JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

A
GEOHERMAL TARGET
IN THE
DEER LODGE VALLEY, MONTANA

for

SUN OIL COMPANY

by

GeothermEx

February 1975

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JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

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MURRAY C. GARDNER (503) 482-2605

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CONCLUSIONS

1. There is a geothermal anomaly in the southern part of Deer Lodge Valley, Montana, characterized by three hot springs to 78°C (172°F) and travertine terrace.
2. Deer Lodge Valley is a graben that formed during middle Tertiary time in response to east-west extension. Faulting continued until at least early Pleistocene time, resulting in a graben 6 miles across and 35 miles long from north to south.
3. No igneous rocks are dated as younger than Miocene, although certain undated volcanic rocks of the region may be Pliocene in age.
4. The region is believed still to be active seismically. This seismicity probably is related to growth of graben faults, which in turn may serve as the locus for renewed plutonic activity. This plutonism could serve as heat source.
5. Hydrologic and stratigraphic data suggest that a shallow, unconfined ground-water aquifer in the valley is fed by infiltration of runoff from the bounding mountain ranges. The deep flow (confined aquifer) system is unknown.
6. There is a 5,000-foot-thick section of Tertiary sedimentary and volcanic rocks beneath the valley, overlying more than 5,000 feet of Mesozoic and Paleozoic sedimentary rocks. The potential for geothermal reservoir may exist in Tertiary volcanics or in Mesozoic sandstone and shale units.
7. Storage capacity in these rocks is believed great, with recharge occurring in adjoining mountains where potential reservoir units crop out.
8. It is possible that the thermal manifestations represent circulation of water to 7,000 to 10,000 feet along graben faults, in response to a temperature gradient averaging only 2°F per 100 feet. In this case, the heat source would be radiogenesis within Early Tertiary granitic plutons believed present at depths of a few miles. Such a system is likely to be uneconomic. Available data are inadequate to answer this question.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

9. Geologic data are barely adequate; geophysical data are very sparse; geochemical data are lacking entirely, probably because of efforts by the mining industry to constrain such surveys.
10. The floor of Deer Lodge Valley is fee land. A target has been identified therein for exploration. Two large landowners of the region are the Anaconda Company and the Burlington Northern Railroad. Each is involved marginally in geothermal evaluations.
11. The area has sufficient potential to warrant an exploration effort. The mining and railroad industries are potential consumers of energy, and might represent suitable partners in exploration of the region.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

RECOMMENDATIONS

1. Geothermal leases should be sought for a block of at least 15,000 acres in the target area on the floor of Deer Lodge Valley.
2. Exploration should begin with photogeology and field mapping of areas of inadequate mapping. Age-dates should be obtained for Tertiary (Quaternary?) volcanic rocks of uncertain age.
3. A microearthquake survey might serve as a useful reconnaissance technique, despite the very great background of industrial noise in the region.
4. If reconnaissance exploration is encouraging, geoelectrical and seismic surveys should be planned, to define basement, identify intrusions, define aquifers and model faults at depth.
5. Water chemistry should be carried out only on a test basis, to determine if there is contamination of the ground water aquifers by effluents from mines, mills and smelters of the Anaconda area. Thereupon, decisions should be taken regarding further hydrologic and geochemical work.
6. Consideration should be given to approaching either the Burlington Northern or Anaconda Company for access to their lands in a joint venture.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

LOCATION AND DESCRIPTION OF THE
DEER LODGE VALLEY AREA

Location.

This area includes the Deer Lodge Valley and adjacent portions of the Flint Creek and Anaconda Ranges and the Deer Lodge Mountains, in west-central Montana (see Figure 1, location map). Parts of Deer Lodge, Powell, and Silver Bow Counties are within the target area. The town of Anaconda is in the southwestern part of the area; it is about 20 miles northwest of Butte, 80 miles southwest of Helena and 90 miles east of Missoula, Montana. The area studied may be considered as the drainage basin of the Clark Fork River and the lower parts of its tributaries. About 400 square miles are considered in this report. The boundaries of the area are the Continental Divide, 6 miles south of Gregson Hot Springs; the Deer Lodge Mountains, whose crest is 12 miles east of the Deer Lodge Valley; the junction of U. S. Highways 10 and 12 at Garrison, 30 miles north of Anaconda; and the crest of the Flint Creek Range about 5 miles west of Anaconda.

The study area is included within Townships 3 N. to 9 N., and Ranges 9 W. through 12 W. The area is included on the Butte and Dillon sheets of the A.M.S. 1:250,000 series, published by the U. S. Geological Survey. The target is mainly within the Anaconda, Butte North, Butte South, Deer Lodge, Avon and Garrison 15-minute U. S. Geological Survey topographic quadrangles. These include the following 7-1/2-minute quadrangles: Dickie Peak, Burnt Mountain, Dewey, Wise River, Mount Powell, Rock Creek Lake, Conleys Lake and Race Track.

Topography.

Deer Lodge Valley is a basin trending north-south at the center of the Northern Rocky Mountain physiographic province (Fenneman, 1931). Elevation at Warm Springs State Hospital, on the valley floor, is 4,814 feet. Figure 2 shows main drainage and topographic features of the area.

The Continental Divide is nearly parallel to the axis of the valley, and 5 to 15 miles to its east. The mountains forming the divide are known locally as the Deer Lodge Mountains. They

Figure 1. Location of the Deer Lodge Valley area, Montana

Figure 2. Principal topographic and drainage features of the Deer Lodge Valley area, Montana (from Konizeski et al, 1968)

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MURRAY C. GARDNER (503) 482-2605

generally do not exceed 8,000 feet in altitude. Cliff Mountain, elevation 8,381 feet, and Thunderbolt Mountain, elevation 8,597 feet, are among the highest peaks. Topography in the mountains is rolling, with open parks, and does not appear to be controlled structurally. A deeply glaciated area east of the town of Deer Lodge has great relief, reaching nearly 4,000 feet in 10 miles.

West of Deer Lodge Valley is the Flint Creek Range, a deeply dissected granitic dome 28 miles long from north to south and 20 miles wide from east to west. Mount Powell, 12 miles west of the valley axis, is 10,171 feet high, representing nearly 6,000 feet of relief with respect to the valley floor. From north to south, Pikes Peak (9,335 feet), Twin Peaks (9,057 feet) and Olson Mountain (8,827 feet) are other high peaks of the range. Many gorges, such as Rock Creek, Racetrack Creek and Lost Creek, are U-shaped canyons, having more than 2,000 feet of relief within less than one mile. Knife-edged divides, cirques, and other evidences of recent glaciation exist. Many tarns occur in the interior of the range.

The range is composed of fault-bounded Precambrian to Tertiary sedimentary and volcanic rocks, deformed and domes over a Tertiary granitic batholith. Topography generally reflects the lithology and structure.

South of the valley is the north slope of the Anaconda Range. The range follows the western trend of the Continental Divide. At Mount Haggin, 10 miles southwest of the town of Anaconda, the elevation is 10,665 feet. Mount Evans is 10,648 feet high and Grassy Mountain is 8,026 feet in elevation. Relief is great. There is a 2,500-foot rise from the town of Anaconda to the crest at Sugarloaf Mountain, 7 miles southward, and a 5,500-foot rise to the crest of Mount Haggin. Glaciation has modified the slopes above the 7,000 foot level, as in the Flint Creek Range. French Gulch and Silver Bow Creek interrupt the continuity of the range, thereby separating it from the Deer Lodge Mountains on the east. Warm Springs Creek, flowing eastward, separates the Anaconda Range from the Flint Creek Range.

At the northern end of Deer Lodge Valley, the southeast end of the Garnet Range completes the encirclement of the valley. The Garnet Range has a maximum elevation of 7,511 feet at a peak south of Devil Mountain.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

Topography of the valley is characterized by a flat central portion, and by sets of terraces at the margins of the Clark Fork's flood plain. The high terraces slope gently downward from the mountains and end in abrupt scarps above low terraces, which border the broad flood plain. In the northern part of the valley, the high terraces are nearly 5 miles wide. They become narrow toward the southern part of the valley. Slopes across the terraces range from 5° near the mountains to less than 1° near the lower terraces. Flood plains of the tributaries of Clark Fork coalesce and merge with the lower terraces. In the southwestern part of the Deer Lodge Valley, the terraces have been dissected by post-Wisconsin stream erosion. Deposition of alluvial fans further has masked the terrace forms. The valley floor itself slopes from an elevation of 5,107 feet at its southern boundary near Gregson Hot Springs to 4,422 feet at its northern boundary near Garrison, for an average slope of 22 feet per mile.

Climate.

Deer Lodge Valley has a semi-arid climate, characterized by cold, long winters, and cool, short summers, with low annual precipitation. The climate becomes predictably moister and more alpine in the surrounding mountains. The Flint Creek and Anaconda Ranges create a rain shadow in Deer Lodge Valley.

At Deer Lodge, near the northern end of the valley, elevation is 4,688 feet, and average annual precipitation is 10 inches, of which nearly half occurs during May, June and July (see Figure 3). About 2 inches falls in July alone. Years of extreme precipitation were 1938, when there were nearly 15 inches, and 1935 when there were less than 6 inches. At Anaconda, elevation 5,265 feet, the average annual precipitation is 13 inches, and comes in much the same seasonal proportions as at Deer Lodge. The Anaconda and Flint Creek Ranges receive average annual precipitation of about 25 inches, of which 10 inches (equivalent 80 inches of snowpack) are in the form of snow between November and March.

The average annual temperature at Deer Lodge is 40°F. The average mean temperature in January is 19°F, and the average mean temperature in July is 60°F. The recorded high at Deer Lodge was 100°F, along with a record low of -39°F. Diurnal changes of more than 30°F are common during summer months and 20°F during winter

Figure 3. Average monthly precipitation and temperature for East Anaconda, Montana

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

months. Early June to early September usually is frost-free in the valley. Temperatures below 32°F will be likely 200 days annually. The temperature is likely to exceed 90°F only 5 days annually.

The area is likely to have an annual precipitation of 250 to 300 gallons of water per square mile, integrated over both valley and bounding mountains. Much of this is in the form of snowpack. Amount and timing of snowfall and melt rate govern recharge to the ground-water system of the semi-arid valley. Mean annual pan evaporation is 35 inches.

Hydrology.

Clark Fork, above its junction with the Little Blackfoot River at Garrison, has a drainage area of about 1,200 square miles. The Clark Fork enters Deer Lodge Valley at the southern end of the valley through a narrow gorge at an altitude of about 5,100 feet near Gregson Hot Springs. Prior to that point, water is carried mainly by Silver Bow Creek, a tributary flowing westward from Butte. Clark Fork exits the valley at an altitude of about 4,400 feet. Between Gregson and Warm Springs, the average gradient is 26 feet per mile, while between Warm Springs and Garrison the gradient is 8 feet per mile. The stream meanders through a mile-wide flood plain in its northerly reaches. The mean annual flow at Deer Lodge is estimated at 250 cubic feet per second (cfs). Much flow is lost to infiltration during the summer months, and to evaporation and evapotranspiration in numerous oxbow cutoffs, sloughs, and marshes, in which grow phreatophytic vegetation.

There are seven main perennial tributaries that enter the valley from west of Clark Fork, two that enter the valley from the south and two from the east. The area east of the valley is semi-arid whereas the west is sub-humid. Therefore the streams entering from the Deer Lodge Mountains generally are small. Numerous intermittent streams are tributary to Clark Fork from the several bounding mountain ranges.

The principal tributaries are, counter-clockwise from the south, Willow, Silver Bow, Peterson, Cottonwood, and Freezeout Creeks, Little Blackfoot River, Rock, Joe, Powell, Dempsey, Race-track, Modesty, Lost, Warm Springs, and Mill Creeks (see Figure 2). Mill, Warm Springs and Lost Creeks, at the southwestern part of the valley, have deposited great coalescent fans which force the Clark

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

Fork to keep its course along the eastern wall of the valley. The tributaries to the Clark Fork flow from consolidated rocks in the mountains onto unconsolidated fill in the valley, where much of their flow is lost by infiltration. Most of the remaining flow is diverted for irrigation and industrial use. The mining industry and municipal users at Anaconda are principal consumers of available water, and all water rights have been appropriated.

The principal source of ground water in the Deer Lodge Valley, and consequently the only well-known aquifer, is the upper few hundred feet of unconsolidated valley fill. Most wells tapping these deposits are less than 250 feet deep. Water exists both in artesian conditions and as unconfined ground water. Unconfined ground water is encountered as deep as 150 feet below ground surface. Well yields range from a few gallons per minute (gpm) to more than 1,000 gpm. Highest yields occur on the flood plain of Clark Fork and on the coalescent fans of Warm Springs and Mill Creeks. Most of the 7,000 acre-feet of ground water discharged by wells goes for municipal use in Anaconda.

Seasonal fluctuation of the water table is less than 10 feet. So small a yearly fluctuation indicates that recharge from direct precipitation and snow melt is in approximate balance with the discharge from evapotranspiration, seepage into streams, and pumping from wells.

The mapped water table in the valley indicates that ground water moves toward Clark Fork from the east and west, and that complex variations occur. In the southwestern part of the valley, ground-water movement is northeast at a gradient of 50 feet per mile. In other parts of the valley, water moves toward Clark Fork at a gradient of 70 feet per mile or more, and then northward at about the same gradient as the surface stream. Velocity of ground water in the valley is estimated at less than 3 feet per day, but may exceed that rate in areas of steep gradient and higher permeability.

The only standing bodies of water in the area, other than tarns at high altitude, in the Anaconda and Flint Creek Ranges, are settling ponds for the Anaconda smelter between the towns of Opportunity and Warm Springs. Small, cold springs dot the eastern slopes of the Flint Creek and Anaconda Ranges. Thermal springs and wells are considered in subsequent sections of this report.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

Several hundred water wells are used for irrigation and domestic supply in the target area. Available data and a location map are reproduced as table 1 and Plate III, respectively. No chemical data are presented in this report: no samples were collected for hydrochemical analyses in this or previous studies, because of opposition by the main landowner of the area, Anaconda Company. Anaconda is concerned that a conjectured plume of contamination from the smelter ponds would be verified by chemical analyses.

Transportation.

Access and communication within the lower elevations of the Deer Lodge Valley and adjacent ranges varies from good to restricted. The steep fronts of the high terraces, and the water saturation of lower fans and flood-plain marshes are obstructions to transportation. Within the mountain areas, roads and jeep trails are limited to the creek valleys, except for some unimproved dirt roads which ascend the ridges of the Flint Creek Range to mining and prospect areas.

The main line of the Burlington Northern railroad traverses Deer Lodge Valley, en route from Butte to Deer Lodge, and thence to Missoula and Helena. A main switching point and junction at Garrison joins the Burlington Northern with the Northern Pacific main line. The Chicago, Milwaukee, St. Paul and Pacific Railroad parallels the Burlington Northern line in the Deer Lodge Valley. Both systems have been electrified through the valley. The Butte, Anaconda, and Pacific Railroad operates a spur track between Butte and Anaconda, hauling ore concentrates and processing materials for the Anaconda smelter.

Interstate Highway 90, from Butte to Missoula, also traverses the Deer Lodge Valley. Interstate 90 incorporates sections of the former U. S. Highway 10.

U. S. Highway Alternate 10 branches from Interstate 90 at Opportunity and proceeds westward beyond Anaconda. U. S. Highway 12 connects with Interstate 90 at Garrison and leads eastward to Helena.

A small connecting road, State Highway 48, extends from the east part of Anaconda to Warm Springs. County Highway 274 is

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

an improved road that leads from southeast to Anaconda, southwestward through the Continental Divide toward the Big Hole River area. Other improved dirt roads lead west and east from Interstate Highway 90 in Deer Lodge Valley into the mountains, to such recreational areas at Lost Creek and Rock Creek Lake. Thus, both within and providing access to the Deer Lodge Valley are good land transportation routes. The towns of Deer Lodge and Butte have airports with commercial air service.

Settlement.

The area is comparatively populous for Montana. Within 50 miles of Deer Lodge Valley, the town of Deer Lodge has a population of about 4,500; Anaconda has about 10,000 residents; Butte has a population of just under 20,000; and Helena has a population of almost 25,000. There are another 2,000 inhabitants living in smaller communities and on farms in the Deer Lodge Valley, including the residents at the hospitals at Warm Springs and Galen.

Economy.

The economy of the area is dominated by mining, milling and smelting of copper ore. Secondary contributors are logging and lumber milling, irrigated crop farming, and cattle ranching. The State Hospital at Warm Springs and the State Sanitarium at Galen also add to the economic base of the area. Deer Lodge is also important as a railroad center.

The areas surrounding Deer Lodge Valley were among the earliest of the bonanza mining districts in Montana. Butte and Philipsburg boomed in the last half of the 19th Century. More than \$75 million in silver, zinc and manganese were extracted from quartz veins of the mines of the Philipsburg District in the western part of the Flint Creek Range. At Butte, the "richest hill on earth" has yielded more than 20 billion pounds of copper since 1885, together with gold, silver, lead, zinc and manganese. The Garnet Range is the site of phosphate mining activity. However, it is the copper industry centered at Anaconda that forms the framework of the regional economy. This includes mine operations, trucking and railroading of ore, milling and concentration, refining of copper and shipment of copper out of the area. Directly or indirectly, three of every four people in the area are dependent upon this industry for their livelihood.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

The flood plain of the Clark Fork River, and the low and high terraces adjoining the flood plain are devoted to farming of hay, potatoes, wheat, barley and corn. The west side of the valley is the major irrigated area. There, hay is raised and used to feed cattle.

Logging of pine and spruce from the Flint Creek and Garnet Ranges began about 15 years ago. Lumber is processed at a sawmill at Deer Lodge.

Electric Utility Service.

Three electric utilities operate power transmission lines and substations in the Deer Lodge Valley and vicinity (see Figure 4). These are Montana Power Company (MoPo), Bonneville Power Administration (BPA), and the Chicago, Milwaukee, St. Paul and Pacific railroad (ChMS).

MoPo and BPA each operate a 230-kVe line, connecting hydro-power plants in the northwest with load centers at Anaconda, Butte and Billings. MoPo also operates a 161-kVe line in the same region. ChMS has twin 161-kVe lines to serve its own demand for electricity along the railroad.

There are major switching facilities and power substations at Anaconda, and other points southeast of Deer Lodge Valley, near Butte.

Other, smaller lines distribute power to smaller communities throughout the region.

The Anaconda region ranks with the areas around Great Falls and Billings as a chief consumer of electric power in Montana.

GEOLOGIC FRAMEWORK

Regional Geology.

Deer Lodge Valley is a deep graben, filled with more than 5,000 feet of Tertiary and Quaternary volcanic rock and sediment. Mesozoic and Paleozoic sedimentary rocks underlie these rocks. The

Figure 4. Electric power transmission lines and generating stations in Deer Lodge Valley and vicinity, Montana

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

graben resulted from subsidence along north-trending boundary faults early in Tertiary time. An earlier, regional, tectonic episode had included volcanism and intrusion of the Boulder and Philipsburg batholiths (see Figure 5).

Valley alluvium combines clastic debris from erosion of the surrounding mountains with minor interbeds of later-stage volcanic ejecta. The only known evaporites are calcarenite beds within the Tertiary sediments of the central part of Deer Lodge Valley.

The mountains east of Deer Lodge Valley contain rocks of Precambrian to Tertiary ages, but are mostly Cretaceous to Lower Tertiary granitic rocks. The granitic rocks comprise the Boulder batholith. The batholith is a great composite body, with several main stocks and satellite plutons, exposed over an area of approximately 2,200 square miles. It cuts rocks ranging in age from Early Precambrian to Late Cretaceous, and in turn is cut and overlain by Eocene and younger rocks.

The Early Precambrian rocks have been described as pre-Beltian metamorphics by Tilling and Gottfried (1969). Early Precambrian gneiss, schist, marble and quartzite, along with gabbro, occur near the east edge of the batholith, according to mapping by Knopf (1963). The Late Precambrian Belt Series (Supergroup) extends along the northeastern margin of the batholith, domed by intrusions and exposed by subsequent erosion. Paleozoic and Mesozoic formations crop out parallel to the Belt rocks. The Paleozoic and Mesozoic rocks are evidence of a recurrent miogeosyncline that existed in the area, congruent with the present eastern Rocky Mountains.

Andesite, basalt and rhyodacite flows and welded tuffs, together with hypabyssal graniodiorite, were emplaced in the area between Helena, Butte and Deer Lodge during the Late Cretaceous period. On the west side of the Continental Divide these are known as the Elkhorn Mountains Volcanics. They form the immediate roof of the Boulder batholith.

A second episode of volcanism followed the emplacement of the batholith by about 20 million years. The Lowland Creek Volcanics were erupted onto the eroded surface of the batholith, and remain as an extensive section between Butte and Deer Lodge Valley. Intra-volcanic episodes of faulting, tilting and erosion caused unconformities within this unit. Another episode of Tertiary volcanism is

Figure 5. Geologic map of Deer Lodge Valley and vicinity, Montana (from Ross et al, 1955). See plate VI for map explanation.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

represented by rhyolite plugs, dikes and flows that crop out principally in the northern and northwestern region of the Boulder batholith, and in the marginal highlands east and south of Deer Lodge Valley. These rocks are younger than Lowland Creek Volcanics, according to Tilling (1969), Ruppel (1961, 1963), Smedes (1966) and Knopf (1913). They are Miocene or Pliocene in age.

West of the Deer Lodge Valley there are Precambrian to Cretaceous sedimentary rocks atop a core of Lower Tertiary granitic rocks. The Flint Creek Range contains a great variety of deformed Precambrian metamorphic rocks and Paleozoic and Mesozoic sedimentary rocks. These layered rocks have been intruded by granitic masses, including the Philipsburg batholith, of latest Cretaceous age (Hyndman et al., 1972). The lowland Creek Volcanics mantle the eroded surface.

Ancient sedimentary rocks crop out in a belt around the eastern and southeastern sides of the Philipsburg batholith. The Precambrian rocks are farthest west from Deer Lodge Valley, and the Paleozoic, Mesozoic and Tertiary rocks crop out successively eastward, as shown by Prinz (1967), Wanek and Barclay (1966) and Konizeski et al. (1968). The Precambrian rocks, consisting of portions of the Belt Supergroup, comprise about 25,000 feet of fine-grained clastic rocks. The Paleozoic rocks comprise some 6,000 feet of limestone, dolomite and quartzite. The Mesozoic rocks consist of about 15,000 feet of fine-grained clastic sediments. A cross-section by Wanek and Barclay (1966) showed the carbonate units of Paleozoic rocks to be present at least 5,000 feet below the surface on the eastern slopes of the Flint Creek Range, and probably deeper than that beneath Deer Lodge Valley (see Plate IV). The Precambrian, Paleozoic and Mesozoic rocks have been folded, faulted and metamorphosed. A great, northerly trending anticline, with satellite northerly trending synclines and anticlines, complicates the stratigraphy of the Flint Creek Range. A further complication is the presence of both normal and thrust faults.

The Philipsburg batholith is an elliptical body, trending east-west, with an area of about 45 square miles. Most of the batholith is medium-grained granodiorite and quartz diorite, quite homogeneous in texture. There are few aplite and pegmatite phases and alternation is minor, except near mineralized veins in the Philipsburg mining district.

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

After intrusion of the batholith, normal faulting and uplift occurred during the last episode of the Laramide orogeny. The area was subsequently eroded, the batholith unroofed, and minor basins and ranges were formed.

The Lowland Creek Volcanics accumulated rapidly on the resultant surface during the Eocene epoch. Nearly 3,000 feet of welded tuff (Smedes, 1962, 1965; Wanek and Barclay, 1966; and Konizeski *et al.*, 1968) crop out along the base of the Flint Creek Range from the south side of Warm Springs Creek northward to Spring Gulch in a 1- to 2-mile-wide band. The unit dips eastward and apparently underlies the entire Deer Lodge Valley. However, the unit crops out only intermittently to the east, except for a large north-northeast-trending belt northwest of Butte.

In summary, the highlands northeast of Deer Lodge Valley are formed of andesitic rocks; the highlands southeast of the valley are formed of siliceous volcanic rocks and sedimentary rocks; and the highlands on the west side of the valley are, from east to west, formed of siliceous volcanic rocks, and deformed sedimentary and granitic rocks.

The tectonic history of the area, as interpreted from structure, metamorphism and geochemistry has been quite complex. At least four episodes of deformation have occurred: Precambrian, Cretaceous-to-early-Tertiary (Laramide), Oligocene-Miocene, and Pliocene. The area lies in a major mobile belt, the Mesozoic thrust belt of the eastern Rocky Mountains. Large thrust faults, with west side upthrown, occur east of Helena and in the Philipsburg Valley. Since the time of thrusting, extension and uplift have predominated in the region.

According to Hamilton and Myers (1974), the Boulder batholith lies within a belt approximately 200 kilometers wide, formed of imbricated thrust sheets along the west side of the North American craton. The Boulder batholith was emplaced during a very short part of the period of regional eastward thrusting of upper Precambrian to lower Tertiary strata over the cratonic crystalline basement. Apparently this thrusting occurred from Late Jurassic into Eocene time, whereas the Boulder and Philipsburg batholiths were emplaced between 78 and 68 million years ago (Hyndman *et al.*, 1972; Tilling, 1973). Hyndman *et al.* (1972) postulated that the Flint Creek Range batholith may represent part of a coeval link between the Boulder and Idaho batholiths, all of them formed during the

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

same period and by the same process. Geochemical and isotopic studies of the Boulder batholith (Tilling, 1973) strongly indicate that it was formed from two distinct magma series, one of which is related genetically to the Elkhorn Mountain Volcanics, and the other of which is related to the Lowland Creek Volcanics. This is discussed further in the section on stratigraphy, below.

Summaries of the periods of deformation in the Flint Creek Range by Prinz (1967) and Wanek and Barclay (1966), in the Deer Lodge Valley by Konizeski et al. (1968), and in the areas south and east of the Deer Lodge Valley by Tilling (1969), Smedes (1962, 1965), Robinson (1968), and Knopf (1957, 1963) are quoted and discussed in following sections. These same authors, along with Ruppel (1961), Klepper (1957), and Becraft (1961), are quoted and discussed in connection with the stratigraphy of the area.

Stratigraphy.

The stratigraphy of the area surrounding Deer Lodge Valley is described best via quotations from the principal workers in the area, mainly Wanek and Barclay (1966). The stratigraphic column of the southern Deer Lodge Valley is shown in Figure 6.

Wanek and Barclay stated:

The oldest rocks exposed are the Newland and Spokane Formations of late Precambrian age: these two formations have been assigned to the Belt Series. . . . The Belt rocks occupy about 4 square miles in the northwestern part of the quadrangle. . . . In general, the strata are silty shale, sandstone, and thin limestone beds that were deposited in shallow seas. The sequence is unconformably overlain by the Flathead Quartzite of Middle Cambrian age. In places the Belt Series is truncated by volcanic rocks of Tertiary age. The aggregate thickness of the Belt is about 14,000 feet. . . .

Several periods of deformation occurred in the late Precambrian and in the Paleozoic. The most intense deformation, however, was

EXPLANATION

Modified after Emmons and Calkins (1913)

GENERALIZED STRATIGRAPHIC SECTION OF THE NORTHWEST QUARTER OF THE ANACONDA QUADRANGLE, DEER LODGE COUNTY, MONTANA

Figure 6.

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MURRAY C. GARDNER (503) 482-2605

much later during the Laramide orogeny in the Late Cretaceous and the early Tertiary. Compressive folding and intrusion by granite locally altered the Precambrian and younger rocks into schist and low-grade metamorphic rocks. . . .

The Newland Formation, the older unit in the Belt Series, is well exposed in the steep cliffs along Lost Creek. . . . In the northwest quarter of the Anaconda quadrangle, the calcareous argillaceous strata of the Newland Formation have been altered to hornfels in areas bordering large granite intrusions. The low-grade metamorphic rocks are very fine grained, siliceous, and dark gray to grayish green. The weathered strata show bedding 1-6 feet thick. . . . The thick beds of purer limestone have been locally altered to light-gray marble on the divide between Timber Gulch and Modesty Creek. . . .

The Spokane Formation, the uppermost unit in the Belt Series, is exposed in discontinuous outcrops along faults north of Lost Creek and in more extensive outcrops at the head of Timber Gulch. Emmons and Calkins (1913) estimated that the thickness of the Spokane Formation ranged from 200 to more than 9,000 feet in the Flint Creek Range and recognized that the variation in thickness is caused by an unconformity at the top of the formation. The Spokane rocks in the area are medium- to thick-bedded dark-gray impure quartzite intercalated with dark-green, greenish-gray, and brownish-black cordierite schist. . . .

Farther east, the Spokane Formation is the oldest separable unit of the Belt Series in the Helena region, according to Knopf (1963). Other units are the Empire Formation, a 1,000 foot thick argillite; the Helena Dolomite, a 4,000 foot thick siliceous dolomite; the Marsh Formation, a 300 to 3,000 foot thick argillaceous siltstone with interbedded quartzite; and the Greenhorn Mountain

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MURRAY C. GARDNER (503) 482-2605

Quartzite, an impure and dense quartzite. The argillaceous units have cordierite hornfels associated in their contact metamorphic zones.

Wanek and Barclay continued:

The Silver Hill, Hasmark, and Red Lion Formations of Middle and Late Cambrian age, the Maywood and Jefferson Formations of Late Devonian age, the Phosphoria Formation of Permian age, sedimentary rocks of Jurassic age, and the Kootenai Formation of Early Cretaceous age are present in the subsurface but are absent at the surface due to faulting. These rocks are well exposed in the adjacent Philipsburg quadrangle to the west. . . .

The Flathead Quartzite . . . of Middle Cambrian age forms several isolated outcrops in the northwestern part of the quadrangle where blocks of the quartzite are preserved along the faults. The quartzite is very resistant to erosion, and west of the mapped area it forms steep cliffs. Emmons and Calkins (1913) estimated the Flathead Quartzite to be 20-200 feet thick. This unit is cliff-forming massive- to thick-bedded light-gray to white vitreous quartzite that locally is tinted rose by hematite and limonite impurities. The white vitreous quartzite can be readily distinguished from the gray quartzite beds in the Spokane Formation.

The base of the Flathead Quartzite was not observed in the northwest quarter of the Anaconda quadrangle

The Flathead is widespread in Montana and northwestern Wyoming, and has been generally recognized as the base of the Paleozoic section in this region. At most places it rests unconformably on the Belt Series or older Precambrian schist or gneiss. The rocks of the Spokane and the Flathead Formations are believed to have been deposited in shallow-water environments.

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The Flathead Quartzite is conformably overlain by the Silver Hill Formation, which is not exposed in the Anaconda quadrangle.

The Silver Hill Formation of Middle Cambrian age is 100-600 feet thick and consists of light-gray, brown, and greenish-gray calcareous shale and intercalated limestone beds that contain thin siliceous laminae. The Silver Hill Formation is conformably overlain by the Hasmark Formation.

The Hasmark Formation of Late Cambrian age is about 1,000 feet thick and is composed mainly of carbonate rocks. The upper 350 feet and the lower 550 feet consist of cliff-forming thick-bedded light-gray dolomite separated by 150 feet of dark-brown shale and nodular limestone. The Hasmark Formation is conformably overlain by the Red Lion Formation.

The Red Lion Formation of Late Cambrian age is about 280 feet thick and is composed of an upper part of thin-bedded light- to blue-gray limestone which has closely spaced wavy siliceous laminae and a lower part of black shale which has some interbeds of olive-green shale, gray-green sandstone, and flaggy red magnesian limestone. The Red Lion Formation is unconformably overlain by the Maywood Formation.

Three other Cambrian formations have been recognized in the area by Knopf (1963), near Helena. They are the Wolsey Formation, overlying the Flathead Quartzite, and the Meagher Limestone and Park Argillite in turn above the Wolsey Formation. The Wolsey Formation consists of 200 feet of micaceous siltstone with Middle Cambrian fossils. The Meagher Limestone is 640 feet thick. It is comprised of a lower siliceous-dolomitic limestone, 360 feet thick, and an upper, massive, pure limestone, 280 feet thick. There are prominent exposures near Helena, where the limestone is quarried for flux. The Park argillite is about 200 feet thick. It is a high-density, non-fissile, argillite with Middle Cambrian fossils. It is overlain by the Hasmark Formation.

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Wanek and Barclay continued:

The Maywood Formation of Late Devonian age is about 250 feet thick and consists mainly of thin-bedded reddish- and light-gray dolomitic limestone intercalated with gray and olive-green calcareous shale. The Maywood Formation is conformable with the overlying Jefferson Dolomite.

The Jefferson Dolomite of Late Devonian age is about 1,000 feet thick and consists mainly of cliff-forming massive light-gray dolomite and intercalated limestone beds. The formation is conformably overlain by the Madison Limestone, which crops out at the surface in the quadrangle.

The Madison Limestone . . . of Early and Late Mississippian age crops out in a wide belt that crosses Lost Creek near its confluence with Timber Gulch . . . and also crops out north of Warm Springs Creek. . . . The unit is about 1,200 feet thick and consists of cliff-forming massive dark-gray fossiliferous limestone containing numerous thin chert layers. Rocks in the lower part of the formation are thin bedded and contain some intercalated shale beds. Beds of light-gray limestone are increasingly numerous in the upper part of the formation, and the limestone comprising these beds is finely crystalline. The abundance of chert varies by locality. The chert layers are, in general, irregular masses roughly parallel to bedding and are most abundant in the upper massive limestone.

Most of the Madison Limestone exposed in the quadrangle is in the upper part of the formation. The strata are fossiliferous, and crinoid stems are the most abundant fossil remains. In localities where the rock is altered by contact metamorphism, the Madison Limestone is coarsely crystalline or marbleized and varies from light gray to very dark gray. . . .

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The lower part of the Madison Limestone is . . . well exposed along the highway in the vicinity of Silver Lake. . . . The lower part consists of an estimated 300 feet of very dense flaggy limestone that is dark bluish gray to nearly black. Thin beds of black compact shale are intercalated with the limestone beds.

The upper part of the Madison Limestone is conformable and gradational with the Amsden Formation.

The Amsden Formation . . . of Mississippian and Pennsylvanian age forms several isolated outcrops in secs. 4 and 16, T. 5 N., R. 11 W. This formation is about 300 feet thick and near Lost Creek consists of slope-forming soft reddish-brown shale interbedded with thin grayish-red fossiliferous limestone and medium- to thick-bedded fine- to medium-grained sandstone. The Amsden Formation is overlain conformably by the Quadrant Formation. . . . Elsewhere . . . the Amsden Formation is faulted against Precambrian, Paleozoic, and Mesozoic strata. The Amsden is poorly exposed but the extent of the formation is usually indicated by red float.

Emmons and Calkins (1913) included the Amsden Formation as a unit of the Quadrant Formation.

Strata assigned to the Quadrant Formation . . . of Pennsylvanian age crop out in the high ridge between Warm Springs Creek and Lost Creek . . . and in Timber Gulch. . . . The Quadrant is 150-200 feet thick and consists of cliff-forming massive light-gray quartzitic sandstone that is locally much fractured and cut by veinlets of calcium carbonate. The massive beds show poorly defined cross-lamination. The sandstone is well sorted, medium grained, and cemented by quartz and some iron oxide. . . . Along Timber

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Gulch the Quadrant Formation is faulted against the Madison Limestone and Amsden Formation.

The Phosphoria Formation . . . of Permian age ranges from 150 to 200 feet in thickness. The lower part consists of interbedded cherty limestone, black calcareous shale, and a thin dark-gray oolitic phosphate bed, and the upper part is massive- to thick-bedded gray to grayish-orange quartzitic sandstone and some thin beds of soft calcareous shale. The Phosphoria Formation is unconformably overlain by sedimentary rocks of Jurassic age.

The sedimentary rocks of Jurassic age are about 400 feet thick; the lower part consists of black calcareous shale interbedded with limestone and is overlain by thin- to thick-bedded grayish-green to dark-gray sandstone containing a few beds of chert conglomerate. The sedimentary rocks of Jurassic age are overlain unconformably by the Kootenai Formation.

The Kootenai Formation . . . of Early Cretaceous age is about 1,500 feet thick and consists in the lower part of a basal cliff-forming reddish-brown to grayish-green conglomerate which is overlain by 500 feet of reddish-brown and grayish-green shale and intercalated thick-bedded dark-gray limestone. . . .

The Kootenai Formation is conformable and gradational with the overlying Colorado Shale, which is widely distributed at the surface in the quadrangle.

Strata of the Colorado Shale . . . of Early and Late Cretaceous age are exposed in a northward-trending outcrop in the central part of T. 5 N., R. 11 W. The base of the Colorado Shale is not exposed in the mapped area, and the top of the formation is beveled by erosion and overlain unconformably by Tertiary volcanic rocks. The Colorado Shale is about 1,500 feet thick in the Philipsburg quadrangle. . . .

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The lower part of the Colorado Shale is predominantly dark-gray to grayish-brown calcareous shale interbedded with siltstone and thin limestone beds. Overlying these strata are several massive cliff-forming dark-gray to grayish brown quartzitic chert-pebble conglomerate beds. The conglomerate beds crop out in the hogback immediately west of the quarry on Lost Creek. . . . Here, these beds are truncated by basal Tertiary strata. . . .

The upper part of the Colorado shale consists of thick-bedded dark-gray coarse-grained sandstone intercalated with thin dark-gray to olive-green shale beds. Near the top the sequence grades into thick dark-greenish-gray siltstone, black calcareous shale, and some thin flaggy limestone. . . .

In general, the strata of the Colorado Shale are folded, faulted, and locally altered to phyllites and quartzites. . . .

East and northeast of the area, the Elkhorn Mountains Volcanics are significant. Although not present at the surface, and possibly absent in the subsurface, the unit is described here (Tilling, 1968) for completeness:

At its type locality, the Elkhorn Mountains Volcanics consists of pyroclastic and epiclastic volcanic strata, lavas, and welded tuffs having a combined stratigraphic thickness of more than 10,000 feet and ranging in composition from basalt to rhyolite. . . . Because of their similar lithology and stratigraphic position, Upper Cretaceous volcanic and clastic rocks in the Wolf Creek area to the north of the Elkhorn Mountains area and in the Three Forks and Maudlow areas to the south and east . . . are considered to be grossly contemporaneous with the Elkhorn Mountains Volcanics . . . the Upper Cretaceous volcanic pile represented by rocks in all

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these areas may have covered as much as 10,000 square miles. . . .

Although the Elkhorn Mountains Volcanics is cut by even the earliest rocks of the Boulder batholith, geologic evidence and K-Ar age data indicate that the prebatholith volcanism and the onset of batholith emplacement were separated by only a very short time interval, not detectable geochronometrically, for both events are dated as ~78 m.y. (million years) B.P.

Wanek and Barclay stated further:

The Colorado Shale is overlain unconformably by strata of the Lowland Creek Volcanics. . . .

. . . the basal conglomerate which consists of boulders of decomposed granite, volcanic rocks, and quartzite cobbles, rests on an erosion surface that has more than 50 feet of relief. Blocks of quartzite in the basal member of the Lowland Creek Volcanics were derived from the underlying rocks and accumulated as talus along the slopes of an ancient valley.

Intercalated dark-grayish-brown to dark-brown coarse arkose beds and cobble conglomerate beds overlie the basal conglomerate and generally constitute the main body of the basal member. The beds are cross-laminated, friable, and weather into rounded benches. The cobbles in the conglomerate beds are chiefly quartzite and are as much as 4 inches in diameter; however, pebbles of volcanic rock are abundant, and some limestone pebbles are present. The matrix is coarse sand consisting of quartz, feldspar, and mafic minerals and in places some tuff.

The arkose interbeds are thick, cross-laminated, coarse grained, and weather readily to gravel and soil. . . .

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The thickness of the basal member varies as a result of an erosion surface which separates it from the overlying ash-flow tuff member.

The ash-flow tuff member is widely distributed along Lost Creek and Antelope Creek. . . . It is from 0 to about 3,000 feet thick and is composed chiefly of massive light-gray ash-flow tuff and gray, buff, and grayish-red quartz latite flows that are interlayered with gray lapilli tuff, some welded tuff, and a few beds of greenish-gray conglomerate. In some places near the base of the member, thin beds of coarse-grained arkose are interbedded with the ash-flow tuff.

The sedimentary rocks [of the Flint Creek Range] were intruded . . . by the Philipsburg granodiorite batholith. The batholith is elliptical in plan and underlies an area of about 45 square miles. The Philipsburg district lies along the western margin of the batholith. . . .

Most of the batholith is medium-grained granodiorite. . . . Aplite and pegmatite phases of the granodiorite are uncommon. The rocks of the batholith are generally very fresh and show only slight alteration of feldspar to sericite or epidote and of mafic minerals to chlorite. Near veins, however, the rock is intensely altered, and only traces of the original feldspar, biotite, and hornblende remain. . . .

Steeply dipping to vertical fractures that commonly strike east and that are filled with vein quartz cut the batholith and sedimentary rocks. Displacement along these fissures is small; normally beds on the north side are offset eastward less than 8 feet, but locally they are offset as much as 20 feet. A subordinate set of fractures that strike northwest and dip southwest is also present in the sedimentary rocks.

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Bedding faults at several horizons displace the steeply dipping veins. These faults may be marked by a single plane or by a shear zone as much as 60 feet thick. . . .

Before intrusion of the Philipsburg batholith, the rocks in the district had been folded, and thrust faulting had occurred in the valley to the west. The fold axes and the thrust fault both trend north to northeast and were probably the result of compression oriented west-northwest. Northwest-trending high-angle reverse faulting . . . postdates the folding and thrusting.

During intrusion of the batholith the nearby sedimentary rocks were metamorphosed, and at this time or perhaps slightly later, metasomatic deposits of magnetite formed at several places along the border of the batholith and along the Redemption fault.

After consolidation of at least the border of the batholith, compressive forces were renewed, probably oriented in about the same direction, and steeply dipping fissures formed in both the batholith and the sedimentary rocks. The most prominent set of fissures strikes west; apparent displacement is north side to the east, which is to be expected along shear planes resulting from the postulated compressive forces. A subsidiary set of fissures strikes northwest.

According to Hyndman et al. (1972), the Philipsburg batholith, as well as the two other granitic plutons of the Flint Creek Range, may represent part of a coeval link between the Boulder and Idaho batholiths, the magma having been developed during the same episode and by the same processes. Potassium-argon age dates of the concentrically zoned Philipsburg batholith range from 72.0 m.y. to 76.7 m.y., suggesting that this batholith was intruded at about the same time as the two major units of the Boulder batholith: the Butte Quartz Monzonite and the Rader Creek pluton.

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Wanek and Barclay concluded:

A pluton of granitic rock is intruded into Precambrian and Paleozoic rocks in the canyon of Lost Creek. It covers several square miles in the canyon and in an area to the south of the quadrangle just north of Warm Springs creek. . . .

The rock is a biotite granite that is light gray on the fresh surface and weathers buff to light orange. It is medium to coarse grained and in places pegmatitic. The megascopic constituents are feldspar, quartz, biotite, and abundant hematite. . . . Fluorite is present in all samples and is generally associated with biotite; it also occurs in fractures in albite. . . . The fluorite is late magmatic and much of the hematite is probably derived from the alteration of biotite by the corrosive action of fluorine. The locally fractured and bent albite associated with hematite, and the fluorite filling in fractures may indicate minor adjustments within the intrusive body just prior to or during the late stage of crystallization. . . .

Medium- to coarse-grained granite dikes cut the granite mass and also the Newland Formation.

Hamilton and Myers (1974) have concluded that the Boulder batholith and its satellitic plutons are shallow in depth, flattened at top, supported on narrow necks, and possibly all interconnected at depth as though they were fingers rising from a single buried hand. They described its origin as follows:

The Boulder batholith formed as a thin and shallow mass that spread over a floor of pre-magmatic rocks and that was covered for the most part only by its own volcanic ejecta. The original roof consists of volcanic rocks of the same age and composition as the intrusive rocks beneath it.

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Hamilton and Myers (1974) also pointed out that the batholith was emplaced during a small part of the period of regional eastward thrusting of miogeosynclinal and foreland-basin strata, lasting from Late Jurassic to Eocene time. They go on to say that:

West of a line passing irregularly southeastward and southward from Deer Lodge to Butte . . . all exposed roof rocks are premagmatic. Contact-metamorphosed Cretaceous strata lie above the batholith with subhorizontal contact 12 km southeast of Deer Lodge. Between there and Butte, contact metamorphosed Pennsylvanian, Permian, and Mesozoic strata form a dozen or so small, irregular roof remnants.

In addition, Hamilton and Myers (1974) speculate that the Boulder, Philipsburg, Pioneer, and Royal batholiths, and other batholiths and stocks may be interconnected at depth.

Tilling et al. (1968) have shown that the constituent plutons of the Boulder batholith were emplaced within the 10 m.y. interval 78 to 68 m.y. before present. Knopf (1963) commented that there were many prebatholithic and synbatholithic intrusions in the region of the Boulder batholith. He identified at least five stages of successive magma emplacements, each with increasing silica content.

The description following is from Tilling and Gottfried (1969), who lucidly summarized the lithology and history of the Boulder batholith and the succeeding Lowland Creek Volcanics:

The composition of the batholith ranges from syenogabbro to leucogranite; rocks of granodiorite and quartz monzonite composition form about 95 percent of the exposed batholith. . . . In general, the younger batholithic rocks are more felsic than the older ones. Earliest in the intrusive sequence are the mafic rocks (syenogabbro, syenodiorite, and monzonite), which occur as plutons near the margin of the batholith. Next in the intrusive sequence are granodiorite plutons. All these are cut by the Butte Quartz Monzonite, which is the largest single pluton of the batholith and constitutes about 80 percent of the total area of the batholith. . . .

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Field and petrographic evidence demonstrates that a continuous genetically related series exists between the Butte Quartz Monzonite, its silicic variants, and alaskite. Both sharp and gradational contacts were observed between various members of this series, even within a single outcrop; however, where sharp contacts separate any two members, the more felsic of the two generally is the younger. . . .

Latest in the intrusive sequence in the batholith are leucogranodiorites and leucoquartz monzonites . . . which invariably are in sharp contact with the Butte Quartz Monzonite and older rocks.

The Boulder batholith is fringed by numerous satellitic plutons. . . . Because these satellitic bodies are widely separated and intruded into country rock of diverse ages, they cannot confidently be assigned positions in the intrusive sequence of the batholith. However, K-Ar ages on biotite and hornblende from several of these plutons fall within the range of ages obtained for the batholith proper. . . .

Approximately 20 m.y. after the emplacement of the leucocratic rocks, the youngest rocks of the batholith, the Lowland Creek Volcanics was extruded in early Eocene time (48-50 m.y.) onto the eroded surface of the batholith. . . . These volcanic rocks, which occur in the southwestern part of the Boulder batholith region . . . consist mainly of quartz latitic to rhyolitic flows, pyroclastics, welded tuffs, and reworked volcanic debris. . . . Dikes, probably feeders associated with the Lowland Creel Volcanics, locally injected the batholith and associated hydrothermal veins. . . .

Another period of Tertiary volcanism is represented by rhyolite plugs, dikes, and flows, which crop out principally in the northern and northwestern part of the Boulder batholith

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region. . . . Field relations . . . demonstrate that these rocks are younger than the Lowland Creek Volcanics and may be as young as Miocene or Pliocene.

More recent work by Tilling (1973) demonstrated that the Boulder batholith is composed chemically of two main magma series:

(1) a main series, defined principally by plutons in the central and northern parts of the batholith; (2) the sodic series, defined mostly by plutons in the southern part. For any given SiO_2 content, the rocks of the main series tend to be higher in K_2O and lower in Na_2O than rocks of the sodic series. The chemical distinction between the two series is also expressed by variation patterns for U, Th, Rb, and Sr abundances and by Pb isotope compositions, but not by strontium isotope compositions.

The prebatholith Elkhorn Mountains Volcanics (late Cretaceous), especially the mafic members, are chemically and isotopically similar to the main series, confirming the genetic association between them. The postbatholith Lowland Creek Volcanics (Early Eocene), though chemically more closely related to the sodic series, isotopically are more akin to, but slightly more radiogenic than, the main series. Post-Lowland Creek volcanic rocks (Miocene or Pliocene) are compositionally similar to the sodic series rocks. Spatial distribution of the batholith and the volcanic rocks exhibits a very crude chemical zonation of the region: for a given silica content, relatively more potassic rocks (main series and prebatholithic volcanic rocks) tend to occur in the north and east, whereas relatively more sodic rocks (sodic series and postbatholithic volcanics) predominate in the south and west.

Available field, chemical, and isotope evidence collectively suggests that the observed compositional variations . . . are most reasonably

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interpreted in terms of a model involving two magma series derived from two or more magma sources within the lower crust or upper mantle. These source regions are inferred to vary chemically and isotopically, either laterally or vertically; in view of the rather small areal extent of the Boulder batholith, however, a vertically zoned source region is more probable.

Konizeski et al. (1968) carefully examined the Lowland Creek Volcanics in Deer Lodge Valley and reported:

. . . these volcanic rocks are distributed over 600 square miles in Jefferson, Silver Bow, Deer Lodge, and Powell Counties, Mont. The type locality is Lowland Creek in the Elk Park quadrangle northeast of Butte, where the stratigraphic and structural relations of the rocks were first determined.

More than 2,800 feet of welded tuff, described . . . as a rapidly accumulated unit of the Lowland Creek Volcanics, crops out intermittently along the base of the range northward from the south side of Warm Springs Creek to Spring . . . a potassium-argon date of 49 million years (middle Eocene age) from biotite in a dike . . . part of a system of dikes that cut the welded tuff unit west of Butte.

The Lowland Creek strata are at the surface in the barren foothills of the Flint Creek and the Anaconda Ranges . . . and are well exposed along the valleys of Warm Springs Creek, Lost Creek, and Antelope Creek in the northwest quarter of the Anaconda quadrangle. The rocks have an aggregate thickness in excess of 4,000 feet and consist predominantly of intercalated beds of volcanic breccia, quartz latite flows, ash-flow tuff, welded tuff, and sedimentary strata.

The Lowland Creek Volcanics in the mapped area has been divided into three members. In ascending order they are the basal member, the ash-flow

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tuff member, and the volcanic breccia and red-bed member. . . . The basal member, locally as much as 400 feet thick, consists of massive-to thick-bedded grayish-brown cross-laminated arkose, lenticular conglomerate beds that contain abundant volcanic pebbles, and gray to buff tuffaceous siltstone and claystone beds. A basal conglomerate is present locally. . . .

The ash-flow tuffs and lapilli tuffs are hundreds of feet thick and seem to lack any distinctive structures. They are, therefore, difficult to separate. These volcanic rocks contain abundant crystals of quartz, feldspar, biotite, and hornblende in a fine-grained matrix. . . . The main mass . . . seems to be nonwelded ash-flow tuff.

The quartz latite lavas form thick flows that are gray, brown, and grayish red. . . . The rock is coarse grained and has some phenocrysts of quartz with finer grained hornblende, plagioclase, and biotite; euhedral crystals of sanidine are abundant. . . . The flows are interstratified with tuff beds and weather into a sharp relief. In other localities the flows are from 5 to 10 feet thick and many contain flow structure. Some are brecciated at the base. Several flow units in . . . T. 5 N., R. 11 W., have been altered and show a color change from grayish red to predominantly green. These flows are fine grained, but the larger crystals of plagioclase, biotite, and hornblende are altered to epidote and chlorite.

The greenish gray conglomerate beds are lenticular and were probably deposited in water. Well rounded cobbles and pebbles of volcanic rock and some quartzite occur in a matrix of pumice, lapilli tuff, and sand. Alteration of the constituent minerals in the cobbles and coarse-grained matrix has changed the conglomerate to dark green. The alteration products, as in the other units, are chlorite, epidote, and celadonite.

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The ash-flow tuff member is truncated by erosion and overlain unconformably by the volcanic breccia and red-bed member, and in some places it is unconformably overlain by a conglomerate of probably Miocene age.

The third and youngest unit of the Lowland Creek Volcanics is the volcanic breccia and red-bed member that is exposed . . . in a wide belt of outcrop north of Antelope Creek. It is from 0 to about 600 feet thick.

In the southern part of the mapped area, the member consists of massive gray to reddish-brown quartz latite breccia and agglomerate interstratified with quartz latite flows, thick-bedded buff conglomerate, sandstone, and thin coaly shale beds. To the north, this sequence intertongues with buff and grayish-orange conglomerate beds containing boulders and cobbles of limestone, gneiss, and some volcanics. The conglomerate is interbedded with reddish-brown coarse-grained sandstone and gray tuffaceous siltstone. . . .

Near the top of the member, the volcanic rocks grade into sedimentary strata. . . .

Along Antelope Creek, a thick sequence of red beds is present. These beds overlie the ash-flow tuff member and consist of a massive conglomerate that contains large boulders of limestone and Precambrian rocks, arkosic sandstone, siltstone, and gray tuff beds. The red beds are correlated with the upper part of the Lowland Creek Volcanics in the south on the basis of stratigraphic position and lithology. The red-bed sequence intertongues with the volcanic strata south of Lost Creek. The red beds rest unconformably on the Colorado Shale along Antelope Creek and are overlain unconformably by the gravel of middle Pliocene age. In the southern part of the quadrangle the volcanic breccia and red-bed member is overlain unconformably by the conglomerate of Miocene(?) age.

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Wanek and Barclay (1966) noted some minor intrusives in the Flint Creek Range and commented:

Small plugs of andesite or trachyandesite are intruded into the Tertiary sedimentary rocks along the valley of Warm Springs Creek in sec. 2, T. 4 N., R. 11 W., and secs. 35 and 36, T. 5 N., R. 11 W. The plugs are composed chiefly of volcanic breccia or vent agglomerate.

Other small intrusive bodies cut the Tertiary strata at localities south and west of the northwest quarter of the Anaconda quadrangle. These plugs are of similar andesitic composition and may represent volcanic pipes that were a source of lava flows now removed by erosion.

Konizeski et al. (1968) also observed igneous features in Deer Lodge Valley, which were not adequately age-dated. He wrote:

An elongate belt of rocks near the axis of the valley has been described as the Garrison Vent. . . . It . . . is about 2 miles wide by several miles long. These volcanic rocks are relatively resistant to weathering and form an erosional remnant of the high terrace. Around the southeastern margin of this high terrace remnant they intrude metamorphosed Kootenai Formation and Colorado Shale. The volcanic rocks are bordered locally to the southwest by Miocene sediments and to the southeast by sediments of probably Miocene age. The contacts are poorly or not at all exposed, but some of the sediments of probably Miocene age contain locally derived volcanic detritus. The vent is believed to be of Tertiary, probably pre-Miocene age.

Wanek and Barclay summarized the Tertiary-Quaternary basin fill as follows:

The Deer Lodge Valley is partly filled with a great mass of material (valley fill) eroded from rocks in the surrounding mountains and with smaller amounts of volcanic ejecta. The

JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

valley fill consists mostly of unconsolidated to semiconsolidated Tertiary sedimentary deposits, but some consolidated Tertiary sediments are exposed around the western margins of the valley, and others probably occur at depth. All are referred to here as Tertiary strata.

Tertiary strata underlie the high terraces and are elsewhere overlain by Quaternary alluvium. More than 2,000 feet of section is exposed over about 120 square miles or two-fifths of the valley. A series of gravimetric profiles . . . indicate a maximum thickness of more than 5,500 feet of valley fill on a basement profile of moderate relief. An average of about 25 feet of this material is believed to be Quaternary alluvium; the remainder, Tertiary strata.

Details of the Tertiary stratigraphy are given in Figure 6 herein. A diagrammatic cross-section showing the relationship between Tertiary and Quaternary sediment in Deer Lodge Valley appears as Figure 7.

Structure.

The structural details and sequence of tectonic events in the Deer Lodge Valley and adjacent mountain regions is presented in the form of quotations from Konizeski et al. (1968) and Wanek and Barclay (1966). Konizeski et al. stated:

The principal structural features of the area originated in Late Cretaceous and early Tertiary time during the Laramide orogeny. After broad folding early in the orogeny . . . the Precambrian rocks were thrust eastward over younger rocks along the Philipsburg thrust fault. Folding continued, as is shown by the fact that the thrust fault is also folded. High-angle faults . . . displaced the sedimentary rocks after they were folded.

Intrusion of the Philipsburg batholith followed the folding and faulting, and after the batholith

Figure 7. Composite diagrammatic cross section of Deer Lodge Valley showing topographic, stratigraphic, lithologic, and structural relations (from a 1961 Montana State Office report by Konizeski)

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MURRAY C. GARDNER (503) 482-2605

had consolidated enough to fracture, steeply dipping fissure veins were formed. The period of ore deposition continued after fissuring stopped, and it culminated in the deposition of manganese-rich replacement deposits. . . . Normal faulting along bedding postdated mineralization and was the last event of the Laramide orogeny that can be recognized in the district.

The Laramide orogeny probably left southwestern Montana with considerable relief at or shortly after the beginning of Tertiary time. Crustal stability and erosion characterized most of Paleocene and Eocene time, and by Oligocene time the area had been reduced to a surface of moderate relief . . . and the Philipsburg batholith probably unroofed. Slow crustal movements during the Oligocene and Miocene Epochs formed basins and ranges approximately in the present pattern. Erosion kept pace with uplift, and the ranges were reduced to low relief while the basins were filled with sand, clay, gravel, and volcanic ash . . . the resulting surface [has been called] the "Late Tertiary peneplain."

Crustal movements accelerated late in the Miocene, culminated in the Pliocene, and ended in the early or middle Pleistocene. The basin deposits were tilted and faulted, and most of them were removed by erosion; remnants crop out in the Philipsburg Valley south of the district. . . . The present mountain ranges were uplifted at this time, some along faults and some by warping. Warping rather than faulting is believed to have formed the Flint Creek Range and the Philipsburg Valley. . . .

A topography largely the same as today's was formed before glaciation in the Pleistocene Epoch . . . glaciers . . . sharpened topographic features, formed moraines, and deposited outwash in many valleys. Since glaciation, there has been some erosion of the uplands and filling of the valleys and basins with alluvium.

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Wanek (1968) described the geologic structure as follows:

The major geologic structure in the region are folds and faults in the Flint Creek Range; these features formed during the Late Cretaceous and the early Tertiary. They are nearly contemporaneous with the intrusions of the granite batholiths. . . . In the northwest . . . Precambrian and Paleozoic rocks are thrust faulted against Mesozoic strata, and granite is locally intruded along the thrust fault. Tertiary strata bevel the older rocks and in many places are in fault contact with them. Minor deformation occurred during the Eocene, Miocene, and the Pliocene Epochs.

Along the lower slopes of the canyon of Lost Creek, Precambrian rocks are thrust faulted against Carboniferous strata. . . .

Two major reverse faults younger than the overthrust in Lost Creek cut rocks near the border of the granite stock in . . . T. 5 N., R. 11 W. They are high-angle reverse faults and seem to have several thousand feet of vertical displacement at places where Carboniferous rocks are against Colorado Shale. The faults probably join beneath Quaternary cover in sec. 15, T. 5 N., R. 11 W. . . . the relation of the northwestward-trending reverse fault to the overthrust in Lost Creek could not be determined because of the predominance of surficial deposits. . . . It is thought that the reverse faults formed nearly concurrently with the overthrusting and the emplacement of the granite and that the faults consequently are related more to the intense diastrophism of the Laramide orogeny than to the period of normal faulting that followed.

In the area underlain by Precambrian and Paleozoic rocks, normal faulting occurred after the major thrusting but earlier than the period of normal faulting that cut the Tertiary rocks. . . .

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The Colorado Shale is exposed in a large broad faulted anticline that seems parallel to the trace of the overthrust in the canyon of Lost Creek. . . . strata in the west flank of the anticline are folded in a syncline trending parallel to the reverse fault. The shale beds in the Colorado Shale are altered to slate and phyllite and have excellent cleavage. The sandstone and chert conglomerate beds are altered locally to quartzite. The metamorphism and folding can be attributed to the early phases of the Laramide orogeny and the consequent granite intrusion. Minor folds in the Colorado Shales . . . seem related to the period of earlier normal faulting.

Some folding and the system of normal faults that cuts the Tertiary strata are related to the latest deformation in the area. In general, the normal faults strike northward and northeastward and are downthrown to the east; in places they are intersected by transverse faults. . . . The throw on the faults seems to increase to the south where strata of Miocene(?) age are in juxtaposition with Eocene rocks. North of Lost Creek the basal Tertiary rocks are locally in fault contact with the Colorado Shale. In this area Tertiary rocks bevel steeply dipping older formations, and the unconformities can be easily mistaken for faults.

In sec. 35, T. 5 N., R. 11 W., the conglomerate of Miocene(?) age is folded and cut by faults. The large anticlinal fold exposed in the abandoned tramway is cut on the north end by a northeastward-trending fault. Another anticline that is subparallel and lies to the east is cut by two eastward-trending cross faults. The axis of this anticline is offset to the east. Other faults occur in the vicinity of small andesite intrusive bodies. At these localities the faults seem to have been emplaced concurrent with the intrusive bodies or shortly thereafter. . . .

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MURRAY C. GARDNER (503) 482-2605

In secs. 29, 30, and 32, T. 6 N., R. 10 W., along Deer Lodge Valley, two fault scarps are in the Pliocene gravel. In this area the underlying Miocene(?) strata are sharply folded in a northwestward-trending anticline which seems to be on the upthrown side of the fault zone. On areal photographs the fault scarps appear as linear features where they cut the Pliocene gravel. The gravel beds are not as tightly folded as the underlying Miocene(?) rocks, and the faults that cut the gravel beds probably are superimposed on an older fault system. This latest period of faulting is related to the most recent deformation in the area.

Most of the sedimentary basement rocks in the mountains around Deer Lodge Valley have been folded and faulted. Along the front of the Flint Creek Range they are generally folded into a series of anticlines and synclines that trend northeast-southwest. The Range has been described . . . as a domal structure that was probably formed by folding rather than faulting. . . . the northern part of the Flint Creek Range appears to be arched . . . the change from broad gentle slopes around the margins of the northern part of the range to abrupt valley-wall relief south of Rock Creek is probably due to recent faulting. The remarkably straight erosion scarp between Rock Creek and Robinson Creek cuts uniformly across basement rocks and unconsolidated drift along its 2-1/2-mile extent . . . and may be a recent faultline scarp.

Most of the exposed lower or middle Tertiary beds and the associated welded tuff unit of the Lowland Creek Volcanics have been greatly deformed by folding, faulting, or slumping. Some are completely overturned. Near the mouth of Warm Springs Canyon they are variously oriented; but between Spring Gulch and Dempsey Creek, there is generally a westward trend in dip. . . .

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MURRAY C. GARDNER (503) 482-2605

Much of the Miocene fill is also deformed. Across the north end of the valley, in the area between Marsh Creek and Rock Creek, the dip trends south-southeast. . . . The few patches of exposed Miocene sediments on the east side of the valley are undeformed.

The dip of the exposed Pliocene strata is about parallel to the slope of the high terrace and is probably a function of the original environment of deposition. However, some of the Pliocene strata between Modesty Creek and Spring Gulch are down faulted to the west and dip into the Flint Creek Range. . . . The down faulting and the westward dip of the lower or middle Tertiary strata are probably due to local subsidence along the base of the Flint Creek Range.

. . . major folding and local thrust faulting in the northern Boulder batholith region east of the Deer Lodge Valley culminated in the very Late Cretaceous or very early Tertiary emplacement of the batholith. . . . Uplift and erosion during Paleocene and Eocene time resulted in a mountainous terrane and partial deroofing of the batholith. Oligocene gravel and rhyolitic sediments accumulated in subsiding intermontane basins; tilting of Oligocene basin deposits, partly associated with movement on the range front faults, preceded deposition of stream gravels of Miocene and Pliocene age. Pediments formed in late Tertiary to Pleistocene(?) time. . . .

The Deer Lodge Valley probably was a major topographic low during deposition of the Lowland Creek Volcanics (early Eocene). The volcanics filled various canyons about the base of the Flint Creek Range and the abrupt relief and orientation of these canyons suggests a major topographic low to the east. . . .

During Miocene time the ancestral Clark Fork may have flowed southward. . . . In late Miocene or early Pliocene the north end of the Deer Lodge

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MURRAY C. GARDNER (503) 482-2605

Valley was down faulted at least several hundred feet and the Tertiary deposits were faulted and tilted.

Uplift, which occurred after deposition of the older moraine and as late as Recent time, affected the southeastern areas of the valley. The uplift was accompanied and followed by northward migration of tributary streams on the east side of the valley. The recently formed scarp trending north-south at the base of the mountain slopes between Robinson Creek and Mullan Creek may be a fault-line feature.

Geophysical Data.

There is a significant body of geophysical data for the Boulder batholith and portions of Deer Creek Valley. Principal among these data are Bouguer gravity maps and cross-sections and aeromagnetic maps and cross-sections.

Gravity studies were made by E. A. Cremer; the results were included as a residual gravity map and cross-sections with explanatory text in Konizeski *et al.* (1968). The map is at a scale of 1:62,500 and is contoured at 2 milligals. The 300 gravity stations almost all were located along a line parallel to the main axial road of the valley and along 4 traverses perpendicular to it. Station density is great south of Opportunity, near Anaconda and near Gregson Hot Springs. As many as 20 stations are strung out within a single section. However, there are areas within the central part of the valley, about 4 square miles in area, where there are no stations. The map is included as Plate I accompanying this report.

The residual gravity map and accompanying cross-sections show a maximum thickness of 5,500 feet of valley-fill in the southern part of the valley, north of Opportunity. A gravity low with a 5-mile diameter and maximum of 8 milligals of closure, is centered one mile north of Opportunity. There is a total of 20 milligals of relief between the low and the bedrock areas at the margins of the valley.

There appears to be at least 5,000 feet of valley fill in the valley as far north as the town of Deer Lodge. However, Cremer's sections indicate that there are volcanic flow rocks or basement horsts

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MURRAY C. GARDNER (503) 482-2605

that reduce the thickness of fill to less than 3,000 feet in the west-central part of the valley. Bedrock probably consists of Early Tertiary volcanic rocks or pre-Tertiary sedimentary rocks.

The steep gradient on the east side of the valley is indicative of a major fault. The fault, masked by surface deposits and apparently older than middle Tertiary, would be the logical continuation of a fault mapped southeast of the valley by Konizeski et al. (1968). Cremer also postulated faults bounding the western side of the valley, and a general thickening of valley fill from north to south. Another very steep gradient (14 milligals in 1 mile) occurs along a 5-mile northwesterly trend from Gregson Hot Springs to Anaconda. The regional gravity gradient, represented by a flat surface sloping southward, was filtered from the completed Bouguer map.

The entire east side of Deer Lodge Valley, south of Deer Lodge, is included within one gravity low. The same low extends eastward to Butte and Elk Park. Hanna's gravity profiles do not extend to the central part of Deer Lodge Valley, because he was concerned mainly with gravity and magnetic changes over mineralized areas. He equated gravity lows in the region with low-density volcanic rocks, such as the Lowland Creek Volcanics, as well as with youthful sedimentary rocks and alluvium. These rocks are much less dense than the Boulder batholith. However, the Boulder batholith was noted by Hanna to have the form of a 70- by 35-mile regional gravity low. Thus, it is important to separate regional features from specific local features.

A comprehensive aeromagnetic map by Johnson et al. (1965), at a scale of 1:250,000, includes the Deer Lodge Valley and bounding mountain ranges (Plate II of this report). Aeromagnetic map features parallel gravity features rather closely along the west side of Deer Lodge Valley. A steep gradient, ascending eastward, runs north-northeast from Gregson Hot Springs to about 5 miles south of Deer Lodge. Magnetic relief is about 400 gammas, from a maximum at the mountain front 5 miles east of Opportunity, to a low shelf between Anaconda and Opportunity. The same gradient, about 100 gammas per mile, was noted by Hanna (1969) to exist near the edges of the regional magnetic high associated with the Boulder

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batholith. Positive aeromagnetic features, with 5-mile diameters of closure and more than 100 gammas of relief within the area of closure, are located south of Gregson Hot Springs, where a high is approximately coincident with Sugarloaf Mountain. Other highs occur along the Continental Divide, along the axis of the Flint Creek Range, and in the central part of the Garnet Range. Lows occur within these highs, especially in the area of the Boulder batholith north of Butte. However, this area cannot be said to exhibit strong magnetic relief.

Aeromagnetic features within the Deer Lodge Valley are still more subtle than those of the mountain ranges. Gradients outline the valley; steep gradients are on the east and south, and gentler gradients occur on the west and north sides.

Within the valley, there are magnetic highs with less than 30 gammas of closure centered 5 miles northeast of Anaconda and 3 miles west of Deer Lodge. A low with 20 gammas of closure is centered 2 miles north of Galen. Gregson Hot Springs is on a narrow neck or saddle between 2 magnetic highs. This relief is too small to be interpreted without detailed studies of magnetic susceptibility of rock types in the area and careful processing of the intensity data.

Two magnetic trends are apparent on a regional basis. One is a north-northeasterly trend; the other an easterly trend. Together, there is an en echelon effect which gives a false impression of a single northeast trend.

Hanna (1969) discussed the aeromagnetic anomalies in the Boulder batholith area. He concluded that negative anomalies in the region of the Boulder batholith are associated with weakly magnetic rocks, normally polarized, in contact with somewhat more strongly magnetic rocks, also normally polarized. It was apparent to Hanna that certain of the plutonic and volcanic rocks are less magnetic than other plutonic and volcanic rocks within or bordering the batholith. Gravity data indicate that the rocks in areas of magnetic lows also are somewhat less dense than rocks of similar lithologies elsewhere. It was therefore concluded that intrusion of masses of silica-rich vein material within the batholithic complex caused both the low gravity and low magnetic values in the rocks of the batholith. The originally low amounts of magnetic iron oxides, combined with subsequent hydrothermal alteration to

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MURRAY C. GARDNER (503) 482-2605

non-magnetic iron oxides during episodes of mineralization, may account for the anomalously low magnetic and gravity values.

Other magnetic lows, such as one northwest of Butte, are attributed to centers of silicic intrusion within the batholith. Finally, lows east-southeast of Deer Lodge and near Basin were determined to result from reversed polarity. Shallow magnetic depressions, which appear at the northwest and southeast edges of the batholith, appear to represent relatively non-magnetic sedimentary rocks and alluvium.

The gross structures and lithologies determined by geologic mapping are confirmed by the accumulated gravity and magnetic data. The presence of large areas of altered rock in the subsurface is also indicated by these data. The alteration zones appear to be fossil effects from the mineralization episodes of Cretaceous to Middle Tertiary time, rather than effects of a current phase of thermal activity.

The Montana Power Company recorded seismic data (apparently reflection or refraction profiles) in the Flint Creek Range and Deer Lodge Valley. The data were not available for this report. However, according to Konizeski et al. (1968), information gathered in the seismic survey support the interpretations obtained from the gravity survey and geologic mapping. The seismic data indicate that the Powell Mountain fault, bounding the Deer Lodge Valley, extends from the Flint Creek Range into the Deer Lodge Valley near Deer Lodge; at least the oldest Tertiary strata are affected. Seismic exploration data also indicate that the major normal and thrust faults associated with the Powell Mountain structural zone have decreasing vertical displacement as they are followed from the mountain front for several miles into the valley. The location of the principal bounding faults and the depth of basin fill are consistent with the concept of a graben structure. It was not positively determined whether Pliocene and younger strata were cut by faults.

No heat-flow studies are known to have been conducted in the Deer Lodge Valley, but Professor David D. Blackwell of Southern Methodist University, who did detailed heat flow work at Marysville, obtained two values of heat flow nearby. One measurement, from a drill hole in the Butte Quartz Monzonite of the Boulder batholith, was 2.2 microcalories per square centimeter per second (H.F.U.) and

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one in the underground workings at Butte was 2.1 H.F.U. Calculations by Tilling and Gottfried (1969) indicate that the observed heat flow can be fully attributed to radiogenic heat in a column of rocks about 30 kilometers thick. Limited seismic refraction data indicate that the crust is 45 kilometers thick in the Boulder batholith area.

There are no published electrical resistivity surveys of the area, but it is certain that shallow surveys have been accomplished by the major mining companies in the mineralized zones of the Boulder batholith and Philipsburg mining district.

Radiometric age-dates have been obtained for rock samples of the Boulder batholith and Lowland Creek Volcanics. Smedes and Thomas (1965) obtained potassium-argon dates of 48 to 50 m.y.b.p. from 4 samples of flows and feeder dikes of the Lowland Creek Volcanics. Boulder batholith specimens examined by potassium-argon methods have given age-dates similar to those of the Idaho batholith in Idaho and western Montana, namely latest Mesozoic. The most common dates are distributed between 66 and 80 m.y.b.p. It appears that the episode of pre-batholith volcanism, which produced the Elkhorn Mountains Volcanics, and the initial emplacement of the batholith, were quite close in age. Geochronometry has not been able to separate the events; both were dated by potassium-argon method at about 78 m.y.b.p. Only 20 million years separates the end of the emplacement of the Boulder batholith from the onset of Lowland Creek volcanism. Post-Lowland Creek volcanic rocks apparently have not been age-dated, but a Miocene-Pliocene age has been conjectured based upon field relationships. The younger rocks are rhyolite and quartz dacite plugs, dikes and flows, which crop out mainly in the northern and northwestern part of the Boulder batholith area.

Subsurface Data.

Many wells have been drilled in and adjacent to Deer Lodge Valley. An inventory in 1957 and 1960 listed data from 270 wells and springs. Most of the wells are shallower than 200 feet, and are drilled along the Clark Fork flood plain. Information from selected wells, from Konizeski *et al.*'s open-file summaries, is shown in table 1. Water-level measurements, well yield, lithology and other hydraulic factors are given. Chemical data, unfortunately, are lacking.

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MURRAY C. GARDNER (503) 482-2605

There are few deep wells, at scattered locations in the valley. A Montana Power Company test well (the utility considered construction of underground gas-storage facilities in the area) about 5 miles southeast of Deer Lodge penetrated to a depth of 2,536 feet. The top 2,500 feet were in Tertiary sediments, and the well apparently bottomed in tuff. The uppermost 300 feet of the section was considered to be middle Pliocene by Konizeski et al. (1968), and the remainder younger than middle Eocene in age. The well apparently is east of the fault that bounds the west side of the valley.

A water well was drilled at Garrison by the Northern Pacific Railroad. From a collar elevation of 5,000 feet, the well penetrated more than 650 feet of Cenozoic sediments. It bottomed in "basement" rocks, which may have been either Early to Middle Tertiary volcanic rocks, or Mesozoic metamorphic rocks.

There are three municipal wells one mile west of Anaconda and three municipal wells at Deer Lodge; none penetrates below Tertiary sediments. Wells at the State institutions along the Clark Fork channel are completed in Tertiary sediments.

GEOHYDROLOGY

Surface Water.

The drainage system of Deer Lodge Valley and the adjacent mountain ranges was described earlier in the report. It includes the master stream of the area, Clark Fork, and its tributaries.

The mean annual flow of the Clark Fork at Deer Lodge varies from 175 to 325 cfs, but may drop below 50 cfs during May to September. Most of the flow of tributary streams is lost by seepage and diverted to irrigation and industrial uses, except during flood stage.

The Clark Fork normally is an effluent stream. For a short period during spring runoff it rises with snow melt, and some water is recharged into the ground-water reservoir. Water taken from the stream to irrigate 5,000 acres in the valley also eventually percolates to the water table.

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Major tributaries are perennial and influent in their upper reaches, but are dry during the summer in their lower reaches due to loss by diversion for irrigation. Some of the streams flow in their lower reaches, notwithstanding diversion for irrigation, notably Warm, Willow, Mill, Lost, Modesty, Dempsey, Peterson, Cottonwood and Tincup Creeks. An extreme example of seasonal variation is Cottonwood Creek, which may drop from 160 cfs to 1 cfs between the end of May and the beginning of September. A total flow of 75,000 acre-feet, or 2.3×10^{10} gallons of water, was measured in the tributaries during 1961. Nearly one-third of the total flow (24,000 acre-feet) was accounted for by Warm Springs Creek. Almost all the flow from the tributary streams is diverted to irrigate 30,000 acres of land, with lesser amounts for industrial use.

Lost, Dutchman, Warm Springs, and Willow Creeks are effluent in their lower reaches during most of the year, and particularly during April and May. More than 70 cfs of ground water is estimated by Konizeski *et al.* (1968) to be discharged during that period into all 4 creeks. It may thus be seen that the hydrologic system is complex and a water budget difficult to assess. Further complications occur because irrigation drainage ditches in the valley may discharge as much as 30 cfs into Clark Fork. Also, two open drains from the Anaconda settling ponds have a combined discharge of about 15 cfs: this includes discharge of tailings water from the Anaconda Company (Washoe) smelter. The results of percolation from the tailings are unknown. These may carry large amounts of heavy metals and other chemical contaminants in solution. This has made the Anaconda Company object to sampling and analysis of water from the Deer Lodge Valley. Certain apparent effects on vegetation and the obvious need for remedial action have made company officials uncooperative toward hydrogeochemical surveys.

Gregson Hot Springs, Anaconda Hot Springs, and Warm Springs together discharge several hundred gallons per minute. These thermal manifestations are described in a later section of the report.

Ground Water.

Ground-water information for the area is mostly limited to conditions of the upper few hundred feet of the valley fill within Deer Lodge Valley. Most wells in the area are less than 250 feet deep, with the exception of the few observation holes previously discussed.

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Ground-water conditions range from slightly artesian to having static levels about 150 feet below surface. Deeper levels are found mostly in the alluvial fans and beneath terraces. Ground water occurs both as intergranular fluid in Quaternary and Tertiary sediments and in joints and fractures of indurated volcanic rocks. Water in the Tertiary rocks is generally confined, whereas that in the thin mantle of Quaternary rocks is not confined. Consolidated rocks in the surrounding mountains, according to Konizeski et al. (1968), are aquitards. Such conditions would cause boundaries to exist between the Deer Lodge Valley and adjacent basins, and would cause minor ground-water divides at the intra-basin ridges underlain by basement rocks. However, almost nothing is known of the ground-water basin from direct observation, as no deep wells penetrate the consolidated pre-Tertiary rocks within the valley.

The concept of divisions described by Konizeski et al. are a bit antique: it is well established that pressure gradients rather than small changes in permeability determine flow regimes. There are too little data available to assume anything about the permeability of the rocks in the mountain ranges surrounding Deer Lodge Valley or beneath the valley.

The alluvium beneath the flood plain of the Clark Fork consists of medium- to well-sorted unconsolidated gravel. Coefficients of transmissibility ranged from 25,000 to 80,000 gallons per day per foot (gdf) in sections tested by wells (table II). Specific capacities ranged from 6 to 36 gallons per minute per foot in the same area (table II). The alluvium of the flood plain is limited in thickness and extent. No wells occur in the moraine deposits, whose sorting and clay content indicate low transmissibility. Transmissibility varies greatly within the thick alluvial-fan material west of the Clark Fork flood plain: values range from 20,000 to 175,000 gdf in tested wells. Specific capacity also has a wide range: 26 to 1,200 gallons per minute per foot of drawdown were observed in the U.S.G.S. well-testing program (Konizeski et al., 1968).

At depth, the Tertiary sediments consist of unconsolidated to semi-consolidated fluvial silt with interfingering sand and gravel. Transmissibility, measured in 5 wells scattered across the valley, ranged from 600 to 70,000 gdf. Specific capacities were mostly less than 10 gallons per minute per foot of drawdown; the range was from less than 1 to 40. The Tertiary sediments generally are less permeable than the younger alluvium. Thicknesses of individual beds are greater than in the Quaternary sediments.

Table I. Data on selected water wells of Deer Lodge Valley, Montana
(from a 1961 Montana State office report by Konizeski)

Well number: See explanation of well-numbering system in text.
Type of well: Dn, driven; Dr, drilled; Du, dug.
Depth of well: Reported depths are shown in whole feet below land surface; measured depths are shown in feet and tenths below land surfaces.
Type of casing: C, concrete; P, pipe; R, rock; W, wood.
Type of pump: C, centrifugal; Cy, cylinder; J, jet; N, none; P, pitcher; T, turbine.

Type of power: E, electric; H, hand; N, none.
Use of water: D, domestic; F, firefighting; I, irrigation; O, observation; S, stock; U, used; PS, public supply; In, industrial.
Measuring point: Tca, top of casing; Tco, top of cover.
Altitudes determined by spirit level.
Remarks: Log.

Well number	Owner or tenant	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Type of pump	Type of power	Use of water	Description	Measuring point		Depth to water level below measuring point (feet)	Date of measurement
											Distance above or below land surface (feet)	Altitude		
3-10-1aa	John Green		Du	23.1	24	C	J	E	U	Tco	-5.0	5142.1	9.76	8-3-60
3-10-1cd	William Peterson		Dr	26.4	6	P	J	E	D	Tca	-3.9	5113.7	4.94	--do--
3-10-2ba	Ray Spangler		Dr	23.1	4	P	C	E	D	Tca	-6.3	5127.6	3.63	--do--
4-9-3lbd	-----do-----		Dr	70.2	6	P	N	N	O	Tca	2.7	5110.7	24.95	--do--
4-10-8dc	Dave Williams		Du	45.3	48x48	W	Cy	H	U	Tco	.3	5130.1	28.50	7-28-60
4-10-9ab	Jospeh Blevins		Du	6.2	30	R	N	N	U	Tca	0.0	5004.8	3.86	9-7-60
4-10-9bd	Mt. Haggin Land and Livestock Co.		Du	29.3	48x48	C	N	N	D	Tco	1.0	5037.3	18.46	7-6-60
4-10-9da	Anaconda Country Club		Du	12.7	---	C	Cy	E	U	Tco	1.3	5003.1	10.70	7-27-60
4-10-10ad	Olga Hansen		Du	5.4	18	C	P	H	D	Tco	1.1	4941.1	4.58	--do--
4-10-10cc	Opportunity Fire Dept.		Br	22.6	6	P	N	N	F	Tca	1.9	5003.9	5.52	7-26-60
4-10-10db	Darcy Delong		Du	6.1	30-24	C	N	N	U	Tca	1.5	4963.3	6.30	7-27-60
4-10-10dcl	Opportunity Fire Dept.		Dr	17.1	6	P	N	N	F	Tca	2.1	4973.0	5.68	7-26-60
4-10-10dc2	-----do-----		Dn	20.0	4	P	N	N	F	Tca	1.3	4978.8	5.35	--do--
4-10-11dd	U.S. Geol. Survey	1960	Dn	8.2	3/4	P	N	N	O	Tca	3.0	4925.7	8.75	8-16-60
4-10-15aa	James Rouse	1958	Dr	23.1	6	P	N	N	O	Tca	.5	4947.9	2.80	7-27-60
4-10-15ac	Opportunity Fire Dept.		Dn	18.4	6	P	N	N	F	Tca	1.6	4974.4	5.77	7-26-60
4-10-15ba	-----do-----		Dn	20.8	6	P	N	N	F	Tca	2.4	4994.6	5.90	--do--
4-10-15cb	Mt. Haggin Land and Livestock Co.		Du	9.2	36x36	W	C	E	S	Tco	0.0	5012.9	2.44	7-27-60
4-10-15da	Opportunity Fire Dept.		Dn	18.6	6	P	N	N	F	Tca	1.4	4965.2	3.34	7-26-60
4-10-16cd	Mt. Haggin Land and Livestock Co.		Dr	70.6	4	P	J	E	D,S	Tca	-2.0	5061.6	4.00	7-28-60
4-10-17bb	Raymond Patterson		Du	51.2	---	--	J	E	D	Tco	.5	5178.1	17.60	--do--
4-10-17bd	Bonneville Power	1953	Dr	125.0	10-5	P	T	E	O	Tca	-7.3	5162.1	40.93	8-2-60
4-10-18ac	Edward Noll		Du	20.0	24	C	N	N	U	Tca	-5.70	5207.5	5.81	7-28-60
4-10-18db	Bill Latray	1960	Dr	68.4	6	P	J	E	D	Tca	1.0	5231.0	25.74	--do--
4-10-22bb	U.S. Geol. Survey	1960	Dn	6.8	3/4	P	N	N	O	Tca	3.7	5017.3	6.94	8-16-60
4-10-22dcl	Leonard Roffler	1957	Dr	37.8	6	P	N	N	F	Tca	3.0	5008.1	7.56	8-2-60
4-10-23cc	W.F. Ritschel		Du	7.3	30	R	N	N	S	Tco	0.0	4987.2	4.28	8-3-60
4-10-25bc	Montana Power Co.	1931	Dr	78.8	6	P	N	N	O	Tca	3.0	4996.1	43.69	9-12-60
4-10-26cb	Ben Poston	1957	Du	15.8	24	C	J	E	D	Tca	.4	5014.6	13.83	8-2-60
4-10-26dd	L.S. Johnson	1955	Dr	57.9	6-4	P	J	E	D	Tca	.3	5035.1	43.68	8-3-60
4-10-27ac	Mt. Haggin Land and Livestock Co.		Du	8.7	48x60	W	Cy	H	S	Tco	1.0	5009.9	4.44	8-2-60
4-10-36abl	Lewis Wertz		Dr	73.0	6	P	N	N	O	Tca	2.0	5054.5	50.97	8-3-60
4-11-1bb	Anaconda Copper Mining Co.	1957	Dr	82.7	2	P	N	N	O	Tca	.5	5192.9	23.63	7-26-60
5-9-5ba	Paul Noack		Du	31.3	30	R	Cy	H	U	Tca	0.0	4769.5	26.64	8-9-60
5-9-5cd	-----do-----		Du	17.0	48	R	J	E	D	Tca	0.0	4765.5	12.33	--do--

Table I, continued

5-9-6dc	U.S. Geol. Survey	1960	Dn	9.5	3/4	P	N	N	O	Tca	1.0	4758.1	5.04	8-8-60
5-9-7cb	-----do-----	1960	Dn	9.6	3/4	P	N	N	O	Tca	1.0	4780.7	7.50	8-17-60
5-9-17bc	Montana Power Co.	1931	Dr	131.0	6	P	J	E	D,O	Tca	0.0	4827.4	42.95	8-9-60
5-9-18ab	U.S. Geol. Survey	1960	Dn	8.1	3/4	P	N	N	O	Tca	2.4	4783.6	7.46	8-10-60
5-9-29bc	Anaconda Copper Mining Co.		Du	20.0	20	P	J	E	D	Tca	-3.5	4843.5	5.23	9-12-60
5-10-2aal	Mt. Haggin Land and Livestock Co.		Du	34.5	48	R	J	E	D,S	Tco	1.0	4870.5	25.80	6-20-60
5-10-3aa	-----do-----		Dr	105.4	6	P	N	N	U	Tca	0.0	4926.0	64.90	8-1-60
5-10-3cb	-----do-----		Dr	152.0	6	P	Cy	N	U	Tca	2.0	5029.9	88.37	9-13-60
5-10-3dd	-----do-----		Dr	80.0	6	P	N	N	O	Tca	2.6	4924.3	55.05	6-22-60
5-10-4aa	C.P. Shonnard	1958	Dr	245.5	8	P	N	N	O	Tca	3.5	5084.6	149.46	--do--
5-10-10cb	Mt. Haggin Land and Livestock Co.		Dr	74.8	6	P	N	N	U	Tca	1.0	4963.8	61.91	9-7-60
5-10-13bc	U.S. Geol. Survey	1960	Dn	9.8	3/4	P	N	N	O	Tca	1.0	4831.9	8.65	8-16-60
5-10-13da	-----do-----	1960	Dn	9.0	3/4	P	N	N	O	Tca	1.7	4808.7	7.98	--do--
5-10-14dc	Mont. State Hospital	1939	Dr	8.2	6	P	N	N	U	Tca	1.2	4857.6	8.05	9-22-60
5-10-15ba1	Mt. Haggin L. & L. Co.		Dr	56.2	5	P	N	N	O	Tco	0.0	4888.7	13.71	6-22-60
5-10-16ac	-----do-----		Dr	98.3	6	P	N	N	O	Tca	.5	4966.0	37.40	7-4-60
5-10-16dc	-----do-----		Du	14.8	24	C	Cy	H	U	Tco	0.0	4933.0	11.26	--do--
5-10-17ca1	Steve Tribovitch		Dr	59.1	6	P	N	N	O	Tca	.8	5035.9	43.04	7-5-60
5-10-17cb	-----do-----		Dr	89.5	12-8	P	T	N	U	Tca	1.0	5059.9	66.63	--do--
5-10-20cd	Mt. Haggin L. & L. Co.		Dr	59.4	6	P	Cy	H	D	Tca	.6	5031.4	37.40	--do--
5-10-22dd	Mont. State Hospital	1949	Dr	141.5	12	P	N	N	U	Tca	.5	4903.7	3.40	8-9-60
5-10-23dc	Simplex Homes	1959	Dr	48.0	6	P	C	E	U	Tca	.7	4881.7	5.37	7-5-60
5-10-23dd	Harold Slye	1957	Dr	51.2	6	P	J	E	D	Tca	0.0	4874.0	11.40	--do--
5-10-24cb	U.S. Soil Cons. Ser.	1954	--	8.4	3	P	N	N	O	Tca	.8	4858.5	6.74	8-16-60
5-10-24da	U.S. Geol. Survey	1960	Dn	9.2	3/4	P	N	N	O	Tca	1.2	4841.0	7.67	--do--
5-10-25da	-----do-----	1960	Dn	4.1	3/4	P	N	N	O	Tca	1.3	4856.5	1.90	8-23-60
5-10-33ab	-----do-----	1960	Dn	8.3	3/4	P	N	N	O	Tca	2.2	5009.1	7.11	8-16-60
5-10-33da	Anaconda Copper Mining	1937	Dr	52.2	16	P	N	N	U	Tca	0.0	4996.0	2.73	9-21-60
5-11-33ca1	-----do-----	1937	Dr	46.0	16	P	T	E	In,PS	---	---	flows	---	---
5-11-33ca2	-----do-----	1937	Dr	47.0	16	P	T	E	In,PS	---	---	5.00	---	---
5-11-33ca3	-----do-----	1937	Dr	52.0	16	P	T	E	In,PS	---	---	4.00	---	---
6-9-19ac2	U.S. Geol. Survey	1960	Dn	8.1	3/4	P	N	N	O	Tca	2.0	4728.8	7.35	8-16-60
6-9-19db	Fred Jacobson		Du	21.5	48	C	N	N	U	Tca	-5.5	4737.2	3.19	8-10-60
6-9-20bd	Lewis Pinocci		Dr	25.5	6	P	J	E	D	Tca	-2.0	4689.7	1.32	8-8-60
6-9-21cd1	Wallace Beck		Dr	150.0	6	P	S	E	D,S	Tca	.5	4785.5	91.25	9-12-60
6-9-21cd2	Quintin Rickter		Dr	160.0	6	P	J	E	D,I	Tca	0.0	4809.6	115.37	9-7-60
6-9-29ac	Robert Johnson		Dr	15.6	6	P	N	N	U	Tca	0.0	4703.9	2.66	8-8-60
6-9-29bb	U.S. Geol. Survey	1960	Dn	8.2	3/4	P	N	N	O	Tca	2.3	4708.2	3.45	8-22-60
6-9-30ab2	-----do-----	1960	Dn	6.1	3/4	P	N	N	O	Tca	1.5	4727.7	.64	9-6-60
6-9-30cd	Donald Beck		Du	10.0	---	---	C	E	D	Tco	1.6	4754.5	6.46	8-10-60
6-9-31bb	Mont. T.B. Sanitarium	1956	Dr	208.0	30-12	P	T	E	PS	---	---	25.00	---	---
6-9-31cd	Mt. Haggin L. & L. Co.		Du	157.0	6	P	J	E	D	Tco	-8.5	4772.3	.73	9-7-60
6-9-31dd	U.S. Geol. Survey	1960	Dn	8.2	3/4	P	N	N	O	Tca	2.5	4745.0	5.39	8-10-60
6-9-32aal	Robert Johnson		Du	18.8	48	R	N	N	O	Tca	0.0	4732.2	12.95	8-8-60
6-10-22dd	Art Job		Du	5.0	---	W	N	N	U	Tco	0.0	4929.3	1.35	6-20-60
6-10-23bb	Andy Nicholes		Dr	175.0	4	P	Cy	H	O	Tca	1.0	4926.6	21.94	6-21-60
6-10-23bc	-----do-----		Du	37.4	12	P	J	E	S	Tco	-6.0	4925.6	11.38	--do--
6-10-23da	Catherine Vanisko		Dr	96.7	6	P	J	E	S	Tca	-6.2	4890.2	62.32	--do--
6-10-23dc	-----do-----		Dr	113.0	8	P	T	N	I	Tca	1.0	4906.7	16.12	9-7-60
6-10-26ab	Alfred Joseph		Du	19.9	12	P	C	E	I	Tco	0.0	4893.9	7.78	6-20-60
6-10-26dc	Frank Jones		Du	6.2	36	C	Cy	N	O	Tco	1.1	4880.7	3.08	--do--
6-10-27aa	Amelia Donich		Du	12.4	24x36	W	N	N	O	Tca	1.0	4929.1	1.48	6-22-60
6-10-27cc	Mt. Haggin L. & L. Co.		Dr	88.7	6	P	N	N	O	Tca	.5	5005.7	60.88	6-21-60
6-10-28bb	Dell Jennings		Du	71.5	48	C	J	E	D	Tca	2.8	5114.7	55.78	--do--
6-10-34ad	Mt. Haggin L. & L. Co.		Du	27.2	60	R	N	N	U	Tco	1.0	4914.8	12.81	6-22-60
6-10-34dd	-----do-----		Dr	84.9	6	P	N	N	O	Tca	.5	4924.7	24.58	6-21-60
6-10-35ab	Donald Beck		Du	3.3	18	C	N	N	D	Tca	.2	4868.6	.71	6-20-60

Table I, continued

Well number	Tenant or Owner	Year drilled	Type of well	Depth of well (feet)	Diameter of well (inches)	Type of casing	Type of pump	Type of power	Use of water	Description	Distance above or below (-) land surface (feet)	Altitude above mean sea level (feet)	Distance to water level be- low measuring point (feet)	Date of measurement
6-9-4ab	R. J. Johnson		Dr	17.1	6	P	-	G	D,S	Tca	1.0	4631.1	6.03	7-31-57
6-9-4bb	-----do-----		Du	14.3	-	R	-	G	I	Tco	0.0	4644.1	7.56	7-31-57
6-9-4cc	-----do-----		Du	7.9	-	-	-	H	S	Tco	0.1	4658.0	4.05	7-31-57
6-9-4da	Frank Jensen		Du	23.2	42	R	-	H	N	Tco	0.0	4645.0	20.74	7-31-57
6-9-6ac	Albert Beck		Du	15.7	-	-	C	E	S	Tco	0.0	4710.4	8.49	8-1-57
6-9-7ad	Melvin Beck		Du	6.7	-	-	N	N	N	Tco	0.0	4718.9	4.59	9-4-57
6-9-7cd	Kate Vanisco	1900	Du	11.3	-	-	-	H	D	Tco	0.2	4756.5	6.23	8-2-57
6-9-8aa	Frank Staffanson		Du	8.1	-	W	-	E	S	Tco	0.1	4673.3	4.64	8-29-57
6-9-8ad	U.S. Geol. Survey	1957	Dn	10.2	3/4	P	N	N	O	Tca	0.7	4685.9	4.95	8-25-57
6-9-9da	P. Hanson		Dr	-	6	P	-	E	-	Tca	-5.0	4648.8	2.68	12-3-57
6-9-9dd	U.S. Geol. Survey	1957	Dn	10.6	3/4	P	N	N	O	Tca	1.0	4657.0	6.18	8-26-57
6-9-17aa	Geil and McGhee	1955	Dr	21.0	-	-	C	E	I	Tco	0.0	4688.8	4.66	7-31-57
6-9-17da	Wendel Peterson		Du	5.8	-	-	N	N	N	Tco	2.2	4690.0	5.33	7-31-57
6-9-18ab	Paul Peterson	1952	Dr	16.6	6	P	J	E	D	Tco	1.0	4738.9	8.89	8-2-57
6-9-18dd	Sid Bennet	1948	Dr	61.7	10	P	N	N	N	Tca	3.5	4734.7	18.17	8-2-57
6-9-21ba	Alvin Beck	1945	Du	9.8	-	-	N	N	S	Tca	0.5	4680.4	7.51	7-31-57
6-10-1ad	Peter Fleming	1952	Dn	22.1	-	-	-	H	D	Tca	1.7	4762.8	14.35	8-5-57
6-10-5aa	Tom Ryan		Dn	18.0	16	-	-	-	N	Tca	0.0	5167.0	8.15	8-5-57
6-10-8bd	Henry Huot		Du	17.4	-	-	-	H	D,S	Tco	0.1	5076.0	7.70	8-5-57
6-10-12da	Ray Kelly		Du	16.3	-	-	-	H	D	Tco	2.3	4769.9	8.30	8-2-57
6-10-14ac	Jos Jette		Du	8.1	-	-	-	-	N	Tca	0.0	4854.4	7.03	3-2-57
6-10-14ca	Jack D. Kelly	1947	Dr	84.0	6	P	J	E	D,S	Tco	-6.0	4878.8	8.50	8-7-57
6-10-15aa	Superior School		Du	12.6	-	-	N	N	N	Tco	0.0	4884.2	7.23	8-2-57
7-8-5ba	Zosel Sisters		Du	11.7	-	-	-	-	N	Tco	0.0	5094.0	10.54	8-7-57
7-8-6bb	Bob Cowan	1948	Du	4.7	-	-	C	E	D	Tca	-4.0	4954.0	3.14	9-5-57
7-8-7db	Lloyd Cowan		Du	22.0	3½	R	C	E	D	Tco	4.0	5317.0	12.20	9-6-57

Table I, continued

7-8-17da	C. K. Warren		-	20.5	-	W	N	N	N	Tca	1.2	5691.0	16.31	9-5-57
7-8-18aa	-----do-----		Du	21.9	-	R	N	H	S	Tco	0.0	5430.0	8.35	9-5-57
7-8-20cb	-----do-----		Du	6.8	-	-	N	N	N	Tco	0.0	5518.0	2.31	9-6-57
7-8-21ba	-----do-----		Du	51.7	-	R	-	-	N	Tco	0.1	5803.0	39.95	9-5-57
7-8-29cd	Havens & Croonquist		Du	9.8	-	-	N	N	N	Tco	0.0	5883.0	7.86	9-6-57
7-9-8ad	Thom Woodward		Du	12.7	-	-	N	N	N	Tco	0.0	4550.5	6.47	8-1-57
7-9-9aa	Carl Ulver	1914	Du	34.7	-	-	C	E	D, I	Tca	0.4	4558.4	32.54	7-31-57
7-9-10bc1	J. D. Gabelhei		Dr	112.0	6	P	J	E	D	Tca	-8.0	4588.5	57.23	8-20-57
7-9-10bc2	Gale Singleton		Dr	113.5	6	P	J	E	D, S	Tca	-7.0	4598.7	63.20	8-20-57
7-9-14ba	F. B. Wisner		Du	31.9	-	C	Cy	E	D	Tco	0.5	4796.0	26.40	9-6-57
7-9-16bb	Melvin Reistad		Du	15.0	-	-	-	H	D, S	Tco	0.8	4558.9	8.03	8-1-57
7-9-16cc	Glen Foley		Du	14.0	-	-	-	E	D	-	0.0	4557.7	3.20	7-31-57
7-9-17aa	Charles Beck		Du	7.8	-	R	C	E	D, S	Tco	0.0	4577.5	7.28	8-1-57
7-9-24bc	Walter Schurch		-	54.8	-	-	-	E	D	Tca	0.4	4927.0	42.25	9-6-57
7-9-28cc	Havens & York		-	7.5	-	-	N	N	N	Tco	0.0	4599.1	6.09	7-31-57
7-9-29ab	G. M. Lowery		Du	8.1	-	-	C	E	D	Tca	-4.5	4582.6	0.35	8-1-57
7-9-29db	J. B. Hare		Du	16.8	-	-	-	H	S	Tca	0.3	4606.1	10.50	8-1-57
7-9-30dd	A. A. Kelson		Du	85.3	-	-	J	E	S	Tco	-5.7	4698.9	34.45	8-2-57
7-9-31cd	Lewis Johnson		Du	47.9	-	-	-	E	S	Tco	0.0	4729.0	40.67	8-2-57
7-9-31db	Allen Johnson		Du	81.8	-	-	-	E	S	Tco	0.0	4714.7	40.47	8-2-57
7-9-32da	Albert Beck		Dr	34.0	6	P	J	E	D	Tca	0.0	4643.1	15.10	9-15-57
7-10-3dd	State Prison Farm		Dr	64.7	6	P	N	N	N	Tca	1.0	5020.0	14.95	8-5-57
8-9-3bd	Eugene Boger	1955	Dr	29.2	6	P	J	E	D	Tca	-8.0	4464.6	10.60	8-8-57
8-9-4da	U.S. Geol. Survey	1957	Dn	10.4	3/4	P	N	N	O	Tca	1.5	4428.2	5.05	8-20-57
8-9-14cd	Christofferson Bros	1952	Dr	385.0	-	P	N	N	N	Tca	1.3	4635.0	119.65	9-5-57
8-9-15aa	-----do-----		Du	19.1	36	R	N	N	N	-	0.0	4476.1	11.43	7-21-59
8-9-15ab	Mabel Hoskyn		Du	12.2	48	W	C	E	N	Tca	0.3	4467.3	9.57	7-21-59
8-9-15cb	U.S. Geol. Survey	1957	Dn	10.4	3/4	P	N	N	O	Tca	1.5	4460.1	2.64	8-20-57
8-9-15cd	-----do-----	1957	Dn	-	3/4	P	N	N	O	Tca	1.3	4474.4	0.96	8-26-57
8-9-16da	Prison Hog Ranch		Du	8.8	48x 48	-	-	N	N	-	0.0	4461.5	3.89	8-20-57
8-9-21db1	Lee Olson		Du	14.4	30	R	C	E	D, S	Tco	0.0	4480.4	9.99	8-7-57
8-9-25ca	Kenneth Smith		Du	13.9	-	R	-	E	D, S	Tco	0.0	4706.0	5.79	9-5-57
8-9-27bd	Robert Olson		Du	11.1	-	-	-	H	S	Tco	0.2	4573.3	9.95	8-7-57
8-9-28ac1	Don Valiton		Du	24.8	-	R	C	E	D	Tco	0.0	4509.5	20.87	8-7-57
8-9-28ac2	-----do-----		Dr	19.4	6	P	C	E	D	Tca	-6.0	4506.1	11.08	8-7-57
8-9-28da	-----do-----		Dr	28.4	12	P	N	N	N	Tca	1.0	4544.1	6.82	9-5-57
8-9-32dd	Carl Salmonsens		Du	25.1	-	R	-	H	S	Tco	0.0	4527.0	11.34	8-29-57
8-9-33ba	C. K. Warren		Du	6.3	30	R	C	E	D, S	Tco	0.0	4504.4	2.15	8-7-57
8-9-34cd	Christine Star		Du	6.9	-	-	N	N	N	Tca	2.5	4591.3	6.19	8-7-59
9-9-34cc	Bill Heltborg	1900	Du	17.4	-	-	N	N	N	-	0.0	4438.1	12.44	8-8-57

Table II. Aquifer test data, Deer Lodge Valley, Montana
(from Konizeski et al, 1968)

—Aquifer test data
[Geologic source: A, Quaternary alluvium; T, Tertiary sediments]

Well	Geologic source	Depth of well (feet)	Pump- ing rate (gpm)	Draw- down in pumped well (feet)	Length of test (minutes)	Specific capacity (gpm per ft)	Coefficient of transmis- sibility (gpd per ft)	Remarks
B4-10- 5ab....	A, T	160	61		30		95,000	Casing too wet to measure water level while pump- ing.
15aa....	A	23.1	11	10.6	470	1	20,000	Large entrance loss into casing. Ob- servation well 40 ft away.
B5-10-17dc....	A(?)	71.1	270	29.5	1,800	9	77,000	Large entrance loss. Observation well 550 ft away.
23cb....	A, T	150	580	38.2	450	15	20,000	Screened and gravel packed.
24aa....	T	200	975	102.3	220	10	15,000	
B6- 9- 4ab....	A	18.1	28	4.1	300	7	80,000	Large entrance loss into casing.
4bb....	A	14.3	27	.8	200	34	40,000	Observation well 50 ft away.
4cc....	A	8.0	10	1.8	180	6	25,000	
7ad2....	A	35	92	3.8	200	24	35,000	
7dc....	A	40	110	2.2	250	50	175,000	
B6-10-14bc....	A, T	126	85	3.0	300	28	80,000	Observation well 50 ft away.
15aa....	A	12.6	30	2.5	300	12	35,000	
B7- 9-17ad....	T	34	135	7.2	30	19	38,000	Observation well 50 ft away.
32da....	A	34	22	2.7	150	8	60,000	
B8- 9-15ab....	T(?)	19.1	9	4.4	200	2	800	Observation well 50 ft away.
15ba1....	A	23.6	55	2.0	350	28	50,000	
21da1....	A	14.4	25	.7	240	36	50,000	
21da2....	A	12.5	52	2.6	330	20	35,000	
27ac....	T(?)	11.2	5	1.6	120	3	1,000	
B9- 9-34cc....	T	17.4	3	2.0	120	1	600	

—Coefficient of transmissibility values estimated from specific capacities

[Remarks: T, Tertiary sediments; A, Quaternary alluvium]

Well	Specific capacity (gpm per ft)	Coefficient of trans- missibility (gpd per ft)	Remarks
B4- 9-31cb.....	0.6	1,000	T.
10-10ac.....	3	5,000	T(?).
17bd.....	13	20,000	A, T(?). Perforated and developed.
11-1cb.....	1	1,000	T.
B5-11-33ca1.....	50	85,000	A. Perforated and developed.
B6-10- 5aa1.....	26	40,000	A, T. Perforated and developed.
B7- 9- 4ba.....	40	70,000	T. Screened and developed.
20cc.....	13	20,000	T.
10- 2cd.....	.2	2,000	T.
B8- 9-33cc.....	30	50,000	T. Screened and developed.
10-23db.....	.5	800	T.

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A water-table contour map was included in Konizeski et al.; it is included as Plate III of this report. Levels in 159 wells contributed to the plot. The resultant contour map is faulty on account of uneven distribution of the wells. There are few or no data in the northern part of the area, aside from a narrow belt along the Clark Fork. In the southern part of the area there are data points only west of the Clark Fork. No data represent the deep aquifers, and there are none at higher elevations.

The data show that ground water moves toward the Clark Fork, which predictably is the discharge zone for the whole valley. In the southeast part of the valley, ground water moves north-eastward toward the Clark Fork and then northward. The slope of the water table averages 50 feet per mile. A simplistic interpretation based upon topography and dip of beds indicates that ground water east of the river moves northwestward and ground water in the northwest part of the valley moves eastward. All ground water probably exits from the valley in a northward direction. The average rate of movement is estimated at less than 3 feet per day.

Fluctuations of water level were measured in the valley during the period 1957-1961 (Konizeski et al., 1968). Seasonal changes are most pronounced, and longer-term change is noticeable in only one well for the period studied. This decline in water level may be caused by changes in irrigation practice in the vicinity.

There is potential for significant additional withdrawal of ground water from the upper aquifers without lowering the water table excessively or affecting the potentiometric surface of lower aquifers. Wells can produce from 200 to 1,000 gpm with ease if properly developed in the Quaternary and Tertiary sediments. It is not known if aquitards occur within the shallow aquifers. At a depth of 1,200 feet in the central valley, production in excess of 140 gpm, with high sodium content, indicates some isolation of the deeper aquifers.

Only qualitative information was available on chemistry of ground water in the area, and that was oral. A hydrochemical survey in the valley would be difficult to interpret because of probable contamination from mine and smelter effluents.

The explanatory column of the Geohydrologic map of Deer Lodge Valley, included as Plate III, makes a few statements about

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the possible deep aquifers. Basement rocks, consisting of Precambrian to Tertiary undifferentiated sedimentary, igneous, and metamorphic rocks were represented as low permeability materials, with potentially low yield. Fracturing and alteration were not considered in the assessment.

The older Tertiary rocks (Eocene to Oligocene) are unconsolidated to well-consolidated, well- to poorly sorted sedimentary rocks; these range from conglomerate to shale. Aquitards may be expected in such a lithic mix.

GEOHERMAL REGIME

The Deer Lodge Valley has three major thermal manifestations: Gregson Hot Springs, Anaconda Hot Springs, and Warm Springs (near the State hospital). Lines drawn between these points form a triangle enclosing an area of about 40 square miles. The area apparently is a structural depression and hot water at the three thermal springs may be ascending along deep fault zones. The faults appear to be among those active during Late Tertiary time. The heat source is undetermined. The portion of Deer Lodge Valley lying within this triangle exhibits the deepest subsidence and most complex structure of any place within the valley. The existence of a reservoir is predictable, but much exploration is needed to confirm and describe it.

Thermal Springs.

Anaconda Hot Springs is a nearly inactive manifestation in Sec. 13, T. 4 N., R. 11 W., at an elevation of 5,488 feet. It has a measured temperature of 22°C (72°F), and a flow of less than 5 gpm (in 1974). A tufa mound about 20 feet high is present. Other travertine deposits in the vicinity of Anaconda Hot Springs are located on the high terrace remnants south of the mouth of Warm Springs Canyon. Konizeski et al. (1968) described these as follows:

A great bed of travertine slopes gently valleyward and covers about 1 square mile. Outlying patches extend westward about 2 miles above the mouth of the canyon. The

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MURRAY C. GARDNER (503) 482-2605

travertine averages less than 10 feet in thickness but ranges up to 20 feet and overlies about 10 feet of poorly cemented boulder conglomerate. Numerous impressions of plant stems are encrusted in the travertine, which was formed by springs along the base of the mountains. The Anaconda Hot Springs still flow and lime is being added to the extensive travertine deposits.

Gregson Hot Springs is the site of an old resort and greenhouse 15 miles west of Butte. There are several springs in the NW/4, Sec. 2, T. 3 N., R. 10 W. Most of these rise in a large cement-floored pool or tank. Others may rise in nearby swampy meadows or into smaller cement tanks. Total flow exceeds 50 gpm. Temperature of the water was measured at 72°C (162°F). However, this is unlikely to be the maximum temperature of the springs, as access could not be gained into the central part of the cement tank, where bubbling was most vigorous. There are unconfirmed oral reports of temperatures to 88°C (190°F) in these springs. A new resort was in final stages of completion late in 1974. It is anticipated that this will allow even less direct access to the thermal waters. The springs issue from Tertiary volcanic rocks, probably rising along faults in the Lowland Creek Volcanics.

Warm Springs is a community 10 miles northeast of Anaconda, on the Clark Fork River. An old resort was built around the springs; it is now the site of the Warm Springs State Hospital. A large travertine mound has built up around the springs. Thermal waters at a temperature of 78°C (172°F) issue from Tertiary sediments at rates exceeding 100 gpm. It is difficult to estimate flow and to measure maximum temperature. A structure has been built atop the travertine mound, limiting access. Many of the springs, including the highest temperature ones, arise in a swamp covering some 20 to 40 acres, within which access is dangerous.

The position of these springs near the eastern margin of Deer Lodge Valley suggests control by faults.

The travertine noted at Anaconda and Warm Springs, as well as the vigorous bubbling observed at Gregson, suggest a strongly bicarbonated source fluid. Given the abundance of Paleozoic limestone in adjoining ranges, and probably at depth beneath the Tertiary

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and Quaternary fill, this is not surprising. It further suggests storage in or transit of the thermal fluid through a carbonate rock section.

No other thermal waters are known in this region. However, data on water temperatures were not included in the regional well canvass conducted by the U. S. Geological Survey (Table I and II).

Heat Source.

The Anaconda area does not have a readily identifiable heat source. Empiricism suggests two possible sources for the thermal manifestations: deep circulation and young plutonism.

The warm springs are associated closely with structural features: all occur at the margins of mountain ranges and in canyons, strongly suggesting the influence of young faults. In some instances the faults have been mapped geologically and confirmed by gravity and magnetic data. Field mapping throughout the Deer Lodge Valley and observations of deformation in Tertiary and Quaternary strata support interpretations that tectonic activity has persisted at least into Pliocene and probably into Pleistocene time. Displacements have been noted within the Tertiary materials filling the valley and these do not appear to be the result of differential settling. The Quaternary materials are too poorly consolidated to permit measurement and evaluation of fault slip. The entire region has a high degree of seismicity, and historic earthquakes are noted across the entire region.

There were rhyolitic intrusions and eruptions on a very minor scale during Miocene and Pliocene(?) time in the northern Elkhorn Mountains (Smedes, 1962), and around the margins of the Boulder batholith (Becraft, 1960; Pinckney, 1961). Magnetic lows at the western boundary of the Deer Lodge Mountains, near the south of Deer Lodge, may represent ascending silicic magmas, if they are not caused merely by polarity reversals.

The area continues to be active tectonically, with east-west extension predominating. Therefore, it can be assumed permissively that silicic magmas may now be ascending along the zones of greatest structural weakness. As mentioned earlier, Hyndman *et al.* (1972) and Hamilton and Myers (1974) speculated that the Flint Creek Range

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plutons may be interconnected at depth with plutons of the Boulder batholith. If so, deep beneath Deer Lodge Valley there may be apophyses of igneous material rising from a batholithic body. Conceivably, these could be young enough to support a geothermal system.

The southern part of the Deer Lodge Valley would be a good target area, based upon this analysis. Konizeski *et al.* (1968) and Wanek and Barclay (1966) concluded that the southern part of the Deer Lodge Valley was tectonically active up until at least the Pleistocene epoch. Sharply delineated fault scarps, changes in the erosion cycle too great to be the result of climatological changes, and a few measurements of displacement of beds are the evidence supporting their conclusion.

However, a second hypothesis may explain the presence of thermal springs, without the presence of an ascending magma. The hot springs may result from deep circulation of cool meteoric water from recharge zones in the mountains adjoining the Deer Lodge Valley, with rapid ascent of heated fluids along boundary faults to the surface. If this were the case, a gradient of approximately 1°F per 50 feet of depth would yield the maximum observed temperature after circulation to perhaps 7,000 feet. However, discharge is not great, so that there may be conductive cooling in transit or mixing with dilute, cool, ground water. In such a case, still assuming a 50 foot per degree gradient, circulation might come from 10,000 feet or deeper. These depths are not unrealistic, given the thick Tertiary, Mesozoic and Paleozoic section believed to underlie the valley. However, the fact that the Flint Creek Range and the Deer Lodge Range do not have other thermal springs near their margins argues against this theory.

The region appears to have a thick crust, typical of the continental interior of the area of a high-elevation mountain range, so that a shallow mantle seems unlikely in the immediate area.

Magmatism occurred abundantly and frequently during the period from 80 to 45 m.y.b.p. The Elkhorn Mountains rhyodacite flows and tuffs, the Boulder batholith with its central Butte quartz monzonite, and the Lowland Creek quartz latite tuffs and breccias are all too old to provide the heat for a major geothermal system. More recent magmas are required. Tenuous evidence permits the possibility that a new episode of shallow crustal melting and intrusion is occurring. Other evidence continues to favor deep circulation in a regime of granite rocks rich in radiogenic K, Th

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and U. The point remains moot. A single target has been selected for geothermal exploration, and is shown in Plate V, based upon the assumption that the opportunities for magmatism are greatest along the strongly downfaulted southern end of the valley.

Reservoir.

We can be optimistic about the existence of a reservoir in the southern Deer Lodge valley. Cross-sections based on gravity, attitude of beds, displacement along faults, aeromagnetic gradients, and hydrology (Konizeski *et al.*, 1968; Wanek and Barclay, 1966), show a graben at least 5,500 feet deep within the Tertiary and Quaternary rocks of the southern part of the valley. The cross-section of Plate IV indicates that Paleozoic and Mesozoic sedimentary strata are present beneath the Tertiary section, to an unknown depth greater than 5,000 feet beneath the base of the Tertiary section. This implies a column of potential reservoir rocks more than 10,000 feet thick.

The Cenozoic basin fill consists of a diverse section of igneous rocks and sediments. Most of the sediments are clastic materials, ranging from conglomerate to grit, sandstone and shale. Limestone is present as well as calcareous cement within some of the clastic rocks. Bentonitic clays frequently are present at depth below 10,000 feet. Some beds are unconsolidated, whereas others are so well indurated as to fracture across the grains. The Tertiary and Quaternary sediments are about 2,500 feet thick. These rocks are not considered as likely reservoir formations. The underlying Lowland Creek Volcanics, mostly volcanic breccias and ash-flow tuffs, provide a shallow reservoir target from 2,500 to beyond 5,500 feet in depth. Parts of the volcanic sequence may have adequate vertical and horizontal extent, and permeability, to serve as reservoir. Below the Lowland Creek Volcanics, the Colorado Shale extends to about 7,500 feet in depth. The upper part of the Colorado Shale is a coarse, sandy bed hundreds of feet thick, with extensive outcrop area in the Flint Creek Range. The Colorado Shale strata are folded and faulted; locally they are altered to quartzite and phyllite. These thick, silicic, fractured rocks offer the best potential reservoir of the area. Of the remaining Mesozoic and Paleozoic sedimentary rocks found below the Colorado Shale, only the Kootenai Formation, which directly underlies the Colorado Shale, may be shallow enough to be a reservoir target. The Kootenai Formation consists of interbedded grayish-green shale and fresh-water

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limestone. To reach its base, an exploratory hole would have to penetrate to about 9,000 feet. Shales, limestones and phosphate beds occur below the Kootenai Formation, except where apophyses of batholiths, plugs and other volcanic feeders may be intercepted.

Geophysical exploration will be necessary to define the surface of the buried basement.

Fractured early and middle Tertiary volcanic rocks and Mesozoic sedimentary rocks provide the greatest reservoir potential, through a combination of fracture and granular porosity. However, episodes of alteration, mineralization and volcanism may have led to development of a suite of low-density, hydrous minerals that decrease porosity and permeability. Continuous tectonic activity may have maintained an open micro-fracture system in some of the strata. Intensive alteration may have resulted in creation of brittle, dense rocks able to maintain a system of fractures. Rocks younger than the Lowland Creek Volcanics may not have beds of sufficient lateral continuity to support a reservoir.

Fluid in Storage.

The hydrologic study (Konizeski *et al.*, 1968) indicated a system in which pore and fracture void space is saturated with water from very near the surface to that depth pores are closed by confining pressure. Such a depth might be several tens of thousands of feet in depth.

There is opportunity for ample recharge to the deep aquifers from precipitation in the Flint Creek Range and Anaconda Range. Such recharge could maintain mass and aquifer pressure during production. There would be little or no interference between production from the deep aquifers and production for industrial, municipal and agricultural uses from the shallow aquifer. A local flow net with recharge zones in the terrace gravels, intercepting mostly surface flow from the bounding highlands, supplies the upper, cold, generally unconfined aquifers.

Water chemistry is not available for calculations of reservoir temperature or fluid phase. Too little is known of deep circulation and aquifer geochemistry to support speculation on the composition or phase of water in a deep reservoir.

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Target Potential.

The area at the south end of the Deer Lodge Valley is considered to be a good geothermal target; however, there are many unanswered questions about heat source and deep aquifer conditions. Thermal manifestations, seismic history, crustal structure and reservoir potential all are positive factors. Reservoir geometry is unknown. Geology data support the presence of a deep reservoir; the position of impermeable strata cannot be plotted areally or vertically.

Recent volcanic or intrusive activity is not evident. Pliocene is the latest known episode of igneous activity. The existence and configuration of a heat source are problematic. Data are not adequate to assess whether a magmatic heat source exists, and what might be its depth, extent, and shape. Much data need to be obtained and evaluated before a heat source and reservoir can be delineated. The faults at the margins of the graben and faults hidden under Tertiary sediments in the central part of the valley may be pathways for ascending fluids. Identification of the heat source is the initial objective.

The target outlined on Plate V is based on published information, field observations, and the considerations expressed in preceding sections. The southern part of the target area is considered more attractive than the northern part of the target area.

QUALITY OF DATA

Geology.

The southern part of the Deer Lodge Valley is not mapped adequately. Only the southwestern part of the Flint Creek Range, including the city of Anaconda, is represented on a recent map and report (Wanek and Barclay, 1966). The southern part of the valley was mapped at a scale of 1:62,500 by Konizeski et al. (1968), but basement and Tertiary volcanic rocks are lumped into a generalized unit, and formations in the Tertiary sequence are identified principally on the basis of water-bearing and hydraulic qualities. The very old work by Weed (1912), and the preliminary work by Smedes (1967) south of Butte are at the eastern fringes of the

LEGEND

○ thermal spring
78° temperature of spring, °C

□ area recommended for geothermal exploration

Plate V. Geothermal anomalies and target area, Deer lodge Valley, Montana

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Deer Lodge Valley, but are not detailed. Smedes' map is without an explanatory text. The maps by Wanek and Barclay (1966) and Konizeski et al. (1968) are included in this report as Plates III and IV. It would be advisable to extend existing mapping from Butte and the northern Elkhorn Mountains by field and photogeology into the southern Deer Lodge Valley. It is likely that the Anaconda Company and perhaps other mining companies have mapped the eastern Anaconda Range and southern Deer Lodge Range, but this material is not available.

Geophysics.

Aeromagnetic data are the only geophysical data sufficient in detail for useful application to geothermal exploration. All other kinds of geophysical survey are of insufficient detail, or are unavailable. A major portion of the burden of exploration will be carried by geophysical methods: active seismic, passive seismic, gravimetric and electrical resistivity surveys are recommended. Heat-flow and temperature-gradient surveys may be affected adversely by shallow flow of cool ground water.

Geochemistry.

There is a complete lack of geochemical data for the Deer Lodge Valley. The Anaconda Company apparently has prevented public agencies from analyzing ground and surface water. There may be records in private files but none were available to us. Hearsay indicates that the mines, mills and smelters at Butte and Anaconda have contaminated the Clark Fork River and Deer Lodge Valley ground waters. Sampling and analysis would serve to verify the pollution. It would be necessary to obtain samples from deep wells to examine the natural regime. Heavy metals, sulfur compounds, chlorides, and other tailings and smelter effluents are likely to skew ionic ratios seriously and increase total dissolved solids. Isotope geochemistry may be useful to age-date water and establish flow directions and velocity, but not to establish reservoir base temperatures.

Hydrology.

The shallow, unconfined aquifer system has been reasonably well described by Konizeski et al. (1968). Water budgets, effect

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of pumping, and simple water-table models and flow lines have been assessed. The deep system is not known, and potentiometric surfaces for the confined aquifers are entirely unknown.

RECOMMENDED WORK PROGRAM

If it is decided to proceed with leasing and exploration, the following program should be considered.

Photogeologic interpretation of lithologic boundaries, fracture patterns, and alteration zones is advised as a first step. Field work should be carried out in support of photogeology. Igneous rocks that appear to cut Tertiary sedimentary formations should be sampled for radiometric age-dating.

A pilot sampling of springs in the valley and in the mountainous recharge area is advisable for both age-dating and geochemical analysis. This will allow determination of contamination of the ground-water system, and may provide useful data after allowance for the effects of the expected contamination. It may then prove worthwhile to collect a large suite of water samples from wells, especially deeper wells, for chemical analysis.

A new gravity survey should be made across an area of about 8 townships, to gain a clearer understanding of the configuration of basement rocks, possible youthful intrusives, and low-density, alteration zones.

Gravity surveys were made in the area east of Butte by the U. S. Geological Survey and contoured at 5 milligal intervals on a 1:62,500 scale. This is adequate for recognition of gross structures, but appears inadequate for detailed geothermal exploration. A fully terrain-corrected map contoured at 1 or 2 milligals, with residuals, is recommended.

A passive seismic survey could be accomplished early in the program, to determine whether there are microearthquakes occurring in the area, and perhaps to indicate intra-valley faults by alignment of hypocenters. The industrial development and resultant 24-hour background noise of the area may make ground-noise surveys ineffective.

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MURRAY C. GARDNER (503) 482-2605

An active seismic survey may prove of significant value in this area in defining deep crustal structure, identifying faults and graben boundaries and perhaps in identifying intrusions.

Electrical resistivity data will provide valuable information on the subsurface. It may be necessary to perform electrical resistivity surveys over about 75 square miles at the recommended target, both in soundings and as roving dipole survey.

The geoelectric basement may be determined accurately with this powerful tool. The suspected contaminated ground water below the settling ponds may cause some peculiar results in electrical surveys.

It would appear that slim holes to measure temperature gradients and heat flow should await results from the other geophysical surveys. Existing, stabilized holes at the boundaries between the valley and adjacent highlands should be used to obtain initial temperature-gradient data. Holes should be drilled to penetrate at least the first confined aquifer, rather than stopping within the unconfined ground-water system.

LAND STATUS AND COMPETITIVE INTEREST

The Deer Lodge Valley and the lower slopes of the bounding mountain ranges are fee land. Public land in the vicinity is in the Deer Lodge National Forest, which includes portions of the Flint Creek, Anaconda, and Deer Lodge ranges. The target area does not include appreciable public land.

Much of the private lands in the Deer Lodge Valley and along the Clark Fork River eastward toward Butte are controlled by two large landowners: the Anaconda Company and the Burlington Northern Railroad. The Anaconda Company has started to develop a capability in geothermal exploration, according to one of its geologists, Terrence Britt, who works in the Company's Salt Lake City office. Further, it is reported that Anaconda and Geothermal Kinetics, Inc., of Phoenix, have entered into a joint venture of exploration. It is unknown if they have carried out work in Deer Lodge Valley. The Burlington Northern Company has had representatives at geothermal short courses, field trips, and meetings for the past two years.

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Several companies and individuals reportedly have contacted BN regarding geothermal leases or joint ventures. It is not known whether other companies hold leases for exploration in the area. Much of the other fee land in the mountains originated as patented mining claims.

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JAMES B. KOENIG (415) 524-9242
MURRAY C. GARDNER (503) 482-2605

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PLATE I. RESIDUAL GRAVITY MAP AND SECTIONS OF SOUTHERN DEER LODGE VALLEY, MONTANA

EXPLANATION

Magnetic contours
Showing total intensity magnetic field of the earth in gammas relative to arbitrary datum. Contours to indicate closed areas of lower magnetic intensity, dashed where data are incomplete. Contour intervals are 20 and 100 gammas.

Location of measured maximum or minimum intensity within closed high or closed low

Flight path
Showing location and spacing of data

NOTE
Aeromagnetic data are obtained and compiled along a continuous line, whereas ground magnetic surveys are made of separate points. Errors within the normal limits of any magnetic measurement may cause slight discrepancies between flight lines in an aeromagnetic map, which would be more obvious than similar discrepancies between points in a ground magnetic map. For this reason as much care should be exercised in evaluating magnetic features that appear as elongations along a single aeromagnetic traverse as in interpreting an anomaly indicated by a single ground station.

INDEX MAP OF WESTERN MONTANA SHOWING AEROMAGNETIC MAPS PUBLISHED BY THE U.S. GEOLOGICAL SURVEY
(GPIs 429, 444, 456, 458 published at scale 1:62,500)

Base from U.S. Geological Survey 250,000 series quadrangles: Butte, 1958; Dillon, 1953-52; Bozeman, 1957; and White Sulphur Springs, 1938

PLATE II. AEROMAGNETIC MAP OF THE BOULDER BATHOLITH AREA, SOUTHWESTERN MONTANA

By
R. W. Johnson, Jr., J. R. Henderson, and N. S. Tyson

INTERIOR-GEOLOGICAL SURVEY WASHINGTON, D. C. 20548-08244
Aeromagnetic survey flown at 10,500 feet barometric elevation, 1953 and 1955

PLATE III. Geohydrologic map of Deer Lodge Valley, Montana (showing locations of wells)