
2. DESCRIPTION OF GEOLOGY

2.1. GEOLOGY OF THE RICHFIELD PLANNING AREA

A. PHYSIOGRAPHY

The planning area encompasses parts of three physiographic provinces—the Colorado Plateau, the Basin and Range-Colorado Plateau Transition Zone, and the Middle Rocky Mountains (Stokes, 1986), as shown on Maps 3 and 4. Each province is further delineated into subdivisions as shown on the two maps. Other physiographic divisions are published, notably Fenneman (1931) and Hunt (1974). In some physiographic descriptions, the Transition Zone is considered to be part of the Basin and Range, which is to the west of the Transition Zone as defined by Stokes. As Stokes' physiography is specific to Utah, his divisions are used in this report.

The Colorado Plateau Province is characterized by relatively flat-lying, undeformed sedimentary strata that are predominately Paleozoic to Mesozoic in age. In places, the strata are deeply incised by canyons and in other places they form relatively broad benchlands. The sedimentary strata are locally intruded and domed by igneous rocks to form the Henry Mountains.

The Colorado Plateau-Basin and Range Transition Zone has similarities to the Colorado Plateau to the east and to the Basin and Range to the west. Similar to the Colorado Plateau, the sedimentary strata are relatively flat lying. Similar to the Basin and Range, the Transition Zone is characterized by fault-bounded, high plateaus or ranges and separating valleys. The southern high plateaus are capped by Tertiary volcanic rocks, while the northern high plateaus are capped by sedimentary rocks, generally Tertiary in age.

The boundary between the Colorado Plateau and the Transition Zone is approximately at the Waterpocket Fold (Capitol Reef National Park). Thus, the eastern parts of Garfield and Wayne Counties are in the Colorado Plateau, while Sanpete, Sevier, Piute Counties and the western part of Wayne County are in the Transition Zone. In this report, this change in province also approximately coincides with the eastern and western parts of the planning area.

The southern end of the Middle Rocky Mountains Province extends into the northernmost part of Sanpete County. The Middle Rocky Mountains in Sanpete County includes the southern end of the Wasatch Range and is a small portion of the planning area.

The physiography includes rugged, mountainous terrain, deeply incised canyons, and relatively flat valleys. Overall, elevations across the planning area range from 12,173 feet on Mount Delano located on the crest of the Tushar Mountains on the Piute-Beaver county line in the Fishlake National Forest to about 3,700 feet on Lake

Powell in the Glen Canyon National Recreation Area in eastern Garfield County. The summits of the Henry Mountains and the High Plateaus are as high as 10,000 to 11,000 feet. The valleys in the western part of the planning area are generally about 5,500 feet. In the eastern part of the planning area, the Colorado River with the Green and Dirty Devil Rivers are the major drainages, and in the western part, the Sevier River is the major drainage. The Colorado River drains into the Pacific Ocean, while the Sevier River is an internal drainage basin, typical of the Great Basin.

B. Rock Units

Within the planning area, rocks exposed at the surface range from Pennsylvanian through Tertiary in age and unconsolidated deposits are Tertiary and Quaternary in age. All formations are not exposed throughout the planning area. Older Paleozoic and Precambrian strata are present in the subsurface, but are not exposed at the surface. There are no significant exposed metamorphic rocks in the planning area.

The Geologic Map of Utah (Hintze, 1980) is included as Map 5 in this report, and a geologic map of the planning area is shown in Map 6. The explanation sheet that accompanies the Geologic Map of Utah (Hintze, 1980) showing stratigraphic columns and cross-sections at various locations across the State is included as Attachment 1. In addition, the numbers shown on Map 5 correspond to the locations of various regional stratigraphic sections as presented by Hintze (1988).

1. Sedimentary Rocks

Most of the planning area was occupied by either shallow marine platforms and/or basins during most of the Paleozoic and broad areas at or near sea level during the Mesozoic. These depositional environments resulted in the extensive marine, paralic, and continental sedimentary deposits. The Sevier and Laramide orogenies occurred during late Cretaceous and the early Tertiary and terminated sedimentation patterns that had existed through the Paleozoic and Mesozoic. With the Sevier and Laramide orogenies, the land mass became only continental, and depositional environments included terrestrial and lacustrine settings. Representative stratigraphic sections from Hintze (1988) for the planning area are included in Attachment 4. A description follows of the important sedimentary formations present in the planning area.

Cenozoic

Quaternary deposits are unconsolidated deposits of varying textures and colors, including alluvium, colluvium, pediment mantle, eolian, lacustrine, glacial drift, landslide, slope-wash, alluvial fans, and terraces. Quaternary deposits vary in thickness, although generally the valley fill in the valleys of the western part of the planning area are much thicker than those on the eastern side. Glacial deposits are generally present only in the mountains or plateaus at higher elevations. Also,

Quaternary travertine deposits are found around hot springs in the Monroe-Joseph area and are often associated with tufa mounds.

The Miocene Sevier River Formation is only present in the western part of the planning area. This formation is a poorly to moderately consolidated gray-to-pink conglomerate, sandstone, and siltstone locally containing air fall tuff and basaltic lava flows. These rock units were deposited in fluvial and locally lacustrine environments with some volcanoclastic debris. Where exposed, the thickness of the formation is approximately 300 feet, but the subsurface thickness of the formation may be greater.

The Oligocene Bald Knoll Formation is only found in the western part of the planning area. It is a lacustrine deposit of light gray to tan mudstone and claystone with interbedded siltstone, sandstone, and limestone and it ranges up to 1,000 feet in thickness. This formation is also mapped as the Gray Gulch Formation or the Formation of Aurora. The Eocene Crazy Hollow Formation is only found in the western part of the planning area. It is a reddish-brown to white sandstone, shaly siltstone with some conglomerate, and limestone. Salt-and-pepper colored sandstone is also present in some areas at the base of the formation. The conglomeratic facies of this formation contains distinctive chert pebbles. This formation is up to 1,000 feet thick.

The Eocene Green River Formation was deposited in an extensive lacustrine basin in western Colorado, eastern and central Utah, and southern Wyoming. Lithologically, this formation consists of interbedded limestone, calcareous mudstone, and sandstone. In the planning area, the formation is typified by white limestone beds and reddish mudstone and sandstone beds. The formation has been divided into at least five units, but nomenclature varies among different workers in different parts of the State. The formation is up to 6,000 feet thick.

The Colton Formation underlies the Green River in a gradational contact. The Colton consist predominately of mudstone that is few hundred feet thick in the planning area.

The Paleocene Flagstaff Formation, exposed in the western part is a reddish-brown to grayish-brown mudstone with interbedded limestone, calcareous siltstone, sandstone, conglomerate, and minor gypsum. Its thickness varies between 200 and 1,100 feet. This formation was deposited in an ancient lake that occupied much of central Utah.

Mesozoic

The North Horn Formation is a transitional unit that was deposited during the late Cretaceous to the early Paleocene. It is predominately a fluvial deposit with interbedded lacustrine facies. The North Horn Formation is composed of mudstone, claystone, sandstone, conglomerate, and limestone with some coal present along the

east flank of the Gunnison Plateau. Its thickness varies from 500 to 3,000 feet. This formation is present in the western part of the planning area.

The Cretaceous Mesa Verde Group includes: Price River Formation, Castlegate Sandstone, Blackhawk Formation, and Star Point Sandstone. These formations were deposited as fluvial to deltaic deposits between an ancient highland in northwestern Utah and a shallow, intracontinental, marine seaway near the present-day Emery-Sevier county line. The Blackhawk Formation includes the important coal bearing beds. The formations in this group range from a few hundred feet to 1,500 feet in thickness.

The Cretaceous Indianola Group is composed of the Sixmile Canyon Formation, the Funk Valley Formation, the Allen Valley Shale, and the Sanpete Formation. The Indianola Group is correlative, in part, with the Mesa Verde Group, however, the facies generally reflect a depositional environment closer to the ancient highland and are generally coarser grained than the Mesa Verde. The group ranges from a few hundred feet thick near Gunnison to several thousand feet thick near Moroni (Hintze, 1988).

The Iron Springs Formation was formed in a lacustrine environment during the late Cretaceous and early Tertiary and is present only in the western part of the planning area. This formation is a yellow to grayish-green sandstone and shale with some minor coal.

The Cretaceous Straight Cliffs Formation is in part correlative with the Mesa Verde Group and crops out near Antimony. It is dark gray shale to brown sandstone with subordinate coal, carbonaceous shale, and siltstone. It was deposited in a coastal-plain environment with minor interfingering marine shale units.

The Cretaceous Mancos Shale consists of five members – Upper Blue Gate, Emery Sandstone, Muley Canyon Sandstone, Lower Blue Gate, Ferron Sandstone, and Tununk – in the planning area. Overall, the Mancos Shale is a light to dark gray to bluish-gray shale or siltstone with interbedded fine-grained sandstone. Its thickness varies from 2,300 to 6,100 feet. Generally, the shale erodes to flat lowlands and valleys, while the sandstone forms ledges and cliffs. The shale members were deposited on a shallow marine shelf, while the sandstone members were transitional to delta plains.

The Cretaceous Dakota Sandstone is present in the eastern part of the planning area and in the vicinity of Antimony. It is a tan to light brown, crossbedded, quartzose sandstone with thin, discontinuous, carbonaceous seams. Coal beds are present but are generally thin and discontinuous. It was deposited in beach, marginal marine, and deltaic environments. Its thickness is up to 150 feet.

The Cretaceous Cedar Mountain Formation consists mudstone, sandstone, and conglomerate. This formation was deposited in a fluvial depositional system and its

thickness varies from 160 to 300 feet. This formation is only present in the eastern part of the planning area.

The Jurassic Morrison Formation consists of three members: 1) the Brushy Basin Member is a bluish-gray, green, and maroon-purple mudstone with subordinate bentonite, sandstone, and limestone; 2) the Salt Wash Member is a light gray to reddish-purple quartz sandstone with subordinate conglomerate and mudstone; and 3) the Tidwell Member is gray to purple mudstone which is locally gypsiferous. The Morrison Formation forms low cliffs or rounded ledges. The total thickness of the formation is about 400 feet.

The Jurassic Summerville Formation contains shaly siltstone and sandstone with thin interbeds of gypsum. It forms low cliffs and was deposited in a tidal-flat environment. It is exposed in the eastern part of the planning area and its thickness varies between 120 and 250 feet.

The Jurassic Curtis Formation is only present in the eastern part of the planning area. It is a light greenish-gray to light brown quartz sandstone with some siltstone and conglomerate. Its thickness varies from 175 feet to the north and to near zero feet at Tarantula Mesa. In the planning area, it forms ledges that act as resistant caps. This formation was deposited in a marine environment.

The Jurassic Entrada Sandstone is found in the eastern part of the planning area and is typified by rounded ledges with steep slopes and horizontally grooved low cliffs. In places, it has interfingering siltstone and mudstone lenses. It was deposited in a near-shore eolian environment. It has a thickness between 200 and 300 feet.

The Jurassic Twist Gulch Formation is equivalent to the Summerville Formation, the Curtis Formation, and the Entrada Sandstone (Willis, 1986). The Twist Gulch Formation consists of reddish-brown siltstone, mudstone, sandstone, and minor conglomerate that was deposited in a marginal fluvial, near shore environment, and has a maximum thickness of 1,800 ft.

The Jurassic Carmel Formation in the eastern part of the planning area and the Arapien Shale in the western part are more or less equivalent. These formations were deposited in shallow marine to supratidal environments and the Arapien in particular includes evaporate minerals deposited in a restricted marine embayment. These formations are generally several hundred feet in thickness; however, in the Sevier Valley, the Arapien Shale may be up to 13,000 feet thick.

The Jurassic Navajo Sandstone is a crossbedded, quartzose sandstone with subordinate limestone in the upper part of the formation at some locations. The Nugget Sandstone in northern Sanpete County is an equivalent unit. A few scattered outcrops are noted in Sevier and Piute Counties. In prominent outcrops, the sandstone forms

steep cliffs with rounded knolls, which is particularly noteworthy at Capitol Reef. The formation was deposited in an eolian environment and has a thickness up to 1,100 feet.

The Triassic Kayenta Formation contains interbedded sandstone mudstone and conglomerate with variable thickness of individual beds, which is typical of strata deposited in a fluvial environment. It is more easily eroded than the overlying Navajo Sandstone and the underlying Wingate Sandstone and forms a less resistant break between those two resistant, thick sandstone units. It has a maximum thickness of 250 feet.

The Triassic Wingate Sandstone is a crossbedded quartzose sandstone that stands as steep cliffs. It is well cemented with calcium carbonate cement and is strongly stained with manganese oxide (desert varnish) and is typified by a reddish brown color in outcrop. It was formed in an eolian environment. Its thickness varies between 350 and 450 feet.

The Triassic Chinle Formation is exposed across the entire planning area and is divisible into three members, which are, in descending sequence: 1) the Church Rock Member, a sandstone and shaly siltstone; 2) the Moss Back Member (also called the Shinarump Conglomerate), a conglomeratic sandstone with irregular bedding and abundant petrified and fossil wood in places; and 3) the Temple Mountain Member, a mottled sandstone. The formation was deposited in a fluvial environment. The formation can be up to 400 feet thick in the eastern part of the planning area.

The Triassic Moenkopi Formation is divided into four members – the Moody Canyon, Torrey, Sinbad Limestone, and Black Dragon – which contain interbedded sandstone, mudstone, and limestone deposited in alternating continental and marine environments. The thickness of the formation ranges from 375 to 935 feet.

Paleozoic

The Permian Kaibab Formation is present in both the eastern and the western parts of the planning area, while the underlying Toroweap Formation is only present in the western part of the planning area. Both formations contain limestone with interbedded mudstone. Both are marine deposits with a thicknesses of 350 to 500 feet.

The Permian Cutler Group consists of three formations – the White Rim Sandstone, Organ Rock Shale, and Cedar Mesa Sandstone, and the time-equivalent Elephant Canyon and Halgaito Formation. Overall, the strata were deposited in association with structural and sedimentary uplifts and basins (Stokes, 1986, p. 98). The deposition of these formations was associated with the formation of the Ancient Rocky Mountains to the east of the planning area during the Permian. The strata were deposited as mostly clastic debris in a structural basin, the Paradox Basin, on the west side of that ancient uplift and the deeper part of the basin was to the east of the planning area. The strata were deposited in a variety of sedimentary environments

including eolian, fluvial, and shallow marine. The formations range from arkosic sandstone, limestone, and shale, reflecting different depositional environments in the basin and timing of the rise of the Uncompaghre Uplift. The group has a thickness of up to 6,000 feet near Arches National Park and thins to approximately 2,200 feet thick near Hanksville (Hintze, 1988). The depositional basin pinches out westward of Capitol Reef and the Circle Cliffs. Time-equivalent formations in the western part of the planning area include the Toroweap Formation, Queantoweap Sandstone, and Pakoon Dolomite, which were deposited in depositional environments unrelated to the Uncompaghre Uplift.

Rocks older than Permian are not exposed at the surface. The following discussion applies only to the subsurface.

The Pennsylvanian Hermosa Group is divided into the Honaker Trail, Paradox Basin, and Pinkerton Trail Formations. These formations were deposited in the Paradox Basin, associated with the Uncompaghre Uplift, which was initially formed during the Pennsylvanian. The group is only exposed in the eastern part of the planning area and is noted for thick arkosic clastic rocks and thick sequences of evaporate minerals and black organic shale deposited cyclical sequences. This group was deposited in a shallow marine environment and is about 2,400 feet thick near Hanksville and thickens considerably to the east of the planning area. The Callville Limestone is time-equivalent to the Hermosa Group, but was deposited in a different depositional environment related to a marine shelf.

The Mississippian Redwall Formation and equivalent Leadville Formation are dense, crystalline dolomite and limestone with variable chert. These carbonate strata were deposited in deeper water (neritic), marine settings. Toward the western part of the planning area, the Mississippian is represented by the Deseret Limestone and Gardison Limestone. Thickness is up to 1,200 feet with the Mississippian thickening from the east to the west.

The Devonian Ouray Limestone and Elbert Formation are limestone and dolomite interbedded with shale and sandstone. The sandstone beds that underlie the Elbert is assigned to the McCracken Sandstone Member. These strata were deposited in marine settings. The Ouray and the Elbert thicken east to west from approximately 200 feet to about 500 feet, and the McCracken thickens west to east from a few feet to more than 100 feet. Farther west, in the Basin and Range, the facies change and equivalent time-stratigraphic formations have other names.

Silurian rocks are not present in the planning area, except perhaps along the boundary with the eastern Basin and Range. Ordovician rocks are not present in the record in the eastern part of the planning area, but are present in the vicinity of the Valley Mountains. The section is predominately limestone and dolomite with subordinately interbedded shale and sandstone, namely the Eureka Quartzite.

The Cambrian strata are predominately dolomite and limestone with subordinately interbedded shale. Stratigraphic names of the carbonate formations vary from east to west and include the Lynch Dolomite and Muav Limestone. The shale section is represented by the Ophir Shale or equivalents. The lower Cambrian includes the Tapeats Sandstone, which is quartzitic and conglomeratic with occasional interbeds of shale. Equivalent is the Tinctic Quartzite near the boundary with the Basin and Range. Thickness of Cambrian strata generally increase from east to west.

Proterozoic rocks include metasedimentary rocks and the lateral extent of such formations is not well mapped as such are generally known from drill holes in widely scattered locations in the state. Included in the Proterozoic is the Chuar Group, which includes metamorphosed sandstone and shale. Older Proterozoic and Archean rocks include metamorphic and plutonic rocks at the base of the stratigraphic column.

2. Igneous Rocks

COLORADO PLATEAU

The main centers of igneous rocks in the eastern part of the planning area are the stocks of the Henry Mountains (Map 6), which are the classic laccoliths of Gilbert (1877). These stocks and laccoliths are Oligocene in age (31-24 Ma) and intrude and deform the older sedimentary strata (Nelson, et al, 1992). These intrusions are primarily diorite and monzonite porphyries, but also include a few scattered dikes and sills of basalt and aplite composition (Stokes, 1986).

Small diabase dikes and sills are found in northern Wayne County. These are located on the southwest margin of the San Rafael Swell (Map 6).

TRANSITION ZONE

The Marysvale volcanic field is an extensive assemblage of volcanic and igneous rocks in the Colorado Plateau-Basin and Range Transition Zone in the western part of the planning area. This volcanic field is one of the largest in the western U.S. and includes the igneous rocks in the Tushar Mountains and the southern high plateaus. Geographically, the field extends from the eastern side of the Basin and Range to the western side of the Colorado Plateau. Rowley and others (2002) divide the igneous rocks of the Marysvale volcanic field into an older calc-alkaline sequence (32 to 22 million years old) and a younger bimodal sequence (23 million years old to Holocene). This discussion is based largely on Rowley and others (2002). This volcanic field has been studied by numerous geologists, notably Rowley, Anderson, Cunningham, Steven, as well as others since the 1970s.

The middle Cenozoic calc-alkaline assemblage is the most voluminous of the igneous rocks and makes up approximately 95 percent of the total volume of the igneous rocks in this field (Rowley, et al, 2002). This assemblage compositionally

ranges from andesite to low-silica rhyolite, and the deposits are dominantly mudflow breccia and lava flows associated with clustered stratovolcanoes and subordinately ash flow tuffs associated with calderas. These rocks evolved in a magmatic arc tectonic setting related to subduction of the Pacific Plate under the North American plate. Most of the stratovolcano sequences, including vent and alluvial facies, are mapped as the Mt. Dutton Formation or the Bullion Canyon Volcanics.

The field is cut by oblique-slip faults that are not easily recognized, are related to extension above the subduction zones, and trend north-northwest and north-northeast. Plutons are generally aligned along these faults, and represent cupolas of larger magmatic bodies. Also, transverse zones with an east-northeast direction are present. These alignments represent important associations of plutonic rocks and belts of igneous features, particularly the Pioche-Marysvale belt, the Delamar-Iron Springs igneous belt, and the Blue Ribbon lineament.

The Mt. Dutton Formation is prevalent in the southern part of the Marysvale volcanic field, has dates of 27-21 Ma but may be older than 30 Ma, and is the most voluminous of the middle Cenozoic igneous rocks. The Mt. Dutton contains an estimated 5,000 km³ and sections are up to 7,000 feet thick. Magma sources are inferred to be deep-seated as intrusive rocks are generally not exposed.

The Bullion Canyon Volcanics are prevalent in the northern part of the field, are similar in age to the Mt. Dutton with possible dates as old as 34 Ma, and are the second-most voluminous of the middle Cenozoic igneous rocks. The Bullion Canyon is mostly dacitic in composition. This unit contains an estimated 1,700 km³, and sections are up to 5,000 feet thick. The source intrusive rocks are widespread, indicating that the magma bodies were shallower in the Bullion Canyon Volcanics than the Mt. Dutton Formation. The Bullion Canyon Volcanics and the Mt. Dutton Formation intertongue along the contact.

Ash flow tuff deposits related to calderas represent approximately 10 percent of the middle Cenozoic igneous section. Namely, these are the Three Creeks Tuff associated with a caldera of that name in the Pahvant Range, the Delano Peak Tuff associated with the Big John Caldera in the Tushar Mountains, and Osiris Tuff associated with the Monroe Peak Caldera in the Sevier Plateau and Antelope Range. In addition, the Kingston Canyon, Antimony Tuff, and tuff of Albinus Canyon are related to an unmapped caldera that may be buried in the graben at Joseph. Volume of output ranges from 100-250 km³. Age dates range from 27 Ma (Three Creeks Tuff) to 23 Ma (Osiris Tuff).

The upper Cenozoic bimodal igneous sequence volumetrically is a much smaller component of the Marysvale volcanic field than the calc-alkaline sequence, and the bimodal sequence is about 5 percent of the field. This assemblage contains two separate compositions: basalt and high-silica rhyolite at distinct eruptive centers. This change in

composition is inferred to coincide with the regional extension associated with the formation of the Basin and Range Province, which began about 25 to 20 million years ago. This tectonic setting changed from subduction in the middle Cenozoic to extension and normal faulting in the upper Cenozoic (Rowley, et al, 2002). These rocks are of Miocene to Pleistocene age.

The Mount Belknap Volcanics are the largest unit in the upper Cenozoic igneous section and are one of the silicic components of the bimodal sequence. Two sources are identified: the Mount Belknap caldera with the Joe Lott Tuff in the Tushar Mountains and the Red Hills caldera with a tuff of that name in the Antelope Range. The Joe Lott Tuff has a volume of at least 300 km³, and the Red Hills is considerably less. The Joe Lott Tuff is dated at 19 Ma. Both have associated granitic intrusive bodies. The intrusion associated with the Red Hills caldera is referred to as the Central Intrusion and the Central Mining Area, which is associated with the uranium deposits near Marysvale (Cunningham and Steven, 1979).

In addition, an intrusion underlies Alunite Ridge, southwest of Marysvale, on the east side of the Tushar Mountains. This domed feature is associated with vein alunite deposits and indicates an intrusive body in the subsurface. The intrusive rocks are dated at 14 Ma.

To the west of the planning area, the Mineral Mountains are underlain by an extensive batholith that is 25 to 9 million years old. Although the early phases represent the calc-alkaline sequence, most of the intrusion is associated with the bimodal sequence as it is granitic and alkaline, but the late phases are distinctly granitic and bimodal. This batholith is inferred to underlie most of the Pioche-Marysvale igneous belt.

The basaltic component of the bimodal sequence in the Marysvale volcanic field is represented by lava flows and cinder cones. These are associated with small eruptive centers that are generally younger than 14 Ma and continue into the Holocene. With increasing extension after 10 million years ago, rhyolite domes have also been emplaced in the field.

In northern Sanpete County, the Moroni Formation includes tuffaceous beds and lava flows. These rocks have an origin from the volcanic centers in the Tintic Mountains to the northwest of the planning area. The age is 38 to 34 Ma, and the formation is up to 2,200 feet thick at the Cedar Hills.

C. Structural Geology and Tectonics

In general, the structure of the eastern part of the planning area is less complicated than the structure of the western part of the planning area and is

dominated by the relatively flat-lying stratigraphy characteristic of the Colorado Plateau.

Major structural features in the Colorado Plateau include the Paradox Basin, the Waterpocket Fold, the Henry Mountains syncline, the laccoliths of the Henry Mountains; and the San Rafael Swell. The Waterpocket Fold, the Henry Mountains syncline, and the Swell are Laramide structures, developed at the end of the Cretaceous and early Tertiary.

The Paradox Basin is an older structure not exposed at the surface. This is a fault-bounded basin that developed during the Pennsylvanian and lasted through the Permian. The basin development was related to the uplift of the Ancient Rocky Mountains, most notably the Uncompaghre Uplift. (The present-day Uncompaghre Mountains are unrelated to this older uplift, except the faults were reactivated by different tectonic events.) The deeper part of the basin was to the east of the planning area. Basin development was related to complex deposition of salt and other evaporitic minerals, carbonate mounds, clastic strata, and black organic shales; the formation of salt domes and diapirism; and active block faulting. This basin extends into the eastern part of the planning area, east of Hanksville.

The Waterpocket Fold is an east-dipping monocline at Capitol Reef on the west side of the Henry Mountains. This fold is the west limb of the Henry Mountains syncline. The San Rafael Swell is an anticline to the north of the planning area.

On the western side of the planning area, structures include late Cretaceous thrust faulting, late Cretaceous to early Tertiary Laramide folding, late Cenozoic normal faulting, and diapiric folding. Thrust faults associated with the Sevier Orogeny are mapped in the Pahvant Range and the Canyon Range to the west and the Wasatch Range to the north of the planning area and may underlie the western part of the planning area in parts of Sevier and Sanpete Counties. The Charleston-Nebo Thrust cuts rocks in the northern part of Sanpete County.

Laramide deformation is less clearly represented in the western part of the planning area than the east. Structures along the northern plateaus may be Laramide, in part.

Normal faulting is associated with extension of the Basin and Range, and this faulting is largely responsible for the present-day topography of mountains and valleys in the western part of the planning area. Two major Basin and Range faults are the Sevier fault and the Pausaugunt fault. The major valleys are down-dropped and the adjacent ranges are uplifted, such as the Sevier Valley with the Sevier Plateau and the Pahvant Range, respectively, on the east and west sides of the valley.

The Wasatch Hingeline is a topographic expression of the eastern edge of the Basin and Range. It represents a change in structure from extension in the Great Basin to relatively undeformed rocks in the Colorado Plateau. The line is also a demarcation of a change in depositional environments from marine shelf settings in the early Paleozoic to near-shore and continental in the late Paleozoic and Mesozoic. The line also coincides with a change in seismic activity, where the Transition Zone is very active seismically in what is known as the Intermountain Seismic Belt and the Colorado Plateau is relatively inactive.

Diapiric, soft-sediment deformation is present in the Sevier Valley and Sanpete Valleys and is associated with the Jurassic Arapahoe Shale (Willis, 1986; Witkind, et al, 1987). The Arapahoe contains interbedded gypsum, salt, mudstone, sandstone, and limestone, and the gypsum and salt as well as the mudstone is susceptible to weight-loading and plastic deformation, or diapirism. The deformed strata in the vicinity of the Sevier and Sanpete Valleys are attributed to compressional tectonics, such as the Sevier orogeny thrusts and Laramide folding; extensional tectonics, such as normal faulting of the Basin and Range; and diapirism (Willis, 1986; Witkind, et al, 1987). The Arapahoe Shale is also the surface expression of the Sevier Valley-Sanpete Valley anticline, where the Arapahoe represents the axis of the structure that trends generally north on the east side of the Sevier Valley and into the southern end of the Sanpete Valley.

Map 7 shows some of the major structural features of the planning area. Regional cross-sections are provided in Attachments 1 and 4.

Cross sections from the Geologic Map of Utah are in Attachment 1. Cross section K-L shows the structure in the Colorado Plateau from the Straight Cliffs in southern Utah across the Circle Cliffs and Waterpocket Fold, the Henry Mountains, and Paradox Basin. Cross section J-I shows the structure of the Basin and Range, the Transition Zone, and the eastern Colorado Plateau. The section in the Transition Zone in the planning areas includes the Valley Mountains, Gunnison Plateau, Sanpete Valley, and Wasatch Plateau.

3. MINERAL DEPOSITS AND ENERGY RESOURCES

The first part of this section discusses energy and mineral resources in the planning area. The second part discusses mineral exploration, development, and production. Leasable commodities are discussed first (such as coal bed methane, oil and gas, tar sands, and geothermal resources), followed by locatable minerals (such as metallics and nonmetallics), then salable minerals (such as sand and gravel, clay, and stone).