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GEOLOGY AND MINERAL DEPOSITS OF THE NORTHWEST QUARTER WILLIS QUADRANGLE AND ADJACENT BROWN'S LAKE AREA, BEAVERHEAD COUNTY, MONTANA

A preliminary report by W. B. Myers

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INTRODUCTION

Geologic mapping in the Argenta area was started in the spring of 1946 with the support of Missouri River Basin funds from the Bureau of Reclamation. This work was done to study the geology and mineral resources of an area adjacent to the Kelley and the Apex dam sites, the locations of proposed irrigation dams on tributaries of the Beaverhead River, one of the headwaters of the Missouri River in southwestern Montana. The results of the first season's work were summarized in a preliminary report and geologic map of the Argenta mining district, submitted to the Bureau of Reclamation in 1947.

Field work was continued in the summers of 1947-1950 to complete the mapping of the four 7½-minute quadrangles which constitute the northwest quarter Willis 30-minute quadrangle. This study was carried on with the continuing aid of Missouri River Basin funds, in part to accurately map the distribution of the Phosphoria formation. In the fall of 1951 mapping was extended northward to include the Brown's Lake tungsten area.

The geology of the mapped area has been plotted on air photos with an approximate scale of 1:24,000. Geologic data were transferred to a planimetric base with a Vertical Sketchmaster. The base was compiled largely from recent photogrammetric maps of the Beaverhead National Forest made by the Forest Service. A radial-line plot was made of the unmapped township in the northwest corner of the area (T. 4 S., R. 11 W.). The narrow strip outside of the forest along the east margin of the area, as well as a strip along most of the southern margin, was compiled with the Vertical Sketchmaster with a minimum of control.

The geologic map of the Brown's Lake area was similarly compiled on a base adapted from photogrammetric contour maps made by the Forest Service. Small errors in location of geology in relation to drainage and culture may be expected anywhere on the maps; in areas of strong relief, topographic distortion may result in errors of several hundred feet.

Able assistance in the field was given at different times by R. H. Thurston, Robert A. Zeller, Jr., John R. Cooper, Walter E. Bauer, C. E. Weaver, and J. W. Odell. Roger W. Swanson has reviewed the map and text and offered many valuable suggestions.

Geography

The NW$\frac{1}{4}$ Willis quadrangle lies between 112° 45' and 113° 00' west longitude and 45° 15' and 45° 30' north latitude. The mapped area of about 235 square miles includes this quadrangle plus variable but generally narrow selvages on the west, north, and east sides. Mapping has been extended northward at the northeast corner of the quadrangle to include the Brown's Lake area on Rock Creek.

The mapped area is largely within the Pioneer Mountains but piedmont slopes facing the Beaverhead Valley fringe the eastern boundary and extend across much of the southernmost part of the area. The highest summits in this north-trending range are in the northwest corner of the area with two peaks at altitudes of about 11,150 feet. Crest altitudes diminish southward and in the southwest corner of the area the rugged peaks give way to rolling country with isolated high points at altitudes of less than 7,500 feet. The area is drained to the east by four perennial streams. Rattlesnake Creek, the southernmost, flows southeast to the Beaverhead River. Birch Creek and Willow Creek in the central part of the area and Rock Creek in the extreme north flow easterly into the Big Hole River. Willow Creek leaves the map area at an altitude of about 5,300 feet, the lowest point of the area. The total relief is nearly 6,000 feet; local relief is a little more than 3,000 feet.

GEOLOGY

The mapped area lies athwart a northerly trending zone of eastward overthrusting 1/ of early Tertiary age. This zone is traceable northward from its point of emergence beneath the Snake River volcanics along the Montana-Idaho border to a point a few miles beyond the mapped area; farther north it is believed to be linked with the great zone of thrust faulting which includes the Lewis thrust, extending into Canada. The mapped area further lies on or very slightly west of the eastern boundary of the province of late pre-Cambrian Belt sediments. This boundary is traceable southerly to the Idaho border—in general along the zone of thrusting—and in the opposite direction can be traced north-northeasterly a score of miles. To the east the Paleozoic rocks are relatively less deformed and lie directly on an older pre-Cambrian crystalline basement. To the west a thick section of Belt sediments intervenes between the Paleozoic rocks and the

1/ This term is used for convenience and is only intended to apply in a relative sense.

concealed basement. This area has been one of repeated tectonic activity; the earliest recognized being pre-middle Cambrian in age.

Stratigraphy

Pre-Cambrian

Clastic sediments of the Belt series of late pre-Cambrian age underlie a large part of the mapped area. Sandstone and quartzite, largely feldspathic, strongly predominate with shaly rocks and a very little conglomerate making up the remainder.

These rocks crop out in two areas of rather different lithology separated by a major thrust fault, the Kelley thrust, and a two-mile-wide zone of lesser thrusting. The western area, above the Kelley thrust, has been displaced upward and southeastward a minimum of perhaps five miles in relation to the eastern area below the zone of thrusting. On the preliminary map the Belt rocks have been divided into two units—an upper light-colored quartzite and a lower red member—present in both areas.

On the upper plate of the Kelley thrust the lower red member is a cross-bedded arkosic quartzite, apparently a wedge deposit. It is more than a mile thick in the southwestern part of the quadrangle and thins northward to a thickness of about 2,000 feet in less than 8 miles. In the eastern area the member is dominantly shaly and contains green and gray strata, though reddish tints are more common. Shallow-water structures are abundant. Only the uppermost 1,000 feet is exposed.

The overlying light-colored quartzite is much less variable in the two areas than the rocks that underlie it. The chief difference is in the nearly complete lack of feldspar and cross-bedding in many of the eastern rocks. Due to steep faulting of unknown displacement within this unit in the eastern area, thicknesses cannot be compared, but more than a mile of these rocks appear to be exposed west of the Kelley thrust.

The Belt strata exposed in the upper plate of the Kelley thrust appear to be at least 8,500 feet thick. The eastern area, below the thrust zone, exposes a few hundred feet of beds believed to be stratigraphically higher than the highest beds of the upper plate. In addition, the base of the section is nowhere exposed in the mapped area. The lowest beds exposed in the upper plate of the Kelley thrust may be essentially at the base, but even so, the total thickness of the Belt sediments before subsequent erosion could not have been much less than 10,000 feet.

The source area of these sediments, as evidenced by variation in grain size and composition, appears to have been to the west or northwest rather than to the east—the direction of the exposed crystalline basement. The abundant microcline of the Belt sediments points to granitic or gneissic source terrane.

The relation of these beds to other and better-known sections of Belt sediments is uncertain. Ross (1949, p. 113) speculates that they may possibly be equivalent to the Missoula group, the uppermost of four major divisions of the Belt series. No Belt rocks are exposed below the Kelley thrust south of the latitude of Argenta. Fourteen miles to the south, in the core of an anticline lying below the lowest thrust exposed in the mapped area. Cambrian sediments are underlain by pre-Belt crystalline rocks (Lowell).

Paleozoic

Cambrian sediments in the mapped area are in unconformable contact with both the upper and lower members of the underlying Belt series. Of the four middle Cambrian formations generally present in southwestern Montana, only the lower two—the Flathead quartzite and the overlying Wolsey shale—are represented within the mapped area.

The oldest Cambrian formation, the Flathead quartzite, is absent over most of the area of Cambrian outcrop apparently by non-deposition in large part; but northwest of Argenta an abnormally thick section of Flathead quartzite is present. The overlying Wolsey shale is believed to have been deposited over most of the area but locally has been removed by later Cambrian erosion. In part this stripping took place in areas underlain by the abnormally thick section of Flathead quartzite.

The interval of middle Cambrian time, which in most places in southwestern Montana was marked by the deposition of the Meagher and Park formations, appears in this area to have been a time of uplift, block faulting, and erosion. Proof of this disturbance lies in the overlap of a dolomite unit of Cambrian age upon an uneven surface cut across a faulted complex of Middle Cambrian and pre-Cambrian sediments. The dolomite, provisionally correlated with the Pilgrim formation, and a thin overlying sandy unit correlated with the lower member of the Red Lion formation (Emmons and Calkins, 1913, pp. 61-63), wedge out in the south-central part of the quadrangle against an upper Cambrian positive area comprised of block-faulted Wolsey, Flathead, and Belt rocks.

The interval between upper Cambrian and upper Devonian in the mapped area, as over much of southwestern Montana, was one of non-deposition though no erosion of the uppermost Cambrian formation has been detected.

Sedimentation was renewed in the south-central part of the area with local deposition of the lower member of the Jefferson dolomite. The occurrence of outcrops of this lower member tentatively correlated with the Maywood formation (Emmons and Calkins, 1913, pp. 64-65) is restricted to an area of less than 10 square miles, west of Argenta in the south-central part of the mapped area. Although the lower Jefferson is absent over much of the area of upper Cambrian deposition it locally transgresses upper Cambrian sediments and laps against older rocks of the positive area. Continued deposition of the upper member of the Jefferson dolomite reduced and finally covered the lingering positive area. The conformably overlying Three Forks shale, succeeded by the Lodgepole limestone and the Mission Canyon limestone, form an unbroken sequence. In southwestern Montana the overlying Amsden formation of upper Mississippian-lower Pennsylvanian age is commonly unconformable on the Mission Canyon limestone, widely considered to be lower Mississippian in age; but within the map area no field evidence for unconformity has been noted; indeed, locally the contact appears gradational. On the other hand, the exposures are not adequate to disprove unconformity.

The scanty fossil evidence is in general non-commital on this point. Yet at one locality the uppermost beds of the Lodgepole limestone have yielded "some types of brachiopods previously thought to be more or less characteristic of the Brazer" (J. S. Williams, 1950, written communication). The presence of forms with affinities to the upper Mississippian Brazer fauna of northern Utah and southeastern Idaho, in beds more than a score of feet below the base of the Mission Canyon limestone, suggests that the time of Mission Canyon deposition in this area may have extended well into the Upper Mississippian. Stated differently, it implies that the Brazer and Mission Canyon formations are correlative—a conclusion reinforced by lithology and stratigraphic position.

The Amsden formation is characterized by alternations of carbonate units and reddish or yellowish clastic units and by rapid lateral variation in thickness and detailed lithology, which indicate oscillating conditions in shallow-water marine environment and mark the end of a long period of carbonate deposition. It grades upward into the Quadrant quartzite, which from base to top consists of a homogeneous unit of clean quartz sand, commonly cross-bedded, and almost everywhere converted to a vitreous quartzite. A conformably overlying fine-grained dolomitic sandstone and sandy siltstone unit has been included with the Phosphoria formation (A member of Klepper, 1950, pp. 61-66). The lack of resistance of the member to erosion contrasts it to the resistant Quadrant quartzite and allies it with the overlying members of the lower Phosphoria, with which it forms a natural cartographic unit. Yet petrographically the non-resistant unit appears related to the older formation (Weaver, 1949).

Continuity of exposure in the mapped area is not sufficient to permit delineation of the five individual members of the Phosphoria formation which are recognized over southwestern Montana in a large number of prospect trenches (Swanson and others, 1951). The uppermost member, predominantly a dark-colored chert, constitutes the upper one-third to one-half of the formation and forms relatively resistant outcrops which have here been mapped as the Upper Phosphoria. The underlying members are commonly less resistant and have been grouped as the Lower Phosphoria.

Mesozoic

The richly fossiliferous marine Dinwoody formation of lower Triassic age, which overlies the Phosphoria with apparent conformity, grades upward into a calcareous red siltstone unit. On the basis of color and general lithologic character these red beds have been provisionally correlated with the Woodside formation.

The red beds have been largely removed by erosion in the interval between lower Triassic and upper Jurassic. To a lesser degree the upper limestone member of the Dinwoody formation, and very locally the lower shale member and the underlying Upper Phosphoria chert, was stripped off during this interval, in places with noticeable truncation.

An assemblage of fine-grained clastics, including some volcanic material, overlying the surface of unconformity, has been tentatively correlated with the non-marine upper Jurassic Morrison formation. These typically shaly rocks grade upward into coarse sandstone at the base of the non-marine lower Cretaceous Kootenai formation. The Kootenai is naturally divisible in the field into four members. The basal member, of coarse conglomeratic sandstone and overlying red and green mudstone, passes upward into a fine-grained limestone member, which in turn grades into a red mudstone member. The uppermost member of the formation as presently defined is the "gastropod limestone", a ridge-forming unit typified by abundant and conspicuous fresh-water gastropod shells.

About 100 feet of reddish siltstone overlies the limestone and may represent the uppermost part of the Kootenai cycle of non-marine deposition. For mapping purposes these beds have been grouped in map unit Ku_1 along with more than 500 feet of sandstone, with subordinate mudstone, siltstone, and carbonaceous shale. A few specimens of a poorly preserved marine pelecypod (Anomia sp.)(Cobban, W. A., 1950, written communication) and an indeterminable gastropod were collected from the middle third of the map unit and mark what appears to be the only marine tongue in the Cretaceous section of the map area. This marine tongue grades upward into mudstone of the Ku_2 unit, the upper half of which contains a few beds of light-colored tuff. Similar white tuff and blue-green porcellanite characterize the overlying Ku_3 unit. Locally the tuff contains plant fragments and rare dichotomous leaf impressions. The lithology, coupled with the general stratigraphic position, suggests that the Ku_3 tuff member may be a coarse-grained non-marine equivalent of the Aspen formation of southwestern Wyoming and the Mowry shale of the Black Hills region. Above it lie a great thickness of varied clastics, mostly greenish-gray in color and characterized throughout by much volcanic material.

This sequence, mapped as the Ku_4 unit, has at several localities yielded a few leaf impressions considered by Brown to be of "Late Cretaceous age, probably somewhere near Judith River or later" (1948, written communication). The stratigraphically lowest and best preserved assemblage was collected from calcareous concretions in brownish-gray mudstone about 1,500 feet above the base of the unit in the NW¼ sec. 30, T. 6 S., R. 9 W. The following forms were identifiable:

Araucarites longifolia (Lesquereux) Dorf

Ficus psuedopopulus Lesquereux

Trapa? microphylla Lesquereux

Platanus sp. and *Winchellia* sp. were collected from beds several hundred feet below the exposed top of the Cretaceous section in the SE¼ sec. 18, T. 4 S., R. 9 W., where more than 4,000 feet of this uppermost member are exposed.

Cenozoic

In the southwestern part of the area an incomplete section of volcanic rocks and tuffaceous sediments shown on this map as units Ta and Tt is exposed beneath a thrust plate of Paleozoic rocks. Although the volcanic rocks are locally seen to rest unconformably on upper Carboniferous sediments below the thrust, no relationships between the volcanic rocks and the Cretaceous rocks have been found.

However, in the quadrangle to the south, pre-thrust volcanic rocks are underlain by a thick conglomeratic sequence which laps unconformably across truncated beds of the Kootenai formation and older rocks, resting locally on beds of the Lodgepole limestone (Lowell). Lowell's mapping indicates to the writer a probable intertonguing relationship between the volcanic series and the underlying conglomeratic sequence, the middle member of which has yielded fresh-water gastropods of probable Paleocene age (Lowell and Klepper). Thus the physical evidence of strong unconformity beneath the conglomeratic sequence and the paleontologic evidence of its probable Paleocene age leave little doubt that the overlying volcanic series is considerably younger than, and probably unrelated to, the uppermost Cretaceous sediments exposed in the mapped area.

A gap occurs in the stratigraphic record between the accumulation of the volcanic rocks of probable Paleocene or early Eocene age and a later series of Oligocene volcanic rocks, comprising rhyolite tuff and associated rhyolite and basalt flows. This gap, which corresponds approximately to the Eocene epoch, spans the climax of orogeny—thrusting, steep faulting, emplacement and consolidation of plutonic igneous rocks—and the development by through-going streams of a mature land surface on the products of orogeny.

The Oligocene volcanic series in this area accumulated on gentle piedmont slopes beveling the older rocks, presumably on the margin of a basin bounded on the northwest by the Pioneer Mountains, largely in their present form but lacking the sharp accents of later differential uplift, canyon cutting, and alpine glaciation. Basalt flows fed from local vents poured out over part of the upland area. Fragmentary teeth of an Oligocene rhinoceras, Hyracodon sp., collected just east of the mapped area from earthy tuff beds probably 2,500 feet above the base of the volcanics and apparently stratigraphically higher than beds exposed within the quadrangle, indicate a probable lower Oligocene age (Hough, J., 1950, written communication), for at least the upper part of the series.

Unconsolidated fan gravel and fan breccia of the Ts_1 map unit blanket a pedimented surface of moderate local relief cut on the Oligocene and older rocks along the southern and eastern part of the mapped area. Gravel extends several miles into the mountains along the side slopes of the canyon of Birch Creek and probably was originally much more extensive in upland areas than at present, recording a time of accelerated downcutting which followed a long interval of mild erosion to a mature land surface. Associated mudflows, from within the central mountainous portion of the area, were at least in part the result of the mechanically unstable bentonitic material which formed the matrix of the gravel. This weathered tuffaceous matrix, probably supplied in part from the underlying Oligocene tuffs, permitted transportation of very large "erratics" for a number of miles on gentle slopes. The age of these gravels cannot be stated more closely than post-Oligocene and pre-Pleistocene.

An overlying unit of limestone pebble gravel is exposed over a considerable area northeast of Argenta. Lowell (oral communication) reports similar gravel members interbedded with the cemented equivalent of the tuffaceous boulder gravel in the quadrangle to the south.

Brown-stained quartzite gravel locally forms a conspicuous veneer, commonly no more than a few feet thick, on a prominent pedimented surface cut across Tertiary gravels and older rocks in the low foothills east of Argenta. Mapping indicates that this gravel is either limited to areas underlain by Tertiary tuffaceous boulder gravel, or lies downslope from such area. Elsewhere the pediment surface is thinly soil-mantled. This gravel and the pediment surface beneath it are referred more or less arbitrarily to the Pleistocene.

The lower course of Rattlesnake Creek is through a flat gravel-floored valley a few hundred feet to several hundred yards in width above Argenta and widening rapidly to a broad plain downstream. These gravel deposits, and a similar gravel on a broad graded surface formed by an earlier course of Birch Creek, have been mapped as Pliestocene valley gravel. The present stream channels are as much as 80 feet below the older gravel surface.

Alpine glaciers have deposited extensive moraine within the mountains of the quadrangle. At least two stages are recognized, by physiographic evidence rather than a discernable difference in weathering of the morainal material. Glaciers of the first stage were widespread. Their extent is traced by high-level moraines that lie as much as 1,000 feet above the present canyon floors. On Rattlesnake Creek, the terminal moraine of the early stage appears to rest on the valley gravel. Glaciers of the more recent stage or stages have deepened the earlier glaciated valleys and deposited more restricted moraines.

Post-glacial deposits include Recent talus, alluvial fillings of glacial basins, and most if not all of the alluvium along the present stream courses. On the map Recent talus and alluvium have been shown separately. Older, weathered talus has been mapped as part of the multifarious "cover" unit, which also includes landslide debris, slope wash, and areas of residual rock fragments and soil which effectively mantle the bedrock; some of these later deposits would be included by many geologists in a more broadly defined alluvial unit. These diverse deposits grouped in the "cover" unit probably range in age from Tertiary to Recent.

Igneous Rocks

Volcanic rocks

The earliest igneous activity recorded in the rocks of this district appears to have been local vulcanism during the accumulation of the upper Jurassic Morrison formation. Small amounts of altered silicic lava and andesitic pyroclastic rocks occur locally and many of the Morrison strata are more or less tuffaceous. Basaltic glass shards of microscopic dimensions occur in minor amounts in Kootenai rocks and important amounts of volcanic debris occur throughout much of the post-Kootenai Cretaceous sediments.

An incomplete section of Paleocene intra-orogenic volcanic rocks, comprising altered trachytic(?) tuffs and an associated trachyte porphyry intrusive, and overlying andesite agglomerate and flows, is exposed beneath a thrust plate of Paleozoic rocks in the southwestern part of the mapped area.

Post-orogenic rhyolitic tuff and rhyolitic and basaltic lavas of Oligocene age lap across truncated folds and faults in the southeastern foothills. Two small plugs appear to be the source of part of the basaltic lava. Minor masses of intrusive rhyolite may have been feeders for the tuff and rhyolitic lava.

Intrusive rocks

Plutonic intrusive rocks, of granitic texture, emplaced during the interval between the Paleocene volcanic rocks and the Oligocene volcanic rocks, occupy the entire northwestern part of the area. They also occur as smaller masses within the belt of Paleozoic carbonate rocks running southerly from the eastern margin of the major pluton. The major pluton and the majority of the smaller masses are dominantly biotite-hornblende quartz monzonite. The rocks of the smaller masses are distinctly finer grained and more variable in composition, but lack the associated biotite quartz monzonite facies which characterizes the larger body.

Biotite granite is exposed at Brown's Lake on Rock Creek. This coarse-grained rock is porphyritic in many exposures, containing orthoclase phenocrysts commonly a centimeter across. The granite is discontinuously exposed along the walls of Rock Creek canyon for a distance of about one and a quarter miles west of the lake. It is almost everywhere roofed by a quartzite unit at or near the base of the Amsden formation. At only one or two localities has the intrusive penetrated this impeding layer. Dikes and accordant sheets of aplite are locally abundant near the contact of this granite body with the overlying quartzite. On the west the granite is in irregular gradational contact with the major pluton of quartz monzonite.

The remainder of the smaller plutonic masses are granodioritic in composition; in a few instances, adjacent dikes of andesite porphyry appear to grade to granodiorite porphyry which in turn merges into granodiorite. Andesite porphyry masses distant from granodiorite exposures occur in the southern part of the quadrangle, notably at the Ermont mines. These bodies are in part sill-like and in part emplaced along pre-existing faults.

Independent evidence for both the quartz monzonite plutons and the granodiorite-andesite masses indicates that these rocks were emplaced after the cessation of thrusting and later than most but not all of the associated steep faulting. No evidence as to the relative age of the two rock groups has been recognized. The biotite granite at Brown's Lake is presumed to be younger than the quartz monzonite but definite evidence is lacking.

Latite porphyry sills and sill-like bodies intruded along thrust faults occur on French Creek and extend southward across Rattlesnake Creek. This rock resembles the trachyte porphyry further south, which is apparently cut by thrust faults, but the latite is less strongly altered, contains more plagioclase, and is definitely later than the thrust movements. West of French Creek a vitrophyric body of probable latitic composition with a markedly angular or blocky outline crosscuts the Kelley thrust. The mass is heavily charged with sedimentary rock fragments and although devitrified is commonly fluxion-banded. No cross-cutting relations between these rocks and the plutonic masses have been found.

Contact metamorphic effects

All the plutonic rocks—the granodiorite, the quartz monzonite, and the Brown's Lake granite—have contact-metamorphosed the intruded rocks. The most extensive area of contact-metamorphosed rocks lies adjacent to the eastern margin of the main quartz monzonite mass. North to Lost Creek from a point near the Greenstone mine the sediments have been metamorphosed for a distance ranging from a mile to a mile and a half east from the contact. North of Lost Creek contact metamorphism is even more extensive but limits have not yet been closely determined. At Tower Mountain, in the central part of the mapped area, the sediments in the broad thrust zone beneath the Kelley thrust have been contact-metamorphosed for a distance of two miles south of the closest exposure of quartz monzonite. At both these localities, and at numerous others more restricted in extent, the carbonate rocks have been recrystallized to marble and the quartz-rich sediments to quartzite; the argillaceous rocks, especially those with an appreciable proportion of carbonate, have been reconstituted to various types of hornfels. Additive metamorphism, such as that which locally produced tactite, is limited to areas not more than a few scores, or at most a few hundreds, of feet from intrusives.

Structure

The area is one of repeated tectonic activity. The late pre-Cambrian Belt sediments were mildly folded and probably broken by faults of large displacement before the deposition of the middle Cambrian sediments. Later the middle Cambrian rocks and the underlying Belt rocks were block-faulted and locally folded, before the deposition of upper Cambrian beds. Mild local folding occurred during the post-Triassic pre-upper Jurassic erosional interval. Folding at the end of Cretaceous time was followed by strong folding and thrusting during the Eocene epoch. There is a suggestion that minor additional uplift and folding may have resulted from the intrusion of plutonic igneous masses after most of the faulting and prior to the deposition of the lower(?) Oligocene volcanic rocks. Later steep faults cut the Oligocene volcanic rocks. Faults of this period of movement are believed to have modified the configuration of the mountain range. No faults of Quaternary age are recognized in the mapped area although they occur within the region.

Pre-middle Cambrian folding and faulting

The Belt sediments were folded and probably faulted before middle Cambrian time. On the east flank of Humbolt Mountain the middle Cambrian Wolsey shale rests on light-colored Belt quartzite above a thin and distinctive dark shaly unit. Five miles south, near the Goodview mine in the Argenta district, the middle Cambrian Flathead quartzite rests on thin-bedded argillaceous quartzite and reddish shale at least several thousand feet and possibly as much as a mile lower in the Belt series. Mapping indicates a southward truncation of the Belt rocks by an unconformity, but much of the uplift of the southern locality may have been due to faulting. South of Humbolt Mountain Wolsey shale has been dropped in the southwest block of a prominent northwest-trending fault by post-Carboniferous movement, but the net throw of the fault as measured by the pre-Cambrian rocks is down on the northeast. The lack of an unfaulted section of the upper unit of the Belt rocks on Humbolt Mountain precludes measurement of the probable pre-middle Cambrian throw on this fault.

Near the western boundary of the quadrangle, at a point a mile and a half northeast of Black Mountain, a northeast-trending fault in a poorly exposed area appears to drop Wolsey shale in the southeast block against Belt quartzite on the northwest. However, the throw of the fault as measured by the pre-Cambrian rocks is up to the southeast by a large amount. Similar relations appear to occur a mile farther to the northeast where the net stratigraphic throw of the Belt sediments is believed to be of the order of 5,000 feet.

Many other faults, active in later periods may well have been in existence in pre-middle Cambrian time. Present evidence indicates faults of northwest and north-northeast trend; the orientation of fold axes cannot be confidently stated from present knowledge, but available evidence suggests a northerly trend.

Mid-Cambrian block faulting

After the deposition of the middle Cambrian Flathead and Wolsey sediments, but prior to the deposition of the upper Cambrian Pilgrim(?) dolomite, the rocks in the lower plate of the Kelley thrust were broken by a mosaic of steep faults, mostly of small displacement. Two miles northwest of Argenta, the Pilgrim(?) dolomite of upper Cambrian age and the Jefferson dolomite of upper Devonian age overlap Belt and Flathead rocks. The older rocks are broken by faults trending a little east of north, as well as by faults of westerly and northwesterly trend. Later movement on these faults has affected the overlying rocks but Cambrian displacement is made evident either by a change in rock units below the surface of unconformity or by a difference in the amount or direction of throw as measured above and below the unconformity. The largest fault appears to have a Cambrian throw of several hundred feet.

In the area previously described the rocks below the unconformity dip gently southward; the dolomite beds above the unconformity strike about N. 30° E. and dip 30 to 45 degrees to the southeast. At the time of deposition of the dolomite beds the rocks below the unconformity in general had north-northeast trends and dipped to the northwest at angles of 15 to 40 degrees. The strongly angular relations along this contact are believed to be the result of erosion of a linear flexure of north-northeast trend, possibly a Cambrian forerunner of the major anticline trending southward from Humbolt Mountain. Coarse boulder breccia exposed along this contact just north of Rattlesnake Creek indicates local sharp relief on the older rocks.

Cambrian faulting has been recognized on the east flank of Humbolt Mountain five miles north-northeast of the area described above. At the Humbolt Mountain locality a near-vertical fault trending N. 70° W. brings Wolsey shale against Belt quartzite and is overlapped by unbroken Pilgrim(?) dolomite.

Early Tertiary folding and thrusting

The gross structural pattern in the area is the result of north-northeast-trending folds and thrusts. The folds, commonly overturned towards the east, and the thrusts, which rise from the west, involve volcanic rocks which are of probable Paleocene age and are overlapped by volcanic rocks of probable lower Oligocene age. In the northwestern third of the area this structural pattern is obliterated by a large pluton of quartz monzonite, younger than most of the faulting and folding and older than the Oligocene volcanic rocks.

The dominant structural element is the Kelley thrust which outcrops in the west-central part of the area. This fault, which has a westerly dip near the surface, carries Belt rocks over tightly folded Mesozoic and Paleozoic rocks. North of Kelley Dam on Rattlesnake Creek the thrust has an average dip of about 45 degrees to the west at the surface. South of Kelley Dam the fault appears to flatten and locally may be almost horizontal. Throughout a distance of twelve and a half miles the undulating trace of the fault almost everywhere coincides within a few degrees with observed local strikes in the overlying quartzite beds.

Beneath the Kelley thrust the Paleozoic and Mesozoic rocks are folded into a series of narrow synclines and anticlines, overturned toward the east and broken by relatively minor thrusts. These faults, which vary in number from four to eight at different localities, form a two-mile-wide zone which simulates the undulating trace of the major thrust. The displacement across the Kelley thrust and the underlying zone of lesser thrusts is unknown but can hardly be less than five miles; it may be much greater.

Just east of the thrust zone in the central part of the area, north-plunging Belt rocks are exposed along a major fold, the Humbolt mountain anticline. In the southern part of the area south-plunging Paleozoic rocks are exposed along the southern extension of the anticline. This compound structural high, which probably had its inception in a pre-middle Cambrian period of folding and faulting, was certainly affected by middle Cambrian orogeny. The early Tertiary axis, strongly modified from the earlier axes, is molded into conformity with the trace of the broad thrust zone that parallels the Kelley thrust itself.

The Humbolt Mountain anticline is a broad fold; dips steeper than 45° are uncommon within a distance of two miles east of the axis. Farther east the beds steepen and are thrown into a series of assymetric folds, generally with west-dipping axial planes. In townships 4 and 5 south the folds plunge to the north at angles up to 25°. To the south in T. 6 S. the plunge angles are smaller and not consistent in direction.

The Humbolt Mountain anticline and the folds to the east are believed to lie in the upper plate of a major low-angle thrust. This fault, the Ermont thrust, is exposed in rolling country of low relief along the south border of the map area south and east of the Ermont no. 2 mine. Carboniferous limestone dipping gently towards the southeast is carried over Paleocene(?) pyroclastic rocks, which generally dip eastward. A mile east of the mine a mosaic of segments of the upper plate, slightly displaced by intersecting steep faults, is overlapped by tuffaceous boulder gravels. The Ermont thrust is depressed on the west by a north-trending fault zone which passes about 3,000 feet west of the mine. Farther west, a large fenster, largely of Paleocene(?) lapilli tuff and intrusive trachyte, beneath the folded thrust, is truncated along its northwestern margin by the basal fault of the broad zone of thrusting underlying the Kelley fault.

The Ermont thrust is not exposed within the mapped area north of the localities described above. Neither does any Paleocene(?) volcanic rock crop out north of these localities although such rocks occur in a broad area in the quadrangle to the south (Lowell).

From the foregoing it is postulated that the trace of the Ermont thrust trends east-southeasterly beneath gravels from near the Ermont mines to some point near the southeast corner of the mapped area and there bows to the north beneath Oligocene volcanic rocks. Minor low-angle thrusting in tightly folded Mesozoic sediments at two localities near the eastern margin of the pre-thrust rocks suggests the presence of the major thrust at a shallow depth. The displacement on the Ermont thrust is unknown, but must be at least several miles. Two miles southeast of the Ermont mines, east-trending minor folds with north-dipping axial planes in andesitic rocks beneath the thrust suggest southward movement of the upper plate.

There is a suggestion in the crosscutting relationships shown by the early Tertiary faults that the orogeny took place in several episodes of thrust movement, each followed by an episode of steep faulting. No evidence has been found to suggest long intervals between these episodes.

Steep faults with early Tertiary movement have various trends; two groups of these faults are particularly numerous and are dominant among those mineralized. One group trends northwest and predominates in the mineralized section two miles northwest of Argenta. They are also prominent in the Ermont mining area. A second important group of steep faults trends nearly north; most of the mineralization at Argenta has taken place along such fractures.

Later Tertiary folding and faulting

Mapping indicates that Oligocene lavas have been displaced against older rocks by steep generally north-trending faults at several localities in the southwestern quarter of the area. No exposures of actual fault surfaces have been seen nor has any hydrothermal alteration or mineralization been noted along the presumed fault contacts. It is possible that some of these steeply dipping linear contacts represent accumulation of lava against older fault scarps as has been recognized at one locality along the Kelley thrust, but it is believed unlikely that all may be due to this process. None of these presumed fault displacements need be greater than several hundred feet.

The major quartz monzonite pluton is cut by north-northeast trending faults believed post-Oligocene in age. Along the canyon of North Creek in the northeast part of the area the quartz monzonite is cut by a broad fault zone trending about N. 30° E. On the preliminary map this has been shown as a single fault but later detailed mapping indicates a chloritized and mildly sheared zone as much as a quarter of a mile wide lying along and immediately west of the axis of the canyon. Mappable lentils of fresh, unsheared biotite-hornblende quartz monzonite are enclosed within the fault zone. A few thin veins of siderite constitute the only mineralization noted. Northeast of North Creek the fault zone is traceable as a soil-mantled swale and at Lost Creek joins a major braided fault zone in the pre-plutonic sediments. Movement along this portion of the fault zone, which has offset the beds in the northwestern block as much as half a mile eastward, is believed to be largely pre-intrusive in age.

To the west, three and one-half miles from the canyon of North Creek, a parallel pre-glacial trench is believed to be underlain by a similar fault zone. The trench extends completely across the northwestern quarter of the Willis quadrangle and is everywhere mantled with moraine. In the southern part of the Brown's Lake area a deep saddle in the quartz monzonite marks the zone and north of the broad morainal cover in Rock Creek canyon pre-plutonic sediments are slightly offset by the continuation of the zone which here has a northerly trend. This offset, which cannot be more than several hundred feet, may well be the result of later Tertiary movement superimposed on Eocene pre-plutonic displacement. The postulated post-quartz monzonite movement is believed to have elevated the western block.

The Oligocene volcanic rocks are commonly gently warped and folded. Dips up to 20 degrees are common, but to an uncertain extent are due to inclined deposition. East of the southern part of the mapped area a thick tuff section in the Frying Pan Basin has a regional east dip towards the axis of Beaverhead Valley, commonly as steep as 20-25 degrees. Two and a half miles north in sections 7 and 8, T. 6 S., R. 9 W., Mesozoic sediments on the strongly overturned and thrust-faulted east limb of a major anticline are overlapped by Oligocene tuff. These Tertiary rocks in general strike north and dip east at moderate angles but about a half mile east of the contact they steepen rather suddenly to 80 degrees. The base of an overlying thick flow sequence is vertical and individual flow layers dip steeply westward. Tertiary fan gravels lap across the volcanic rocks to the east and cover most of the area along the

the strike. The locally intense folding is believed due to a renewal of movement on the Ermont thrust, which in this vicinity is suspected, from independent evidence, to underlie the Mesozoic rocks at a very shallow depth.

ECONOMIC MINERAL DEPOSITS

Ore Deposits

The metallic mineral deposits of the mapped area are estimated to have yielded ores worth about $5,000,000.00. Almost all the production has come from the Argenta district, which embraces a large area south of the Birch Creek drainage divide. Most of the remainder has come from the small Utopia district on Birch Creek.

The Argenta district, one of the oldest mining camps in Montana, was originally a producer of lead and silver. However, in later years, the value of the lead and silver produced has sometimes been overshadowed by the value of the gold production. Total production of the district through 1951 is estimated at $4,650,000.00.

The presence of commercial ore deposits in the Argenta district became known with the discovery of the Legal Tender, the Brownell, and the Tuscarora lead-silver deposits in 1865. A small smelter, the first in Montana, was constructed in the same year. During the next five years three more lead-silver deposits were discovered and two more local smelters were built and operated. Thus by 1870 six of the nine largest lead-silver producers in the area were in operation.

In the succeeding years new deposits were found and the ores were smelted in the Argenta smelters until after the building of the railroad in 1882. Since that time the ores have been shipped to smelters or in a few cases milled locally and the Argenta smelters have long been abandoned 2/.

Although some gold was produced from earlier mining of lead-silver ore, the Golden Era deposit, the first in which the ore was largely valuable for the gold content, was not discovered until 1880; the bulk of the gold production has come from deposits discovered since 1926. In that year the first of the Ermont deposits was located; gold produced from the Ermont mines in the decade from 1932 to 1942 accounts for more than one-third of the estimated total production of the Argenta district.

The Utopia district, on Birch Creek, has been a small producer of copper. Copper ore was discovered during the 1860's but no significant production was made until after 1900. A small copper smelter was built in 1903 and operated for several years. For the period from 1903 to 1912 the district is credited with a production, mostly of copper, valued at $264,647.00 (Winchell, 1914, p. 65). Since 1912 production has been slight. Recently the district has been reactivated by prospecting and testing of low-grade tungsten-molybdenum mineralization associated with the copper mineralization.

The mines within the mapped area are mostly small and shallow. The deepest by far are the Ermont no. 19 and the Indian

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2/ Data for historical sketch taken largely from Shenon, 1931, pp. 57-58.

Queen, which attain depths of 450 feet and more than 500 feet, respectively. Most of the deposits are opened by steep shafts with but a small amount of workings along the strike.

Some of the larger mines are described below in the sections devoted to the various metals.

Gold

Two groups of lode gold mines and a small placer gold deposit have in the aggregate yielded about $2,000,000.00. The lode gold production makes up by far the greater part of the total and has all been won since 1932. Gold is the only metal of commercial importance, although silver occurs in small amounts and antimony and mercury are associated locally. A considerable additional gold production has come from lead-silver-gold deposits discussed elsewhere.

Ermont group.—The Ermont group of mines, which has been much the larger producer, was discovered in 1926 (Shenon, 1931, p. 69), and produced from 1932 to 1942. The Ermont deposits are in the southern part of the Argenta district in moderately east-dipping upper Devonian dolomite and shale beds intruded by compound sills of andesite porphyry. The andesite was in part controlled by northwest-trending steep faults, some of which were active after consolidation of the intrusive. The no. 19 mine exploits a post-andesite fault zone for a length of 600 feet and to a depth of 450 feet, production coming wholly from the hydrothermally argillized and partially silicified andesite making up two leaves of a compound sill. The black Jefferson dolomite separating the leaves of the sill has been silicified along the fault zone but does not contain commercial amounts of gold. Stopes range up to 20 feet in width along the fault zone. The no. 2 mine produced ore from an acute strike-wise wedge of partially silicified basal Three Forks dolomitic shale under a gently transgressing sill-like hanging wall of andesite. Post-andesite fracturing is not conspicuous in the underground workings; only a minor amount of ore was won from the andesite. Mining was nearly continuous along a strike length of 350 feet and down the dip from outcrop for about 400 feet, at which lower point the andesite cut nearly vertically downward across the gently dipping favorable shale beds. All the ore seen by the writer from these two mines is oxidized; limonite as pseudomorphs of pyrite is the only metallic constituent recognizable, gold is but rarely detectable by panning. The operators report that unoxidized ore was found on the bottom level of the now caved no. 19 mine. A small nearby deposit along a northwest-trending fault zone in dolomitic shale produced some ore containing a considerable amount of stibnite and a little cinnabar.

Shafer group.—The Shafer group of gold deposits, on French Creek, was discovered in 1934. The group has been exploited by four mines, the Discovery, the Park, the Cross, and the Yellow Band. They are in Jefferson dolomite along or a little below a gently west-dipping thrust fault. At the Discovery mine strongly crushed fine-grained gray quartz containing visible metallic gold has replaced banded cave sediments(?) formed in the footwall of a thrust fault. The fault dips westerly 22 to 28 degrees carrying upper Mission Canyon limestone over the Jefferson dolomite. The deposit has been stoped along the strike for about 200 feet and down the dip for 240 feet, with trial stopes for an additional 175 feet of dip length. Several small north-trending steep faults have influenced ore deposition. At the Yellow Band deposit, discovered in 1946, banded cave sediments, deposited in bedding-plane openings in the nearly horizontal black dolomite, have been faulted, buckled, and silicified to form the host rock for the gold. North-trending steep faults appear to have localized the mineralization. This deposit has been the richest of the group. During the three-year period 1946-1948, 5,150 tons of gold smelting ore averaging 0.774 oz. gold and 2.95 oz. silver to the ton was shipped from the Shafer group (Minerals Yearbooks, 1946-1948). This ore, with an average value of $29.74 a ton had a total value of $153,150.00 and was almost all mined from the Yellow Band deposit. The ore is commonly a finely crushed light-gray or white quartz carrying visible gold, locally it contains stibnite and cinnabar. Production was stopped by a cave-in in the fall of 1950.

Lead and silver

The lead and silver production has come from a large group of mines in the Argenta district, some of which have also produced considerable amounts of gold, others zinc or copper.

Replacement deposits in Paleozoic carbonate rocks are the most numerous and account for the largest production. Lead is the dominant metal in most of the deposits. Silver, which almost everywhere is associated with the lead, is commonly subordinate in value. Gold is present in minor commercial quantities in a number of deposits but its value almost never approaches that of the lead and silver. Zinc is commonly minor but is becoming more abundant in recent mining of one deposit; copper is very minor. Sulphide ore is rarely found in these deposits less than 150 feet from the surface except where galena is the only sulphide. The presence of much pyrite has invariably resulted in nearly complete oxidation of the ores.

Fissure vein deposits along steep faults and fractures in Belt shale and Belt and Flathead quartzite have yielded ore estimated to be worth more than a half million dollars. Gold is the most valuable product, with lead and silver as poor second and third in value respectively. The ratio of the gold value to the sum of the lead and silver values appears to be considerably greater in those deposits occurring mostly in shale than in those largely in quartzite. The deposits have in general produced relatively high-grade ore. Ore from one substantial producer for several years averaged about 0.75 oz. gold and 7.5 oz. silver to the ton, and perhaps 2.5 percent lead. The veins appear for the most part, to be simple fissure fillings which vary in thickness from several inches to several feet, and consist of galena and pyrite, in some cases accompanied by dark sphalerite, in a quartz gangue. Oxidation of the ores has generally not been as severe as the oxidation of similar ores in carbonate rocks but in one deposit, that exploited by the Midnight mine, the oxidized zone was reported to extend to a depth of 200 feet (Winchell, 1914, p. 67).

Fissure vein deposits in fracture zones within the quartz monzonite stock at Argenta have supplied a relatively small production to which lead, zinc, and copper have probably contributed about equally.

<u>Tuscarora and Tilden mines.</u>—The Tuscarora mine in the north-central part of the Argenta district was discovered in 1865 and the adjoining Tilden mine within a few years later (Shenon, 1931, p. 60). Most of the production was made before 1900 according to Shenon, who

estimates a total yield of from 7,000 to 10,000 tons (1931, p. 60). Most of the underground workings of the Tuscarora mine are inaccessible; the Tilden workings are accessible in part.

These mines have yielded lead ore largely from the lower gray member of the Jefferson dolomite a short distance south of the Tuscarora fault, an east-trending vertical fault zone, pre-mineral in age, which brings these rocks against the upper member of the formation. The rocks trend northeast and dip 20 to 40 degrees southeastward.

Close to the Tuscarora fault, the intersection of fractures parallel to that fault with one or several favorable bedding zones a few feet thick has controlled the formation of pipe-like ore shoots which locally coalesce to "Mantos". In the Tilden mine the favorable zone is about 55 feet below the top of the lower member of the Jefferson. At a greater distance from the Tuscarora fault, particularly in the Tilden workings, steep joints and faults of very small displacement trending from N. 10° W. to N. 30° W. have controlled small ore shoots. These include vertical tabular bodies along the fractures as well as underlying, nearly horizontal small pipes at the intersection with the favorable bedding zone. These shoots terminate at distances of 100 to 120 feet from the east-trending Tuscarora fault.

South of the Tuscarora fault several north-trending faults, pre-mineral in age but only weakly mineralized, have progressively raised the lower member to the east, repeating the favorable zone or zones. North of the Tuscarora fault in the Tilden mine is a pipe-like ore shoot controlled by the intersection of that fault and the uppermost beds of the lower member of the Jefferson.

At these mines ore has been produced discontinuously along an east-west strike length of about 800 feet and to a maximum vertical depth of about 150 feet. The ore was largely oxidized, much of it is reported to have been a granular "sand carbonate," but locally plumbojarosite was mined; residual galena can be found in the siliceous rinds or casings left on the walls of some of the pipes.

The ore shoots are believed to have replaced the dolomite, but some present the appearance of having formed as fillings of solution caves. The tubulular openings of the ore-pipes, now stripped of their oxidized lead ore, are strikingly similar to those formed by underground circulation of meteroic waters. The uppermost parts of some of the tubes, away from which the ore contracted during shrinking caused by oxidation, is a gently undulating solution surface on which neither bedding planes nor fractures can be detected.

Mauldin mine.—The Mauldin mine, atop the low hill just north of the village of Argenta, was located early in the history of the district. The mine was little developed until 1942, the beginning of the present period of operation. In recent years the mine has produced the majority of the district's annual yield, with a total ore value of $387,250.00 in the three-year period 1947-1949 (Minerals Yearbooks, 1947-1949).

In late December of 1949 the mine workings totaled about 2,500 feet and reached a depth of 210 feet. They explored a series of replacement veins, seven of which were then being mined or had recently been mined. All but one vein lies in north-trending steep faults which slightly displace interbedded hornfels and marble. These rocks, originally a series of carbonate layers with shaly interbeds in the lower part of the Amsden formation, have a general northerly strike and dip 20 to 30 degrees eastward. They have been contact-metamorphosed by the Argenta quartz monzonite stock which outcrops a few hundred feet to the south. The upper limit of commercial mineralization in at least several of the veins is formed by the intersection, in the eastern block of the vein fault, of the fault surface and the base of a thick bed of sheared sericitized hornfels overlying carbonate beds. Just below the hornfels the vein commonly swells outward into a pipe parallel to the intersection. One ore shoot has been mined along a strike length of 150 feet and through a dip length of more than 100 feet, commonly to widths of a few feet.

Much of the ore, especially in the upper part of the mine, was a mixture of jarosite and plumbojarosite, formed by complete oxidation of an original sulphide assemblage that probably contained much pyrite. This ore is soft and massive with a velvety surface, is minutely foliated, and varies in color from yellow to clove-brown. When lightly rubbed with the fingers, the tiny scales adhere to the skin like bronzing powder. Some of the material mined has been cave sediment and collapse breccia, bounded by natural solution walls of barren marble. Cerussite and residual galena are common locally in the lower part of the mine. Shipments made during 1951 have contained important amounts of zinc.

For the three-year period 1947-1949, a total of 7,131 tons of ore was produced having an average value for the contained metals of $54.31 per ton. During this period the ore averaged 12.5 percent lead, 1.7 percent zinc 3/, and 0.4 percent copper and contained 0.10 ounces of gold and 5.8 ounces of silver to the ton (Minerals Yearbooks, 1947-1949).

3/ Average for 1948-1949 only.

Copper

Most of the copper production has come from one mine, the Indian Queen. In addition, the Greenstone mine in the Utopia district has produced a small amount of copper from pockets of oxidized ore in tactite adjacent to quartz monzonite; but the greater part of the remaining copper production has come from four small lead-zinc-copper mines in the quartz monzonite stock at Argenta. These mines worked small tabular ore shoots in north-northwest-trending vertical fractures and fracture zones.

Indian Queen mine.—The mine is said to have been found in 1887 (Stevens, 1906, p. 581), but apparently did not yield more than test lots of ore until the early 1900's. Most of the mine's recorded output was made from 1903 to 1908, but lessees continued to make small sporadic shipments of copper ore until 1923, mostly, if not entirely, from reworking of stope fill and dumps.

The workings are reported to total about 1,600 feet (Stevens, 1906, p. 581). They explore a strongly faulted tactite body to a reported depth of more than 500 feet along a north-trending contact between quartz monzonite on the west and Mission Canyon limestone on the east. The ore is reported to have occurred in irregular bodies along the faulted contact between the intrusive and the tactite and also within the tactite (Winchell, 1914, p. 63). The stoped areas are inaccessible but various reports and the configuration of the accessible workings indicate that at least two apparently unrelated ore shoots were discovered. Excessive water on the lowest level, well below the altitude of the adjacent Birch Creek, is said to have forced abandonment of mining operations. Most of the ore was oxidized with malachite and azurite predominating, but much rich chalcocite ore was mined; bornite and chalcopyrite were reported by Winchell (1914, p. 63).

Regional ore control

A north-northeast alignment of hydrothermal mineral deposits and districts is noticeable in the mapped area and vicinity. From the Bannack district south of the mapped area to the Utopia district on Birch Creek, a span of 20 miles is marked by 5 small districts or groups of deposits in a remarkably linear arrangement. These entities, the Bannack district, the Blue Wing district, the Ermont deposits, the cluster around the Tuscarora-Tilden deposits in the northern part of the Argenta district, and the Utopia district, account for nearly one-half of the mineral production of the county. The alignment of these small camps disregards the surficial structural patterns, and while no more than intriguing, permits the speculation that a through-going basement lineament may have been a fundamental control in the location of the ore-districts.

Tungsten

The presence of tungsten mineralization within the mapped area has long been known, but until recently the low grade of the mineralized areas and the unfavorably high molybdenum content of the ore mineral, scheelite, had discouraged extensive prospecting. Only small test lots of ore have so far been produced. Increased demand for tungsten caused large price increases late in 1950 and resulted in a guaranteed price of $65.00 a unit 4/, more than double

4/ A unit is 20 pounds of contained WO_3.

the earlier prevailing prices. This factor and the more favorable buying schedules for high-molybdenum tungsten ores resulted in an unprecedented search for and development of tungsten deposits in the area.

Insofar as is known at present, tungsten mineralization in more than trace amounts is confined to areas of contact rocks along the margin of the major pluton of quartz monzonite. The only known exception is the reported presence of isolated molybdenum-free scheelite crystals in quartz veins within the major intrusive at a considerable distance from the margin. Most of the tungsten prospects that from present knowledge give promise of commercial grade and tonnage lie in contact-metamorphosed carbonatic rocks of the Amsden formation along the eastern margin of the main quartz monzonite mass. However, older limestone of Carboniferous age and dolomite of Upper Cambrian age have been mineralized south of Birch Creek in the Utopia district. No roof pendants or mappable inclusions are known except a very small and nearly barren one west of the Greenstone copper mine.

From a point near the Greenstone mine, a short distance north of Birch Creek, to a point northwest of Brown's Lake, a distance of 8 miles, the eastern margin of the quartz monzonite roughly parallels the regional strike of the sedimentary rocks at an average horizon near the base of the Quadrant quartzite. In detail the contact horizon is not everywhere the same, with the result that locally remnants of the Amsden formation are preserved between the igneous rocks and the overlying Quadrant quartzite. These metamorphosed remnants of carbonate rocks and interbedded, more or less carbonatic shaly rocks are the host for the tungsten mineralization.

Five known areas of contact-metamorphosed Amsden formation are recognized along this segment of the pluton's margin; each area contains more or less tungsten. Tungsten, as fine-grained high-powellite scheelite, is largely confined to bodies of tactite formed by addititive contact-metamorphism of marble and hornfels. The dominant and ever-present component of the tactite is brown andradite garnet, typically in well-formed crystals up to a centimeter or more in diameter, which in many places makes up almost the entire volume of the rock. It is generally accompanied by more or less interstitial quartz, in some places by calcite. Epidote and/or diopside occur locally in variable amounts, accompanied in some areas by magnetite or specular hematite. The high-powellite scheelite commonly occurs as very small equant crystals, typically a few tenths of millimeter across, sprinkled through interstitial quartz and the outer shells of garnet crystals. Secondary powellite is widespread as small disseminated grains and also fills joints and fractures. The scheelite almost invariably fluoresces a creamy yellow or golden yellow so nearly identical to the fluorescence of powellite that the two minerals commonly cannot be distinguished by this property.

From the Greenstone copper mine north for about 5 miles to Lost Creek the contact is roughly accordant with the sediments, which strike north and dip east. In general the dip steepens from about 40 degrees in the south to about 75 degrees in the north. At the Greenstone mine several very small shoots of high-powellite scheelite occur associated with oxidized copper ore sheared magnetite and garnet-rich tactite rock at the hanging wall of a thick body of tactite. Three hundred yards south of the mine a conspicuous dip-slope exposure of contact rocks can be traced for a strike length of about 600 feet. At the mid-point the exposure is about 175 feet in width but is relatively thin, made up of a veneer of Amsden tactite underlain by a layer of garnetized quartz monzonite. Fine-grained high-powellite scheelite and splotches of powellite occur throughout the exposure but available information suggests that the tungsten content is very low. The intrusive transgresses the Amsden rocks north of the mine; 1,000 feet north the quartz monzonite is in contact with the overlying Quadrant quartzite.

The southern tip of a mile-long belt of Amsden sediments lies 600 yards north of the Greenstone mine. Scheelite occurs in tactite at several points, accompanied at one locality by considerable molybdenite. To the north no contact zones have been recognized between this belt and a long band of contact-metamorphosed Amsden sediments extending for a mile and a quarter south of Lost Creek. This band is cut off by a northeast-trending fault zone just south of the creek.

At the Lost Creek group of tungsten prospects, parts of a 4,400-foot strike length of this belt were explored in 1951 by bulldozer cuts. Tungsten is reported south of the present limits of bulldozer exploration but the outcrop belt appears to be sharply thinned by transgression of the quartz monzonite. Prospect cuts along a 1,000-foot length at the north end of the belt indicate a potential ore zone of tactite about 20 to 25 feet in thickness, separated from the intrusive by 50 to 75 feet of tactite and marble. The mineralized zone appears to be about 150 feet below the gradational base of the Quadrant quartzite but lack of adequate exposures precludes a definite statement. At the southern limit of exploration, just northeast of West Adams Peak, bulldozer cuts have exposed a very promising tactite body for 550 feet of strike length. The intrusive contact is crosscutting in part and an apparently continuous tactite body follows the contact. A score of feet from the intrusive the tactite breaks up into fingers at several stratigraphic horizons, separated by bands of marble. The richest concentration of scheelite is believed to occur where the quartz monzonite cuts across the bedded rocks and in part is localized just beneath steeply dipping marble hanging walls.

Present information suggests that the Lost Creek area may contain a very large tonnage of marginal ore.

North of Lost Creek the margin of the quartz monzonite pluton has a rather linear northwest trend and a very steep dip and is believed to have been controlled by a pre-intrusive fault zone. The intrusive cross-cuts the sediments which in general dip gently eastward. Half a mile north of Lost Creek a small area of contact-metamorphosed Amsden rocks contains powellite and a little scheelite. A quarter of a mile farther to the northwest a bulldozer cut is reported to have exposed unmineralized carbonate rocks at the contact. These were not seen by the writer. Northward to the Ivanhoe tungsten prospect on Rock Creek the quartz monzonite at the surface is in contact with rocks stratigraphically above the Amsden formation.

The Amsden formation is exposed along both walls of Rock Creek canyon east of the quartz monzonite intrusive; here the beds generally trend a little west of north and dip gently eastward. A

50-foot unit of fine-grained thin-bedded quartzite, believed to be the basal unit of the formation, forms the accordant roof of a mass of biotite granite. On the west the granite is in irregular gradational contact with the quartz monzonite approximately along the projected trend of the east margin of the major pluton. The granite is presumed to be younger than the quartz monzonite and is certainly younger than most of the faults exposed in the north wall of the canyon.

Tactite is limited to the lower part of the Amsden formation a short distance above the biotite granite. Scheelite concentrations of commercial promise appear to be restricted to a northwest-trending zone which lies along the projected trend of the east margin of the quartz monzonite.

The Ivanhoe tungsten prospect is located on the steep, glaciated south wall of the canyon in an isolated 1,300-foot strip of outcrop surrounded by glacial moraine, slope wash, and talus. Biotite granite forms the lower part of the outcrop and is in accordant contact with the basal(?) Amsden quartzite. The quartzite and the overlying beds are on the west limb of a small anticlinal flexure; the beds strike northwest and dip southwest at varying angles up to 50 degrees. Quartz monzonite of the major pluton is exposed less than 350 feet southwest of the Ivanhoe outcrop. Tabular garnet-rich tactite bodies alternate with marble and hornfels; known layers are within 125 feet of the basal(?) Amsden quartzite. The tactite contains some scheelite over the entire length of the outcrop but commercial amounts are known at present only from an area about 1,000 feet southeast of the northwest end of the outcrop, in the vicinity of shallow inclined workings sunk on copper veins. Copper mineralization was controlled by bedding-plane shear zones in both tactite and marble. Chalcopyrite and bornite are the common sulphides. Three cars of ore were shipped in 1928 and 1929 (Minerals Yearbooks, 1928-1929).

Scheelite-impregnated garnet-rich tactite overlying biotite granite is exposed along the north wall of the canyon at the Mammoth adit. The tactite, believed correlative with the lower part of the tactite zone at the Ivanhoe prospect, has replaced a single bed about 8 feet thick and is separated from the granite by 15 feet of marble. The westward extension of the tactite is covered by glacial moraine but several hundred feet to the west a prospect pit discloses scheelite-impregnated tactite with veinlets and small masses of malachite and azurite. Quartz monzonite of the major pluton is exposed a short distance southwest of the pit.

At the Star claims about half a mile north-northwest along the east margin of the quartz monzonite, scheelite-impregnated tactite is exposed in two pits about 700 feet apart. These were dug on small outcrops of tactite and marble along the very irregular contact of the quartz monzonite, whose margin here appears to be controlled by northeast-trending pre-intrusive faults. No biotite granite is exposed but if the granite body at Rock Creek continues northwestward, roofed by the basal(?) Amsden quartzite and flanked on the west by the quartz monzonite pluton, the crest of the granite mass would lie below the Star claims at a depth of not more than several hundred feet. Talus and glacial moraine, which mask most of the bedrock at the Star claims, cover the entire belt of Amsden rocks as well as the contact zone for a mile to the north-northwest. No tactite nor any introduced contact-metamorphic minerals were found more than

1,000 feet beyond the Star no. 1 pit, either as float in the covered area or farther to the northwest along the exposed contact of the intrusive in the extreme northern tip of the mapped area. The carbonate rocks here were mapped as Amsden but may include some older rocks.

Non-Metallic Deposits

Phosphate

A few prospect pits and hand trenches have been opened in the Phosphoria formation by private individuals but no phosphate has been mined. During 1948 the phosphatic shale of the Phosphoria formation was trenched and sampled by the Geological Survey at four localities in the NW¼ Willis quadrangle (Swanson and others, 1951). The relatively low grade of the thin phosphate rock layers makes it very improbable that they will be exploited in the foreseeable future.

Petroleum possibilities

Anticlinal folds traced by the prominent outcrops of Mesozoic sediments in the Frying Pan Basin have on several occasions attracted the attention of wildcatters. Two dry holes were drilled about 1920 on the ill-defined surface trace of the axial plane of the eastern anticline, one hole in the NW¼ sec. 35, T. 6 S., R. 10 W.; the other a mile to the south in the NW¼ sec. 2, T. 7 S., R. 10 W. Both holes collared in the shale member of the Dinwoody formation of Triassic age; the depths to which the holes were drilled is not known. Very little closure seems provable along either anticline. However, another factor of more fundamental importance in assessing the oil possibilities of the area is the probability that the Ermont thrust underlies these anticlines at a depth not more than a few thousand feet. This does not rule out the possibility of structural traps in the upper plate of the thrust or of compound traps below the thrust, but will render any search for oil essentially a blind risk until the subsurface position and configuration of the thrust surface is known with some accuracy.

The effect of the nearby plutonic igneous rocks on the oil possibilities of the Frying Pan Basin area is uncertain. Quartz monzonite of the Argenta stock, which has strongly contact-metamorphosed the surrounding rocks, outcrops less than three miles from the axis of the eastern anticline, yet fresh Dinwoody shale near the site of the southern dry hole has a strong odor of petroleum.

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PLATE 2