west-trending normal fault has displaced one outcrop northeast of Steven's Narrows as much as 39 feet (12 m). Numerous other north-south-trending faults occur along the monoclinal flexure, somewhat parallel to the fold axis, and have caused minor offsets in the coal zone ranging from 5 to 10 feet (1.5 - 3.0 m).

Stratigraphic and structural discontinuities make potential development of the coals of the Ferron Sandstone very unlikely. Although overburden is slight in the area east of Steven's Narrows, coal thickness and multiple faulting of the seams does not warrant development.

Even in situ coal gasification appears likely to be hampered by the shallow burial and stratigraphic and structural complexities. No coal outcrops were recognized in the Muley Canyon Sandstone. Law (1979a) indicated that the coals are very lenticular south of Steven's Narrows. Just south of the quadrangle, in section 25, T. 32 S. R. 9 E., Law (1979a) reported that coal 2.4 feet (0.7 m) thick occurs in one zone. Whitlock (1983) reported the coal immediately south of Steven's Narrows occurs in two zones, is lenticular, and ranges from 0 to 7 feet (0 - 2.1 m) thick.

The Muley Canyon Sandstone dips to the west and southwest at 11 - 17 degrees and is offset by three normal faults ranging from approximately 39 to 59 feet (12 - 18 m) in vertical displacement. Structure of the area is rather simple, but stratigraphic relations are much more complex, making possible coals of this part of the column unlikely prospects for future development.

PETROLEUM

Wells drilled in and adjacent to the quadrangle have all been dry and abandoned. Likely stratigraphic targets for production in the Henry Mountains Basin include: Moenkopi, Kaibab, White Rim, Honaker Trail, and Paradox Formations. Oil shows in the Triassic and Permian beds are common, and several large tar sands deposits occur along the basin margin to the west and east. Petroleum potential for the basin has been described by Irwin et al. (1980).

Faulting around the laccoliths, a shatter zone around the Mt. Ellen stock, and other occurrences of brittle deformation suggest that the rate of intrusion was quite rapid. Hunt et al. (1953) reported that hornblende inclusions in the diorite porphyry suggest the magma was exceedingly viscous and that the temperature of the intrusion could not have exceeded 600 degrees Celsius. Baking of the roof and floor rocks is slight. In many localities strata are altered only a few centimeters from the contact. Oil and gas could have been easily trapped up-dip in formations domed and subsequently ruptured by the stocks. Up-dip traps could be present along the wall of the stocks, similar to those found associated with salt diapirs in the Gulf Coast region.

METALS

Metal deposits were only given cursory attention in this study. About 75 percent of the gold, silver and copper produced from the Henry Mountains has come from workings in Bromide Basin (Doelling, 1980, p. 287). Doelling reported that since 1889 approximately 700 ounces of gold, 3000 ounces of silver, and 17,500 pounds of copper have been extracted from ores of the Bromide Basin. Primary ore minerals include: chalcopyrite, pyrite and specularite, and are generally found with quartz in breccia pipes and fissures of the Mt. Ellen stock. The small and sporadic nature of the ore bodies makes potential future production appear limited.

Suspected hydrothermal alteration appears at the Wickiup Ridge laccolith. This is substantiated by the occurrence of sulfides, local bleaching and a circular, 100-gamma magnetic anomaly on or under Wickiup Ridge (Affleck and Hunt, 1980, p. 111).

No known placer gold deposits occur in the quadrangle, although some occur in the adjacent quadrangle to the east (Raggy Canyon), apparently derived from the Bromide Basin area. Some potential for placer deposits may exist in the quadrangle along Crescent Creek. No known uranium-vanadium deposits occur in the quadrangle, however, substantial deposits occur in the Salt Wash Member of the Morrison Formation, some 2.5 miles (4 km) to the east, in the north-south-trending Henry Mountains mineral belt (Chenoweth, 1980).

GRAVELS

Gravel deposits are abundant along the western and southern portions of the quadrangle. Thickness of the deposits is difficult to determine, but ranges up to 121 feet (37 m) have been estimated. They consist of subangular to subrounded pebbles, cobbles and boulders, some as large as 4.6 feet (1.4 m) in diameter, but most fragments fall into the 2.8 to 5.5 inches (7 - 14 cm) range. Pebbles and cobbles are of diorite porphyry in a matrix of light brown, very fine- to fine-grained, sand. They appear to be suitable for road base or concrete aggregates with screening. Such processing may be avoided by utilizing gravels in the alluvial fans found in the lower elevations east or west of the quadrangle. Readily accessible gravels include deposits west of McClellan Spring, in a beheaded pediment west of Birch Spring, and in the Airplane Spring area. Excessive removal of such gravels would destroy a major aquifer, could jeopardize the purity of local surface waters by exposing the mineral-rich Blue Gate Shale, and would activate stream erosion processes. Erosion and leaching of the shales would pollute surface waters with added detritus and detrimental minerals such as gypsum.

WATER RESOURCES

Springs in the quadrangle generally occur near gravel/colluvium - shale contacts. Water stored in these highly permeable aquifers is derived from annual snow and rain. Yield as measured by Goode (1980, table 1) of the springs in the quadrangle varies from 11-454 liters per minute (3 - 120 gpm).

No perennial streams are found in the quadrangle. Those of major importance, Bullfrog Creek, South Creek, Dugout Creek, Cedar Creek, Bull Creek, Granite Creek, Crescent Creek, Copper Creek, and Slate Creek carry water most of the year but generally dry up during the summer months except for periodic flash floods. Hunt et al. (1953) estimated the largest of these streams, Bull Creek and Dugout Creek, have annual discharge rates of a few 1,000 acre-feet (a few 1,000 cubic-meters). Copper, Crescent, and Granite Creeks may discharge a few 100 acre-feet (few 100 cubic-meters) annually, and the remaining streams even less.

SUMMARY

A thick section of Jurassic to Upper Cretaceous sedimentary rocks are exposed in the Mt. Ellen quadrangle. These strata represent environments that ranged from interdeltaic-coastal, shallow marine, and tidal flat of the San Rafael Group to fluvial, lacustrine and flood plain of the Morrison and Cedar Mountain Formations. The Dakota Sandstone marks the beginning of a marine transgression that resulted in accumulations of the interfingering deltaic sandstones and marine shales of the Mancos Shale.

These rocks and others, now removed by erosion, were folded into the Henry Mountains basin by the early Tertiary Laramide Orogeny. Subsequent to the folding, stocks of the Mt. Ellen complex invaded strata along the eastern limb of the basin. During intrusion of the stocks, sill-like lateral intrusions invaded the incompetent strata and overlying formations were lifted upward. As the stocks worked surfaceward, invading the shales and doming and rupturing the sandstones, the sill-like laccolithic intrusions became more bulging as magma temperatures dropped and confining pressures decreased.

Closer to the surface, a spectrum of intrusions developed. Some of the laccoliths remained concordant, folding the strata above them. Others developed linear normal faults in their roof, or low-angle reverse faults along their distal margins, yet remained dominantly concordant. Still others became discordant. Roof rocks were displaced by high-angle faults along the distal margins of the intrusions. Some of the bysmaliths underwent continued intrusion, uplifting overlying strata, and resulting faults circumscribed the bysmaliths.

A great thickness of igneous material was inserted during development of the complex. A large dome formed and erosion immediately began to carve into the highland. Erosion continues with streams carrying debris away from the peaks and depositing it on the flanks of the complex. Pediments document distinct periods of erosion.

Ferron Sandstone coals exposed in the southwestern corner of the quadrangle are thin and extremely lenticular. Subsequent structural deformation and their thinness has made mining of them uneconomical at present.

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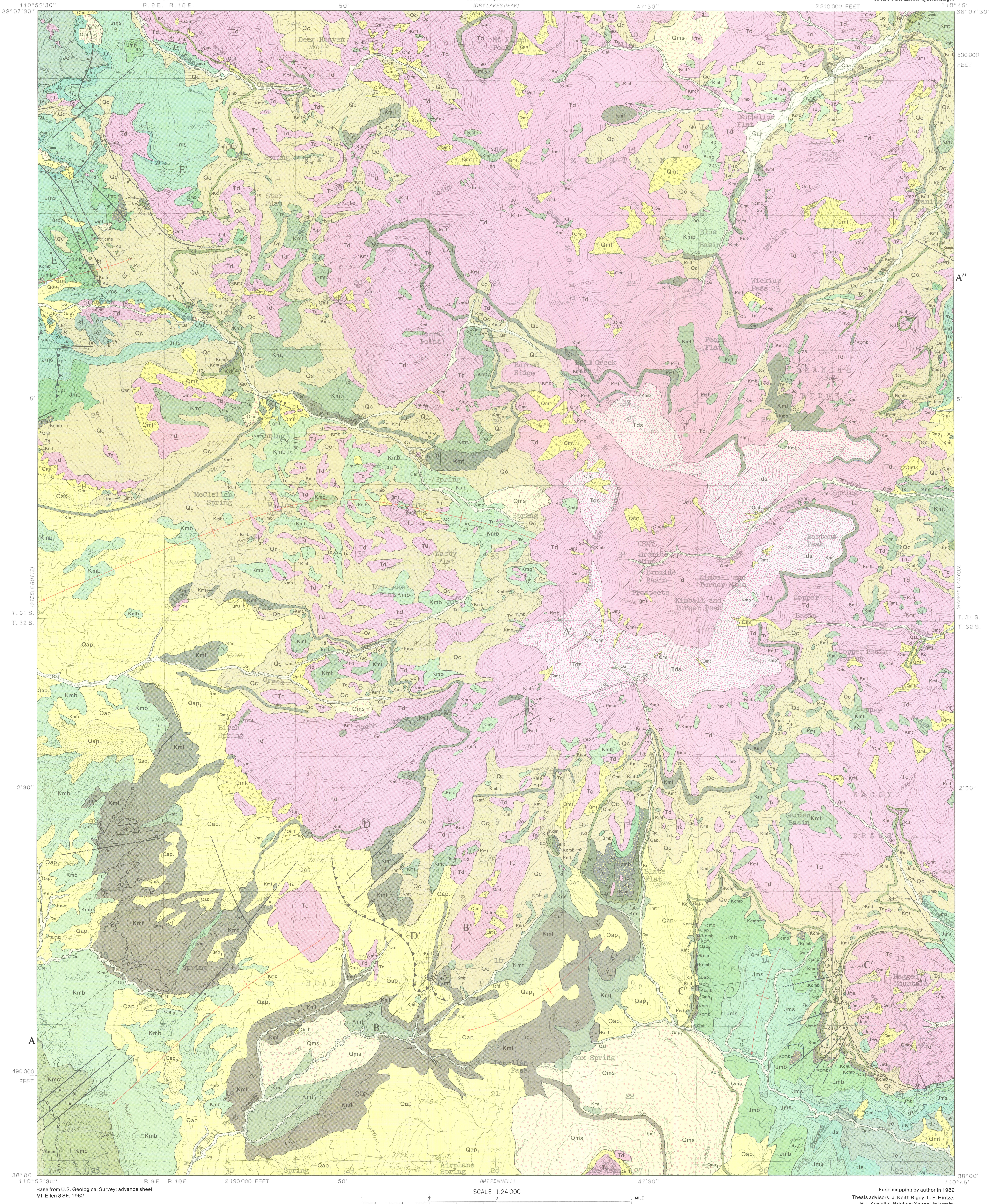
Plate 1
Utah Geological and Mineral Survey Map 90
Provisional Geologic and Coal Resources Map
of the Mt. Ellen Quadrangle



Base from U.S. Geological Survey: advance sheet
Mt. Ellen 3 SE, 1962

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET

Field mapping by author in 1982
Thesis advisors: J. Keith Rigby, L. F. Hintze,
B.J. Kowallis, Brigham Young University
Patricia H. Speranza, Cartographer

PROVISIONAL GEOLOGIC AND COAL RESOURCE MAP OF THE MT. ELLEN QUADRANGLE, GARFIELD COUNTY, UTAH

by
Loren B. Morton

1986 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

QUADRANGLE LOCATION

1986

90

CONTACT
Dashed where location inferred; dip indicated

INFERRED OUTCROP
Indicated by surficial evidence

FAULTS
Dashed where location inferred; dotted where covered

Normal fault
Bar and ball on downthrown side

Strike-slip fault
Arrows show relative movement

Low-angle reverse fault
Sawteeth on upper plate

Gravity slide block

TRACE OF AXIAL SURFACE OF FOLD
Arrows show direction of plunge; dotted where covered

Anticline

Syncline

STRIKE AND DIP OF BEDDING

29
Inclined

Vertical

Horizontal

34
Overturned

COAL OUTCROP

Dry hole

DESCRIPTION OF MAP UNITS

QUATERNARY

Qal | Qmt | Qms | Qc | Qap_1 | Qap_2

Quaternary—Alluvium talus, landslide debris, colluvium, pediment gravels.

TERTIARY

Td | Tds

Tertiary—*Diorite porphyry of Mt. Ellen stock, light grey with abundant oligoclase phenocrysts, weathers to dark brown. Associated minor basalt sills, contact metamorphics, and shatter zone.*

UPPER CRETACEOUS — Mancos Shale

Kmm — Masuk Shale Member—*Irregularly bedded, sandy grey shale, sandy carbonaceous shale and sandstone.*

Kmc — Muley Canyon Sandstone Member—*(Upper) Interbedded sandstone, siltstone, carbonaceous mudstone, shale, and coal. (Lower) Sandstone, thick-bedded, cliff-forming unit.*

Kmb — Blue Gate Shale Member—*(Upper) Interbedded yellowish-grey, very thin bedded to laminated, very fine grained, calcareous, quartzose sandstone and medium grey, gypsiferous shale. (Lower) Dark grey, calcareous shale, upper portion bentonitic.*

Unconformity

Kmf — Ferron Sandstone—*(Upper) Lenticular carbonaceous shale; coal; olive-grey marine shale; light-grey, fine-grained, quartzose sandstone. (Middle) Grayish-orange, fine- to medium-grained, quartzose sandstone with minor coaly and carbonaceous horizons. (Lower) Very thin-bedded, greyish-orange, calcareous, kaolinitic siltstone, sandstone, and shale; coarsening upward.*

Kmt — Tununk Shale Member—*Medium bluish-grey, thinly laminated to laminated, silty, calcareous, gypsiferous shale; minor thin beds of very fine-grained, quartzose sandstone.*

Kd — Dakota Sandstone Formation—*Pale-orange to greyish-yellow, calcareous, very thin to medium grained; with minor interbeds of siltstone; ledge forming.*

Unconformity

LOWER CRETACEOUS — Cedar Mtn. Fm.

Kcm — Upper Unnamed Member—*Interbedded, light-grey to brownish-grey, carbonaceous, laminated shale and siltstone with minor laminations of sandstone; coarsens upward.*

Kcmb — Buckhorn Conglomerate Member—*Brownish-grey to yellowish-brown sandstone and conglomerate. (Upper) Thin-bedded, fine-grained, cross-laminated sandstone. (Lower) Massive-bedded conglomerate.*

Unconformity

UPPER JURASSIC — Morrison Fm.

Jmb — Brushy Basin Member—*(Upper) Pale-greenish-yellow with minor, thin-bedded, fine-grained sandstone; mudstone; claystone. (Lower) Moderate-red mudstone and claystone.*

Jms — Salt Wash Member—*Light-grey to brownish-grey, very fine- to granular-grained sandstone with subordinate reddish and greenish bentonitic mudstone. General upward coarsening in sandstone.*

Unconformity

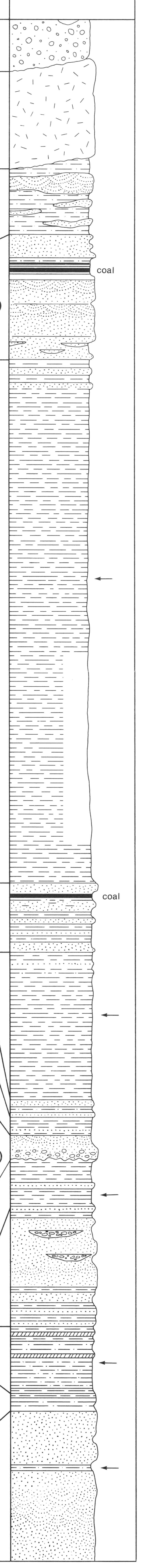
Js — Summerville Formation—*Pale-reddish-brown to light-brownish-grey siltstone, mudstone, and shale interbedded with occasional hematitic gypsum.*

Jc — Curtis Formation—*Light-greenish-grey, glauconitic, calcareous siltstone, with minor greyish-purple shale.*

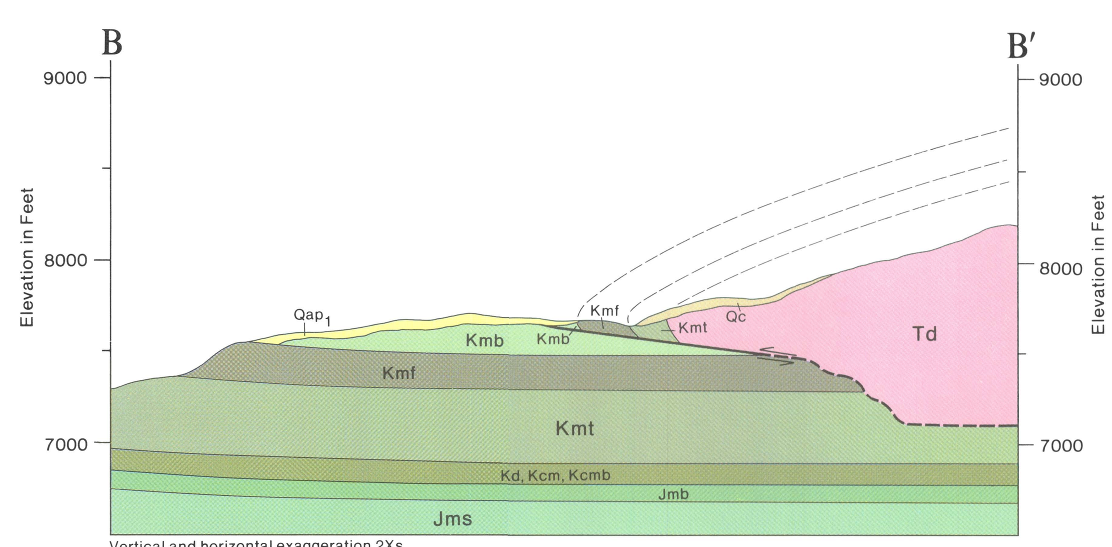
Unconformity

Je — Entrada Sandstone—*Pale-red to pale-orange, very fine grained, thin-bedded to massive, calcite-cemented, sandstone and minor siltstone; minor gypsum. Weathers to ledges with minor slopes and low, resistant, rounded outcrops.*

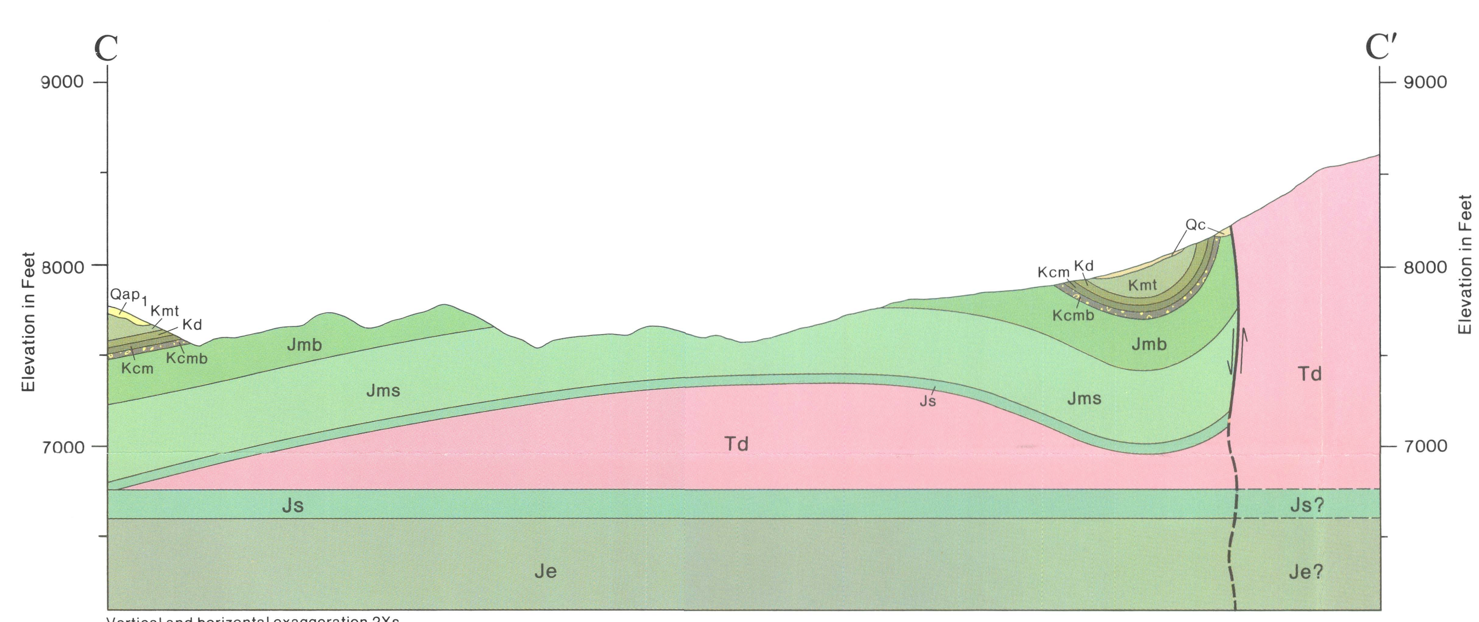
PERIOD		FORMATION	SYMBOL	THICKNESS feet (meters)	LITHOLOGY
QUATERNARY		Alluvium, talus landslide debris, colluvium pediment gravels	Qal Qmt Qms Qc Qap_1 Qap_2	0-50 (0-15)	
TERTIARY		igneous intrusions	Td Tds		
UPPER CRETACEOUS	Mancos Shale	Masuk Shale Member (lowest unit of Whitlock, 1983)	Kmm	175 (53)	
		Muley Canyon Sandstone Member	Kmc	345-390 (105-119)	coal
		Blue Gate Shale Member	Kmb	1525 (465)	
		Ferron Sandstone	Kmf	195 (59)	coal
		Tununk Shale Member	Kmt	440 (134)	
		Dakota Sandstone	Kd	40 (12)	
LOWER CRETACEOUS	Cedar Mtn. Fm.	upper member	Kcm	25 (8)	
		Buckhorn Conglomerate Member	Kcmb	25-55 (7.5-16.5)	
UPPER JURASSIC	Morrison Fm.	Brushy Basin Member	Jmb	120 (37)	
		Salt Wash Member	Jms	390 (118)	
		Summerville Formation	Js	190 (58)	
		Curtis Formation	Jc	30 (9)	
		Entrada Sandstone	Je	450 (137)	



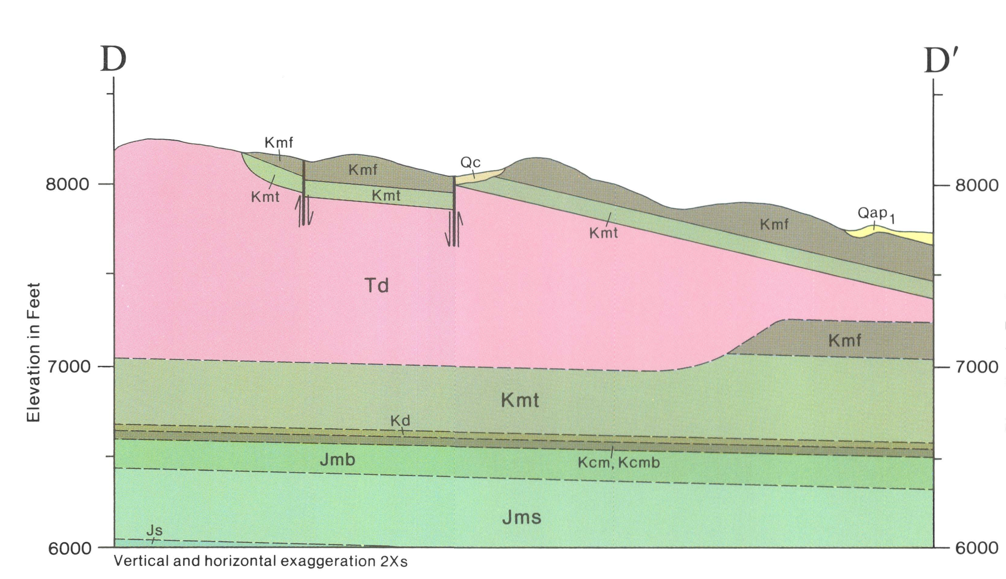
Arrows indicate preferred levels of intrusion



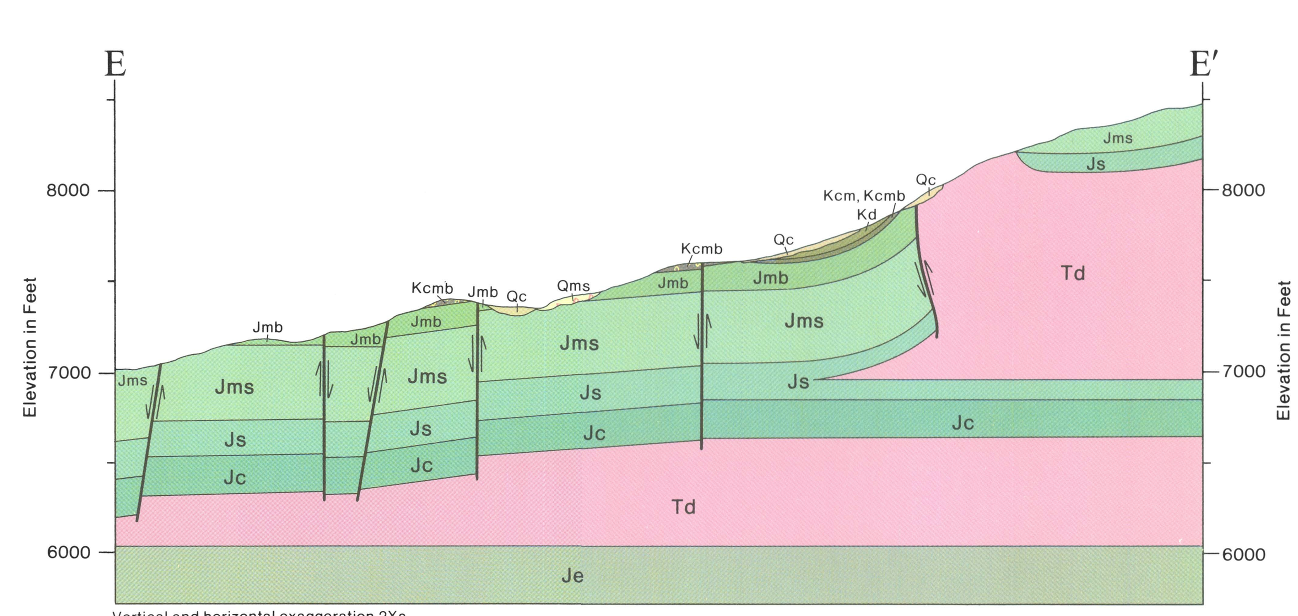
Vertical and horizontal exaggeration 2Xs



Vertical and horizontal exaggeration 2Xs



Vertical and horizontal exaggeration 2Xs



Vertical and horizontal exaggeration 2Xs

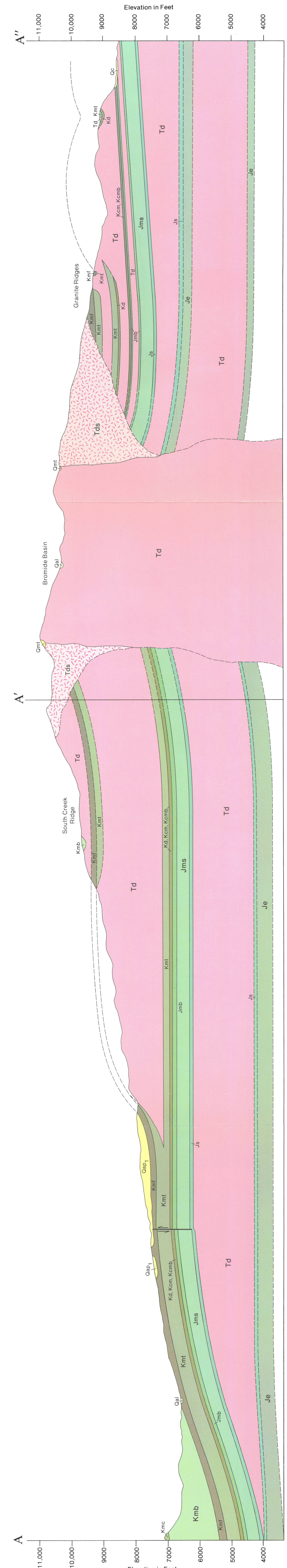


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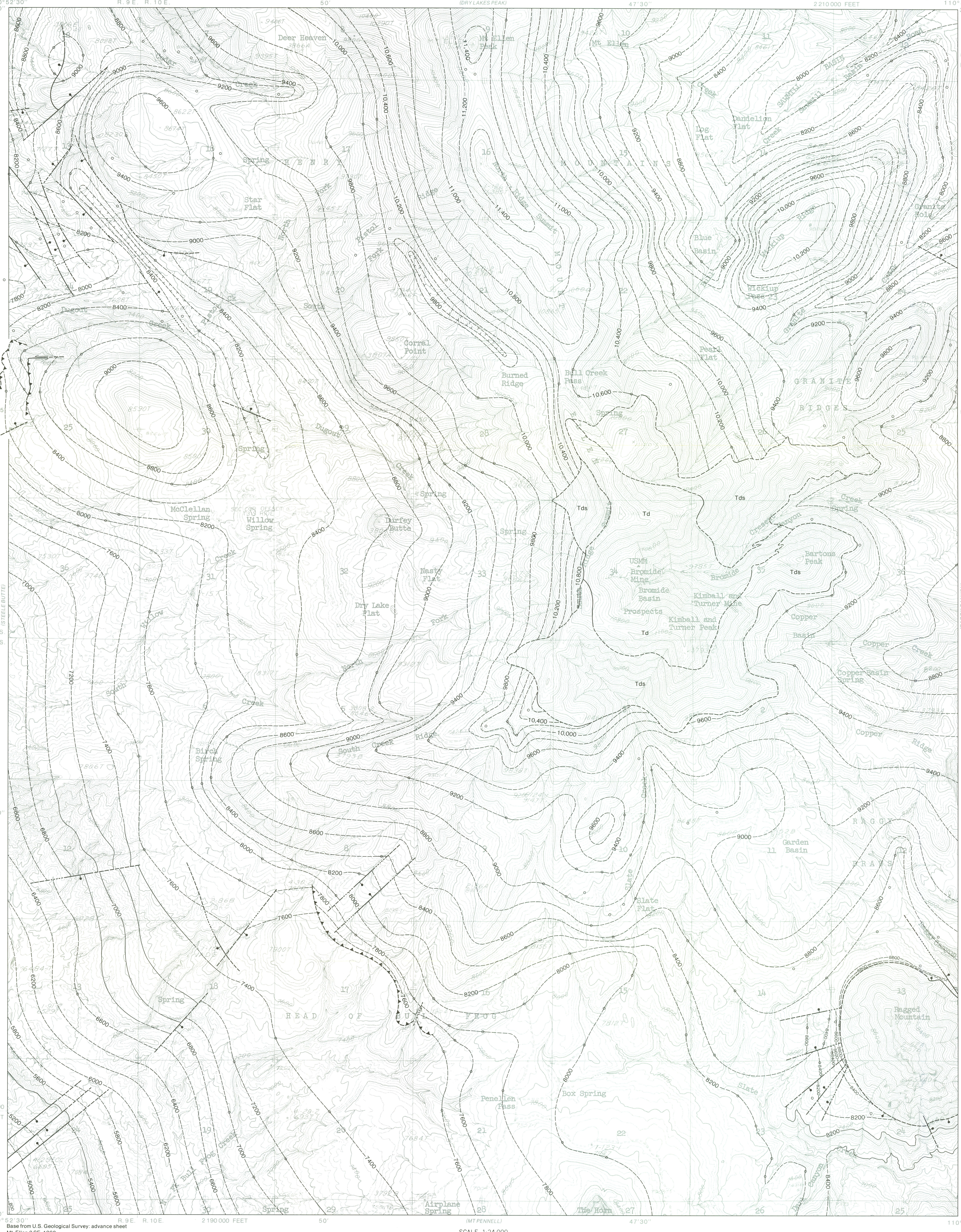
Plate 3
Utah Geological and Mineral Survey Map 90
Provisional Geologic and Coal Resources Map
of the Mt. Ellen Quadrangle



Base from U.S. Geological Survey: advance sheet
Mt. Ellen 3 SE, 1962

SCALE 1:24 000

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 40 FEET

UTAH

QUADRANGLE LOCATION

GN MN 0° 4.2' 13° 33'

1986 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

CONTACT
Dashed where location inferred

FAULTS
Dashed where location inferred

7800

STRUCTURE CONTOUR
Dashed where location inferred; interval 200 feet

Normal fault
Bar and ball on downthrown side

Strike-slip fault
Arrows show relative movement

Td
Diorite porphyry

Tds
Shatter zone

Low-angle reverse fault
Sawteeth on upper plate

Data Point

STRUCTURE CONTOUR MAP OF THE FERRON SANDSTONE