GEOLOGY OF THE RAFT RIVER KGRA

INTRODUCTION

The Raft River Valley in south central Idaho is a cenozoic basin bounded on the east by the Black Pine Mountains and the Sublette Range, on the west by the Jim Sage and Cotterell Mountains, and on the south by the Raft River Range. The valley opens onto the Snake River Plain to the north (Figure 1). The Raft River centers the basin at the south end of the Jim Sage Mountains and flows northward. The Known Geothermal Resource Area (KGRA) is located at the south end of the valley very near the Idaho-Utah border. The present topography near the KGRA is characterized by coallescing alluvial fans fringing the flood-plain of the Raft River.

The ranges surrounding the KGRA vary compositionally and structurally. They are described initially to provide a regional geologic perspective. The Sublette Range and Cotterell Mountains are omitted since they have little direct influence on the geothermal resource.

Black Pine Mountains

The Black Pine Mountains bound the east side of the valley. They are 27 km long and rise 1195 m above the valley floor. The range is composed of a sequence of Late Paleozoic marine sediments, minor Tertiary volcanic sediments and minor Quaternary alluvial and colluvial sediments. The exact formation thicknesses and sequences are difficult to determine because of the tectonic nature of many unit boundaries (French 1975). The lithology consists of the Devonian Jefferson Formation, the Mississippian Milligan Formation and White Knob Formation and undifferentiated Pennsylvanian unit, Tertiary age tuffacious sediments, and Quaternary age sediments of the Lake Bonneville group. Low grade contact and tectonic metamorphism is present in a few local outcrops (French 1975).

The structure in this range exhibits high angle Basin-and-Range normal faulting superimposed on older folds and thrust faults associated with Laramide tectonism. Thrust faulting has moved younger strata over older (French 1975).

Jim Sage Mountains

The Jim Sage Mountains bound the west side of the valley. They are 29 km long, and rise 667 m above the valley floor. Two small blocks are separated from the south end of the range by an inferred right-lateral strike-slip fault (Williams et al, 1974).

The range is composed entirely of the Tertiary Salt. The upper member of the formation is gray to light green tuffaceous siltstone and sandstone with minor conglomerate composed of clasts of quartzite, dolomite, limestone, schist and rhyolite. The middle member is composed of rhyolite flows, tuffaceous siltstone, and vitrophere breccia. The lower member is gray to white, thin-bedded to massive, tuff and tuffaceous sandstone; white to light green shale and siltstone; and sparse beds of fine-grained conglomerate (Williams et al, 1976).

The Jim Sage Mountains are structurally simple. The range is a titled antiform block, the crest very near the eastern margin creating steep scarps facing east and a gentle slope facing west (Anderson 1931). Steep normal faults located along the range fronts are attributed to Basin-and-Range tensional forces.

Raft River Range

The Raft River Range forms the southern boundary of the valley. It is 40 km long, rises 1250 m above the valley floor, and is the only east-west trending range in the area.

Stratigraphic units in the range have been highly deformed and metamorphosed, thinning or erasing them locally. Although many units are cut by thrust faults, younger formations were emplaced over older, so that the stratigraphic sequence is generally in order (Compton 1978). The Precambrian lithology of the range in order by decreasing age consists of the Older Schist, Metamorphosed Adamellite, Elba Quartzite, Schist of the Upper Narrows, Quartzite of Yost, and the Schist of Stevens Springs. Overlying these are the Cambrian Quartzite of Clarks Basin and Schist of Mahogany Peaks; the Ordivician Metamorphosed Pogonip Group, Metamorphosed Eureka Quartzite and Metamorphosed Fish Haven Dolomite; the Mississippian Metamorphosed Chainman or Diamond Peak Formation; the Pennsylvanian Oquirrh Formation; Tertiary age mudstone, sandstone and conglomerate and igneous rocks; and Quaternary age stream deposits, landslides, colluvium and alluvian (Compton).

The metamorphism in the Raft River Range is the type normally associated with Precambrian metamorphism of the region; however, here it is apparently of tertiary age. (Compton 1975). Two stages of metamorphism occured; the first ended 38.2 $\pm$ 2.0 my ago and the second ended 24.9 $\pm$ 0.6 my ago (Compton 1977). Metamorphic grade increases downward and westward in the autochton (Precambrian Adamellite) and downward in the allochtlons.

The Raft River Range exposes two allochthonous sheets composed of Precambrian, Palezoic and Triassic sediments transported tens of kilometers angle along low thrust faults. Transport was westward and northward during the two stages of metamorphism, and eastward after metamorphism. (Compton 1977). Three sets of folds formed during metamorphism ranging from upright to recumbant. Most are strongly overturned to the northwest. A fourth set of folds, formed after metamorphism, vary in form and trend suggesting complex and localized movement. The orientation of these folds, and some high-grade metamorphism in the allochtlons overlying low-grade metamorphism in the autochtlons are evidence of the later eastward movement of the thrust sheets (Compton 1977). Deformation in the range was caused by gravity gliding on a broadly heated dome. The crest of the dome shifted position causing the varying directional movement of the allochtonous sheets. The present Raft River Range formed during the Pliocene as a broadly arched anticline oriented eastwest.

Rhyolite Domes

Two small rhyolite domes have been intruded and exposed in the southern Raft River Valley. Round Mountain near the northeast end of the Raft River Range has been dated at 8.3 $\pm$ 1.7 my and Sheep Mountain on the east side of the Jim Sage Mountains north of the KGRA has been dated 8.42 $\pm$ 0.2 my and 7.8 $\pm$ 1.1 my (Williams et al, 1976). The rhyolite domes lie on a northwest trending tinecnent extending through the Curlew Pass at the east end of the Raft River Range and into the northern end of the Jim Sage Mountains (Figure). Several smaller rhylote bodies lie on the northwest extension of the linedment from Sheep Mountain.

The Raft River Valley is a downdropped basin filled with sediments derived primarily from the surrounding mountain ranges (Table I). The lithology of the basin at the KGRA has been studied in detail using chip cuttings and cores from the shallow and deep wells (Covington, 1977a, 1877b, 1977c, 1977d, 1978, 1979a, 1979b, 1979c, 1979d; Devine and Bonnichsen 1979; Kennedy, 1980; Saunders, 1980). Descriptions of core and well lithology are detailed in Appendices ____ and ____. The upper most sediments are quaternary alluvium and colluvium. Underlying these deposits is the Pleistocene Raft Formation consisting of unconsolidated quartz sand and silt, tuff, and minor rhyolite gravels. The sediments are poorly sorted, angular and reach up to 300 m in thickness. Chip cuttings from shallow monitor wells (Figure) at the KGRA indicate a fluvial and alluvial depositional environment much like the present. The lenticular nature of deposition makes well-to-well correlation of sediments impossible (Kennedy 1980).

The Tertiary Salt Lake Formation underlying the Raft Formation is a lacustrine deposit up to 1600 m thick. No definitive break occurs between the Quaternary and Tertiary sediments; the division is based primarily upon the relative abundance of volcanic material which increases downward into the lacustrine deposits.

The lithology of the Salt Lake Formation in the basin consists of light-green, thin-bedded to massive, tuffaceous siltstone and sandstone with minor conglomerates (Devine and Bonnichsen, 1979). The primary rock types in the Salt Lake Formation are shales, siltstone, sandstones and tuff. The major and minor mineral constituents are given in Table II(Devine and Bonnichsen 1979). Quartz and feldspar are the most abundant minerals present. Quartz shows both undulatory and nonundulatory extinction in thin section, indicating origin from both metamorphosed and nonmetamorphosed sources.

Depositional and deformational sediment structures in the Salt Lake Formation can be seen in cores, thin sections and outcrops. Shales and siltstones are thin-bedded to massive. Thin beds are 2 to 3 mm thick and are seldom graded. Massive beds occur primarily in the coarse grained gray wackes and are both normal and reverse graded (Devine and Bonnichsen, 1979).

TABLE I.

Major Constituents		Minor Constituents
Quartz	Ashy metrix	Zeolites
Plagioclase	Clay metrix	Glass shards
Orthoclase	Carbonate cement	Pumice lumps
Microcline	Rock fragments	Fossils
Sanidine	Zircon	Apatite
Muscovite	Monazite	Augite
Biotite	Epidote	Tridymite
Pyrite	Chlorite	Diopside
		Hornblende
		Garnet

The most abundant deformational structures seen are microfaults, breccias, ball and pillow structures and convolute laminations. These indicate rapid deposition and deformation of water saturated sediments. Volcanic shocks may have produced the force necessary to cause rapid slumping of sediments and turbidetes.

Hydrothermal alteration in both the Salt Lake Formation and the Raft Formation has resulted in replacement of primary calcite by silica, fracture filling by secondary calcite, clay mineral alteration, and the emplacement of secondary minerals, i.e., biotite and muscovite and pyrite and other sulfides. (Ackerman 1979). Some of the secondary minerals found in thin sections from Raft River wells were formed by diagenetic processes rather than hydrothermal alteration. (Devine and Bonnichsen 1979). In general, hydrothermal alteration increases downward in the sediments. Clays change downward from montmorrillinite to illite and zeolites change downward from clinoptilolite to anakite to wairakite to laumontite (Covington 1980). Deposition of calcite and silica is the dominant form of alteration near the bottom of the Tertiary sediments. Calcite fills fractures, and the silica forms a "caprock" above the geothermal reservoir (Covington 1980).

Fossils are rare in thin sections from the Raft River wells, but are found in Salt Lake Formation siltstones from well RRGP-5. The fossils are deformed from compaction making identification difficult, but appear to be ostracods and/or Pelecypods. The presence of organic material in this well indicates a deposition environment that is more oxygenated than other parts of the basin. Deposition was probably close to the lake shoreline (Devine and Bonnichsen 1979).

TABLE II

Mountain Range	Detritus
Sublette and Black Pine Mountsins	Limestone and clastic rock fragments
Raft River and Albion Range	Metamorphic and igneous rock fragments, undulatory quartz, microcline, orthoclase
Jim Sage and Cotterel Mountains	Volcanic rock fragments, non-undulatory quartz, equant plagioclase, sanidine.

The Salt Lake Formation unconformably overlies part of the Precambrian rock assemblage seen in the Raft River Range. The following formations are present in the deep wells at Raft River from youngest to oldest.

The Quartize of Yost is a white quartzite with moderate muscuvite and up to 10% k-feldspar (Compton, 1972). Thin sections from this unit show calcite veining, and carbonate cement in fractures (Devine and Bonnichsen, 1979). The unit is absent in wells RRGE-1 and RRGE-2.

The Schist of the Upper Narrows is a dark brown to gray, fine to medium grained biotite schist and fine-grained greiss containing quartz and quartz-feldspar lenses (Compton, 1972).

The Elba Quartzite is a white, tan or dark-green quartzite with interbeds of muscovite-quartz schist (Compton, 1972).

The Older Schist is a brown mica-rich schist. The unit is absent from wells RRGE-1 and RRGE-2.

The Quartz Monzanite (Metamorphosed Adamellite of Compton, 1972) is a light to dark green-gray quartz feldspathic gneiss with k-feldspar prophyroblasts surrounded by mortared quartz with a trace of pyrite and magnetite. The quartz monozonite in the Raft River Valley and the Raft River Range is thought to be partially older than the overlying formations and partially remobilized (Williams, et al, 1976 and Compton 19).

The metasediments and quartz monzonite basement rocks in the basin appears on reflection seismic sections as flat lying with a lack of major structures (Mabey oral communication 1980). Low angle faults have thinned or erased the units, with movements probably related to that seen in the Raft River Range. The upper part of the allocthons, Cambrian through Mississippian units, are absent in this part of the valley.

The geologic structure of the Raft River Basin near the KGRA has been studied extensively using geophysical techniques, surface geological mapping and aerial photography. Geophysical surveys run in the basin include: (1) gravity; (2) magnetic; (3) audiomagretotellurics; (4) seismic reflections and refraction; (5) self-potential; (6) direct current resistivity; and (7) Schlumberger soundings and field measurements. (Ackermann, 1975; Crosthwaite, 1974; Hoover, 1974; Lofgren, 1975; Mabey, 1973; Mabey and Wilson, 1973, 1974; USGS, 1974; Williams et al, 1976; Zohdy, 1975).

The gross structure (Figure   ) as defined by geophysical techniques, is a downdropped basin with steep normal faults inferred at the range fronts (Williams et al, 1976). The principal faults exposed at the surface lie in a north trending core on the west side of the Valley called the Bridge Fault Zone. Gravity data indicate the zone is narrow on the east side of Sheep Mountain and has the greatest amount of vertical displacement at this location. South of Sheep Mountain the fault zone widens to the west and distributes vertical displacement between a series of normal faults trending slightly east of north. Surface dip of the faults is 60-70^{0}. Early interpretations (Mabey et al, 1978) show the Bridge fault zone continuing with steep dips to depth, displacing the metasediments and quartz monzonite basement rocks (Figure   ).

Later interpretations (Covington 1980) infer a shallowing of dip with depth, flattening to parallel the bottom of the Tertiary sediments, with no displacement of the basement (Figure) (Covington, 1980) postulates that movement on the concave upward faults produced many near vertical open fractures and cracks near the base of the Tertiary sediments.

Gravity data show additional normal faulting on the west side of the Bridge Fault Zone (Mabey et al, 1978). This Horse Well Fault Zone closely approximates the Bridge Zone in strike and dip (Covington 1980).

The Bridge and Horse Well Fault Zones are terminated north of the Raft River by a poorly understood geologic structure called the Narrows Zone. This structure trends to the northeast across the basin and is thought to be a basement shear associated with a large regional feature called the Humbolt Zone (Mabey et al, 1978). The Narrows Zone was inferred by a compilation of anamolous data from geophysical surveys that suggest major changes occurring in a northeast trend (Mabey et al, 1978).

The geothermal system in the Raft River Basin occurs at the intersection of the Narrows Zone and the Bridge Zone. Hydrothermal water is believed to circulate to depth along basement fractures possibly along the southwest extension of the Narrows Zone, then rises at the intersection where it spreads laterally into the Tertiary sediments. Upward leakage through fractures in the Salt Lake Formation provides hot water to the shallow hot wells in the valley (Crank and BLM wells). No evidence of a local heat source is apparent (Mabey et al, 1978).