Geology of the Coeur d'Alene District Shoshone County Idaho

GEOLOGICAL SURVEY PROFESSIONAL PAPER 478

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By S. WARREN HOBBS, ALLAN B. GRIGGS, ROBERT E. WALLACE, *and* ARTHUR B. CAMPBELL

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A description of the stratigraphy and structure of one of the world's largest lead-, zinc-, and silver-producing mining districts

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

GEOLOGY OF THE COEUR D'ALENE DISTRICT, SHOSHONE COUNTY, IDAHO

By S. Warren Hobbs, Allan B. Griggs, Robert E. Wallace, and Arthur B. Campbell

ABSTRACT

The Coeur d'Alene district, near the base of the northern panhandle of Idaho, is one of the world's larger lead-, zinc-, and silver-producing areas. The greater part of the district is included within five map areas, from east to west the Pottsville, Mullan, Wallace, Kellogg, and Smelterville, which were geologically mapped during this study. These quadrangles encompass an area about 26 miles long in an east-west direction and about 9 miles wide. The district lies wholly within the Coeur d'Alene Mountains, the part of the Bitterroot Range that is drained by the Coeur d'Alene River. The Bitterroot Range is a rugged, deeply dissected mountain mass which extends on both sides of the Idaho-Montana boundary for more than 200 miles and is a part of the Northern Rocky Mountains; within the district the range has a relief of 3,000–4,000 feet. The westward-flowing South Fork of the Coeur d'Alene River bisects the district, and roads along this river and its major tributaries generally provide easy access to the communities and many mines.

Except for a few square miles underlain by igneous rocks, the bedrock consists of the Precambrian Belt Series, the host rocks of the ore deposits. This series consists of a thick conformable group of fine-grained clastic rocks laid down in a large geosyncline, which is seen from the outcrop pattern to cover central and northern Idaho, much of western Montana, a large area in southeastern British Columbia and adjacent Alberta, and at least a small part of northeastern Washington. The Coeur d'Alene district probably lies on the west side of the geosyncline because the thickest exposed section, nearly 50,000 feet, lies to the east in western Montana. Batholithic masses intruded in Mesozoic time along the western side of the Belt Basin. The Idaho batholith, 50 miles to the south, is the nearest intrusion and the Gem stocks in the district are probably satellite outliers. Uraninite, determined to be 1,250± million years old, in relatively undisturbed veins in an overturned fold in Belt rocks in the district, shows that deformation began relatively early. Apparently, however, the intense phases were local, for remnants of sedimentary rocks of Middle Cambrian age found at several localities in the surrounding region cap the Belt Series with only slight unconformities. No younger sedimentary rocks are found within 100 miles of the district, and thus this general region may have been a positive landmass since Middle Cambrian time.

The Belt Series in the Coeur d'Alene district consists, from oldest to youngest, of the Prichard and Burke Formations, the Revett Quartzite, and the St. Regis, Wallace, and Striped Peak Formations. In mapping, the Prichard, St. Regis, and Wallace Formations were divided into lower and upper parts, and locally the upper part of the Wallace Formation was further subdivided into three units. The Prichard Formation consists predominantly of gray quartzose argillite having several interbedded quartzitic zones. A maximum of 12,000 feet is exposed; the remaining basal part of unknown thickness is buried. The upper several hundred to 2,000 feet of the Prichard Formation consists of a transitional zone of alternating argillite and quartzite. The overlying Burke Formation, 2,200–3,000 feet thick, mostly consists of light greenish-gray sericitic quartzite interspersed with some fairly pure to pure quartzite. The contact between the Burke Formation and the overlying Revett Quartzite is the most indefinite within the entire series; it lies within a transition zone 500 feet or more thick and has been placed arbitrarily where thick-bedded vitreous light-colored quartzite strata characteristic of the Revett begin to predominate. These vitreous quartzite beds make the Revett the most distinctive formation in the area. Impure to fairly pure quartzite is interbedded in the lower and upper parts. Within the district, the Revett Quartzite thickens from about 1,500 feet in the east to about 3,400 feet in the west. The next overlying formation, the St. Regis, grades from interbedded quartzite and argillite upward into a dominantly thin-bedded argillite, almost all of which is a characteristic purplish-red to red. The upper several hundred feet of the St. Regis Formation is characterized by a porcellaneous greenish-yellow finely laminated argillite, which is found most extensively in the southeastern part of the area. The Wallace Formation, 4,500–6,500 feet thick, is a heterogeneous group of rocks comprising quartzite, argillite, dolomite, and limestone. It is distinguished from the rocks above and below by having a greater content of carbonate minerals. The lower ½–⅔ of the formation is alternating dark argillite and light quartzite, containing various amounts of carbonate. The remaining upper part of the formation consists of thinly laminated dark-colored argillite, usually containing a central dolomite-rich zone. Only the basal 1,500 feet of the Striped Peak Formation lies in the district. This interval consists of interbedded platy reddish and greenish quartzite and argillite having some interbedded arenaceous dolomite.

The rocks of the Belt Series are universally fine grained, and their principal minerals are quartz and sericite. Quartz is more abundant, as even most of the argillitic rocks are silica rich, but some thin argillite beds or laminae are almost entirely composed of sericite. A characteristic suite of accessory minerals includes feldspars, muscovite, magnetite, ilmenite, zircon, tourmaline, rutile, and titanite. Rock fragments are common in the arenaceous rocks. Hematite, other iron oxides, and carbonaceous matter, along with sericite and chlorite, impart the varieties of colors exhibited. Carbonate minerals, usually ferroan dolomite and less commonly calcite, may be found in all formations, but are common only in the Wallace Formation, and to a lesser extent in the St. Regis and Striped Peak Formations. Chlorite is abundant in some rocks, but usually is present in only very minor amounts. Pyrite or

pyrrhotite are very abundant, but are in amounts of less than 1 percent in the Prichard Formation. A relatively mild regional metamorphism was probably responsible for most of the sericite and chlorite, some recrystallization of the quartz and, where slightly more intense, a green-brown biotite. Orientation of the sericite and chlorite is noticeable in the argillitic rocks and reflects axial-plane or shear foliation.

Depositional sedimentary structures are common throughout the Belt Series. Those diagnostic of a shallow-water origin—such as mud cracks, mud-chip breccia, and cross-stratification—are abundant at many places in the upper 15,000 feet of the Belt section but are sparse in the lower part of the Prichard Formation, where they are found in the quartzitic zones. Other features include ripple marks, pseudoconglomerate, flow casts, and raindrop impressions. Postdepositional structures include interbed crumpling, minor slump features, and miniature clastic dikes. Boudinage and disrupted thin beds, which on weathering etch into molar-tooth structures, are common in parts of the Wallace Formation.

Igneous rocks make up only a small part of the bedrock in the Coeur d'Alene district. They consist principally of two groups of small monzonitic intrusives, diabase and lamprophyre dikes, and an assortment of other dikes mostly related to the monzonitic bodies. The monzonitic rocks of Late Cretaceous age occur in two small stocks north and west of Gem, after which they are named, and seven smaller bodies clustered together several miles to the west. These intrusives consist of monzonite, quartz monzonite, syenite, and diorite. Contact metamorphic halos extend as much as 1,000 feet or more from these intrusives but usually considerably less. Both the lamprophyres and diabase dikes cut the monzonitic rocks; the lamprophyre dikes also crosscut many of the ore deposits, and field relations indicate that the diabase dikes are also younger than these deposits. The lamprophyre dikes are divisible into two groups: in one, biotite makes up the recognizable phenocrysts and in the other, hornblende. These dikes characteristically trend north to northwest, whereas the diabase dikes mostly trend west and commonly intrude preexisting faults along which there has been some subsequent movement. The Wishards sill, a large diabasic intrusive which crops out just south and east of the district, is probably Precambrian in age, and thus is much older than the diabase dikes.

Two old erosion surfaces are evident in and near the Coeur d'Alene district. Remnants of the older, the summit erosion surface, occur along the crests of the accordant main ridges; the other, the subsummit erosion surface, is represented by shoulders on subsidiary ridges about 1,000 feet below the crests. Considerable uplift and erosion, which followed the formation of the two old erosion surfaces, are indicated by remnants of older gravels which cap ridges and fill remains of abandoned stream channels. These gravels are found as much as 1,100 feet above the present valley bottoms. This aggradation probably took place in middle Miocene time while the Columbia River Basalt was forming the great plateau to the west. Erosion was again interrupted in Pleistocene time when lobes of the continental ice sheet twice dammed the main stream draining to the west at the Purcell Trench near the Idaho-Washington border. The valley of the South Fork of the Coeur d'Alene River is still aggraded west of Wallace. Many cirques on the north side of the higher ridges and small accumulations of drift show that mountain glaciation was active within the district, mostly within the last of the Pleistocene glacial epochs.

The Coeur d'Alene district lies at the intersection of a north-trending broad anticlinal arch and the west-northwest-trending Lewis and Clark line as represented by the Osburn and related faults. Folding and faulting were more intense in the vicinity of this intersection and caused the formation of a structural knot. The Gem stocks crop out near this intersection and are alined, together with several other small igneous bodies of similar composition, along the axis of the arch. The Osburn fault, the major structural feature, bisects the district and was traced continuously for more than 100 miles and extends well beyond the mapped area both to the east and to the west. Offset folds and faults along the Osburn fault strongly indicate a maximum of about 16 miles of right-lateral strike-slip movement.

Faults are the dominant structural features in the area, and a myriad of them cut the country rock into a complex pattern of blocks. For every one shown on the maps, hundreds of others of lesser displacement were seen underground. As a result of this faulting plus the folding, most of the bedded rocks within the district are tilted at an angle of 45° or more and some are overturned. A genetic grouping in the general sequence of formation consists of relatively low-angle reverse faults, steep-dipping normal and reverse faults, strike-slip faults, and late normal faults. The Carpenter Gulch and Page-Government Gulch faults are good examples of the reverse faults, whose early age is deduced from their segmented and irregular character and from the indication that they have resulted from compressional stresses responsible for the folding. The association of uraninite-bearing veins of Precambrian age with the Alhambra fault of this group shows that the fault formed early. A large number of faults which dip at angles usually greater than 70° and along which the movement may be normal on one fault but reverse on the next probably have resulted from vertical adjustments. Many of the faults in the northern part of the Mullan and Pottsville map areas are of this group, although other faults scattered throughout the district are also of this group. The close spatial relation of many of these faults to a pervasive hydrothermal alteration, called bleaching, shows that they existed prior to this alteration, and that some predate the vein formation of the main period of deposition.

The major strike-slip movement along the Osburn fault took place after the main-period veins had formed. The Placer Creek fault, which parallels the Osburn about 4 miles to the south for the full length of the district, and the Thompson Pass fault, just north of the mapped area, each had a mile or more of right-lateral strike-slip movement along them; other parallel to subparallel lesser faults within the district also had such movement along them. The Dobson Pass fault, which trends north from the Osburn fault in the vicinity of Wallace, is a low-angle normal fault, dipping 30° W., which was probably formed contemporaneously with the Osburn. The small monzonitic bodies almost 4 miles west of the Gem stocks are probably cupolas of the stocks that were displaced this distance along the Dobson Pass fault. Late normal faults of relatively small displacement cut several veins of the main period.

The major folds probably formed the earliest structural framework of the Coeur d'Alene district and are all part of the early-formed broad anticlinal arch. South of the Osburn fault most folds and faults trend parallel to subparallel to the fault, whereas to the north both the major folds and faults have a more nearly northward trend. In gross pattern, the folds to the north of the Osburn fault can be matched with those to the south, which appear to have been warped into their present position during the strain that culminated in the major strike-slip faults. On the west, the Pine Creek anticline to the south and the Moon Creek anticline to the north match well as offset segments of a domelike structural feature. Farther east, the Big Creek anticline, Lookout syncline, and Lookout anticline seem to be offset segments of the Burke anticline, Granite Peak syncline, and Glidden Pass anticline to the north. Structural complexities within a zone that extends for about a mile north of the Osburn fault, together with the en echelon arrangement and right-angle position of the southern set, all superimposed during the warping and strike-slip deformation, have masked the relation of these features, but the fact that these features constitute the only similar set on opposite sides of the Osburn fault plus their similarity in size and amplitude is good evidence that they are offset segments. The northern limbs of the Big Creek and Lookout anticlines are in part overturned, whereas the folds to the north are generally open and less complicated.

Veins of the main period, mostly in west-northwest-striking fracture zones along which movement was minor, formed during the time the warping took place across the Osburn fault. The productive veins lie within a group of near-parallel separate mineral belts, also of a west-northwest trend, which, with only two exceptions, show no disruption due to subsequent strike-slip movement in spite of the fact that major displacement followed their emplacement.

INTRODUCTION

This report is a restudy of the general geology of the Coeur d'Alene district. The importance of the district as a major source of base metals and silver, the mode of occurrence of the ore minerals, and the potentialities for future discoveries have stimulated many workers to do research on various phases of the geology. Most of the work has gone into the study of local areas, individual mines, or special problems, but two exceptions to this pattern are outstanding: the work of Ransome and Calkins (1908) on the geology and ore deposits of the Coeur d'Alene district, Idaho, and that of Umpleby and Jones (1923) on the geology and ore deposits of Shoshone County, Idaho. Both studies used a districtwide approach to the geologic problems, but the 1902–03 work of Ransome and Calkins that culminated in U.S. Geological Survey Professional Paper 62 embodied the fundamental mapping and description of the lithology and structure used by Umpleby in his report on the ore deposits of Shoshone County. Umpleby republished the geologic map from Professional Paper 62 and made no attempt to refine or add to this picture of the surface geology. Most of his report was aimed at reviewing and updating the information about the mines and prospects and documenting current ideas on origin and development of the Coeur d'Alene and other ore deposits in the county.

In view of the continuing importance of the area as one of the major lead-, zinc-, and silver-producing districts in the world, the need for a comprehensive review of the geologic setting has long been felt. Professional Paper 62 (Ransome and Calkins, 1908) is a remarkable accomplishment; that it is still eagerly sought and is used daily by geologists attests to its excellence and to the need for the type of study it represents. In the decades following these early publications there has been a tremendous expansion of mining activity; early-discovered ore shoots have been mined out; new ore shoots and new veins have been found; many miles of workings have been driven, both in mining the veins and in searching for new ones; and extensive new surface exposures have been made in the course of road building and bulldozer trenching. All this activity has added a vast amount of data to the already impressive accumulation of geologic information on the area. Although the opportunity to collect some of these data in the caved workings of old mines is lost beyond recall, much information is still available; a great treasure of invaluable information is preserved in published reports on parts of the district or various phases of the geology, in private reports, and principally in the map files of the mining companies. The collection, compilation, and analysis of this information and its integration into the geologic patterns inherited from previous investigations has been one of the fundamental goals of this work. If we have added new evidence, developed new ideas, stimulated thought, or applied modern concepts that brought us closer to the ultimate understanding of why the ore deposits occur in the Coeur d'Alene district, our effort will have been worthwhile.

The mining area under investigation has been remapped at the scale of 1:24,000, and the geology has been compiled on five special maps. From west to east these maps are Smelterville, Kellogg, Wallace, Mullan, and Pottsville (pls. 1, 2, 3, 4, and 5). Full advantage was taken of the very extensive underground workings in interpreting the surface geology and in preparing sections. Many of the geologic maps of these workings came from mine-company files, but a large number of crosscuts were mapped during the investigation to gain firsthand knowledge. A set of five companion maps combined on the previously mentioned plates illustrates as much as is practical of the geologic data that have been collected from mine workings. These compilations have been annotated only so far as necessary to present the data legibly at the scale of publication. In many mines having multiple superimposed levels, levels were selected for illustration that give maximum information. These sheets are intended not only as support for our interpretation but also as a collection of facts to be used by anyone who may wish to reshuffle the ideas presented in this report.

Much of this report is a description of the geology of the mining area illustrated in the five surface maps previously described. In the course of the work, however, it soon became apparent that many of the answers to basic problems in the geologic history of the district lay outside the immediate area of the detailed study. This consideration, together with a desire to test the surrounding region for possible extensions of the ore deposits, led to geologic reconnaissance mapping to the east, north, and west. Reports by Wallace and Hosterman (1956), Hosterman (1956), Campbell (1960), and Campbell and Good (1963) have been published by the U.S. Geological Survey on this work. Considerations of the regional setting and the sequence and timing of geologic events in the mining area have drawn heavily on the previously mentioned extradistrict work as well as on the earlier work of many geologists. It will become evident to the reader that more regional work must be done before possible ultimate answers are attained. Field and laboratory work on the details of the ore deposits followed the completion of the general geologic studies and the results of this work constitute a separate paper (Fryklund, 1964).

LOCATION AND ACCESSIBILITY

The Coeur d'Alene mining district, one of the preeminent lead-, zinc-, and silver-producing areas in the world, is near the base of the panhandle of northern Idaho. Spokane, Wash., is about 75 miles to the west and Missoula, Mont., about 110 miles to the east of the district (fig. 1). The area mapped for this report, which includes the major ore deposits, extends from the Montana State line westward for slightly more than 26 miles and is approximately 9 miles wide.

The South Fork of the Coeur d'Alene River, heading at the divide forming the boundary between Idaho and Montana, traverses the length of the district on a course slightly north of west, and its conspicuous valley bisects the area and affords easy access both from the west and east. U.S. Highway 10 follows the main valley except at the east edge where it crosses the Idaho-Montana State line over Lookout Pass. A branch line of the Union Pacific Railroad from Spokane terminates at the city of Wallace, near the center of the district, and a branch of the Northern Pacific Railway connects Wallace by way of Lookout Pass with the main line at St. Regis, Mont.

Most of the principal towns and settlements are scattered along the floor of the main valley. From west to east, these include the communities of Pinehurst, Smelterville, Kellogg, Osburn, Silverton, Wallace, and Mullan. Gem and Burke, two other towns within the district, are along Canyon Creek, a tributary from the northeast connecting with the main valley at Wallace. Several smaller settlements are scattered throughout the region.

All the centers of population and many of the major mines are accessible by main highways or hard-surfaced roads. Well-graded gravel roads connect all principal centers of population or industry, and miles of Forest Service access roads allow formerly remote areas to be easily reached. Fieldwork was greatly facilitated by miles of bulldozer roads, most of which were accessible by Jeep.

TOPOGRAPHY AND DRAINAGE

The Coeur d'Alene district lies within what is generally called the Bitterroot Range, or sometimes the Bitterroot Mountains, a part of the Northern Rocky Mountains. At this latitude the Rocky Mountains encompass the panhandle of northern Idaho and much of western Montana, and consist of an area of poorly defined mountain ranges that are rugged and deeply dissected. In the western part they are generally separated by major drainage channels that are usually narrow floored, and in the eastern part they are north-trending elongate ranges separated by intermontane basins. The boundary between the States of Idaho and Montana follows the crest of the Bitterroot Range for more than 200 miles. The northern part of this crest trends northwest and forms the drainage divide between the Clark Fork River system to the northeast and the streams draining westward into Coeur d'Alene Lake and thence into the Spokane River. Although indivisible from the rest of the Bitterroot Range, that area within the drainage system of the Coeur d'Alene River is sometimes called the Coeur d'Alene Mountains, and similarly the area immediately to the south that lies within the drainage of the St. Joe River is sometimes called the St. Joe Mountains. The Coeur d'Alene district lies wholly within the Coeur d'Alene Mountains, and almost all of it is adjacent to the South Fork of the Coeur d'Alene River. This stream and its numerous tributaries drain almost all the mapped area.

The area is one of high relief and generally rugged terrain. Ridge slopes are consistently steep; many are inclined at angles of about 30° or greater. Valley flats are restricted to the main stream and the lower reaches of some major tributaries; in only a few places do the flats exceed half a mile in width. The ridge crests are usually narrow and are at similar altitudes for long distances. Toward the east edge of the Pottsville map area, the South Fork of the Coeur d'Alene River is at an altitude of 3,600 feet, and near Kingston at the west edge of the area, it is at an altitude of 2,150 feet. The ridge crests and the peaks

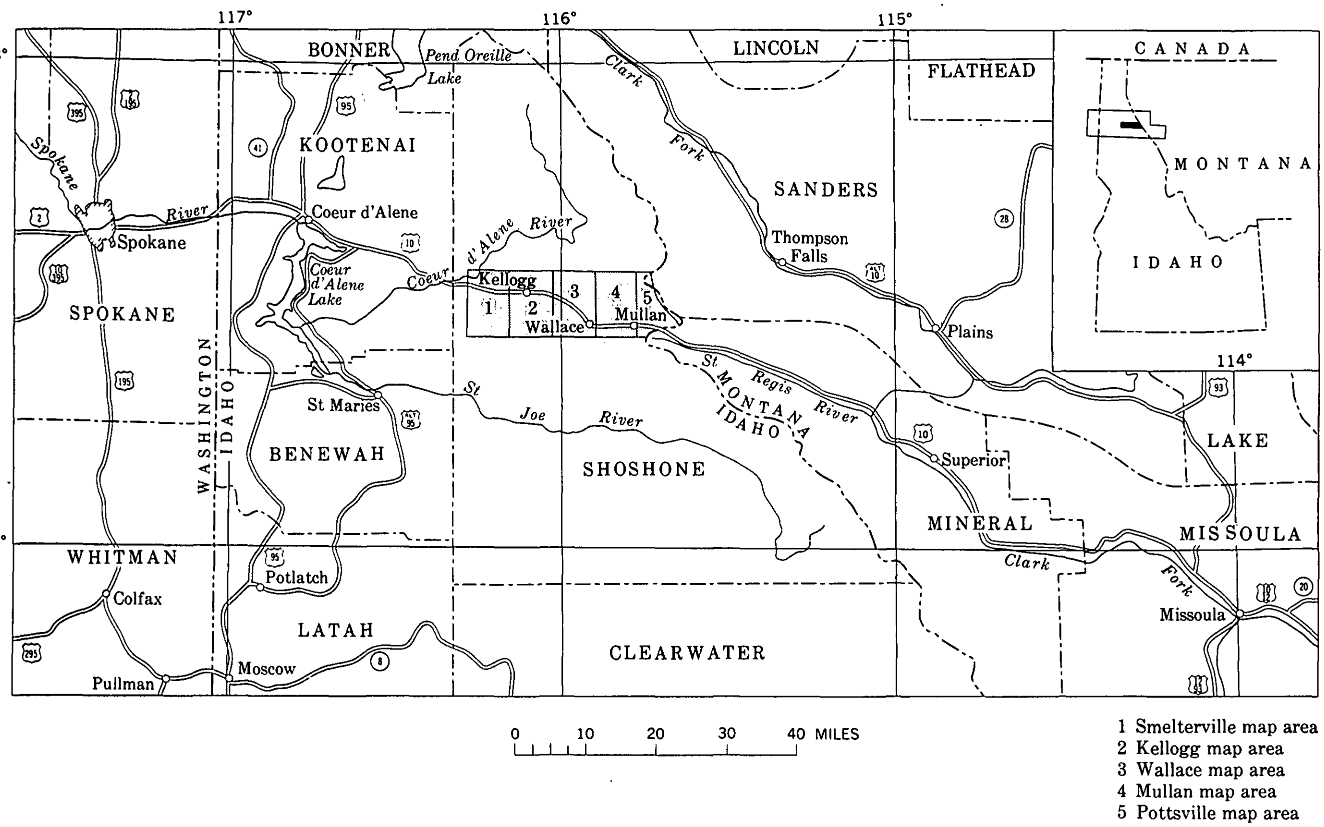

FIGURE 1.—Map of part of northern Idaho and adjacent areas showing the location of the geologic maps covering the Coeur d'Alene district.

along them, which commonly extend only a few hundred feet above the general level of the crests, range in altitude from 6,000 to 7,000 feet. Thus the maximum relief between valley floors and adjacent ridge crests and peaks ranges from 3,000 to 4,000 feet.

Stevens Peak, at the south edge of the Pottsville map, is the highest point in the area with an altitude of 6,844 feet. Some other prominent peaks within the area include the following: Granite Peak, altitude 6,821 feet, at the north edge of the Pottsville map; Tiger Peak, altitude 6,626 feet, in the northern part of the Mullan map; and Kellogg Peak, altitude 6,304 feet, to the west near the center of the Kellogg map area.

The major ridges trend westward from the main divide of the Bitterroot Range at the east edge of the mapped area. Larger tributaries of the South Fork of the Coeur d'Alene River such as Canyon and Ninemile Creeks, which flow from the north, and Placer, Big, and Pine Creeks, which flow from the south, appear to have breached these major ridges in the past. The divide which separates the drainage basins of the South Fork of the Coeur d'Alene River and the St. Joe River to the south is generally at least a mile south of the mapped area but, from the vicinity of Gold Hill eastward, the divide follows the southern borders of the Mullan and Pottsville map areas. The divide to the north which separates the drainage basins of the South Fork of the Coeur d'Alene River and the main stream has an irregular pattern within the mapped area from Granite Peak to the east on the Pottsville map to Capitol Hill to the west on the Wallace map. West of the mapped area this divide trends slightly north of west.

Ninety-five percent of the mapped area is drained by the South Fork of the Coeur d'Alene River and its tributaries. Only parts of the northeast corner of the Wallace map area and the northwest corner of the Mullan map area, through which Beaver and Granite Creeks flow north to join the main Coeur d'Alene River, lie outside of this drainage system. The larger tributaries entering the South Fork of the Coeur d'Alene River from the north include Montgomery and Moon Creeks in the Kellogg map area, Twomile Creek in the Wallace map area, and Ninemile and Canyon Creeks in the Mullan map area. From the south, Pine Creek in the Smelterville map area, Big Creek in the Kellogg map area, and Placer Creek in the Wallace and Mullan map areas are major tributaries. Except for the part of the course of Pine Creek where the stream sinks underground for some distance during the summer, these larger tributaries flow in all seasons. Many of the smaller tributaries and gullies have a perennial flow, but others go dry in midsummer or late summer.

CLIMATE AND VEGETATION

The climate of the Coeur d'Alene district and its environs is strongly seasonal and generally similar to the climate of the whole western slope of the Northern Rocky Mountains (U.S. Weather Bur., 1936). Precipitation ranges between 30 and 40 inches a year; the largest amount falls as snow during the winter months. Rains are abundant in the early fall and spring. Warm sunny weather generally prevails from mid-June through August, although some thunder showers occur. October and November are usually clear and cool following a mid- or late-September rainy spell. Daytime temperatures in the summer are usually moderate, but there are occasional short spells ranging between 90° and 100°F. Winter temperatures are generally well below freezing, and zero and below-zero temperatures are common. Snowfall is heavy for the whole district. In the lower valleys toward the west end of the area, the snow may not persist through the winter but may melt away between storms; however, at higher elevations snow persists as a cover several feet thick from late fall to late spring. Many great drifts accumulate on the lee side of high ridges, in deep swales, in densely wooded areas, and in areas protected from the sun and may remain there through July or even mid-August. Deep accumulations of snow in the higher and deeper cirque basins may persist until covered by the next winter's snowfall.

Vegetation (Standley, 1926) is abundant, although local differences in environment, both natural and man-made, effect a pronounced change in type and amount of the plant cover from place to place. Only a few small areas of the original coniferous forest that once covered the district remain. Harvesting of the trees in the early years of lumbering for mine timbers and fuel stripped large stands of mature forest near the major mines. The great forest fire of 1910 swept through the district and laid waste much of the remaining forest cover. Only local patches of vegetation such as timber stands in deep ravines remained unburned after this holocaust. Stands of second growth and brush now have replaced much of the logged-off and burned-over areas.

Conifers found in the area are pine, fir, hemlock, larch (also known as tamarack), cedar, and spruce. Douglas fir *(Pseudotsuga taxifolia)* may well be the most common tree in the district. Western yellow pine *(Pinus ponderosa)* thrives on drier well-drained slopes, but the few stands of size support only sporadic logging operations. Western white pine *(Pinus monticula)* is common, but large stands are mostly outside the area of study. Lodgepole pine *(Pinus contorta)* is abundant as second growth in burned-over areas. Grand or white fir *(Abies grandis)* and some western hemlock *(Tsuga heterophylla)* are increasingly abundant toward the eastern and higher parts of the district. Alpine fir *(Abies lasiocarpa)* dominates the highest ridge crests, where groves of mountain hemlock *(Tsuga mertensiana)* and some Engelmann spruce *(Picea engelmannii)* also may be found. Western larch *(Larix occidentalis)*, or tamarack, is scattered throughout the district in isolated clusters and fairly large patches and groves. Numerous large stumps of the western red cedar *(Thuja plicata)* are evidence of the many groves of this noble tree that once covered most of the water-saturated valley flats; a few specimens still remain in the more remote and inaccessible valley bottoms and ravines.

Deciduous trees, mainly species of willow *(Salix)*, alder *(Alnus)*, and black cottonwood *(Populus trichacarpa)*, are restricted principally to valley flats and perennial stream courses, although some willow and alder grow in thickets on ridge slopes where the moisture content of the soil is sufficient to nourish them. Some aspen *(Populus tremuloides)* flourish on high, open slopes. A large variety of brushy plants and other ground cover are distributed unevenly over the district, and their abundance ranges from sparse growth on the drier slopes of thin soil cover to dense thickets in moist swales. Deer or buckbrush *(Ceanothus velutinus)*, huckleberry or tall whortleberry *(Vaccinium membranaceum)*, twinberry *(Lonicera utahensis)* and *(Lonicera involucrata)*, syringa *(Philadelphus lewisii)*, salal *(Gaultheria shallon)*, service berry *(Amelanchier almifolia)*, chokecherry *(Prunus melanocarpa)*, mountain ash *(Sorbus sitchensis)*, and devilsclub *(Echinopanax horridum)* are common species of the brushy plants. The deerbrush commonly forms almost impenetrable thickets, which on some slopes cover many acres, and luxuriant growths of devilsclub make thorny barriers of many damp shaded ravines. Tall whortleberry is abundant in patches on open slopes, and it is difficult to pass up its berries when in season. Various grasses thrive in open areas and the more open pine forests, and hummocky clumps of the grasslike lily, bear grass *(Xerophyllum tenax)*, are the most conspicuous growth on many open slopes and meadows in the highest terrain. Although very little if any of the district is above timberline, the highest rocky ridges and crags are nearly barren or support only scraggly trees and shrubs.

INDUSTRY AND POPULATION

Mining is the sum and substance of the economy of the immediate Coeur d'Alene mining district. Lumbering has become more important within the past decade, but much of the production is directed toward use in the mines. Practically all other industry is directly related to exploitation of the mineral resources or to supporting and serving the people directly engaged in mining.

Shoshone County had a population of 22,806 in 1950, and of this number, at least two-thirds lived in the Coeur d'Alene district. Kellogg, Wallace (the seat of Shoshone County), and Mullan, having populations of 4,913, 3,140, and 2,036, respectively in 1950, are the three main business centers. Osburn and Silverton have grown rapidly in the past few years, principally as residential adjuncts to the larger communities. The historic town of Wardner on Milo Gulch has been gradually assimilated into the expanding city of Kellogg. Smelterville, named for the nearby Bunker Hill lead smelter, is another rapidly growing community, having a population of more than 1,000. Pinehurst, near the mouth of Pine Creek is the westernmost settlement in the area. The town of Burke, 6 miles northeast of Wallace, is at the focal point of several of the early mine discoveries on Canyon Creek and still serves as a major center of mining activity in this part of the district. Several minor settlements and a great many houses occur predominantly along the main routes of travel and the principal side roads. As in any mining area, the population fluctuates with the seasons and with the vicissitudes of the mining industry.

PREVIOUS WORK

Reference is made in the introduction to several of the more important studies on the Coeur d'Alene district, notably those of Ransome and Calkins and Umpleby and Jones. Other competent workers have also contributed much to the fund of geologic knowledge on the district and its immediate environs. Of these, special reference is made to P. J. Shenon and J. T. Pardee, and again to Calkins, Jones, and Umpleby, all of the U.S. Geological Survey; A. L. Anderson and W. R. Wagner of the Idaho Bureau of Mines and Geology; and R. E. Sorenson of Hecla Mining Co., R. H. McConnell of Bunker Hill Co., and O. H. Hershey, for many years geologist for the Bunker Hill and Sullivan Mining and Concentrating Co. (now the Bunker Hill Co.).

Much fundamental information on regional geologic relations and the distribution and stratigraphy of the Belt Series has been drawn from reconnaissance studies by many workers in areas both near and far. Here again we owe much to the work of Calkins, Pardee, and Jones, but also to the early work of W. H. Weed, C. D. Walcott, Bailey Willis, and R. A. Daly and the later work of C. H. Clapp, C. F. Deiss, C. P. Ross, and others. Reference to the works of the aforementioned authors and to many other studies is made in the bibliography on pages 134–136.

HISTORY, PROCEDURE, AND PERSONNEL

In 1935, the U.S. Geological Survey in conjunction with the Idaho Bureau of Mines and Geology began a detailed reexamination of the Coeur d'Alene district; P. J. Shenon was in charge of the work. Because of the interest in gold in the mid-1930's, the study was started with an investigation of the Murray district north of the main base-metal province. A report on the gold-tungsten deposits of this district was prepared by Shenon (1938). In 1936, work was started in the Silver Belt of the Coeur d'Alene district—an area embracing the vein systems south of the South Fork of the Coeur d'Alene River and extending from the vicinity of Wallace westward to beyond Big Creek. During the winter and spring of 1936–37, most of the accessible underground workings of the Silver Belt were mapped, and in the summer of 1937 about 60 square miles of surface geology was mapped on the scale of 1:24,000. A preliminary map of the Silver Belt with a short description of the geologic features was prepared by Shenon and McConnel (1939). Mr. Shenon revisited the area in 1941 to bring his information up to date, and a detailed report on the Silver Belt was prepared. Unfortunately, the exigencies of the war years and other factors delayed publication of this report and postponed the continuation of fieldwork in the area. In 1943, under the Strategic Minerals program of the U.S. Geological Survey, a study was made of the Pine Creek mineral belt at the west end of the Coeur d'Alene district. This work was under the direction of J. D. Forrester, who was assisted by V. E. Nelson and J. F. Smith, Jr., and resulted in two preliminary open-file releases—one a geologic map of the Pine Creek area (Nelson and Smith, 1943) and the other a report on the lead and zinc deposits of the Pine Creek area (Forrester and Nelson, 1944).

The current project was begun in July 1947 with S. W. Hobbs and A. B. Griggs as coworkers. A short summer season, in which general reconnaissance of the area and measurement of stratigraphic sections was undertaken, was followed by a winter devoted to some underground mapping and compilation of data. This preliminary activity set the stage for the mapping program that followed. At the beginning of the field season in 1948, the original coworkers were joined by R. E. Wallace, S. E. Good, and A. B. Campbell. Unusually competent assistance was provided by H. C. Rainey III during the summer of 1949 and from March 1950 to February 1952 and by Ben Bowyer for 30 months between November 1949 and March 1953. V. C. Fryklund, Jr., joined the project in 1952 to start the work on the ore deposits. The report on these studies is separate from this one on the general geology, but acknowledgment is made of the many facts and ideas that Fryklund's work has added to the overall picture and of his critical review of this report. J. C. Hosterman assisted in the investigation of the adjacent area to the east in Mineral County, Mont., in 1953, and made a study of the Murray district immediately to the north in 1954. For capable assistance during single field seasons, acknowledgment is due G. E. Becraft, Richard Cifelli, John Kolars, Clarence McCormack, and James Noel.

Four or five months of each summer from 1948 to 1953 was devoted to fieldwork, which included both surface and underground work. Some underground work was done during the winter months, but most of this time was devoted to compilation of maps, writing, laboratory work, and preparation of open-file releases. Although Good was attached to the party from June 1948 to October 1949, his entire efforts were spent in working in the Twin Crags quadrangle just west of the district, where he was assisted by Campbell. Griggs was away from the project for 3 years during the period 1951–54, but he returned to spend parts of 1954–56 on manuscript preparation. Wallace spent part of 1952 on a reconnaissance study of part of Mineral County, Mont., which lies immediately east of the district, but then left the project to return in 1955 and 1956 to assist with manuscript preparation. From 1953 to 1955 Campbell made a study of the St. Regis-Superior area, Montana, as part of the investigation of the region peripheral to the district. He also spent part of this time and part of 1956 in the preparation of the manuscript for this report. Various members of the project spent the equivalent of about 2 man-years on duties for the Defense Minerals Exploration Administration. Although a total of 12 people worked for longer or shorter periods on the project, field work, the prosecution of the project, and the interpretation of the data was largely the responsibility of the present authors.

We cannot close our acknowledgments to our coworkers without special reference to Stanley E. Good, who lost his life in the area of his work. His assignment to map the Twin Crags quadrangle as a part of the overall district study was a difficult one. Not only is the country rugged and, in part, difficult of access, but the geology is far from clearcut and at many places it is indecisive. He approached his task with energy and enthusiasm and during two summers, with the able assistance of Mr. Campbell, roughed in the the general framework of the geology. In the fall of 1949, while hunting elk in the vicinity of Twin Crags, Mr. Good was caught in a heavy snowfall and fell a victim to overexhaustion.

Fieldwork was done largely by the combined use of topographic maps and aerial photographs in the field and compilation on enlargements of the topographic maps in the office. Full advantage was taken of the very numerous and extensive underground mine workings to gain geologic information not otherwise available. Such information was especially useful in areas where surface cover masked the bedrock, and many formational contacts and faults were located on the surface by projection from underground observations.

The five special maps, Smelterville and vicinity, Kellogg and vicinity, Wallace and vicinity, Mullan and vicinity, and Pottsville and vicinity, used as a base for the geology, were prepared by the U.S. Geological Survey in 1937–39 by planetable methods. Of these, only the Smelterville map was field checked and released in the final published form. Mainly because of this, but partly because of their method of preparation, these special maps do contain minor inaccuracies. The discrepancies became most apparent when attempting to plot mine workings, whose locations had been determined by careful transit surveys by the mining companies upon the topographic maps. Some of these errors were corrected, but because many of the locations of the openings of mine workings could only be resolved by compromise, the perpetuation of minor discrepancies in their position and altitude became inevitable. The configuration of the terrain as depicted by the contours on the maps, however, is for the most part excellent.

Aerial photographs were an invaluable adjunct to the fieldwork. They provided relatively recent data on the location of roads, exploration openings, tunnels, and outcrops; they helped the planning of field traverses and were a good plotting base. Most of the aerial photographs were taken by the U.S. Forest Service in 1937, 1939, 1947, and 1948. Geological Survey aerial photographs taken in 1947 and 1948 in the area of the Twin Crags quadrangle were used where they overlapped the Smelterville map area.

The division of major responsibility for the fieldwork is shown on the index map that accompanies each special map sheet. Problems of the integration of field observations were resolved by frequent community review of maps and field areas and interchange of personnel between different parts of the district. Such procedure was necessary to ensure a uniform interpretation for the five maps that are described as a unit area in the report. Three parts of the district that had recently been competently mapped are incorporated, with minor revision, into the maps that accompany this report. These parts include: the Silver Belt surface map prepared by P. J. Shenon and R. H. McConnel for the U.S. Geological Survey in 1937; the surface geologic map of the Pine Creek mineral belt prepared by V. E. Nelson and J. F. Smith, Jr., also for the Geological Survey; and the map of surface geology in the area of the Bunker Hill mine, which has been taken from the company's maps prepared by its geological department. The reconciliation of the geologic interpretation given on these maps with that of the new work presented certain problems that were largely overcome through extensive field checking and consultation with the personnel involved. Even though certain changes and adjustments were made on the maps of these areas, the basic work remains unchanged and the primary credit belongs to the original workers.

During the summer of 1948 geophysicists of the Geological Survey made an airborne magnetometer survey of the Coeur d'Alene district. This work was done under the direction of W. J. Dempsey, and its results are discussed elsewhere in the report. Another cooperative enterprise was an extensive project in the general Coeur d'Alene region by geochemists of the U.S. Geological Survey. Their geochemical prospecting techniques for outlining anomalies of base metals were tried both on the surface and underground in order to test their applicability to the district. The project, under the direction of V. C. Kennedy, was eminently successful in laying the groundwork for the practical use of soil-analysis methods and stimulated much interest on the part of the mining companies.

As a result of this general geologic study of the Coeur d'Alene district, various reports and maps were released through open file or published by the U.S. Geological Survey. Those placed on open file were preliminary progress reports which made data available to the public as the work progressed. These various reports and maps are listed below:

Bowyer, Ben, Rainey, H. C., III, and others, 1954, Geologic map of the Wallace and vicinity quadrangle, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., July 14, 1954.

Campbell, A. B., 1953, Geologic map of the Smelterville and vicinity quadrangle, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., June 1, 1953.

——— 1960, Reconnaissance study of the geology and mineral deposits of the St. Regis-Superior area, Mineral County, Montana: U.S. Geol. Survey Bull. 1082–I.

Campbell, A. B., Bowyer, Ben, Shenon, P. J., and McConnel, R. H., 1953, Geologic map of the Kellogg and vicinity quadrangle, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., Aug. 17, 1953.

Campbell, A. B., and Good S. E., 1963, Geology and mineral deposits of the Twin Crags quadrangle, Idaho: U.S. Geol. Survey Bull. 1142–A, p. A1–A33.

Dempsey, W. J., 1950, Five preliminary aeromagnetic maps of Pottsville and vicinity, Mullan and vicinity, Wallace and vicinity, Kellogg and vicinity, and Smelterville and vicinity map areas: U.S. Geol. Survey open-file rept., Oct. 30, 1950.

Good, S. E., 1949, Preliminary report of the geology of some mineral deposits in the Twin Crags area, Kootenai County, Idaho: U.S. Geol. Survey open-file rept., June 20, 1949, 11 p., 2 illus.

Good, S. E., and Campbell, A. B., 1952, Geologic map of the Twin Crags quadrangle, Idaho: U.S. Geol. Survey open-file map July 15, 1952.

Griggs, A. B., 1952, Geology and notes on ore deposits of Canyon-Ninemile Creeks area, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., Oct. 27, 1952, 108 p., 23 pls.

Griggs, A. B., Wallace, R. E., and Hobbs, S. W., 1953, Geologic map of the Mullan and vicinity quadrangle, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., Mar. 16, 1953.

Hobbs, S. W., Wallace R. E., and Griggs, A. B., 1950, Geology of the southern third of Mullan and Pottsville quadrangles, Shoshone County, Idaho: U.S. Geol. Survey open-file rept., July 10, 1950, 24 p., 1 map.

Hosterman, J. W., 1956, Geology of the Murray area, Shoshone County, Idaho: U.S. Geol. Survey Bull. 1027–P, p. 725-748.

Kennedy, V. C., and Hobbs, S. W., 1961, Geochemical studies in the Coeur d'Alene district, Shoshone County, Idaho: U.S. Geol. Survey Bull. 1098–A.

Wallace, R. E., Hobbs, S. W., Rainey, H. C., III, and Bowyer, Ben, 1952, Geologic map of the Pottsville and vicinity quadrangle, northern Shoshone County, Idaho: U.S. Geol. Survey open-file rept., Apr. 18, 1952.

Wallace, R. E., and Hosterman, J. W., 1956, Reconnaissance geology of western Mineral County, Montana: U.S. Geol. Survey Bull, 1027–M, p. 575–612.

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REGIONAL GEOLOGIC SETTING

A large part of western Montana, most of northern Idaho, a large area in southeastern British Columbia and adjoining Alberta, and small parts of northeastern Washington are underlain by the Belt Series of Precambrian age (pl. 6). Except for a few square miles underlain by igneous intrusives, these rocks form the bedrock of the Coeur d'Alene district and are the host for the ore deposits. They consist of a thick conformable group of sedimentary rocks—mostly fine-grained clastic rocks—which are only slightly metamorphosed. In Canada, correlatives of these rocks, named the Purcell Series, were deposited in a geosynclinal basin trending north-northwestward. Nowhere is the base of the Belt Series known to be exposed inside the periphery of the basin; the thickest partial sections, between 40,000 and 50,000 feet (Campbell, 1960, p. 550; Gibson, 1948, p. 9; and Reesor, 1957, p. 152), lie within the central part of the basin. This general area lies just east of the Coeur d'Alene district and also trends north-northwestward, extending into British Columbia.

The outcrop pattern of the Belt Series in general outlines the east margin of the basin of deposition of this thick sequence of sedimentary rocks. The absence of the Belt Series between the Precambrian basement and overlying Paleozoic rocks under much of the plains country of Alberta and the adjacent Sweetgrass arch area of north-central Montana is known from drill-hole data (Reesor, 1957, p. 157; Sloss, 1950, p. 430). From this information, the east margin of Belt sedimentation as far south as central Montana is assumed to lie near the east edge of outcrop, or nearly coincident with the eastern front of the Northern Rocky Mountains. At about the latitude of Helena, Mont., lat 46°30′ N., the Belt basin extends eastward at least as far as about long 109° W., where Belt rocks crop out in the Big Snowy Mountains (Reeves, 1931, p. 145), as well as in the Little Belt Mountains to the west (Weed, 1899). The Belt rocks along the south margin of this embayment, somewhat south of lat 45° N., in part consist of the North Boulder Group (Ross, 1949, p. 113), which contains much coarse clastic material and probably represents a near-shore facies. South of this probable shoreline, older Precambrian rocks are unconformably overlain by Paleozoic sediments which extend westward almost to the Montana-Idaho boundary where the outcrop pattern of Belt rocks indicates a southern extension of the basin. How much farther this Belt geosyncline extended to the south in Idaho is unknown, but the next Precambrian rocks exposed are near the Utah border about 120 miles to the south. These differ in lithology and are probably older than the Belt Series because of their higher degree of metamorphism (Anderson, 1931, p. 28).

The position of the west margin of the basin of Belt deposition can only be inferred, for it is masked by younger rocks. Furthermore, whether the basin was here bounded by a landmass or by an open sea can only be conjectured. In the Coeur d'Alene district, part of the Belt sequence becomes more quartzitic to the west, evidence suggesting a landmass source to the west. A higher percentage of carbonate-bearing rocks throughout the Belt Series section in the east-central part of the basin, of which the Glacier National Park area (Ross, 1959) is an example, also suggests that the dominantly clastic rocks to the west had a western source.

In British Columbia and northeastern Washington, the west margin of the Belt Series outcrop is overlapped by the Windermere Series and its correlatives of later Precambrian age (Walker, 1926, p. 13–20; Rice, 1941, p. 14–22; Park and Cannon, 1943, p. 7–11; Campbell and Loofbourow, 1962). To the south, basalt flows of the Columbia River plateau cover all the underlying rocks. In addition, large areas of the western part of the Belt terrain were invaded by great intrusive masses such as the Idaho and Kaniksu batholiths and their satellites.

To the north in British Columbia the Purcell Series forms the core of a geanticline which plunges northward under younger Windermere rocks at about lat 51° (Reesor, 1957, p. 150). To the northwest in British Columbia and the Yukon territory, rocks considered to be "Lower Cambrian and (or) older" crop out at several places within a rather narrow zone (Gunning, 1957, p. 178). Some of these may be correlative to the Belt Series, and thus favor the postulation that the Belt basin was a continuous seaway to the north (Fenton and Fenton, 1937, p. 1938–1940).

A lead-uranium age of 1,250± million years has been determined for uraninite from veins in the Silver Belt of the Coeur d'Alene district (L. R. Stieff and T. W. Stern, written commun., 1956). These veins were formed in Belt rocks which had been folded and faulted prior to their emplacement. If this age determination is correct—and it seems to be according to computations involving various isotopic ratios—the Belt Series takes on added antiquity. The relatively unmetamorphosed condition of Belt rocks and the general lack of a profound unconformity with the overlying Cambrian rocks seemed to indicate that the Belt rocks were laid down relatively late in Precambrian time; however, the lead-uranium age places the cessation of Belt sedimentation at least 700 million years prior to the beginning of the Paleozoic Era.

North of the basalt-covered Columbia Plateau, the Windermere System (Walker, 1926) and its correlatives (Campbell and Loofbourow, 1962; Park and Cannon, 1943, p. 7–13) crop out in a north east-trending band in northeastern Washington and into southeastern British Columbia (Rice, 1941, p. 14–22). This thick group of sedimentary and volcanic rocks of late Precambrian age were deposited in a geosyncline that formed along the west side of the Belt geosyncline, onto which the system overlapped in an apparent northeast-trending crosscutting arrangement. The Windermere System makes up the record of deposition of this general region for the long interval between the end of Belt sedimentation and the beginning of Paleozoic time, as these Windermere rocks are in part conformably overlain by Cambrian strata. If any other sedimentary rocks were deposited on the Belt terrain during this interval, they have been completely removed by erosion. A widespread accumulation of conglomerate at the base of the Windermere System, which at places is several thousand feet thick (Reesor, 1957, p. 158; Park and Cannon, 1943, p. 7), indicates a mountainous mass to the east as a source. The upwarp of the Belt Series was probably eroded away prior to deposition of Middle Cambrian rocks in places in western Montana (Deiss, 1935, p. 106–112). This deformation which caused the upwarp was not intense, as the discordance between the Belt Series and the overlying Windermere and Cambrian rocks is always at a small angle. The only possible exception is the relatively intense deformation that preceded the emplacement of the uraninite veins in the Coeur d'Alene district and that seemed to be localized.

By Middle Cambrian time the elevated Belt terrain in western Montana and northern Idaho had apparently worn down to a land of low relief, much of it becoming a shelf area that was inundated and covered by sediments. Remnants of Middle Cambrian sedimentary rocks found in downfaulted blocks in the Pend Oreille Lake area 40 miles to the northwest (Sampson, 1928, p. 9–10), in the St. Regis-Superior area 55 miles to the southeast (Campbell, 1960), and in and near the Libby quadrangle 35 to 55 miles to the north (Gibson, 1948, p. 19–20) are good evidence that the Coeur d'Alene district was also covered by these rocks, which, from their outcrop pattern, are seen to cover much of western Montana. No sedimentary rocks younger than those of Middle Cambrian age have been found within a radius of 100 miles or more of the Coeur d'Alene district. Thus the Coeur d'Alene district probably lies within a large area which has been a positive landmass since late Cambrian time.

Igneous rocks as batholithic masses, stocks, dikes, and sills of a variety of rock types intrude the Belt Series in northern Idaho and adjacent areas. The large Purcell sills of diabasic to dioritic composition are numerous in the area extending from north and east of Pend Oreille Lake to and even beyond the Canadian border. Similar tabular intrusives occur at other places in the Belt Series. Some of these intrusives probably belong to the Purcell Series, and are also Precambrian in age. Three batholiths—the Idaho in Central Idaho, the Kaniksu in northeastern Washington and adjacent parts of northern Idaho, and the Nelson in British Columbia just north of the border—are intruded into the Belt Series and younger rocks. Because of their similarity in composition, principally quartz monzonite to diorite, and other characteristics, Ross (1936) suggested that the Idaho and Kanisku are related, and Park and Cannon (1943, p. 24) further suggested that all three batholiths and the many small related bodies are the exposed parts of one great igneous mass.

The largest of these igneous masses, the Idaho batholith, crops out over an area of about 16,000 square miles. The main north border of this mass is about 50 miles south of the Coeur d'Alene district. A salient of the batholith, however, extends northward for a distance of more than 25 miles, and beyond this projection, a group of small igneous stocks, alined north-northeast, crops out for a distance of more than 50 miles. These stocks include the Herrick stock near the St. Joe River, the Gem stocks in the Coeur d'Alene district, and several others to the northeast. An average age of 108 million years for the Idaho batholith has been determined using the lead-alpha method (Larsen and Schmidt, 1958, p. 18–19). A comparable age for the Gem stocks was determined using the same method (Larsen and others, 1958, p. 45); this is additional evidence for related origin.

The structural pattern of the region surrounding the Coeur d'Alene district is characterized by two outstanding and significant features: (a) the gently deformed condition of the rocks over large areas—intensely folded only locally, and (b) a series of northwest-trending major faults of large lateral displacement. The generally uncomplicated structure of the Belt Series rocks has been recognized and speculated upon from the earliest work in the region. There are, of course, numerous local steep and even overturned folds, but generally the rocks occur in great broad, open folds in which the dips are usually less than 45°, and in large areas where the rocks are mainly flat. Fold axes generally trend north to northwest in that part of northern Idaho and western Montana north of the general latitude of the Coeur d'Alene district. In the vicinity of this latitude and south to the Idaho batholith, the fold axes trend more westward.

The rocks in and near the Coeur d'Alene district are cut by a complex of faults that have complicated histories, but the whole pattern of this deformation is dominated by three great transverse faults of fault zones, each of which is marked by major drainage lines: (a) the St. Joe fault in the valley of the St. Joe River in Idaho, (b) the Osburn fault and its related structural features in the valleys of the South Fork of the Coeur d'Alene River in Idaho and the St. Regis River and parts of the Clark Fork in Montana, and (c) the Hope fault in the lower valley of the Clark Fork in Idaho and Montana. Of these great faults, the Osburn fault is the most profound and extensive, and forms a large part of the pronounced linear feature that Billingsley and Locke (1939, p. 36) called the Lewis and Clark line.

From this picture the Coeur d'Alene district can be seen to lie in the central part of a late Precambrian geosyncline of north-northwesterly trend. Furthermore, the district is located at the intersection of a major anticlinal arch of these geosynclinal sediments and a major structural zone of weakness, the Lewis and Clark line, which lies nearly athwart this geosynclinal basin. The downbuckling that produced the eastern prong of the Belt basin, the deformation in the Coeur d'Alene district prior to the emplacement of the 1,250 year-old uraninite veins, and the movement along the Osburn fault system all appear to be reflections of sporadic activity along the Lewis and Clark line. It seems likely that the Coeur d'Alene district is within an area that has been in a positive, emergent position since early in the Paleozoic era. Large masses of igneous rock were intruded into the Belt Series in the western part of the Belt basin in Mesozoic time. Then the mineral deposits of the main period of the Coeur d'Alene district were formed near one of the satellite intrusions within a structural knot in which the rocks had been highly fractured.

BELT SERIES

The Belt Series is predominantly made up of argillite and quartzite in which are intercalated lesser amounts of carbonate-bearing dolomitic rocks. The stratigraphic units are apparently everywhere comformable. Fineness of grain is a general characteristic; the coarsest quartzite usually contains no more than medium-sized sand grains. Exceptions to this are the North Boulder Group of coarse clastic rocks in southwestern Montana (Ross, 1949, p. 112) and some gritty to conglomeratic beds found toward the east margin of Belt rocks such as in the Glacier National Park region (Ross, 1959). Slight regional metamorphism is reflected in the recrystallization of quartz grains and the formation of micaceous minerals, mostly sericite, having a poor to good common orientation. More highly metamorphosed parts of the Belt Series are restricted to relatively small areas where dynamic metamorphism has produced slates and phyllites, or to the peripheries of intrusive masses.

Sedimentary structures such as ripple marks and mud cracks are abundant throughout the Belt sequence. These attest to a shallow-water or subaerial environment of deposition for much of the Belt Series, and affirm a near balance between subsidence and deposition during much of Belt time. Interspersed with the sediments of shallow-water or subaerial origin are other rocks typical of deep-water origin; these include some of the carbonate rocks, the purer quartzite, and thick monotonous sections of argillite devoid of any shallow-water sedimentary structures which were laid down in a marine environment.

The Belt Series is subdivided into thick lithologic units, generally ranging from 1,000 to 10,000 feet in thickness, that are gradational one into another. Some units whose compositional characteristics are noticeably uniform have been traced over large areas; others grade laterally within relatively short distances into dissimilar rocks. As pointed out by Reesor (1957, p. 153), a closer similarity in formations both in succession and lithology is noticeable in a north-south direction in contrast to a usually distinct facies change in an east-west direction. Fortunately, for purposes of correlation, a group or rocks which are carbonate-rich in comparison to the more argillaceous and arenaceous rocks above and below them occur at about the same position in the upper middle part of the Belt sequence, and are distributed throughout the basin; this group seems to be a key zone in correlating from area to area. These rocks have been named the Wallace, Newland, Siyeh, or Kitchener Formations in different areas. Whether or not these formations are exactly of the same age is highly problematical, but at least they indicate a uniform depositional environment throughout the basin for about the same interval of time.

A group of basaltic flows, the Purcell Basalt, +100 feet thick, is intercalated in the upper middle part of the Belt Series in the Glacier National Park area (Ross, 1959); it extends into British Columbia, where its north and west limits are at about lat 50° and long 116° (Reesor, 1957, p. 53). In British Columbia these flows are used to subdivide the Purcell Series into a lower and upper group. Of a probable similar source as these flows are a group of tabular intrusives, mostly sills, dioritic to diabasic in composition, which are called the Purcell (Moyie) sills (Schofield, 1915, p. 56–69). These intrusives have a much wider distribution than the lavas, and are numerous in the northern part of the panhandle of Idaho (Kirkham, 1926, p. 37), adjacent parts of northwestern Montana (Gibson, 1948, p. 20–24), and a large part of the area in British Columbia underlain by Belt rocks (Daly, 1912, p. 207–255; Schofield, 1915, p. 56–69; Rice 1941, p. 24–27). A contemporaneity between the Purcell lavas and sills has been based upon their similarity in composition and restriction of the locale of the sills to Belt rocks older than the lavas. The sills have also undergone the same structural deformation as the invaded rocks and in general are thicker lower in the Belt section. The Wishards sill, which crops out to the south and east of the Coeur d'Alene district, probably belongs to this group of intrusives, and if so is the only one in or near the Coeur d'Alene district.

The thickness of strata within the Belt basin of deposition is very great but varies much from place to place. This variation in thickness results not only from the vagaries of erosion and exposure but also from differences in the amounts of sediments deposited. In the Coeur d'Alene district a minimum thickness for the exposed formations is about 20,500 feet and a maximum is about 28,000 feet. The base of the series is nowhere exposed, however, and an unknown amount of the upper part has been eroded away. Some 30–50 miles to the east-southeast in the St. Regis-Superior area, Montana, the Belt Series has an estimated maximum thickness of about 50,000 feet (Campbell, 1960). Less of the basal Prichard Formation is exposed in the Coeur d'Alene district and more of the upper part of the section apparently has been eroded away in comparison to the St. Regis-Superior section. If compensations are made for these two discrepancies, the total section in the Coeur d'Alene district might approach that of the section in the St. Regis-Superior area in thickness. Partial sections measured near the east margin of the Belt basin in Montana range between 10,000 and 20,000 feet thick, and indicate a general thinning in that direction.

SUBDIVISION OF THE BELT SERIES IN THE COEUR D'ALENE DISTRICT

In the original areal geologic study of the Coeur d'Alene district Calkins (in Ransome and Calkins, 1908, p. 23–25) subdivided the Belt Series into six formations, in ascending order from oldest to youngest: Prichard Formation, Burke Formation, Revett Quartzite, St. Regis Formation, Wallace Formation, and Striped Peak Formation. The basis for the division was the general lithology of the rocks—particularly the composition, grain size, and color. In this report the original units have been retained, to which some further refinements have been made by the subdivision of some of the formations. Where possible the Prichard, St. Regis, and Wallace Formations are separated into upper and lower parts. Locally, the upper part of the Wallace Formation is further subdivided into three units. The subdivision of some of these thick formations and the recognition of several key horizons have greatly assisted the mapping of complex structures in the area.

Characteristic features of the Belt Series in the Coeur d'Alene district are summarized as follows:

Generalized section of the Belt Series in the Coeur d'Alene district

Group	Formation		Lithology	Thickness (feet)
Missoula	Striped Peak Formation		Interbedded quartzite and argillite with some arenaceous dolomitic beds. Purplish gray and pink to greenish gray. Ripple marks, mud cracks common. Top eroded.	1, 500+
Ravalli	Wallace Formation	Upper part	Mostly medium- to greenish-gray finely laminated argillite. Some arenaceous dolomite and impure quartzite, and minor gray dolomite and limestone in the middle part.	4, 500–6, 500
		Lower part	Light-gray more or less dolomitic quartzite interbedded with greenish-gray argillite. Ripple marks, mud cracks abundant.	
	St. Regis Formation	Upper part	Light greenish-yellow to light green-gray argillite; thinly laminated. Some carbonate-bearing beds.	1, 400–2, 000
		Lower part	Gradational from thick-bedded pure quartzite at base to interbedded argillite and impure quartzite at top. Red-purple color characteristic; some green-gray argillite. Some carbonate-bearing beds. Ripple marks, mud cracks, and mud-chip breccia common.	
	Revett Quartzite		Thick-bedded vitreous light yellowish-gray to nearly white pure quartzite. Grades into nearly pure and impure quartzite at bottom and top. Cross-stratification common.	1, 200–3, 400
	Burke Formation		Light greenish-gray impure quartzite. Some pale red and light yellowish-gray pure to nearly pure quartzite. Ripple marks, swash marks, and pseudo-conglomerate.	2, 200–3, 000
	Prichard Formation	Upper part	Interbedded medium-gray argillite and quartzose argillite and light-gray impure to pure quartzite. Some mud cracks and ripple marks.	12, 000+
		Lower part	Thin- to thick-bedded, medium gray argillite and quartzose argillite; laminated in part. Pyrite abundant. Some discontinuous quartzite zones. Base buried.	

CORRELATION OF THE BELT SERIES IN AND AROUND THE COEUR D'ALENE DISTRICT

Workers in areas surrounding the Coeur d'Alene district have been able to use much the same subdivisions of the Belt Series as originally set up by Calkins. From their work it is apparent that thick groups of comparable rocks are persistent over large areas, although changes in facies are evident for some units in these groups. In making such correlations from area to area, it is apparent that contacts between rock groups have not everywhere been placed at the same horizon because of the transitional nature of the breaks and also because of facies changes. For this reason variances in thickness may in part reflect different interpretations of contact placement; but even so, marked changes in thickness of lithologic units are evident. Furthermore, correlations are for recognizable rock groups deposited under similar environments that do not necessarily embrace similar time intervals.

The stratigraphy and correlations of the Belt Series in areas peripheral to the Coeur d'Alene district are described in several different reports. Descriptions used in making the comparisons that follow include: to the south, the south slope of the St. Joe Mountains (Wagner, 1949); to the east, Western Mineral County (Wallace and Hosterman, 1956), and the St. Regis and Superior area (Campbell, 1960); to the north, the Trout Creek and Libby quadrangles (Gibson and others, 1941; Gibson, 1948); to the west and northwest, Kootenai County (Anderson, 1940) and the Pend Oreille district (Sampson, 1928); and a paper on general regional correlation (Harrison and Campbell, 1963). Regional sections, based primarily upon the description of the Belt Series in these areas, are shown on figure 2, where the Belt Series is shown to consist of four general groups of rocks. The oldest rock includes the Prichard Formation; the next combines the Burke, Revett, and St. Regis Formations of the Coeur d'Alene district, because of the loss of characteristic lithology, into the Ravalli Group (Calkins, 1909, p. 37); the third is the Wallace Formation; and the youngest is the Missoula Group (Clapp and Deiss, 1931, p. 677), of which the Striped Peak Formation in the Coeur d'Alene district is a correlative of the lower part.

The Prichard Formation appears to be more uniform throughout the region than any other group. The ratio of argillite to more quartzose rock varies from area to area, but everywhere the formation consists mostly of a monotonous succession of evenly bedded usually medium- to dark-gray very fine grained argillite in which pyrite or pyrrhotite are very abundant as accessory minerals. These sulfides upon oxidizing give the rocks a characteristic rusty weathered surface. Lenticular zones of lighter colored quartzite, ranging from a hundred to at least a thousand feet in thickness, found at different horizons at several places are also characteristic of the formation. At no place within this general region is the base of the Prichard exposed; estimates of the total thicknesses in different areas range from 4,000 to 17,000 feet. Every place where the top of the formation is found, it has been described as a transition zone from darker argillitic rocks below to lighter colored quartzitic rocks above.

The Ravalli Group is composed mostly of quartzitic rock that usually grades into a more argillitic facies at the top. The Revett Quartzite in the central part of the group is unique to the Coeur d'Alene district and its immediate environs. This unit of almost white thick-bedded pure quartzite grades laterally to the west, east, and north into rocks that are indistinguishable from the less pure quartzitic rocks that underlie it and in places overlie it. At the latitude of the Coeur d'Alene district, the group changes from a dominantly quartzitic sequence in the west to one which contains a large percentage of argillitic rock in the east. The most marked change in the St. Regis Formation takes place just east of the Coeur d'Alene district. Here the quartzite and alternating argillite and quartzite grade eastward within a few miles to a succession that is almost entirely argillite. A decided thickening from less than 2,000 feet on the west to more than 5,000 feet on the east also takes place for this unit within the same distance. Purplish red and pale red colors, imparted by the included hematite and used in part to distinguish units within the group, grade out laterally. In some places the gradation is into green-colored rocks in which much of the iron is contained in chlorite; this gradation is probably indicative of a change in chemical environment during deposition.

The Wallace Formation is made up of a variety of rocks including quartzite, argillite, to a lesser degree dolomite and limestone, and all variations between these kinds. The characteristic which sets off the Wallace as a mappable unit from rocks above and below is the prevalence throughout the formation of beds of carbonate-bearing argillite and quartzite. Relatively few rocks contain a high enough percentage of carbonate minerals to be called a dolomite or limestone. The most persistent group of rocks consists of alternating argillite and quartzite, containing some carbonate, that make up the lower part of the formation in the Coeur d'Alene district; these rocks are traceable for considerable distances into adjoining areas. Because carbonate minerals occur in both the underlying and overlying rock units, parts of the groups above and below have probably been included within the Wallace Formation in some areas and not in others. This may account for some of the differences in thickness that have been reported for different areas, but the decided thickening of the Wallace Formation to the north and east of the mining district is most likely due to a greater accumulation of Wallace-type sediments in these directions rather than to differences in interpretation on the boundaries between the groups. Stromatolites which are carbonate-rich laminated structures having a large headlike shape (Rezak, 1957) and which have been called algal growths were reported to occur in the Wallace Formation in several of the areas, but were not found within the Coeur d'Alene district.

The Missoula Group includes all the Belt Series above the Wallace Formation. It consists of a heterogeneous assemblage of rocks which are typically red or green; these colors are variegated within beds or persist through thick zones. Most of the rocks within the group range from rather impure quartzite to argillite although in the St. Regis-Superior area the top unit is a light-colored thick-bedded vitreous quartzite. A variable but usually minor amount of carbonate-bearing rocks is found throughout most of the group, and stromatolites have been reported at several places outside of the district. The apparent poor correlation between formational units from area to area indicates considerable lateral variation in lithology. The most complete and thickest section (15,000+ feet) of the Missoula Group known within this general region is in the St. Regis-Superior area; but even here, apparently an unknown amount of the top of the Belt Series has been eroded away. Accumulations of the Missoula Group thicker than those found in the district are found to the northwest and north as well as to the east. These indicate that the Striped Peak For-

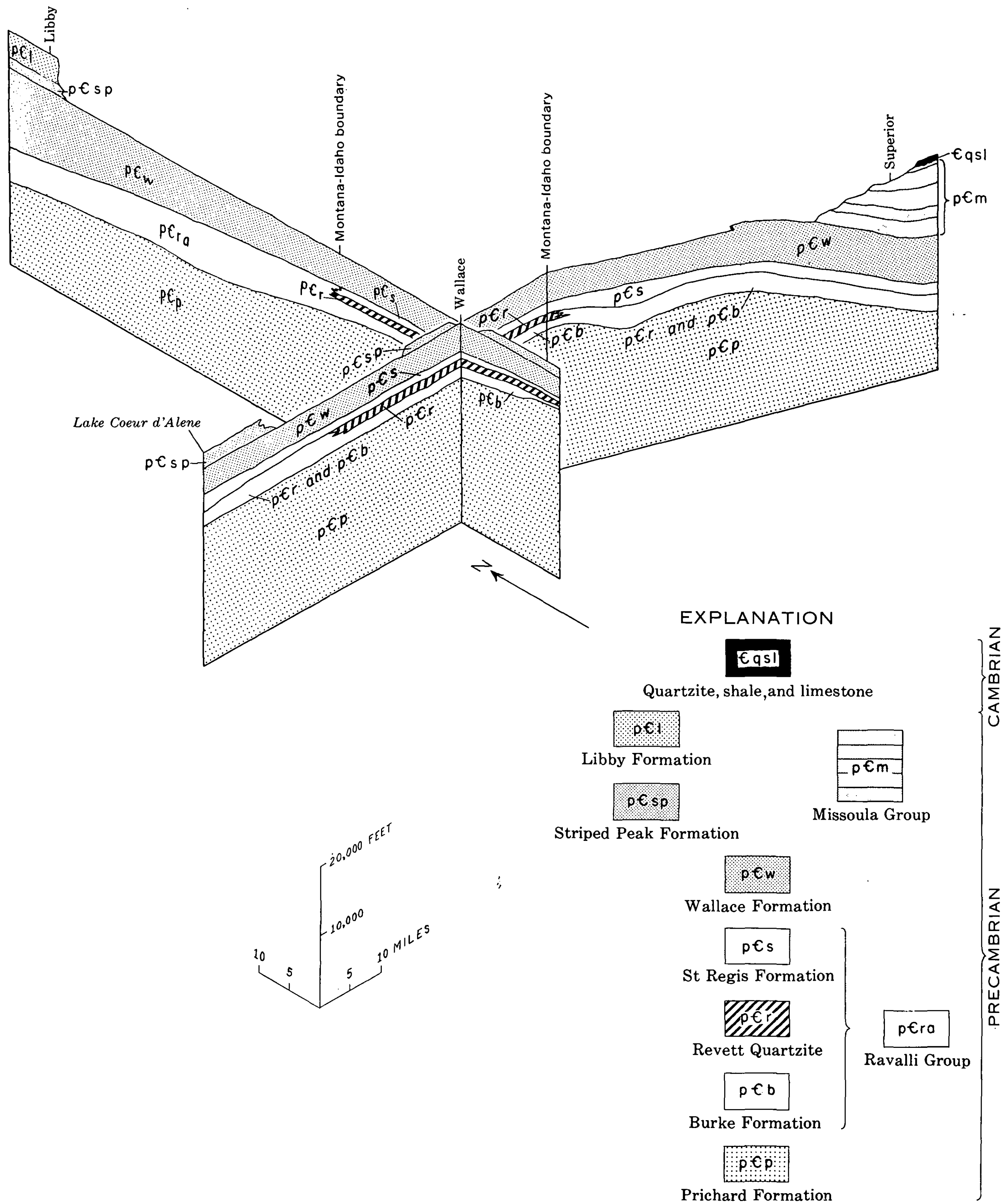


FIGURE 2.—Isometric drawing of regional sections centered on the Coeur d'Alene district showing the general thickening of the stratigraphic section to the north and east.

mation is only a relatively thin erosional remnant of a much thicker sequence at the top of the Belt Series within the Coeur d'Alene district.

PROBLEMS IN MAPPING

Certain characteristics of the Belt Series rocks in the Coeur d'Alene district and the general nature of the terrain have posed problems of mapping that are not necessarily unique, but that should be emphasized to enable the reader to evaluate more fully the maps and text. Difficulties in mapping the Belt Series are posed by a paucity of diagnostic key beds, by the repetition of rock types in more than one formation, by the transitional nature of most contacts, and by the eradication of diagnostic lithologic characteristics over extensive areas by alteration. The general lack of outcrops in many areas compounds the problems posed by these difficulties. All formations mapped in the area are very thick, at least one thousand feet, and even though they contain a variety of rock types, they usually lack distinctive beds that can be easily identified throughout the area and used as keys to the structure and stratigraphic position of isolated outcrops. Any rock type found in the Belt Series occurs in more than one formation, and some types persist through fairly thick sections; thus it is difficult in areas of few rock exposures to distinguish some formations from others, or at least parts of one from parts of another. This similarity of lithologies is particularly true for the St. Regis and Striped Peak Formations, which are lithologically alike throughout large thicknesses; to a lesser extent it is also true for the upper parts of the Prichard and Wallace Formations.

In the Belt Series the boundaries between formations are generally not sharp and usually are drawn arbitrarily within a zone of transition where the investigator believes one rock type begins to dominate over another. The most extreme example is the Burke-Revett contact, where the transition zone is several hundred feet thick and the position of the boundary may vary rather widely depending upon the locality or the predilection of the individual observer. Some contacts are placed where a certain rock type ends or where there is a change in color. Contacts based upon lithologic characteristics alone vary rather widely in their position in the section from one part of the district to another. The nonpersistence of beds and the changes in facies, the inability to walk out contacts, and the measured differences in the thickness of formations are all reasons for the considerable variation in location of the contacts from one place to another.

At many localities widespread hydrothermal alteration has obliterated or partially obliterated the characteristics used to delineate formations. Darker shades of colors are changed to light gray, yellow green, or pale olive. Where intensely sheared, the rocks are changed to phyllite or schist. Because the alteration generally lightens the color of the rocks, the process has been called bleaching. The area of most general bleaching lies south of the Osburn fault from Mullan west beyond Kellogg.

The soil mantle, which ranges from 1 to more than 10 feet in thickness, covers most of the area, and outcrops are not as abundant as a field geologist might desire. Bulldozer trenching has become a common practice of mining companies in detailed exploration work, and was most helpful in mapping. Many of the contacts were traced in the field by examining float, and only in such places as cirques, ridge crests, and a few canyon walls are the rocks naturally well exposed.

LITHOLOGIC TERMS

The clastic rocks of the Belt Series in the Coeur d'Alene district were variously described in the past as argillite, slate, and quartzite, or as shale and sandstone. Because they are well lithified, partly through recrystallization produced by mild regional metamorphism, the rocks of the Belt Series are best restricted to argillite, slate, and quartzite.

Argillite has been the term most commonly used for the finer grained rocks and is retained to describe most such rocks in this text. The definition for argillite set forth by Twenhofel (1937, p. 95–96), "a rock derived either from siltstone, claystone, or shale that has undergone a somewhat higher degree of induration than is present in those rocks, * * * cleavage is approximately parallel to bedding in which it differs from a slate" seems to be the most commonly accepted description. Most of the rocks, however, do not fit the last qualification as they tend to break along irregularly spaced cleavage surfaces, and cannot be broken along finer spaced near-parallel planes. The term "slate" is used to described only those rocks in which cleavage is sufficiently well formed to allow splitting into thin layers. Following this usage, the amount of slate in the Belt Series in the Coeur d'Alene district is relatively small, most of it occurring in the oldest unit the Prichard Formation.

In some shear zones the argillitic rocks are metamorphosed to phyllites. These are well foliated rocks, predominantly sericitic in composition and more lustrous than the slates or argillites.

Some of the argillite, particularly that of the Prichard Formation, contains a high percentage of very fine angular quartz grains. The adjective "quartzose" is used to further qualify such rocks. The silica content of samples 1, 10, and 12, given in table 3, reflects the larger amount of quartz. Such quartzose argillites have the grain size of very fine sand or may be as fine or finer than silt size, are medium gray, and commonly occur in thicker beds than the more sericitic and somewhat softer argillites.

A quartzite is generally considered to be a sandstone so indurated by cementation or recrystallization that it breaks as easily across the quartz grains as around them. Krynine (1948, p. 149–151) pointed out that sandstones so indurated by cementation are not metamorphic rocks. These he has called orthoquartzite, in contrast to those of metamorphic origin, which he has called metaquartzite. Much of the quartzite in the Coeur d'Alene district has been recrystallized into a tight mosaic of irregular grains and therefore is considered to be metaquartzite.

Rocks described as quartzitic in the Belt Series range from those made up largely of quartz to those in which quartz amounts to only slightly more than half of the volume. For purposes of mapping and description, a threefold division for classifying quartzitic rocks was devised which was found adequate during the study and could be used fairly well in the field. Terms used to describe the three divisions are pure quartzite, nearly pure quartzite, and impure quartzite. The pure quartzite contains 90 percent or more quartz in grains of fine to medium sand, is vitreous, and is light gray or nearly white to light yellowish gray. It occurs typically in many of the beds in the Revett Quartzite and occasionally in beds of some other formations. The nearly pure quartzite contains 75–90 percent quartz, mostly of fine sand, is subvitreous, and is light yellow green to light yellow gray. Many of the beds in the upper part of the Burke Formation are typical of this variety. The impure quartzite contains 50–75 percent quartz, is mostly fine to very fine sand, and is greenish gray to greenish yellow. This variety is found in all formations of the Belt Series and is characteristic of much of the Burke Formation.

The sandstone from which the nearly pure quartzite is derived and the impure quartzite are probably analogous to protoquartzite and subgraywacke, respectively, as defined by Pettijohn (1957, p. 291). In addition to quartz, these rocks comprise very small rock fragments, feldspar, and a micaceous matrix. The rock fragments, mostly a fine mixture of sericite and quartz, make up as much as 25 percent of some rock but generally less. The feldspar content is usually less than 5 percent, but may be as high as 10 percent or slightly more. The micaceous matrix is usually less than 10 percent. Occasional grains of chert are found in some of the quartzites.

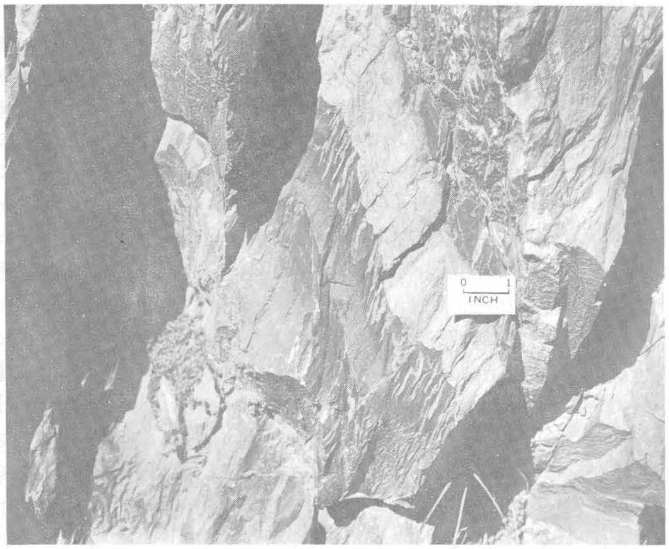
SEDIMENTARY FEATURES

Ripple marks, mud cracks, and other similar features in Belt Series rocks were described by early investigators (Walcott, 1899, 1906; Willis, 1902). Calkins (in Ransome and Calkins, 1908) first described their occurrence in the Belt rocks of the Coeur d'Alene district, and referred to them as shallow-water features. An exhaustive study of such features in Belt rocks in the Glacier National Park area has been made by Fenton and Fenton (1937, p. 1905–1935), and Shenon and McConnel (1940) have described similar features in the Coeur d'Alene district, which they considered diagnostic for determining the tops and bottoms of beds. Wherever rocks of the Belt Series have been studied, these sedimentary features are a common characteristic. Within the Coeur d'Alene district, those features particularly diagnostic of shallow-water origin—such as mud cracks, mud-chip breccia, and cross-stratification—occur in the upper part of the Prichard Formation and all formations above it. In the lower part of the Prichard such features are restricted to the quartzitic zones, where some of them occur sparingly.

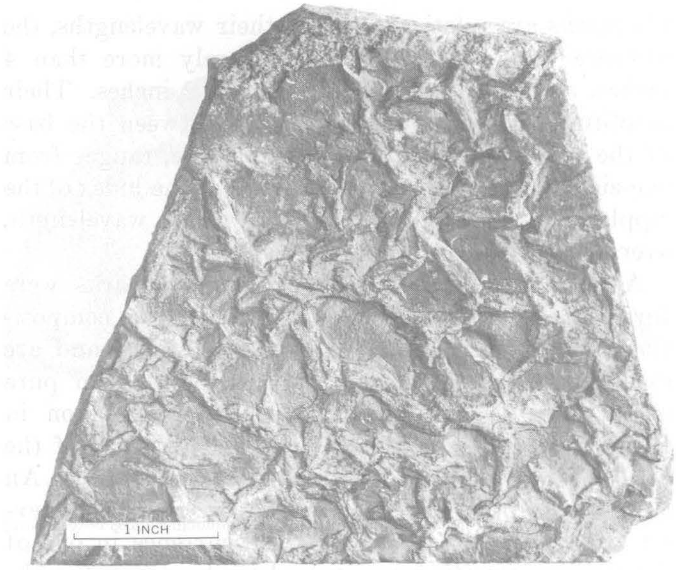
The most abundant of the sedimentary features are graded bedding, mud cracks, cross-stratification, and ripple marks. Other less abundant features include mud-chip breccia, pseudoconglomerate, pit and mound structures, scallops (swash marks), raindrop impressions, and flow casts. Graded bedding occurs both together with and separate from the other features and is common in lower Prichard as well as Wallace and St. Regis rocks. The ripple marks, though not necessarily shallow-water features, are considered to be so in the Belt Series because of their usual close association with mud cracks and mud-chip breccia.

MUD CRACKS

Mud cracks are the sedimentary features most commonly observed in the Belt Series of the Coeur d'Alene district and are found at many horizons from the base of the upper part of the Prichard to the top of the section. They are most abundant in the lower Wallace, upper half of the St. Regis, and Striped Peak Formations but also occur in the upper Prichard and lower Burke Formations and much of the remainder of the St. Regis Formation. Mud cracks rarely occur in the Revett Quartzite and the adjacent, more quartzitic parts of the Burke and St. Regis Formations and very rarely occur in the 10,000 feet or more which makes up the lower part of the Prichard Formation.



A. Mud cracks in argillitic bed in lower part of the Wallace Formation.



B. Casts of shallow mud cracks on the underside of a bed of impure quartzite from the St. Regis Formation.

FIGURE 3.—MUD CRACKS IN THE BELT SERIES OF THE COEUR D'ALENE DISTRICT

Mud cracks are best preserved in the alternating beds of argillite and quartzite in the lower part of the Wallace Formation (fig. 3*A*). All the mud cracks appear to have formed by desiccation of mud layers that had been exposed to the atmosphere. The cracks thus formed are filled with the lighter colored sandy material of the overlying layer. Their size and arrangement differ from bed to bed, depending on the thickness of the muddy layer, the amount of drying that took place, and very likely other factors not yet determined. Some mud cracks are incomplete as the cracks are not joined at all places. The usual ones, however, separate the surface of the muddy bed into groups of irregular polygons, rarely as much as 3–4 inches across and usually only an inch or two across. The largest cracks observed extend downward into the muddy bed a maximum of 4 inches, but they usually range from 1 to 2 inches in depth. The cracks range in width from a very small fraction of an inch to a quarter of an inch and usually taper downward to a sharp edge. Where the muddy layer is thin, the cracks may extend entirely through it. Some of these cracks are apparent only as an irregularity on the surface of the bed or laminae or as a cast on the underside of the overlying strata (fig. 3*B*).

In section, most mud cracks have a crenulated pattern. This crenulation has no particular orientation; some of the small folds may be in one direction and others in another (fig. 4). If these plications were straightened, some of the beds would be at least twice as thick as they now are. These minor folds are probably due to compaction of the sediments during lithification.

RIPPLE MARKS

Both wave and current ripple marks, undulating surfaces on exposed bedding planes, are abundant in the Belt sedimentary rocks. Interference ripples, in which one set of ripple marks crosses another set at a pronounced angle, also are present. The symmetrical to near-symmetrical wave-formed ripple is abundant; the unsymmetrical current-formed ripple is rare. The wave-formed ripples consist of a series of parallel to subparallel symmetrical ridges with sharp to subrounded crests; the intervening troughs are shallow and relatively broad. The current-formed ripples consist of a series of unsymmetrical ridges; one slope is gentle and slopes upcurrent whereas the other is steep; these are separated by shallow troughs. All the rip-

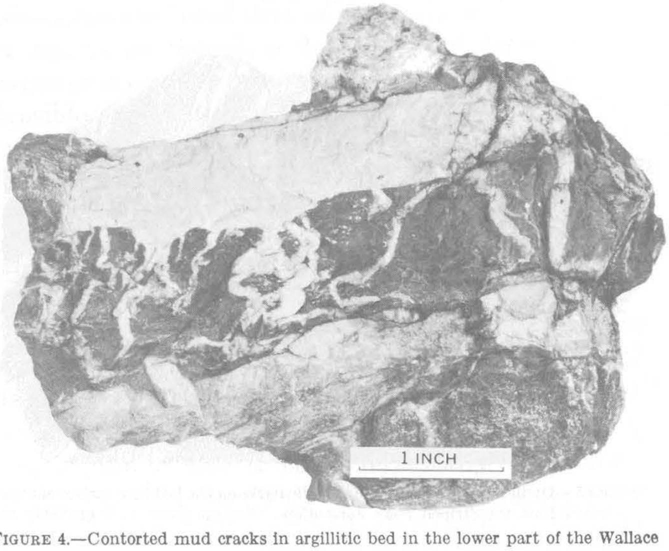


FIGURE 4.—Contorted mud cracks in argillitic bed in the lower part of the Wallace Formation.

ple marks are relatively small; their wavelengths, the distance from crest to crest, is rarely more than 4 inches, and is usually between 1 and 2 inches. Their amplitude, the difference in height between the base of the trough and the crest of the ridge, ranges from one-eighth to more than one-half inch. The index of the ripples, the ratio of the amplitude to the wavelength, averages about 1–7.

Almost without exception, the ripple marks were formed on the surfaces of beds that range in composition from impure quartzite to silty argillite and are exceedingly rare on beds of a nearly pure to pure quartzite or clayey argillite. They are common in Burke and upper Prichard rocks and in parts of the Wallace, St. Regis, and Striped Peak Formations. An occasional ripple mark has been observed in the Revett Quartzite, but except for an occurrence in one of the lower quartzitic zones, none have been noted in the lower part of the Prichard Formation.

All of the associated sedimentary features present in the Belt Series clearly indicate that the ripple marks are subaqueous in origin; their index, averaging about 1–7, also corroborates this. In most places ripple marks are found associated with mud cracks, mud-chip breccias, and other features characteristic of a shallow-water environment. Shallow water is used here to mean depths of considerably less than 100 feet. On some bedding surfaces mud cracks are found superimposed upon ripple marks; this evidence indicates that the rippled surface had been bared of water. An unusual type of mud crack superimposed upon oscillatory ripple marks is described by Wheeler and Quinlan (1951). This type was found on bedding surfaces of the Striped Peak Formation on the south side of Striped Peak and consists of branching sinuous grooves (interpreted as mud cracks), each of which is seemingly controlled by a single trough (fig. 5).

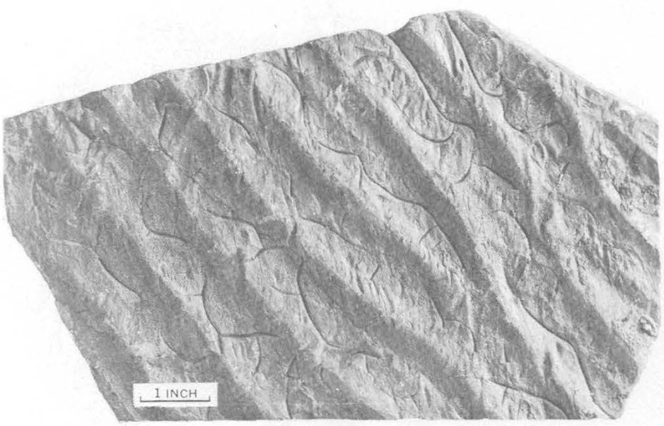


FIGURE 5.—Oscillation or wave-formed ripple marks on the bedding surface of impure quartzite from the Striped Peak Formation. Sinuous grooves are probably mud cracks.

Compressed ripple marks were noted at several places within the rocks of the Wallace and St. Regis Formations south of the Osburn fault. The ripples have been so squeezed that the usual obtuse angle formed between the low point of the trough and the tops of the two adjacent crests has been reduced to about 60°. Whether this compression took place during the period of compaction and lithification or during later deformation is not clear, but the latter is suspected.

CROSS-STRATIFICATION

Cross-stratification occurs in some of the strata of all Belt rocks from the upper part of the Prichard Formation to the top of the section. The most striking cross-stratification is found within the thick pure quartzite beds of the Revett Quartzite and the adjacent gradational parts of the Burke and St. Regis Formations. Only slightly less striking is the cross-stratification within thinner beds of impure to nearly pure quartzite that is most frequently noted in the upper part of the St. Regis and lower part of the Wallace Formations. Following McKee and Weir (1953) all cross-stratification found in Belt rocks is best described as planar; it is truncated along the top of the bed and thus separated from the overlying layer by a planar erosional surface.

The coarsest cross-stratification occurs in the Revett Quartzite and adjacent rocks and is in beds 1 to 5 feet thick. The inclined strata or laminae, which generally range in thickness from a fraction of an inch to an inch or more, are sharply truncated at the top, usually are slightly concave upwards at the bottom, and have good partings. Dark-colored heavy minerals are commonly concentrated near the parting plane. The cross-stratification is medium in scale, as the individual cross-strata or laminae seldom exceed 5 feet and are usually between 2 and 4 feet in length. In rocks of the Wallace and St. Regis Formations, where the cross-stratification is on a much smaller scale, the cross-stratified beds are usually from 2 to 6 inches thick. Exceptionally, a thicker bed may be found. In these thicker beds the cross-stratification has the same appearance as that in the more massive and thicker bedded Revett and similar rocks. The individual laminae generally range from almost the thickness of a piece of paper to approximately an eighth of an inch. Some of these cross-laminated beds are carbonate bearing, and on weathered surfaces the cross-lamination is made more evident by the etching out of the carbonate material.

No systematic notation of attitude of cross-stratification was made during the investigation. However, 35 readings taken at random locations mostly in Revett Quartzite were reoriented on the premise that the cross-stratified bed was originally horizontal. A majority of the cross-strata in their reoriented position dipped either to the northeast or southeast. The number of readings taken were far too few and the selection of locations too random to make any sound generalization as to direction of currents and source area. This evidence, however, does corroborate other evidence that indicates a source of sediment to the west. About 85 percent of the measured cross-laminations originally had dips between 15° and 35°. Most of the rest had dips that closely resembled those of this group.

MUD-CHIP BRECCIA

Mud-chip breccia (sharpstone conglomerate) is common in the upper part of the St. Regis Formation in the Military and Sonora Gulches area east of Burke (pl. 5), and has also been noted in this formation south of Mullan, at the west end of the district, and at several other localities. It is locally abundant in the Striped Peak Formation and has been found in the Wallace Formation. These mud-chip breccias consist of flakes of argillite in a quartzitic to an argillitic matrix. The chips were formed originally from thin layers of muddy material, which had been bared to the atmosphere and during desiccation cracked, curled, and parted from the underlying sandy layer. With the next flooding, the chips were buried before they could be destroyed. The usual environment is one of alternating thin beds or laminae of argillite and quartzite. Some of the chips are almost paper thin and none of those observed were over a quarter of an inch thick. The usual chip is less than an inch in greatest dimension although a few exceed this size. The chips are generally angular, a fact which indicates that they were only slightly disturbed before burial, but some do have rounded edges. Mud cracks and ripple marks are always found somewhere near in the adjacent strata.

PSEUDOCONGLOMERATE

Calkins (in Ransome and Calkins, 1908, p. 31) described a sedimentary feature he found in upper Prichard rocks at the mouth of French Gulch as follows: "The beds there exposed exhibit all the marks of shallow-water origin, and include some rocks made up chiefly of flattened very rudely ellipsoidal masses, half an inch to 3 inches in diameter. These masses have somewhat the aspect of flat pebbles, but their lithologic character clearly indicates that they are not pebbles in the ordinary sense of the word." During the present investigation this feature has also been found in rocks of the Burke Formation where it occasionally occurs as in the upper Prichard (fig. 6). These flattened ellipsoidal masses have the same or nearly the

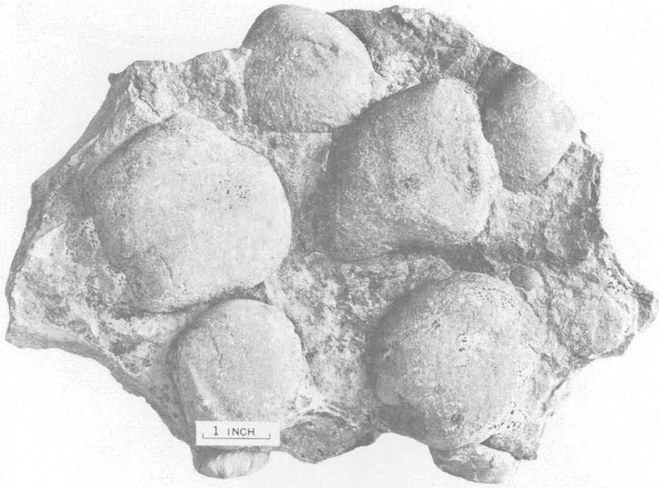


FIGURE 6.—Pseudoconglomerate on the bedding surface of impure quartzite from the Burke Formation.

same composition as the rocks which enclose them: they are made up of impure quartzite or quartzose argillite. They usually part cleanly from the overlying stratum but not from the underlying one, and their exposed surfaces not uncommonly have a decided micaceous sheen. They are only one layer thick, and each one is a separate and discrete mass. When sliced in half at right angles to the bedding plane, some ellipsoidal masses show an internal crumpling and contortion that is not apparent in the more or less unstratified matrix, whereas others are cored with sand somewhat more pure than the matrix. They are usually associated with beds that contain mud cracks and ripple marks.

Calkins believed these ellipsoidal masses were formed by waves rolling up masses of water-soaked sand which flattened horizontally owing to their weight. This hypothesis is plausible only if some bonding agent were present to make them cohesive. In some individuals the basal part of the ellipsoid merges with the matrix as though a flow cast, but their discrete character is counter to this type of structure. The most plausible explanation is that they are a variety of intraformational conglomerate, the individual flat pebbles or gravel having been formed from a partly lithified layer which had been broken up. The fragments were then rounded and distorted by wave action.

CYCLIC SEDIMENTATION AND GRADED BEDDING

The alternation of sandy and muddy beds, quartzite and argillite, the quartzite grading up into the argillite, is common in the Belt Series. In the lower part of the Wallace, the deposition of carbonate material has been rhythmic and is characteristically more abundant in the more quartzitic beds. In some zones in the Wallace thin limestone or dolomitic beds occur in an

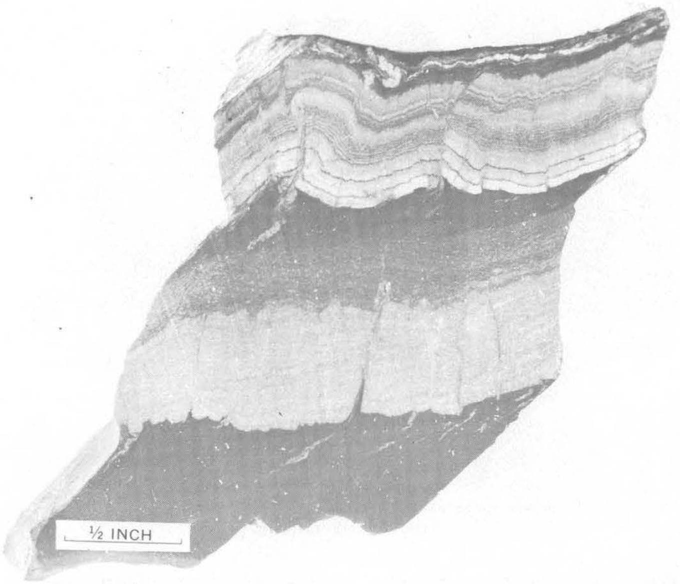


FIGURE 7.—Specimen from the upper part of the Wallace Formation showing fine lamination and graded bedding; also exhibited are minor crenulations, slight dislocations of bedding, and miniature clastic dikes, all evolved prior to lithification.

alternating pattern with quartzite and argillite. Graded bedding is abundant in the Prichard and Wallace Formations and is not uncommon in the St. Regis and Striped Peak Formations (fig. 7). It has been observed in layers that are only laminae as well as in beds of medium thickness. Graded bedding is rarely evident to the unaided eye in Prichard rocks because of the relatively fine grain and slight change in color; however, it can easily be seen in thin sections. Many of the laminated rocks in the upper parts of the Prichard and Wallace appear to be varvelike, but the laminae are irregular in thickness, and many are discontinuous.

OTHER SEDIMENTARY FEATURES

Other sedimentary features observed in the Belt rocks in the Coeur d'Alene district are relatively scarce. On some bedding surfaces, a series of irregular undulatory overlapping festoons that produce a series of shallow scalloped indentations have been called scallops. These were noted on several bedding-plane surfaces of impure quartzite of the Burke Formation in the Glidden Lakes section, and are probably akin to swash marks formed by wave action. Usually, the scallops are marked by a concentration of small mica flakes oriented in the bedding plane which give the surface a lustrous appearance. Calkins (in Ransome and Calkins, 1908, p. 31), in describing the St. Regis Formation, noted small round pittings on quartzite slabs and concluded that they were raindrop impressions. A similar feature was seen on a rock surface of the Burke Formation at the west end of the district. Shenon and McConnel (1940, p. 439) described sharply defined crinkled surfaces on the bottoms of some of the more quartzitic layers in the Prichard as resembling pit-and-mound structures. This structure, however, was not observed during the present study. Elongate bulbous irregularities that in some places impinge one upon another were found in quartzite of the lower part of the Wallace. These are probably flow casts. Mud balls or galls have been noted at several places. Casts of salt and ice crystals have been seen on bedding surfaces of argillaceous rocks farther to the east in the Missoula Group of the Belt Series, but not in the Coeur d'Alene district. Concretions as much as 18 inches long and 6 inches thick have been noted in the Prichard.

Small structures, most likely formed during a period of adjustment prior to lithification, have been found in thinly interbedded and interlaminated argillaceous and arenaceous sediments. These structures include interbed crumpling, minor slump features, and miniature clastic dikes, which are most common in the Wallace Formation but have been seen also in the St. Regis and Striped Peak Formations. Usually, only a single layer or several laminae show such structures, which do not continue into the overlying and underlying rocks. Some of the arenaceous or more silty beds, in part carbonate bearing, were squeezed into boudinage structures or further shaped into irregular lumps separated by septa of a different type of rock. Etching-out of carbonate-bearing material on the weathered surface gives such disrupted rock an irregular appearance, which is probably akin to what

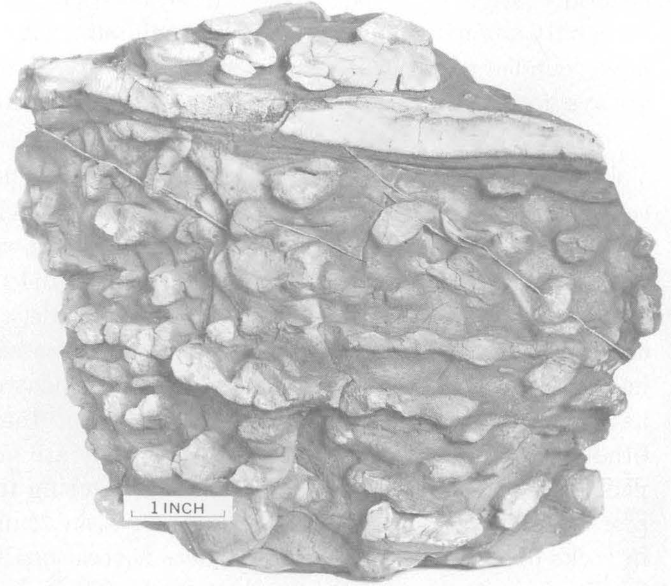


FIGURE 8.—Differential weathering in rock from the lower part of Wallace Formation.

Gibson (1948, p. 16) called "molar tooth" structure because of its resemblance to the grinding surface of an elephant's molar (fig. 8). These structures may have formed prior to lithification but also may have formed or have been shaped further during a later period of deformation.

MINERALOGY

The mineral composition of the Belt Series rocks is similar throughout the section. The two predominant minerals are quartz and sericite; these and a characteristic suite of accessory minerals make up the bulk of the rock. Exceptions are rocks in which carbonate minerals or chlorite and (or) biotite are major components. The original sedimentary rocks have been modified by low-grade regional metamorphism, contact metamorphism near igneous intrusives, and in some areas, alteration to a greater or lesser degree by hydrothermal solutions.

Mineral grains that are definitely of detrital origin are uniformly small. The coarsest quartzite rarely contains grains of quartz or feldspar that exceed 0.5 mm, and usually these rocks are medium- to fine-grained sandstones in which the grains are 0.25 mm or finer. The greater part of the grains in the present rocks is of very fine sand and silt size, 0.1–0.01 mm. The volume of the fraction in which the particle size is less than 0.01 mm is small. The original sediments before recrystallization undoubtedly contained a much larger fraction in the smaller size class. With high magnification, particles as small as about 0.0005 mm are discernible. These minute grains all appear to be accessory material such as iron oxides, rutile, and carbonaceous matter.

Quartz is the predominant constituent in the Belt rocks. The purer quartzite contains 90 percent or more of quartz, and even the least quartzose argillite end member is usually nearly one-quarter quartz. The intermediate varieties, which make up most of the rocks and which contain 65–75 percent SiO_2, average about 50 percent quartz. The grains are angular to subrounded, and some of the fine grains have a shard-like appearance. Secondary growth and recrystallization of the quartz in the quartzite has changed the shape of most of the grains so that in thin section they appear to form an interlocking mosaic. The interstices of the original more quartzose rocks have thus nearly all been filled. The angularity of the smaller grains of quartz may be primary, but a faint rounded outline can be detected within some of the larger grains in thin sections of the coarser quartzite. This outline is evident owing to a dusting of inclusions in the new rims that have grown in the same crystallographic direction as the original grain. The small angular grains of quartz and the sericite form a felted mass in the argillitic rock, make up the matrix in the less pure quartzite, and fill some interstices in the purer quartzite. What were originally rock fragments are also a felted mass of sericite and quartz. A few grains of chert are recognizable in some of the quartzitic rock. The size of the quartz grains generally ranges from 0.003 mm in the finest fraction to a very small percentage that is 0.5+ mm in the coarser quartzite. The finer particles may be found in any of the rocks, but in the finest grained argillite the dominant quartz grain size is about 0.01 mm. The coarser grained quartzite, which is fairly equigranular, has an average grain size of about 0.25 mm. Undulating extinction is common and is particularly noticeable for quartz grains in thin sections of specimens from zones of more intense shearing or from areas where the rocks have been tightly folded.

Sericite occurs throughout the Belt Series rocks, and next to quartz is the most abundant mineral. Only within some of the purer carbonate rock and quartzite is the amount of sericite so minor that the mineral might be considered an accessory. Sericite constitutes at least 10 percent of the rock at most places and nearly 90 percent of some of the most argillaceous laminae. X-ray diffraction work indicates that the mineral is muscovite.

The sericite is generally less than 0.1 mm in long dimension and grades downward to almost micron size. The most common long dimension is about 0.01 mm. This type of mica is the dominant mineral in the more argillitic rock and makes up part of the interstitial matrix and the rock fragments in the quartzitic rock. It is flaky or shredded in habit, and commonly has ragged edges. In almost all thin sections of Belt Series rocks, a preferred orientation of the sericite is evident; in some at least two directions of orientation are discernible. Most commonly, the preferred orientation is at some angle to the bedding.

Flakes of white mica greater than 0.1 mm in long dimension are considered to be muscovite. Some flakes are as much as 1.0 mm in long dimension but most are less than 0.5 mm. They are probably of two different origins. Some quartzitic rocks contain relatively stubby scattered flakes of mica whose edges are smooth. This muscovite is probably detrital. In contrast to this detrital muscovite are other flakes that are ragged and elongate, commonly show some preferred orientation, and in some places bend as if to accommodate themselves between the quartz grains. These are probably secondary and result from regional metamorphism. The secondary mica in part causes the sheen on bedding surfaces, like that which is so characteristic of the Burke Formation, or on the surface of cleavage planes in some of the more argillaceous strata.

The widespread bleaching was at first attributed to the sericitization of the rocks (Rasor, 1934); this explanation was also considered by later workers. Mitcham (1952, p. 429–432), in a mineralogic study of the Silver Belt of the Coeur d'Alene district, came to the conclusion that no difference in the sericite content could be detected between bleached and unbleached rocks. Petrographically, the sericite originally in the Belt Series rocks appears to be the same as any that may have been generated by hydrothermal solutions; X-ray studies also give no indication of any difference. Analyses for K_2O content of intensely altered rocks indicate no detectable enrichment in sericite, except for one specimen from the Gullickson tunnel on Big Creek (table 1).

TABLE 1.—*Partial analyses, in percent, of highly altered argillite*

Specimen	Lab. No.	K_2O	Na_2O
1	MC-1	5.16	0.66
2	MC-2	4.31	.91
3	MC-3	7.23	.12
4	451	10.88	-------------

1. Intensely bleached argillite, St. Regis Formation, from Rock Creek road, Mullan map area. (Analyst, Sarah Neil.)
2. Sericite phyllite, Wallace Formation, from ridge between forks of Rock Creek, Mullan map area. (Analyst, Sarah Neil.)
3. Sericite phyllite, St. Regis Formation, from No. 6 tunnel, Gold Hunter mine, Pottsville map area. (Analyst, Sarah Neil.)
4. Intensely altered argillite, St. Regis Formation, from Gullickson tunnel, Kellogg map area. (Analyst, J. G. Fairchild.)

The K_2O content of several of the samples of unaltered argillite given in table 3 is of the same order of magnitude as that of specimens 1 and 2 in table 1, and Mitcham (1952, p. 431) listed two specimens of unbleached argillite that contained 6.27 and 7.28 percent of K_2O. The specimen from the Gullickson tunnel is indicative of local enrichment in sericite. Such enrichment probably occurs locally elsewhere, but any widespread enrichment cannot be detected by analyses or petrographic work.

Chlorite of several different origins has been recognized in sedimentary rocks of the Belt Series. Mitcham (1952, p. 449) listed six genetic types as follows: (a) Chlorite in detrital biotite, (b) diagenetic chlorite in certain strata, (c) and (d) chlorite in and around monzonitic intrusives, and diabase and lamprophyre dikes, and (e) and (f) early- and late-hydrothermal vein chlorite. In addition, some strata contain chlorite of a regional metamorphic origin.

The chlorite with detrital biotite is scarce, as detrital biotite is present only in very small amounts in some quartzitic rocks. A pale-green chlorite of low birefringence, however, commonly occurs in certain greenish-gray argillitic strata of the St. Regis and Striped Peak Formations but is a minor constituent in beds of other Belt Series formations. The chlorite usually occurs as very small flakes similar in size to the associated sericite and, where evident, has a preferred orientation similar to that of the sericite. Less common occurrence is a much larger, ragged flake, which may be as much as 0.5 mm across. In the greenish-gray strata of the St. Regis and Striped Peak Formations, the chlorite makes up about 1 percent of the volume; some laminae or beds, however, appear to be almost one-half chlorite. The marked relation of chlorite to certain strata strongly indicates that this chlorite is the result of some primary difference in the original sediments. Most such chloritic rocks are within that part of the St. Regis Formation which crops out south of the Osburn fault in the Pottsville map area (pl. 5). Eastward in Montana a rather rapid facies change in the St. Regis Formation has taken place, and much of the formation consists of greenish-gray chlorite-bearing rocks (Wallace and Hosterman, 1956, p. 582).

The chlorite associated with the igneous intrusives is discussed in the sections entitled, "Monzonitic rocks," "Diabase dikes," and "Lamprophyre dikes." Chlorite of hydrothermal origin is widespread in only two areas. One is in the vicinity of Boulder and Willow Creeks in the southern part of the Pottsville and Mullan sheets (pls. 4 and 5), where several east-trending zones contain abundant chloritic alteration. Some of these zones were brecciated prior to the introduction of chlorite and are as much as 200 feet wide and 5,000 feet long. In them, some of the rock fragments and parts of the matrix are largely replaced by chlorite. The chlorite in these zones is light to medium green or yellowish green. Magnetite, pyrite, and barite are other hydrothermal minerals associated with the chlorite. The other area is along the east margin of the Gem stocks in the northern part of the Mullan sheet, where chlorite closely associated with a brown-green biotite occurs in irregular altered zones as much as a mile from the nearest outcrop of the stocks. These altered zones have a general spatial relation to the mineral deposits in this area, as some of the most intense phases of this alteration are adjacent to some of the veins, or parts of them, and the minerals in these altered zones together with a red garnet and grunerite make up a suite of early-formed silicate gangue minerals in the ore deposits. On the outer fringes of this alteration the lighter quartzitic rock is speckled with greenish-black splotches of biotite and chlorite a millimeter or two in size. In the most intense phase the entire rock is greenish black, and red garnet layers up to half an inch wide are common along fractures and bedding partings. Biotite is the most abundant mineral and appears to be partly replaced by the chlorite.

Some of the rocks in the Burke and Prichard Formations in the northern parts of the Pottsville and Mullan map areas, far removed from the Gem stocks, contain a brown-green biotite. A light-green chlorite, usually present only in minor amounts, is commonly associated with this biotite. The biotite occurs in irregular grains and stubby flakes noticeably larger than the associated sericite and quartz and is characteristically concentrated in quartzitic beds or laminae. In some of these beds clots as much as 1 mm across occur, which speckle the rock. The core of these clots commonly consists of coarsely crystalline quartz. This biotite may be present in amounts up to 10 percent but is usually much less. Similar biotite was noted in thin sections of rocks of the Prichard Formation from the Murray area to the north and Mineral County, Mont. to the east (Wallace and Hosterman, 1956, p. 578). The biotite and chlorite, which are apparently restricted to rocks in the lower part of the Belt Series, probably resulted from the regional metamorphism.

Both plagioclase and potassium feldspar are evident in the more quartzitic rocks of the Belt Series. Almost every thin section of arenaceous rocks contains at least a sprinkling of feldspar grains, and in the average quartzite these are estimated to make up about 1 percent of the volume. Feldspar grains are most numerous in specimens from the Wallace and Striped Peak Formations, the upper two formations of the Belt Series. In several thin sections of quartzitic rocks from these two formations, the feldspar was estimated to be at least 5 percent of the volume, and in several other sections it accounted for at least 10 percent of the volume. The grains are in the same size range as the associated quartz but are usually less angular; many are subrounded to rounded. The feldspar grains appear to be part of the original sediments, which were but little changed during diagenesis or metamorphism. The plagioclase is a sodic variety, either albite or oligoclase, and most of the potassium feldspar is orthoclase.

Black opaque minerals are a minor accessory in most rocks; they include both magnetite and ilmenite. Many of these grains are secondary in origin, as they are many times larger than the associated quartz, feldspar, and sericite, and many are either well formed octahedra or platy crystals. Others, which occur concentrated in thin dark laminae with other heavy minerals in quartzite strata or as scattered small grains, are undoubtedly of detrital origin. In no part of the Belt sedimentary rocks are the black opaques a major constituent and even where most abundant make up only a few percent of the volume; usually, they appear only as specks, which adorn the rock with a grain here and there.

Ilmenite is most abundant in the argillitic rocks, especially in the Prichard Formation. Ilmenite grains are liberally sprinkled through such rocks, and amount to almost 1 percent in some very argillitic laminae or beds. These grains are irregular in shape or have a platy habit. The ilmenite grains are as much as 0.2 mm in long dimension but are usually much smaller; even so, a majority of the grains are much larger than the associated quartz and sericite. In many thin sections leucoxene partly or wholly replaces ilmenite; it rims the ilmenite or is pseudomorphic after the platy grains. The almost complete replacement of ilmenite by leucoxene, as seen in many thin sections of bleached argillite of the Prichard Formation, indicates that some leucoxene may be a product of hydrothermal alteration. The more spotty occurrence of leucoxene in unaltered rocks is indicative of its origin through normal weathering processes.

In the red to red-purple rocks of the St. Regis, Striped Peak, and Burke Formations, particularly the more quartzitic varieties, magnetite is fairly abundant, making up about 1 percent of the volume of some beds. Much of the magnetite is in the form of octahedra, which are as much as 0.5 mm in size, although the majority are less than 0.2 mm. Most of these grains are larger than the associated minerals and almost without exception have sharp crystalline outlines. These characteristics are good evidence of the secondary origin of the mineral. Some of the extremely fine particles that cloud parts of the darker rocks, or are scattered in other rocks, also appear to be magnetite.

Scattered through these same red to red-purple rocks are hosts of hexagonal hematite flakes. The hematite also occurs in felted masses or irregular aggregates that appear opaque in transmitted light except along the margins where some very thin translucent flakes are deep red. This hematite dust also forms films around other mineral grains. Much of this dust is measurable in microns although some consists of somewhat larger particles In some of the argillitic rocks the iron oxides make up as much as 5 percent of the volume, but usually they make up only a very small fraction of this amount. In weathered rocks goethite is a common constituent; most of it is secondary after iron-bearing carbonate minerals or after pyrite.

Other accessory heavy minerals in addition to the black opaques include tourmaline, zircon, rutile, and titanite. All are concentrated in some laminae in quartzitic beds, particularly in the Revett Quartzite; some also occur as scattered grains in other arenaceous rocks, but they never make up more than a very small fraction of 1 percent of the whole. They are in minute grains (± 0.05 mm), show some rounding, and some still exhibit a crystal outline. The small slightly rounded grains concentrated in these laminae and sparsely scattered through the rock are detrital. Certain other grains, to be described, are more likely secondary.

At least a few grains of tourmaline can be seen in almost every thin section. In the quartzitic rocks, rounded grains of tourmaline, usually somewhat smaller than the associated quartz, are scattered throughout or are concentrated in laminae containing heavy minerals. Some of these grains have overgrowths of added material which have formed in crystallographic continuity. This tourmaline makes up only a fraction of a percent of the rock and is detrital. Many of the argillitic rocks contain sharp prismatic crystals of tourmaline. These crystals may be similar in size to the associated sericite crystals or several times larger. Many such tourmaline crystals can be seen in one thin section, but they make up less than 1 percent of the rock. Their crystal habit and size class them as secondary in origin. Some hydrothermally altered rocks contain several percent of tourmaline of good crystal habit. Occurrences of this kind and abundance are not common; they probably formed from boron-laden hydrothermal solutions. All the tourmaline in the unaltered sedimentary rocks is of the common variety, schorlite, which has strong absorption and pleochroic colors that range from smoky gray, through bluish gray, to light brown. An exception was tourmaline in two thin sections of contact metamorphosed Burke rock, which exhibited pale-yellow to yellowish-brown pleochroism.

Most of the rutile, at least the very fine needles observed in argillitic rocks, is undoubtedly secondary. In some laminae swarms of these needles about a micron in long dimension, in part of geniculated twin habit, can be seen under high magnification. These needles are common near leucoxene.

Pyrite is only a very minor accessory mineral in all the Belt formations except the Prichard Formation where it is widespread and may account for almost 5 percent of the rock in narrow zones; usually, however, it is much less. The pyrite occurs as irregular grains or well-formed cubes which range from a fraction of a millimeter to 5 mm in size. The pyrite in the Prichard Formation is concentrated within the dark and finer grained laminae, along bedding planes, or less usually is disseminated throughout the rock. The habit, size of grains, and widespread occurrence point to a diagenetic origin for this mineral. In several underground workings on the northwest side of the Gem stocks, pyrrhotite has been found in the same environment as the diagenetic pyrite. Where it is widespread and far removed from veins, the pyrrhotite is probably metamorphic in origin. Pyrite is a common constituent in bleached rocks but is probably a secondary mineral formed during the period of hydrothermal alteration.

Carbonate-bearing beds are locally abundant in the Wallace Formation, are less abundant in the St. Regis and Striped Peak Formations, and are relatively uncommon in the other formations of the Belt Series. The common carbonate mineral is a ferroan dolomite. The carbonate minerals are an important rock-forming constituent in the lower part, and in certain zones in the upper part of the Wallace. Carbonate-rich beds are next most abundant in the underlying St. Regis and overlying Striped Peak Formations, but do not have a large volume relative to the whole formation. In the remainder of the formations carbonate minerals occur as small segregations in quartzitic rocks or locally in the occasional bed or zone. Most of the carbonate segregations that speckle the quartzitic rocks are ferroan dolomite, but grade into ankerite.

Analyses of specimens from typical carbonate-bearing beds requested by P. J. Shenon while working in the Coeur d'Alene district in 1936 are shown on table 2.

The recalculation of the soluble part of these specimens demonstrates that the carbonate mineral in all but specimen 25 is predominantly a ferroan dolomite. In specimen 25 the carbonate mineral appears to be principally a ferroan calcite; specimen 89 contains a considerable amount of calcite in addition to the dolomite. The dense gray argillaceous dolomite (specimen 4, table 3) is similar in composition to specimen 106 (table 2).

Qualitative differential thermal analyses were made of several carbonate-bearing rocks (fig. 9). These analyses corroborate other evidence in pointing out that ferroan dolomite is the major carbonate mineral in the Belt Series in the Coeur d'Alene district. Calcite, much of it iron-bearing, is the next most abundant carbonate mineral and occurs either together with dolomite or as the only carbonate mineral in some

TABLE 2.—*Analyses, in percent, of carbonate-bearing rocks from the Belt Series*

[Analyst, J. G. Fairchild, U.S. Geol. Survey, 1937]

	Specimens			
	25	89	103	106
Insoluble part				
SiO_2	51.62	42.79	20.88	37.88
Al_2O_3	5.26	8.55	4.36	9.13
FeO	.38	2.21	.16	1.09
MgO	.02	3.93	.58	1.49
CaO	None	None	None	None
$(K, Na)_2O$ (calculated)	3.00	3.00	1.60	4.00
TiO_2	.19	.25	.20	.41
Soluble part				
$FeCO_3$	2.08	2.36	2.62	5.23
$CaCO_3$	36.02	27.97	38.67	24.10
$MgCO_3$	.39	7.42	30.13	15.63
$MnCO_3$	1.17	.06	.52	.33
Total	100.13	98.54	99.72	99.29
Soluble part recalculated to 100 percent				
$FeCO_3$	5.32	6.24	3.64	11.54
$CaCO_3$	90.82	73.97	53.73	53.21
$MgCO_3$	.98	19.62	41.90	34.51
$MnCO_3$	2.95	.15	.72	.72

25. Calcareous quartzite interbed in Revett Quartzite 1,000 ft above base at Glidden Lakes-Military Gulch section.
89. Pitted dolomitic quartzite in Wallace Formation 2,000 ft above base at Stevens Lake section.
103. Arenaceous dolomite in Striped Peak Formation 1,300 ft above base at Striped Peak.
106. Argillaceous dolomite in Wallace Formation 1,400 ft below top of formation on Foolhen Ridge, 7 miles south of city of Wallace.

rocks. Iron-free dolomite and ankerite appear to be minor minerals.

In the Wallace Formation, as in other formations of the Belt Series, the quartzitic beds are more commonly carbonate bearing than the argillitic beds. The dolomite and (or) calcite content in most of the beds is appreciable, but well under 50 percent. Even in the few beds in which the carbonate mineral content is high enough to class the rock as a dolomite or limestone, the quartz and sericite contents usually amount to a quarter or more of the rock.

A rusty speckling on the weathered surfaces of quartzitic beds is caused by the oxidation of ferroan dolomite or ankerite segregations within the rocks. For this reason many of the purer quartzitic strata of the Revett, Burke, and St. Regis Formations are spotted on weathered outcrops, and some beds in the other formations are similarly marked. The fact that this phenomenon is district wide indicates that the carbonate was a primary constituent. The concentration

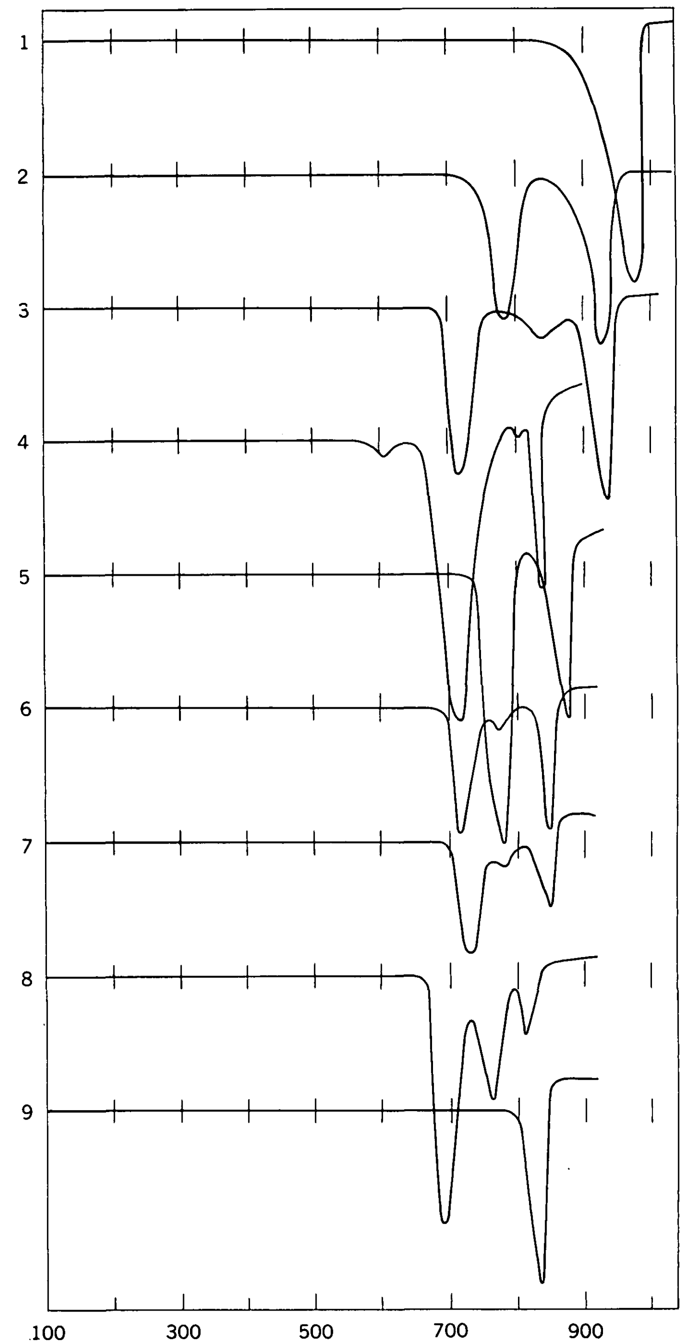


FIGURE 9.—Differential-thermal-analysis curves for some carbonate-bearing rocks of the Belt Series with standard carbonate mineral curves for comparison. (1) Theoretical differential thermal analysis curve for pure calcite after Kulp, Kent, and Kerr (1951, p. 650). (2) Theoretical differential thermal analysis curve for pure dolomite mixture after Kulp, Kent, and Kerr (1951, p. 650). (3) Differential thermal analysis curve for a ferroan dolomite after Kulp, Kent, and Kerr (1951, p. 659). (4) Argillaceous ferroan dolomite from lower part of Wallace Formation in Rock Creek area. For analysis see specimen 4, table 3. (5) Light pink dolomitic quartzite in Striped Peak Formation from near top of Striped Peak. (6) Ferroan-dolomitic argillite from lower part of Wallace Formation in southern part of Twin Crags quadrangle. (7) Ferroan-dolomitic argillite, a boudinage ellipsoid in lower part of the Wallace Formation from St. Joe Creek drainage in southern part of Mullan sheet. (8) Ankerite, which makes up segregations (speckles) in Burke Formation, from Sherman mine in Canyon Creek area. (9) Calcite segregation in molar-tooth structure from lower part of Wallace Formation from Gold Creek drainage in southern part of Mullan sheet.

in clots, however, was probably the result of some later process. The individual segregates range from less than 1 to about 5 mm. They are fairly uniform in size within a single bed and appear to be larger in the purer and coarser quartzite. These clots may make up as much as 1 percent of the rock but usually much less.

The carbonate minerals, like all others that make up the Belt rocks, are uniformly fine grained, ranging from 0.002 mm to about 0.2 mm. They are generally of irregular shape, although some exhibit a rhombic outline. Most carbonate-bearing rocks have a rusty weathered rind on surfaces long exposed to the weather. In a few dolomite or limestone beds, though, no such rind has been noted; in such beds, the carbonate mineral probably contains little or no iron. Carbonate minerals of different origin form much of the gangue of the mineral deposits or occur within the bleached areas. These are usually siderite or ankerite and were deposited from later hydrothermal solutions.

CHEMICAL ANALYSES

Analyses were made of several rocks from the Belt Series in and near the Coeur d'Alene district. Those listed in table 3 are of specimens of unaltered rock. None of the analyses were of the purer quartzitic rock; some of the purest contained mostly quartz. Most of the analyzed specimens are argillite of the St. Regis Formation, but also included are representative specimens from other formations.

Specimens 2, 7, and 12 (table 3) were called impure quartzite or quartzite in the field; but inspection in thin section shows that they contain an assemblage of material typical of subgraywackes. The similarity of the specimens in chemical composition to the graywacke from the Tyler Slate (table 3), a typical subgraywacke, bears out the same fact.

A comparison of the analyses of the argillitic rocks of the Belt Series with an analysis of the average shale of Clarke (1924), table 3, shows that the Belt Series rocks are higher in silica. Ross (1963) noted the same high silica content for argillitic rocks of the Belt Series from Glacier National Park and the region to the south of it in Montana, indicating this to be a common characteristic.

COLOR

A consistent color characteristic of the fresh and unaltered Belt sedimentary rocks is their uniformly low chroma; that is, a general dull tone. Based upon the "Rock-color Chart" (Goddard and others, 1948), which follows the Munsell system, the fresh rock rarely has a chroma that is as high as 3 and for the majority the order of their chroma is between 1 and 2. The major hues exhibited are green, red, and yellow; some of the darker argillitic rocks are neutral to dark gray (*N* 3). The purest of the quartzite usually has a faint yellow or yellow-green hue and approaches white in lightness.

Rocks in the St. Regis, Striped Peak, and Burke Formations described as having various tints of purple are in the red and red-purple range. In the Coeur d'Alene district this so-called purple color is one of the distinguishing characteristics of the St. Regis Forma-

TABLE 3.—*Analyses, in percent, of unaltered rocks from the Belt Series*

[Analysts: H. F. Phillips, P. L. D. Elmore, K. E. White, U.S. Geol. Survey, 1954]

Lab No.	(1)	(2)	54-416SC	54-417SC	54-418SC	54-419SC	54-420SC	54-423SC	54-424SC	54-425SC	54-426SC	54-427SC	54-428SC	54-429SC
Field No.	----	----	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	58.10	76.84	70.3	74.7	70.4	35.4	66.0	62.9	80.8	64.8	66.8	71.9	63.6	81.7
Al_2O_3	15.40	11.76	15.3	13.6	17.6	5.2	17.1	17.6	10.4	16.8	16.6	13.5	12.4	9.4
Fe_2O_3	4.02	.55	3.6	2.8	2.2	.4	1.8	1.7	1.6	4.9	2.7	3.0	1.6	1.9
FeO	2.45	2.88	.62	.60	.27	2.9	1.2	3.8	.76	.63	1.4	.71	2.2	.27
MgO	2.44	1.39	.71	1.3	.26	11.6	3.9	2.9	.86	2.8	2.4	2.2	3.4	1.0
CaO	3.11	.70	.52	.18	.17	16.0	.22	.79	.21	.28	.58	.34	5.8	.23
Na_2O	1.30	2.57	1.4	2.8	1.2	.80	.70	1.6	2.9	.99	1.6	1.8	2.3	3.1
K_2O	3.24	1.62	4.1	3.1	4.9	1.2	5.6	4.3	1.5	5.4	4.8	4.0	1.9	2.0
TiO_2	.65	----	.59	.48	.64	.14	.67	.69	.28	.59	.60	.50	.40	.34
P_2O_5	.17	----	.20	.07	.08	.07	.10	.16	.06	.16	.16	.14	.13	.11
MnO	----	Tr.	.01	.01	.01	.16	.01	.04	.01	.04	.06	.03	.19	.01
CO_2	2.63	----	.81	.05	.05	24.0	.05	.84	.05	.05	.05	.05	4.4	.05
H_2O	5.00	----	1.5	1.2	2.2	.53	3.1	2.8	1.0	2.5	2.6	2.0	2.2	.51
Sum	98.51	98.31	100	101	100	98	100	100	100	100	100	100	101	101

[1] Average shale (Clarke, 1924, p. 34).
[2] Subgraywacke from Tyler Slate (Huronian), near Hurley, Wis.; analyst, H. N. Stokes; (Clarke, F. W., 1924, p. 547).

Field description of rocks:

1. Argillite, St. Regis Formation, from surface at portal of Rock Creek adit, Mullan map area.
2. Impure quartzite, Burke Formation, from Glidden Lakes section just east of Pottsville map area.
3. Laminated quartzose argillite, upper part Prichard Formation, from near town of Burke, Mullan map area.
4. Argillaceous dolomite, lower part Wallace Formation, Stevens Lake section, Pottsville map area.
5. Argillite, lower part Wallace Formation from Placer Creek road southeast corner Wallace map area
6. Argillite, lower part Prichard Formation, Pine Creek road, Smelterville map area.
7. Reddish-purple quartzite, St. Regis Formation, from Silver Creek road near Saltese, Mont.
8. Reddish-purple argillite, St. Regis Formation, from Silver Creek road near Saltese, Mont.
9. Banded argillite, St. Regis Formation, from Lookout Pass east edge Pottsville map area.
10. Quartzose argillite, St. Regis Formation, from Lookout Pass east edge Pottsville map area.
11. Green argillite, St. Regis Formation from roadcut along U.S. Highway 10, 7 miles east of Henderson, Mont.
12. Quartzose argillite, St. Regis Formation, from Murray district north of Mullan map area.

tion. The quartzitic facies of these rocks range in chroma from *5RP* to *5R* and in value from 5 to 7; their best descriptive terms are grayish pink and pale purple red. The argillaceous facies range from *5RP* to *10R* in chroma and from 3 to 6 in value; their best descriptive terms are grayish red purple and grayish red. None of the rocks that were compared with the chart had a color that fell within the true purple range.

The gray argillitic rocks so typical of the Prichard and Wallace Formations are of a neutral shade (*N* 3–*N* 5) or contain some of the green-yellow chroma (*5GY* 4–7/1–2). The descriptive terms which best fit these rocks are dark to medium gray and greenish gray. The Prichard Argillite is more commonly neutral whereas the Wallace rocks usually have a slight green-yellow cast. Dark gray (*N* 3) colored rocks are few; most of the gray argillite is a medium dark gray (*N* 4).

Quartzites range in value between 5 and 9. Relatively few quartzites are neutral in chroma; they usually have a slight tint of yellow green, yellow, red, or red purple. The purer quartzites range from 7 to 9 in value and are usually dark shades. The purer vitreous quartzite is a pale greenish yellow to a pale yellowish gray (*5GY*–*10Y* 7–8/1+). The impure quartzite is a greenish gray to a pale or grayish olive (*5GY*–*10Y* 5–7/1–2). In this category belong the bulk of the rocks in the Burke Formation as well as most of the quartzitic rocks in the Prichard and the lower part of the Wallace. In the latter, many of the quartzitic rocks contain ferroan dolomite.

Some unaltered argillaceous rocks exhibit more of the green chroma than most Belt rocks. Most of these rocks are in the upper part of the St. Regis and scattered in the Striped Peak. They range from light to dark greenish gray (*5GY*–*5G* 4–7/1–2).

Weathering of most of the rocks forms a bleached surface rind and decreases the grayness value by one or two numbers. However, in those rocks which contain appreciable quantities of iron sulfides, as in most of the Prichard Formation, or appreciable quantities of iron-bearing dolomite or calcite, as do parts of the Wallace Formation, coatings and rinds of characteristic colors result from the oxidation of these iron-bearing minerals. Bedding and joint surfaces of argillite in the Prichard Formation are almost universally coated by a dark rusty selvage, brownish gray in color (*5YR* 4–5/1–2). The rind on the carbonate-bearing rocks may be as much as half an inch thick, but is usually less, and varies from light to moderate brown to reddish brown (*5YR*–*10R* 4–5/3–4). The rusty speckles found in many quartzites whose color is toward the red side of the chroma are in this same range.

Several types of hydrothermal alteration have changed the colors of great masses of rocks. The most pervasive bleaching has perceptibly lightened the color of the darker rocks. Where this type of alteration is more intense, the rocks are a grayish yellow green to pale olive (*5GY*–*10Y* 5–7/2–3). Upon weathering, the rocks so altered become somewhat lighter in color, and the chroma changes to a more yellow hue; a typical color is light grayish yellow (*5Y*–*10Y* 7–8/1–2). Rocks containing pyrite are peppered with moderate brown (*5YR* 4/4) speckles, and rocks that contained appreciable carbonate minerals have rinds or contain bands of light to reddish brown (*5YR*–*10R* 4–5/3–4) alternating with light gray bands. Where chlorite and greenish biotite are introduced, they impart a dark-greenish-gray (*5G* 3–6/1) color to the rock.

Colors imparted to the fresh and unaltered Belt rocks are primarily due to the colors of the contained iron oxides, carbonaceous material, sericite, chlorite, and biotite. Also, the finer the grain, the darker the value becomes. Red hues are due to hematite that occurs as exceedingly thin coatings on other mineral grains, and as very small irregular blobs or well-formed hexagonal scales in the matrix. The amount of hematite even in the reddest rocks seldom amounts to more than 2 or 3 percent. Opaque black dust in the gray argillaceous rocks of the Prichard and Wallace Formations is probably carbonaceous material and iron oxides, but the dust particles are too small to be resolved by even the high magnification of a petrographic microscope. When these gray argillaceous rocks are powdered and heated, the powder becomes several shades lighter, indicating an oxidation of the carbonaceous material. Such fine dust is one of the principal causes for the darker shades of these rocks. Green to green-yellow hues are in large part due to sericite. Chlorite, usually a minor constituent, together with the sericite causes the greenish hues. The combination of hematite, sericite, and (or) chlorite is responsible for the red-purple hues so characteristic of much of the St. Regis and Striped Peak rocks.

Quartz, the other important constituent in Belt rocks, lightens the color value but apparently has no effect on the chroma. Ilmenite, a minor constituent in some beds, and rutile may affect the color value of a rock. In places, the alteration of ilmenite to leucoxene may add to the yellow chroma. Iron sulfide in a finely disseminated form may add to the dark-gray value of laminae in the Prichard Formation. Upon heating, the laminae take on a reddish hue, probably as a result of the oxidation of the iron. Other minerals such as magnetite, tourmaline, and zircon are present in such minor amounts that they have little or no effect upon the color of the rock.

PRICHARD FORMATION

DISTRIBUTION

The Prichard Formation is named after excellent exposures along Prichard Creek in the vicinity of Murray, which lies north of the Mullan map area (Ransome and Calkins, 1908, p. 23). Easily accessible exposures can be found between Kellogg and Osburn north of U.S. Highway 10. The general distribution of outcrops of the Prichard Formation can be seen on plate 9, on which the large areas of exposures of this formation are used to outline the position of upwarped or elevated tectonic blocks. Within the mapped area of this report the Prichard is exposed in the cores of three broad upwarps—the Pine Creek anticline on the west in the Smelterville map area, the Moon Creek anticline in the northern part of the Kellogg and Wallace map areas, and the Burke-Trout Creek anticline in the northern part of the Mullan map area. West of the district the Prichard Formation continues to crop out for a distance of almost 25 miles to the eastern shore of Coeur d'Alene Lake. In contrast, younger rocks of the Belt Series dominate the outcrop pattern to the east of the Coeur d'Alene district.

THICKNESS

No estimate of the total thickness of the Prichard Formation can be made for the Coeur d'Alene district, as an unknown amount of the basal part is unexposed. Calkins (in Ransome and Calkins, 1908, p. 29) estimated the maximum amount exposed as 8,000 feet; this was the thickness of a section measured in Butte Gulch near Murray. The greatest exposed thickness of the formation is north of the South Fork of the Coeur d'Alene River between Kellogg and Osburn, but no section of continuous exposure exists here, and the indication of structural deformities detracts somewhat from the accuracy of a measurement; however, Shenon and McConnel (1939, p. 3) estimated the amount exposed as having an apparent thickness of 12,000 feet. This was based upon the measurement of two partial sections, one of 10,000 feet, which started at one of the lower quartzite zones and continued upward to the Burke-Prichard contact, and the other of 2,000 feet, which started at the base of the exposed Prichard Formation and went to the top of the same lower quartzite zone. The first section is in the vicinity of Twomile Creek and the other is near Prospect Gulch (pl. 3). This estimate appears to be as good an approximation as can be made and is accepted as the maximum for the exposed Prichard within the district.

Other investigators working in northern Idaho and western Montana have estimated the thickness of the exposed part of the Prichard within their areas as from 5,000 to 20,000 feet. What appears to be the most reliable of the thicker sections was reported by Wallace and Hosterman (1956, p. 579). It lies along the Clark Fork for 5.5 miles southwest from the junction of the Flathead River with the Clark Fork about 35 miles east of the mapped area. They wrote: "an essentially continuous section of Prichard Formation is exposed in the canyon walls of the Clark Fork and in railroad and roadcuts along the canyon. In this entire section, except for a minor flexure north of Quinn's Hot Springs, dips are uniformly to the southwest and range between 40° and 60°. Discounting unidentified faults, this section is very nearly 17,000 feet." The base of the Prichard Formation is not exposed here. The magnitude of this section indicates that the figure given for the maximum of exposed Prichard Formation within the Coeur d'Alene district is justified.

LITHOLOGIC CHARACTERISTICS

In general, the Prichard Formation consists of a monotonous succession of medium- to dark-gray rocks ranging in composition from quartzose argillite to argillite, which contain several lighter colored quartzitic zones. One part of the section cannot be distinguished from any other except for the quartzite zones. This monotony in lithology makes the interpretation of structure difficult. Many faults must not have been recognized because of this monotony, and the direction and the amount of movement along others cannot be estimated reliably.

Although the Prichard Formation constitutes the bedrock of almost a quarter of the mapped area, large continuous outcrops of the formation are scarce. Most of the rock is hard and indurated, but because of well-formed bedding and jointing, it breaks down relatively rapidly; so, most outcrops are small and patchy. Nowhere within the area does the rock crop out in a large continuous section within cirque basins and on adjacent ridges where the best exposed sections of the other formations have been found. Moreover, a fair evaluation of the original rock based on the weathered outcrops is not always possible because of the usual dark rusty coating. Fortunately, manmade excavations have exposed excellent partial sections in long crosscuts at the Interstate, Carlisle, and Red Monarch mines in the northwest part of the Mullan map area (pl. 4); at the Nabob, Sidney, and Sunset mines in the Pine Creek area (pl. 1); at the Bunker Hill mine near Kellogg; and at the Silverore-Inspiration prospect in Dago Peak Gulch in the Wallace map area (pl. 3). A large number of roadcuts also expose good partial sections.

From all these exposures, a good knowledge has been gained of the common characteristics of the Prichard Formation. The dominant rock type is a fine- to very fine grained medium- to dark-gray quartzose argillite that grades both ways into similar-appearing impure quartzite and, more commonly, argillite. The bedding is regular and well formed; individual beds range from 2 to 18 inches in thickness; most are less than 8 inches. Many beds are faintly to markedly laminated. The laminae are most evident in faded weathered rock. They are usually less than 2 mm wide, but some are coarser. The lighter gray laminae are sandier than the darker. Like the beds, the laminae are regular, and commonly have graded bedding.

Pyrite, as a universal constituent, is unique to the Prichard Formation within the Belt Series. It is found concentrated within the darker laminae or along bedding planes of argillitic rock as irregular grains, ± 1 mm in size. Rarely, it occurs as much larger grains or cubes in the sandier laminae or beds. It is also found sparsely disseminated in nonlaminated beds. In some places the pyrite-rich seams are so abundant that the iron sulfide may make up as much as 5 percent of the rock; usually, though, it probably constitutes less than 1 percent. In some places, particularly on the northwest side of the Gem stocks, pyrrhotite was found instead of pyrite. Gibson (1948) noted the presence of pyrrhotite as well as pyrite in the Prichard Formation in the Libby, Mont., area, as did Calkins (in Emmons and Calkins, 1913) in the vicinity of Philipsburg, Mont. The widespread occurrence and the relation within the beds indicate that the pyrite, although secondary in origin, was formed from the primary constituents of the sediments. The replacement of pyrite by pyrrhotite appears to be due to a metamorphic effect in which heat played a major part.

Carbonate minerals are scarce or absent in the Prichard Formation. A few thin dolomitic quartzite beds were found in the upper part of the formation along the East Fork of Pine Creek. Rust speckles on the weathered surfaces of quartzite beds at other places also show the presence of ferroan dolomite segregations within the rock.

Unidentified stromatolites, all of the same type, were found in the upper part of the Prichard Formation along the east side of the Little Pine Creek Valley about 2 miles southeast of Pinehurst, Idaho. The colonies, which are bowl-shaped laminated structures lying upright in the strata, occur sparsely scattered throughout a 15-foot-thick zone of greenish-gray argillite beds but are especially well preserved in one 2-foot argillite bed that can be traced for 250 feet along strike. This horizon is located about 600 feet stratigraphically below the contact of the Prichard Formation with the overlying Burke Formation. The stromatolite colonies measure from 1 inch to approximately 15 inches in diameter and from 1 to 10 inches in height. Laminae are concave upward and may or may not stand out in relief. The concavity of the laminae varies from weak to rather strong and is smooth but not orderly.

Sedimentary features such as mud cracks, cross-stratification, and ripple marks are common in the upper quartzitic zone of the Prichard Formation but sparse in the lower quartzitic zones.

Rocks of the Prichard Formation usually are easily distinguished in the field. The dark rusty brownish-gray coating, that covers the weathered surfaces of the argillitic rock is most characteristic. This, plus the regular bedding, blocky jointing, and characteristic lithology, distinguishes rocks of the Prichard Formation from the rest of the Belt Series. The only other rocks with which they may be confused are the argillitic zones within the upper part of the Wallace Formation. These, however, contain carbonate-bearing beds, are usually irregularly bedded, usually have a wavy appearance due to small plications, and do not have the dark rusty coating formed by the oxidation of the iron sulfides. Locally, argillitic rocks of the Prichard Formation have a slaty appearance. These are within areas where the deformation of the rock has been more intense.

QUARTZITE ZONES

At least three different quartzite zones have been found within the Prichard Formation. Of these only the uppermost, which forms the transitional zone between the argillaceous rocks of the Prichard Formation and the quartzitic rocks of the Burke Formation, appears to be persistent. It has been mapped separately, where possible, as the upper part of the Prichard Formation, and is discussed later. The other two zones are represented by several isolated exposures, one group about 5,000 feet below the top of the Prichard, and the other about 7,500–10,000 feet below the top. None of them consist entirely of quartzite but are made up of interbedded argillite and quartzite. The maximum thickness for any group of beds that is entirely quartzite is about 150 feet. Such groups generally lens out or grade into more argillaceous rocks laterally.

The intermediate zone is best represented in the northwestern quarter of the Mullan map area (pl. 4), where it consists of an upper and lower quartzite-rich group of beds separated by a more argillite-rich part. The top of this zone is about 4,800 feet below the top of the formation. In the Red Monarch adit the upper quartzite-rich part is 150 feet thick, the central argillite-rich zone is 75 feet thick, and the lower quartzite-rich part is 100 feet thick; in the main Carlisle adit the similar series of beds have thicknesses of 250, 140, and 120 feet, respectively. This section of the zone, totaling 510 feet, is an apparent maximum thickness for it. Many of the quartzite beds in the zone are nearly pure and light gray in color but are interbedded throughout the zone with argillaceous rock.

A quartzite-rich zone, as much as 200 feet thick, has been traced across the ridge between Montgomery and Moon Creeks about 1.5 miles above their mouths in the northeast corner of the Kellogg map area (pl. 2). Stratigraphically it is at the proper horizon to be considered a part of the intermediate zone. This zone appears to be lenticular and grades out both to the west and east. Its probable contemporaneity to the zone in the northwest quarter of the Mullan map area is based entirely upon similar stratigraphic position. The thickness of the Prichard Formation exposed west of Montgomery Creek near Kellogg and in the Pine Creek area suggests that the part of the section containing this quartzite zone should be present, but no evidence of it was found.

The lower quartzite zone, known locally as the middle Prichard Quartzites, is well exposed in the valley walls of Pine Creek in the Smelterville map area (pl. 1). There the zone varies in thickness and is composed of interbedded quartzite and argillite strata. The uppermost quartzite unit is 7,500–8,000 feet below the top of the Prichard Formation. In Highland Creek valley near the east edge of the Smelterville map area, the zone is about 400 feet thick and is composed of an upper massive white quartzite unit about 150 feet thick, a lower similar quartzite unit about 100 feet thick, and about 150 feet of medium- to dark-gray argillite separating the quartzite units (Forrester and Nelson, 1944, p. 7). The upper quartzite unit is continuous but thins considerably along strike from Highland Creek to the northwest. In the vicinity of the Sunset (Liberal King) mine, the upper quartzite unit is only about 30 feet thick; however, at that location the entire zone is about 2,000 feet thick and is composed of four thin, widely separated quartzite units and interbedded argillite. As shown on the geologic map of the Smelterville map area, with the exception of the uppermost unit, the quartzite units are discontinuous and irregular. Some of the apparent discontinuity of the quartzite beds can be attributed to the lack of continuous exposure, but underground observations have shown that these quartzite beds do pinch and swell along both strike and dip. The discontinuity of the quartzite units and the variation in total thickness of the quartzite zone precludes reliable correlation of the individual quartzite units.

The southeast portion of the main quartzite zone in Pine Creek valley has been offset by the Placer Creek fault, and only a few short segments of quartzite units occur south of that fault. Northwest of Pine Creek the zone is covered by older gravels that cap the French Gulch Divide. Short segments of quartzite beds are exposed in an area cleared of gravel near the junction of Hypotheek Gulch and French Gulch and near the Hypotheek mine south of that junction.

Quartzite units that are probably correlative to those found in Pine Creek valley are present immediately north and south of the South Fork of the Coeur d'Alene River in parts of the Kellogg and Wallace map areas. In the area between Moon and Terror Creeks the quartzite zone, 1,200 feet thick, contains at least five beds of nearly white, massive quartzite separated by interbedded argillite. The quartzite units generally range in thickness from 5 feet to 150 feet. Only one thick bed, about 300 feet above the bottom of the zone, is exposed sufficiently along strike to be followed readily and is the only bed shown on the map (pl. 3).

Quartzite beds of the Prichard Formation are also present south of the South Fork of the Coeur d'Alene River from near the mouth of Rosebud Gulch in the Wallace map area to Milo Creek in the Kellogg map area (pl. 2 and 3). These beds cannot be followed continuously because of the extensive gravel deposits that blanket much of the area. Although a single continuous band of quartzite extending from the West Fork of Elk Creek westward to Milo Creek is shown on the map, it is possible that the few exposures in that area are actually on separate discontinuous beds similar to those in the Pine Creek area. The quartzite beds on both sides of the South Fork of the Coeur d'Alene River near Kellogg are probably part of the lower quartzitic zone; however, faulting, complex folding, a cover of alluvium, and terrace gravels have obscured their mutual relation. The apparent proximity of this lower quartzite zone to the upper contact of the Prichard Formation near Sweeney Gulch must have been brought about by complex folding, in part overturning, and by probable undetected faults in the vicinity of Kellogg.

Quartzite beds also occur locally at other stratigraphic horizons of the Prichard, but none of these beds are persistent for more than a few hundred feet in strike length. In most places these beds have not been mapped separately because of their limited exposure or local occurrence. Forrester and Nelson

(1944, p. 7) reported a few small discontinuous lenses of quartzite between the "middle quartzite" and upper quartzite zone in the Pine Creek area. In the area between Montgomery Creek and Moon Creek in the Kellogg map area several quartzite beds occur stratigraphically above and below the intermediate quartzite zone shown on the map. Such quartzite beds grade laterally within a short distance into more argillaceous rock.

The occurrence of these discontinuous zones and isolated beds of relatively pure quartzite at several stratigraphic horizons in the Prichard Formation indicates that local depositional environments changed several times during Prichard time. The well-sorted nature of the quartzite, the presence of shallow-water features, and the discontinuity of the beds suggest a near-shore environment.

UPPER PART OF THE PRICHARD FORMATION

The upper quartzite zone that forms the transition between the Prichard argillitic rocks below and the Burke quartzitic rocks above is generally persistent and recognizable, and was mapped separately whereever exposures permitted.

This upper quartzite zone makes up a large part of the formation exposed around the Gem stocks and is also the only part of the Prichard cropping out along the east margin of the Pottsville map area. Although not mapped separately, this upper part forms a continuous band north of the Osburn fault from Revenue Gulch northwest to the Twomile fault, and is exposed again farther to the northwest where it forms part of the upper plate of the Carpenter Gulch fault. Between Kellogg and Smelterville, immediately north of the Osburn fault, the upper quartzite zone is exposed but not mapped separately; farther to the north beyond the South Fork of the Coeur d'Alene River, it was mapped separately. Around the margins of the Pine Creek anticline the upper quartzite zone is exposed almost continuously but was mapped for only part of the distance along the northeast side of the fold.

The thickness of this upper quartzite zone increases from west to east. In the Pine Creek area it is from 600 to 800 feet thick. In the Silverore-Inspiration crosscut in Dago Peak Gulch, northern half of Wallace map area (pl. 3), at least 1,500 feet of the zone is exposed, even though it is bounded at the top by the Blackcloud fault. A section of this upper zone is well exposed along the crest of the ridge trending northward from Goose Peak, north edge of Mullan map area (pl. 4), where it is 1,850 feet thick. Another section just off the mapped area near Glidden Pass about 5 miles east of the Goose Peak section measured almost 2,000 feet in thickness.

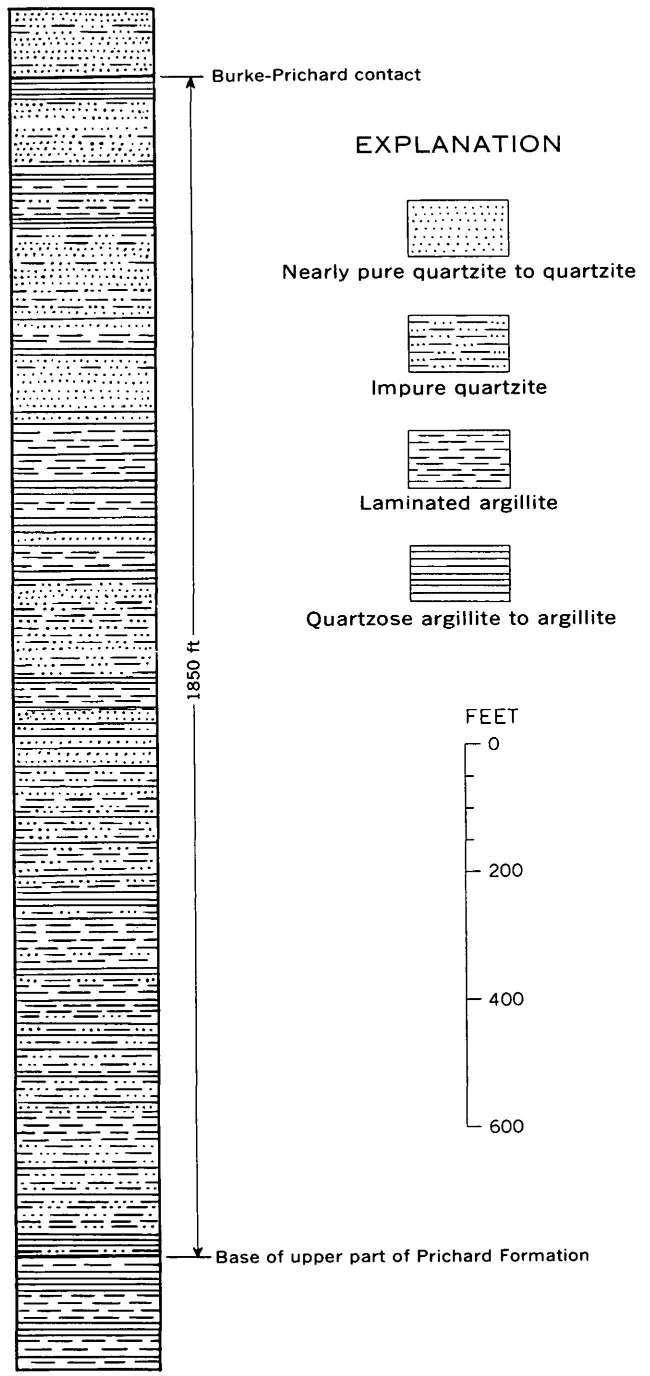


FIGURE 10.—Generalized columnar section of the upper part of the Prichard Formation at Goose Peak, just north of the Mullan map area.

The amount and purity of the quartzite increase toward the top. Usually, in the upper half are found several zones that are from 20 to 100 feet thick and that consist almost entirely of quartzite. These zones are apparently lenslike as they cannot be traced for any great distance. The Goose Peak section is a good example of the lithology of this upper quartzite zone (fig. 10).

In the Goose Peak section almost two-thirds of the rocks is quartzite, of which a third is nearly pure to pure quartzite and the remainder is impure quartzite. About two-thirds of the argillite is thinly laminated (±1 mm). The thinly laminated argillite becomes less abundant towards the base. Generally the more quartzitic the rock, the thicker the beds; some of the purer beds are as much as 4 feet thick. The impure quartzite beds are usually less than 1 foot thick, and the argillite beds are only a few inches in thickness.

Mud cracks, ripple marks, cross-stratification, and pseudoconglomerate are common in this upper quartzite zone, showing that the zone was mostly deposited in shallow water. Such features are less common in the other quartzite zones in the Prichard and their relative abundance is a good criterion for distinguishing the upper zone fron the lower zones. At the Goose Peak section the number of these sedimentary features gradually diminishes downward, which is probably true for the zone at other places. Gradational bedding, ranging in thickness from a fraction of an inch to several inches, is characteristic of these rocks in this section.

Within this section the amount of pyrite present is directly proportionate to the amount of argillite. Thus the dark-brown rusty staining is restricted to the argillitic rocks. Some of the quartzitic beds, however, do contain pyrite either as irregular grains or as well-formed cubes as much as a quarter of an inch across.

Gibson (1948, p. 11) noted a similar quartzitic transitional zone, from 300 to 500 feet thick, at the top of the Prichard Formation in the Libby quadrangle, Montana. Such a zone could be expected to be found wherever there is a change from the dominantly argillitic rocks of the Prichard Formation below to quartzitic rocks of the Burke Formation above. The zone is apparently variable in thickness as indicated by the recorded minimum of 300 feet and maximum of about 2,000 feet.

The contact between the Prichard and Burke has been placed arbitrarily at the top of the uppermost laminated dark-gray argillite of the transition zone. The exact position of this contact is commonly quite difficult to determine, especially in the areas of sporadic outcrop. Although in some localities a few argillitic beds are interbedded with the predominant quartzite of the lower part of the Burke Formation, they are generally greenish gray rather than the neutral medium to dark gray of the argillite beds of the upper part of the Prichard Formation.

BURKE FORMATION

DISTRIBUTION

The Burke Formation, so named by Calkins (in Ransome and Calkins, 1908, p. 32) because of its extensive exposures near the town of Burke, crops out in all five map areas. Exposures of rocks typical of the formation are readily accessible along the Canyon Creek road from the community of Gem to and beyond Burke in the northern part of the Mullan map area (pl. 4).

The largest area of Burke rocks lies north of the Osburn fault and east of the Dobson Pass fault in the northern part of the Mullan and Pottsville map areas. Here the outcrop pattern is one of jumbled blocks, brought about by faulting which was superimposed upon folding. In the northern part of the Pottsville map area, the Burke Formation crops out in two north-trending belts on both sides of the Granite Peak syncline.

In the northeastern part of the Wallace map area, the Burke Formation has been traced continuously along the east flank of the Moon Creek anticline northwest from the Osburn fault to the Twomile fault. Beyond the Twomile fault the Burke crops out in an irregular pattern due to repetition caused by faulting. North of the Osburn fault in the northern part of the Smelterville map area and the adjacent part of the Kellogg map area, much of the southwestern limb of the Moon Creek anticline is underlain by rocks of the Burke Formation. In the McCloud Hill area, northwest of Smelterville, rocks which have characteristics of both the Burke Formation and Revett Quartzite are grouped together and mapped as undifferentiated Revett Quartzite-Burke Formation.

At the western end of the Coeur d'Alene district, the Burke Formation crops out in an irregular pattern around the flanks of the northwest-trending Pine Creek anticline. Both faulting and folding, plus the vagaries of topography, have contributed to these irregularities. In the southwestern corner of the Smelterville map area, the extensive exposure of the Burke Formation lies in the crest of a subsidiary domal feature.

THICKNESS

The thickness of the Burke Formation differs from place to place; in general, though, the formation thickens towards the west. Just north of the outcrop area of the Burke Formation along the east margin of the Pottsville map area, an almost uninterrupted section is well exposed in the glaciated area around Glidden Lakes near the head of Canyon Creek. Detailed measurement of this section shows that the Burke is about 2,100 feet thick. Calkins (in Ransome and Calkins, 1908, p. 32) reported a measurement of 2,000 feet for the same section. A somewhat greater thickness of about 2,500 feet was estimated for rocks of the Burke Formation lying between the Revett Quartzite capping Tiger Peak and the Prichard-Burke contact lying almost vertically below in the Hercules mine No. 5 crosscut (pl. 4). This is just north of the town of Burke. The section exposed along the upper reaches of the East Fork of Pine Creek in the southwest corner of the Kellogg map area measured 2,400 feet thick (P. J. Shenon, written commun., 1948), but this measurement may be in error by several hundred feet because of unrecognized faults which may have duplicated or cut out part of the section. In the vicinity of Kellogg, north of the Osburn fault, the Burke Formation is about 3,000 feet thick. Immediately to the west of the southwest corner of the Smelterville map area in the Twin Crags quadrangle, Campbell (1960) estimated the Burke to be about 3,000 feet thick, which agrees with Anderson's (1940, p. 11) maximum estimated thickness for the formation in the nearby country to the west.

The formation may continue to thicken considerably to the northwest, for Sampson (1928, p. 7), in a discussion of the geology of the Pend Oreille district along the east shore of Pend Oreille Lake, reported that although the thickness of the Burke was not established there with certainty, "It is greater than 2,000 feet but may be more than twice that amount."

The indefiniteness of the contact between the Burke Formation and the overlying Revett Quartzite could cause differences in reported thickness of several hundred feet in these formations. The contact lies within a gradual transition zone at least 500 feet thick and is placed at the horizon above which vitreous pure quartzite predominates. The basal contact of the Burke Formation with the underlying Prichard Formation most likely differs from place to place as a result of the vagaries in the original sedimentation processes. These processes would also cause variations in the thickness of the Burke Formation.

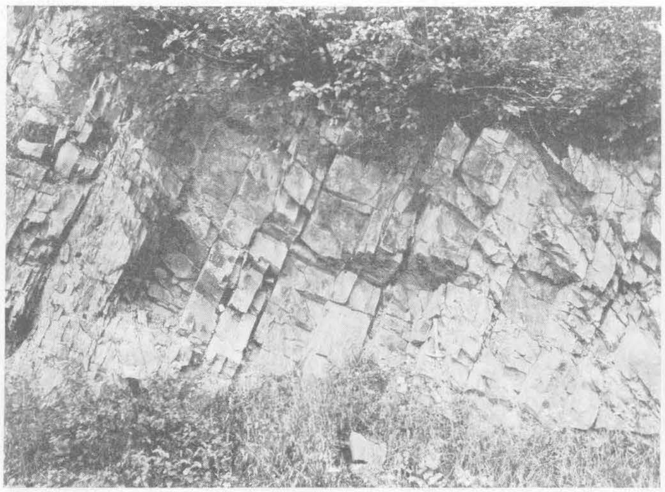


FIGURE 11.—Impure quartzite in the lower part of the Burke Formation exposed in roadcut along Canyon Creek.

LITHOLOGIC CHARACTERISTICS

The gross lithologic characteristics of the Burke Formation reflect a gradual transition from the underlying predominantly argillitic Prichard Formation to the overlying predominantly quartzitic Revett Quartzite. The Burke is composed chiefly of interbedded impure to pure quartzite, quartzose argillite, and a minor amount of argillite. The amount of any one rock in the formation varies from section to section, but the major lithologic variety is a greenish-gray impure quartzite that is generally in beds less than 6 inches thick (fig. 11).

The nearly uninterrupted section of the Burke near Glidden Lakes in the eastern end of the district is summarized as follows:

Generalized section of the Burke Formation along the ridge crest south of Glidden Lakes

	Thickness (feet)
Top of Burke Formation	
Predominantly pure quartzite, thick-bedded, light- to medium-gray; some pure quartzite that is vitreous, thick bedded, nearly white, carbonate speckled; a few thin medium-gray argillite interbeds; ripple marks and pseudoconglomerate. About 115 ft covered	334
Nearly pure quartzite, light-gray, thick-bedded; thin interbeds of impure quartzite are common and are medium gray and laminated; a few pure quartzite beds; some pseudoconglomerate	112
Alternating impure and nearly pure quartzite in zones 10–30 ft thick, greenish- to light-gray, thin- to thick-bedded; in part carbonate speckled; some pseudoconglomerate	227
Nearly pure to pure quartzite, light-gray and pale-red, thin- and thick-bedded; bottom 75 ft contains beds of impure quartzite	244
Nearly pure quartzite, light-gray, thin- to thick-bedded	32
Impure quartzite, thin-bedded, greenish-gray; a few beds of nearly pure quartzite	72
Interbedded impure and nearly pure quartzite, greenish-gray and pale-red; thin- to thick-bedded; some argillite interbeds; ripple marks and scallops	72
Impure quartzite, gray and greenish-gray, thin-bedded	48
Nearly pure to pure quartzite; some scallops	21
Impure quartzite, gray to greenish-gray, thin-bedded; mud cracks and ripple marks. 100 ft covered	414
Impure and nearly pure quartzite, alternating in zones 30 ft thick, greenish-gray to light-gray, mostly thin-bedded; ripple marks and pseudoconglomerate	343
Impure quartzite, greenish-gray, buff weathering, thin-bedded; some nearly pure quartzite	138
Pure to nearly pure quartzite, nearly white, thick-bedded, carbonate speckled	31
Bottom of Burke Formation	
Total thickness	2, 088

From this generalized section it is apparent that the number of purer and thicker bedded quartzite strata decrease from the base towards the center of the formation. In the central part there are several closely spaced zones of purer quartzite 20 feet or more thick. Some of these quartzite zones have a faint reddish tint, but most are light gray to a very light yellowish gray. Above the central portion a reversal takes place in the amount of purer quartzite beds and they become more numerous towards the top. Also, the individual beds become thicker, generally ranging from 1 to 4 feet in thickness. The section exposed along the upper reaches of the East Fork of Pine Creek has been commented upon by P. J. Shenon (written commun., 1948) as follows:

> Beds of white massive quartzite make up more than 10 percent of the Burke Formation exposed on the East Fork of Pine Creek. They occur largely in two zones each about 400 feet thick; one 450 feet and the other 1,500 feet above the base of the formation. In both zones the white quartzites are interbedded with some argillaceous quartzites. Thin beds of limy quartzite are found throughout the Burke Formation on Pine Creek but are estimated to make up only about 1 percent of the total formation. One very limy horizon, about 80 feet thick, occurs approximately 850 feet above the base of the formation.

This section is considerably different from the one near Glidden Lakes, but here again the preponderant rock is a greenish-gray impure quartzite.

The section of the Burke Formation along the East Fork of Pine Creek probably contains the highest proportion of carbonate-rich beds to be found within the Burke Formation in the district, but as already stated, these amount to only about 1 percent of the total volume. In the Glidden Lakes section only rare thin interbeds are carbonate rich. Locally, carbonate-rich strata, whose carbonate content cannot be attributed to later hydrothermal solutions, were found within the Burke Formation in the eastern part of the district. One example is several beds of dolomitic quartzite which crop out in the cirque on the east side of Tiger Peak and which are about 500 feet below the top of the formation. Another example is several beds within a large xenolith of the Burke Formation in the north end of the southern Gem stock. These rocks have gone through contact metamorphism and contain diopside, biotite and hornblende, the characteristic suite of minerals found in carbonate-rich rocks of the Wallace Formation, similarly metamorphosed. Many of the purer quartzite beds within the Burke Formation are speckled with the telltale rusty splotches resulting from oxidation of small segregations of ferroan dolomite or ankerite.

Sedimentary features are fairly common within the Burke Formation and include ripple marks, mud cracks, cross-stratification, scallops, pseudoconglomerate, and graded bedding. Mud cracks and ripple marks are most common in the lower part of the formation, but are scattered throughout; in general they favor the more argillitic beds. Most of the scallops were noted at the Glidden Lakes section. The pseudoconglomerates are not common, but were found at widely scattered places within the district. Cross-stratification occurs in the thick-bedded pure to nearly pure quartzite and is more common in strata in the upper part of the formation. Graded bedding is apparent only in some of the thin quartzose argillite or argillite beds. Laminae containing concentrations of heavy minerals occur in some of the purer quartzitic beds; these darker laminae stand out in sharper contrast on the bleached surfaces of weathered rock than in the fresh specimen.

The quartzitic nature of most of the formation makes it relatively resistant to erosion, and as a result fairly continuous exposures of these rocks are found at many places, particularly along some stream canyons and ridge crests, and in glaciated areas. Partial sections of the Burke Formation are well exposed in the workings of the Hercules, Tamarack, and Black Bear Fraction mines in the Burke area (pl. 4). Along ridge crests the upper part of the Burke Formation, which is predominantly nearly pure to pure quartzite, tends to break down into blocky scree, a characteristic in common with the Revett Quartzite (fig. 12).

Some of the quartzitic beds, even though greenish gray, should be classified as quartzose argillite because of their fineness of grain and sericite content. Dark argillite layers are usually confined to the Prichard Formation, but they are also found locally in the Burke Formation. One such noncontinuous

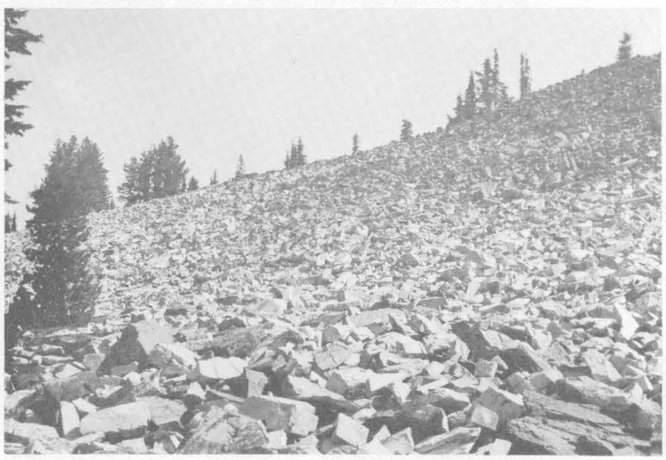


FIGURE 12.—Scree slope of quartzite from transition zone between the Burke Formation and Revett Quartzite. Tree at left is 8 inches at butt for scale.

zone crops out in the ridge between the East Fork of Ninemile Creek and Granite Gulch in the northern part of the Mullan map area, and consists of laminated, medium- to dark-gray argillite interbedded with impure quartzite for a thickness of almost 100 feet. More than 200 feet of lighter colored quartzitic rock lies between this argillitic zone and the base of the Burke Formation.

The boundary between the Burke Formation and the overlying Revett Quartzite is the most subtle one in the entire Belt Series. Calkins (in Ransome and Calkins, 1908, p. 33) described the problem well in his statement, "Even where exposures are good, the line [contact] might not be drawn by a given observer precisely at the same horizon in different places and at different times, nor would two observers be apt to agree precisely as to where the boundary should be placed in a given section." Determining where the thick-bedded vitreous quartzite becomes predominant is difficult, particularly where outcrops are not plentiful.

A common characteristic of the Burke Formation is a pronounced sheen of parallel sericite or muscovite flakes on bedding partings. The general slabbiness of much of the broken rock is also characteristic. These characteristics plus the general lithologic makeup, greenish-gray color, and characteristic sedimentary features are usually sufficient to distinguish the Burke from the other formations.

REVETT QUARTZITE

DISTRIBUTION

Exposures of the Revett Quartzite are widespread within the Coeur d'Alene district, and are prominent in all five map areas. The formation was named by Calkins (in Ransome and Calkins, 1908, p. 35) for the unusually good exposures around Revett Lake, in the extreme northern part of the Pottsville map area (pl. 5). The best exposures of the formation that are easily accessible are along the canyon of Big Creek south of the Big Creek fault in the Kellogg map area.

In the Pottsville map area, the Revett Quartzite forms an almost continuous, broad band around the Granite Peak syncline. The fault-segmented area of Revett Quartzite exposed in the central part of the Mullan map area lies in the southeastern limb of the large Burke anticline. A discontinuous band of Revett Quartzite crops out along the east side of the Moon Creek anticline in the northeastern part of the Wallace map area and adjacent part of the Mullan map area. Along the southwestern limb of this anticline Revett Quartzite has been found in the vicinity of Kellogg and the extreme northern part of the Smelterville map area. The largest areal exposure of the Revett is in the southern limb of the Big Creek anticline mostly within the Kellogg map area. Other segments of this formation are exposed in fault blocks in the overturned northern limb of the Big Creek anticline in the Wallace map area.

THICKNESS

The reported thickness of the Revett Quartzite varies significantly from place to place. A section of Revett Quartzite that lies along the east margin of the Pottsville map area and extends from the ridge west of lower Glidden Lake westward into Military Gulch measured 2,300 feet thick. This section, however, is broken by a long dip slope on which there are no outcrops and also by a fault along which the movement has duplicated part of the section; therefore, this measurement is considered to be too large. For approximately the same section Shenon and McConnel (1939, p. 4) estimated an apparent thickness of 2,100 feet. Calkins (in Ransome and Calkins, 1908, p. 75) reported the thickness of the Revett Quartzite at the same locality and at another area about 6 miles to the northeast near the head of Twentyfour Mile Creek to be 1,000–1,200 feet. The discrepancies between these three measurements lie, in part at least, in the interpretation of the position of the upper and lower contacts. A complete section of the Revett Quartzite is fairly well exposed in the same general vicinity in the cirque at the head of Sawmill Gulch. It was estimated to be about 1,200 feet thick, which is more compatible with the figures given by Calkins. With due consideration for probable discrepancies in locating the upper and lower contacts, the Revett Quartzite exposed in the Pottsville map area probably averages about 1,500 feet in thickness.

A section of the Revett Quartzite exposed on the west-trending spur of Silver Hill in the southern part of the Kellogg map area was measured by Shenon and McConnel (1939, p. 4) to be more than 3,400 feet in thickness. Comparable thicknesses elsewhere in the western part of the district were computed from maps and sections. The section of the Revett well exposed in the cliff just east of the junction of Colusa Creek and the West Fork of Pine Creek in the Twin Crags quadrangle was measured by Campbell (1960) to be about 1,800 feet thick.

LITHOLOGIC CHARACTERISTICS

The Revett Quartzite consists predominantly of light-colored thick-bedded fine- to medium-grained pure quartzite. Lithologically, it is the most uniform formation within the Coeur d'Alene district, and the succession of vitreous pure quartzites makes it the most easily recognized unit of the Belt Series. It forms numerous bold cliffs or, even more characteristically, great felsenmeers of large jumbled blocks that cover rounded ridge crests or mountain tops (fig. 12).

The basal transition zone, even though predominantly thick-bedded pure quartzite, contains numerous beds of nearly pure quartzite, scattered beds of impure quartzite, and a few thin partings of argillitic rock. At the Glidden Lakes-Military Gulch section, the thickness of this zone was estimated to be between 200 and 300 feet, as some of the lower part of the section was covered. At other places within the district, this zone was found to have much variation in thickness. Such variation is expected in a unit like the Revett that grades out into less pure quartzite in all directions from the Coeur d'Alene district.

Above the lower transition zone and to within a few hundred feet of the base of the St. Regis Formation, most of the Revett is made up of vitreous pure quartzite beds from 1 to at least 6 feet thick. Some of these strata are almost snow white, but more commonly the colors range from light gray to pale yellowish gray and greenish yellow, or rarely pale red. Their texture is uniformly fine and compact, the coarsest consisting predominantly of medium-sized sand; some layers even have a flinty appearance. Interspersed at intervals are strata of nearly pure quartzite and more rarely greenish-gray impure quartzite, or carbonate-bearing quartzite. These less pure quartzite beds are concentrated in zones which are measurable in tens of feet and are discontinuous, as they are found at different horizons in the section from place to place.

The carbonate-bearing quartzites are usually thin bedded. They resemble the purer quartzite where unweathered, but are easily distinguished in the weathered outcrop by a rusty rind. The composition of a carbonate-bearing quartzite is shown in table 2, specimen 25. The carbonate mineral is probably a ferroan dolomite rather than a ferroan calcite as in specimen 25.

Fine dark laminae, a millimeter or less in thickness and containing a concentration of dark-colored minerals, are common in some beds of pure and nearly pure quartzite. These laminae usually spaced an inch or less apart. Fainter laminations are also visible in some other beds. Cross-stratification is the most noteworthy sedimentary structure within the Revett Quartzite and is common in the purer quartzitic beds. Ripple marks and mud cracks are found in the more impure beds within the transition zones at the top and base. The ripple marks are very well defined locally and are marked by an abundance of sericite on the surface of the ripple trough. Near the base of the Revett, scallops—a sedimentary feature on the surfaces of beds which are probably swash marks—are common in the Glidden Lakes-Military Gulch section.

A conspicuous feature of many of the pure quartzite beds is the speckling of weathered surfaces by segregations of iron oxide. The speckles result from the oxidation or iron-bearing carbonate minerals that are disseminated in different degrees of density from bed to bed, but these speckles usually account for only 1 percent or less of the rock. Their restriction to certain strata and districtwide distribution show the carbonate mineral to be an original constituent of the sediments.

The upper transitional zone into the St. Regis Formation is almost a replica of the basal transitional zone in reverse. The major difference is a greater abundance of impure quartzite and some argillite, and a change to purplish red and pale red, which is usually characteristic of the St. Regis Formation. In the section at Military Gulch the upper transitional zone is about 300 feet thick, and P. J. Shenon (written commun., 1948) measured it to be about 400 feet thick at Maple Cliff about 8 miles due north of Kellogg.

ST. REGIS FORMATION

DISTRIBUTION

The St. Regis Formation underlies much of the upper reaches of the St. Regis River valley, which lies adjacent to the large outcrop areas of the formation in the southeast corner of the Pottsville map area, and for this reason was so named by Calkins (in Ransome and Calkins, 1908, p. 37). The roadcuts along U.S. Highway 10 for several miles west of Mullan are in the upper, more argillitic part of this formation. The lower, more quartzitic part can be seen only at some less accessible place such as the section at Military Gulch in the northern part of the Pottsville map area. Partial sections of this formation are excellently exposed in the adits of the Silver Dollar and Silver Summit mines in the Wallace map area (pl. 3) and farther east in the adit of the Atlas mine in the southern part of the Pottsville map area (pl. 5). The uppermost part of the formation, which has a distinctive lithology and is characteristically green, has been mapped separately where possible.

Although the St. Regis Formation makes up somewhat less than a tenth of the section of the Belt Series in the Coeur d'Alene district, it forms the bedrock under about a fifth of the area mapped. Much of this disproportionate amount of outcrop is due primarily to the large exposure of St. Regis rocks in the core of the Lookout anticline south of the Osburn fault in the Pottsville and Mullan map areas. Many faulted segments of the formation crop out west and south of the Osburn fault in the limbs of the Big Creek anticline in the Wallace, Kellogg, and Smelterville map areas.

North of the Osburn fault, a nearly continuous outcrop band of the St. Regis Formation parallels the outcrop of the Revett Quartzite around the Granite Peak syncline in the Pottsville and Mullan map areas. The pattern of outcrop in the western limb has been complicated by subsidiary folds and faulting in the vicinity of the Osburn fault. The formation also crops out in a broad northwest-trending zone in the east limb of the Moon Creek anticline in the northern part of the Mullan and Wallace map areas.

THICKNESS

The thickness of the St. Regis Formation differs from place to place. The section at Military Gulch is estimated to be 1,400 feet thick. About 5 miles due south of this location near the head of the East Fork of Willow Creek a partial section, which was measured from the contact with the Wallace Formation down, is more than 1,500 feet thick. Here, an unknown amount of the more quartzitic lower part is not exposed, but well-controlled sections require a thickness of at least 2,000 feet for the St. Regis Formation to accommodate the evidence gained from underground workings and surface outcrops (pl. 5, sections *C–C′* and *D–D′*). The St. Regis Formation thickens abruptly to the southeast beyond the Pottsville map area and, at a distance of about 8 miles in this direction, is more than 5,000 feet thick (Wallace and Hosterman, 1956, p. 582). At Twin Crags, about 5 miles southwest from the southwest corner of the mapped area, Campbell (1960) measured an incomplete section that is 1,600 feet thick. At Maple Cliff, which is about 8 miles north of Kellogg and beyond the mapped area, a section of the St. Regis Formation is well exposed for which Calkins (in Ransome and Calkins, 1908, p. 37) reported a thickness of 1,000 feet and Shenon (1938, p. 5), a thickness of 920 feet.

At Military Gulch, Calkins recorded a thickness of about 1,000 feet and Shenon, 1,400 feet; measurements made during this investigation also totaled 1,400 feet. This discrepancy is due primarily to different interpretations on the position of the upper contact. A green quartzose argillite zone, which is 250 feet thick at Military Gulch, was considered to be the lowermost part of the Wallace Formation by Calkins, but the present authors have included this zone in the St. Regis Formation because of a closer similarity in lithology. This same zone is 450 feet thick near the head of the East Fork of Willow Creek.

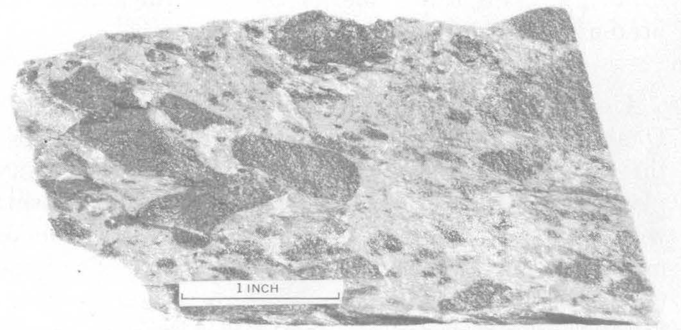
LITHOLOGIC CHARACTERISTICS

The St. Regis Formation and the underlying Revett Quartzite grade one into the other through a transition zone several hundred feet or more thick. In many places the contact is arbitrarily located. Part of this zone placed within the St. Regis Formation includes much vitreous pure quartzite; the greater part of the transition rocks is less pure quartzite and some interbedded and interlaminated argillite. Above the transition zone, purer quartzite beds become progressively less common, and the upper one-half to two-thirds of the formation consists predominantly of thin-bedded impure quartzite and argillite. A diagnostic characteristic of many rocks in the St. Regis is a red-purple to grayish-red color. Even in some of the purer quartzite beds in the basal part of the formation, reddish tints are evident and are most prevalent as darker shades in the central part of the section. In the upper part of the formation, green rocks dominate and the grayish-red color almost entirely disappears.

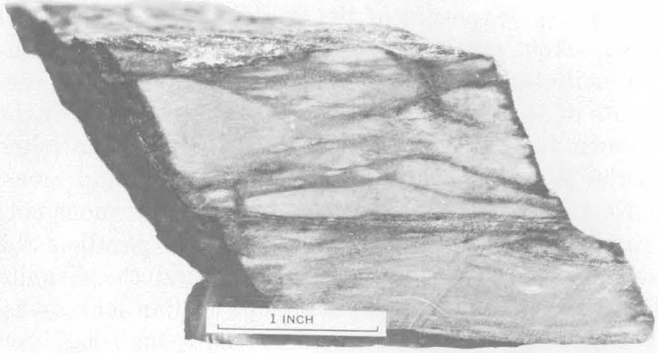
A lateral change in lithology is noticeable from a more quartzitic facies at the west edge of the district to a more argillitic one to the east, within the St. Regis Formation. An analysis of the 1,200 feet of the formation lying immediately below the top green zone in the section measured near the head of the East Fork of Willow Creek at the east edge of the district shows the following composition: about 60 percent argillite containing less than 25 percent interbedded quartzite, 35 percent interbedded argillite and quartzite containing between 25 and 75 percent quartzite, and 5 percent quartzite containing less than 25 percent argillite layers. Most of the quartzite is impure. Toward the western edge of the district, the formation contains more pure varieties of quartzite, and the quartzitic rocks make up a greater volume of the formation.

Alternation of thin beds or laminae of argillite and impure quartzite is common in much of the formation. Gradational bedding, ripple marks, and mud cracks can be seen in these rocks. Mud-chip breccia is a less common feature. Carbonate-bearing rocks, mostly restricted to the quartzitic beds, become more prevalent toward the top of the formation but make up only a small percentage of the formation.

In the valley of Boulder Creek and in the ridge between Boulder and Willow Creeks in the southern part of the Mullan and Pottsville map areas (pls. 4 and 5), several lenticular zones of breccia (fig. 13,



A. Breccia exposed at Boulder Creek. Shape of some fragments is highlighted by chloritization.



B. Breccia exposed in Atlas mine. Rock is partly chloritized.

FIGURE 13.—BRECCIA FROM THE ST. REGIS FORMATION IN MULLAN AND POTTSVILLE MAP AREAS

A and *B*) occur within the St. Regis Formation. Some of this brecciated rock is also exposed in the crosscut of the Atlas mine (in the same area). The breccia is mostly composed of subangular to rounded fragments of argillite and quartzite in a matrix that resembles the composition and texture of the sedimentary layers adjacent to the breccia zones. Most of the breccia fragments are less than an inch in maximum dimension, but some are several inches long. Chlorite and, to a much less extent, associated barite have replaced many of the fragments as well as some of the matrix.

Calkins (in Ransome and Calkins, 1908, p. 38) suggested three possible modes of origin for these breccias: "first, that they are friction breccias; second, that they are true conglomerates; and third, that they are intraformational conglomerates." He concluded that the last explanation was the true one.

Reexamination of the exposures of breccia revealed conflicting evidence. At a few places, well-rounded quartzite pebbles, conceivably a product of water wear, can be found. At these same localities distinct quartzite layers locally border the breccia zones, and the zones in general parallel bedding trends. Such features suggest a sedimentary origin. By far the greater number of exposures, however, consist of angular or subangular breccia fragments in massive, completely unbedded lenses. The breccia fragments are commonly diamond shaped or triangular in section (fig. 13*B*), suggestive of origin as a fault breccia, as contrasted to rectangular shapes more typical of intraformational breccias. Indeed, in some places the breccia is distinctly a fault breccia, and fragments are separated by small shear zones. Some of the fragments have scarcely separated from one another. The conclusion that the breccia lenses are largely a product of shearing seems warranted. Even the rounded pebblelike fragments can scarcely be considered as evidence counter to a fault origin, for in many similar zones rounded breccia fragments commonly have been produced by milling action in fault zones. If the zones do represent intraformational conglomerates, the evidence is conclusive that they were greatly modified by later shearing deformation.

UPPER PART OF THE ST. REGIS FORMATION

A zone of thinly bedded to finely laminated light-greenish-yellow to greenish-gray argillite occurs at the boundary between the St. Regis and Wallace Formations. As noted, Calkins included these rocks within the overlying Wallace Formation, but the present authors have included them in the St. Regis Formation because of a closer lithological similarity to the underlying rocks and because some rocks intercalated within the zone are locally purplish red. Shenon and McConnel (1939, p. 4) also placed this zone within the St. Regis Formation, but they believed that much of the green color resulted from hydrothermal alteration of the rocks, rather than being an original characteristic.

This argillite zone persists throughout the district but is thickest south of the Osburn fault in the eastern part of the district (fig. 14). In the section measured near the head of the East Fork of Willow Creek this zone is more than 400 feet thick; at Military Gulch it is 250 feet thick; and at Maple Cliff it is somewhat more than 150 feet thick (P. J. Shenon, written commun.), which is the more common thickness in the western part of the district.

The most characteristic rock within the zone is a very fine grained thinly laminated quartzose argillite, which is in part porcellaneous in appearance and has a distinctive light greenish-yellow color. In detail, some slightly darker greenish-gray laminae alternate with this characteristic rock, and some rust-stained carbonate-bearing strata are intercalated with these laminae. Interbedded with the argillite are some impure quartzite beds and occasionally a purer quartzite bed. Lenses of purplish-red rocks are found in places but are more common toward the base. The bedding is characteristically very thin, even though no bedding is evident in parts of the zone. Such rocks have a massive appearance.

This unit is well exposed south of the Osburn fault in the southern part of the Pottsville map area, where it has been separately mapped. Farther west in the Mullan and Wallace map areas, it has been mapped only in a discontinuous manner because intense hydrothermal alteration, faulting, and shearing, together with thick cover of soils, mask this unit in part. This upper zone has been recognized at many other places; however, because the zone is masked by alteration or overburden or is poorly defined, it was not separately mapped except at certain favored localities such as Military Gulch and in the vicinity of the National and Copper King mines. Lenses of rock of similar lithology and color have been found at several places below the main zone but still within the upper half of the St. Regis Formation. Several of the more conspicuous lenses that crop out in the cirque at the head of Sonora Gulch in the Pottsville map area (pl. 5) were mapped separately. A good exposure of this upper part of the formation, partly modified by hydrothermal alteration, may be seen along U.S. Highway 10 almost half a mile west of the Golconda mill in the Mullan map area (pl. 4).

WALLACE FORMATION

DISTRIBUTION

Rocks of the Wallace Formation are exposed in all of the map areas except the Smelterville. The greatest single area of outcrop is nearly centered upon the city of Wallace, from which the name of the formation was taken (Ransome and Calkins, 1908, p. 24) and where the alternating beds of quartzite and argillite so typical of much of the lower part of the formation can be seen in many roadcuts (fig. 15). Within the district the best exposures of the upper part of the formation are a mile or more from the nearest road in the southwestern part of the Wallace map area (pl. 3) in the upper reaches of the West Fork of Placer Creek.

From the extensive exposures in the vicinity of Wallace, two prongs of the formation extend eastward to the Montana line—one forms a narrow strip just south of the Osburn fault in the north flank of the Lookout anticline, and the other underlies much of the main ridge south of the South Fork of the Coeur d'Alene River in the south flank of the Lookout anti-

FIGURE 14.—Green argillite in the St. Regis Formation, Lookout Pass.

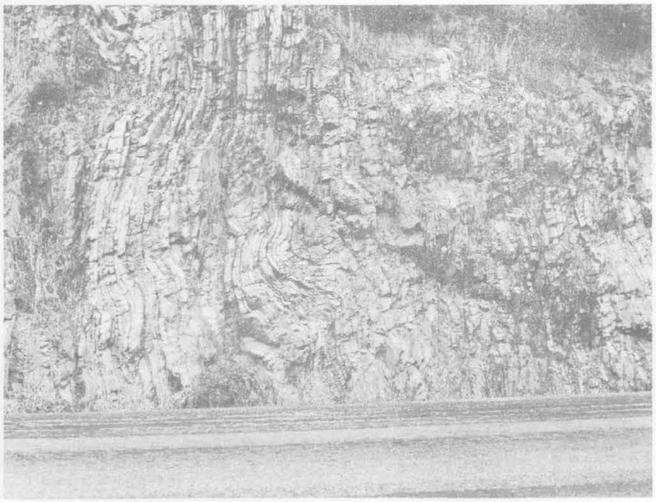


FIGURE 15.—Contorted interbedded quartzite and argillite in the lower part of the Wallace Formation in roadcut along Canyon Creek near Wallace.

cline. West of Wallace, faulted linear segments of the Wallace Formation south of the Osburn fault extend westward as far as Milo Creek in the vicinity of Kellogg; most of these are in the overturned north flank of the Big Creek anticline. The area south of the Placer Creek fault is underlain almost continuously by rocks of the Wallace Formation from the southeast corner of the Wallace map area westward to the south-central part of the Kellogg map area.

North of the Osburn fault in the Pottsville map area the Wallace Formation occupies the trough of the southward projection of the Granite Peak synclinal structure. The outcrop pattern here has been complicated by subsidiary folds and by faulting. West of the Dobson Pass fault in the northwest corner of the Mullan map area and the adjacent part of the Wallace map area, the south end of a north-trending broad band of the Wallace Formation forms the east border of the great Moon Creek anticline.

The upper part of the Wallace Formation crops out within only a relatively small part of the district and is restricted to three separate areas. The largest area lies south of the Placer Creek fault in adjacent parts of the Wallace and Kellogg map areas. Another area borders the valley of Beaver Creek in the northwest corner of the Mullan map area and a small part of the adjacent Wallace map area. The last is a triangular area, almost entirely within the Wallace map area, bounded by the Osburn fault and the valleys of Ninemile Creek and the South Fork of the Coeur d'Alene River; here, the upper part of the formation was not mapped separately from the lower part.

THICKNESS

The Wallace Formation is not well exposed in an uninterrupted section at any place within or near the Coeur d'Alene district. Measurements of parts of the formation were made at several places, and from these disconnected sections the total thickness is estimated to be between 4,500 and 6,500 feet. An unknown but probably small amount of the central part of the formation has not been included in this estimate. This possible gap and a known variation in the thickness of the upper part result in a range in thickness.

The most complete and fairly well exposed section of the lower part of the formation is a continuation of the section of the upper part of the St. Regis Formation near the head of the East Fork of Willow Creek; this section is exposed between Lower Stevens Lake and the crest of Stevens Peak. Shenon and McConnel (1939, p. 5) reported a thickness of about 2,900 feet for this section. During the present investigation the lower 1,500 feet was remeasured, and the remainder of this section was reviewed. The similarity between the two measurements was very close. A fairly good check was obtained from an apparently complete and undisturbed but poorly exposed section of the lower part of the formation that occurs in the northeast corner of the Wallace map area; from attitudes and outcrop pattern this section is estimated to be somewhat more than 3,000 feet thick.

For the upper part of the Wallace Formation, Shenon (1938, p. 6) listed measurements for sections at two different localities. One section is well exposed on the northeastern slope of Striped Peak at the south edge of the Wallace map area and is 1,500 feet thick; the other section exposed along Foolhen Ridge about 7 miles to the southeast and outside of the map area is 2,750 feet thick. At Foolhen Ridge, the upper and lower argillitic zones are at least twice as thick as similar ones at Striped Peak. On both sides of Beaver Creek in the northwest corner of the Mullan map area, the upper part of the Wallace Formation is estimated to be more than 3,000 feet thick. Here, however, the section is poorly exposed and partly covered by alluvium; consequently, the estimate cannot be considered accurate.

The estimates for the total thickness of the Wallace Formation in the Coeur d'Alene district check rather closely with estimates given for the formation in neighboring areas. For the adjacent St. Joe River area to the south, Wagner (1949, p. 12) reported a thickness of not more than 4,500 feet; but this figure is the result of reducing the measured thickness about 30 percent to compensate for minor crumples. Near the head of Savenac Creek in Mineral County, Mont., which is 15 miles east of the district, a nearly complete section is reported to be about 6,500 feet thick (Wallace and Hosterman, 1956, p. 584). To the north in the southwest corner of the Trout Creek quadrangle, the Wallace Formation was found to be about 7,000 feet thick (Gibson and others, 1941, p. 372). This section is 12 miles north of the one lying on both sides of Beaver Creek at the north edge of the Wallace and Mullan map areas, and their similarity in total thickness, 7,000 feet and 6,000+ feet, respectively, gives credence to the estimate for the poorly exposed Beaver Creek section.

LITHOLOGIC CHARACTERISTICS

The preponderance of carbonate-bearing rocks sets off the Wallace Formation as a unit distinct from the rest of the Belt Series above and below. The lower one-half to two-thirds of the formation is made up of alternating carbonate-bearing beds of argillite and quartzite. Interbedded with these rocks are several zones of impure dolomite and dolomitic quartzite. The remaining upper part of the formation consists of thinly laminated argillite separated by a thick central zone of dominantly dolomitic rock. This subdivision into a lower and upper part was followed almost everywhere in mapping; the only exception is within a small area just north of the city of Wallace, where, because of a lack of definitive exposures and because of structural complexities, rocks of both the upper and lower parts of the formation are shown as a single undivided unit. The upper part of the formation south of Placer Creek fault in the vicinity of Striped Peak is shown as three separate units on the Wallace and Kellogg map areas. This is with in the area mapped by Shenon and McConnel. Here, they were able to map separately the central dolomitic zone and the argillitic rock above and below.

LOWER PART OF THE WALLACE FORMATION

One of the most characteristic lithologic features of the lower part of the Wallace Formation is an alternation of thin beds of light-gray quartzitic rock and darker gray argillite. The base of the formation is placed arbitrarily at a horizon where this characteristic becomes distinctive in comparison with the underlying thinly laminated green argillite of the St. Regis Formation. A transition zone in which argillitic rocks predominate over quartzitic rocks continues into the basal part of the Wallace Formation for 100 feet or more, and the green color of the argillitic rock gives way to medium and dark shades of gray. The percentage of carbonate-bearing beds and the amount of carbonate minerals within these beds are appreciably greater than those in the rocks of the St. Regis Formation below.

The well-exposed section of the lower part of the formation between Lower Stevens Lake and the crest of Stevens Peak is fairly representative of this part of the formation, and its description is generally applicable to all other rocks of a similar interval exposed in the mapped area. The lower part of this section consists of a monotonous succession of alternating dark and light layers, characteristically thin bedded. Most layers are from 1 to 6 inches thick, some are between 6 and 12 inches thick, and a minor percentage scattered through the sequence is +12 inches thick. In the upper part of this section, the alternation of argillite and quartzite continues but is interrupted by several zones tens of feet thick in which one lithologic variety predominates. These include zones of quartzite, argillite, and impure dolomite; most are dolomite quartzite zones that stand out because of their rusty weathered surfaces.

In the alternating sequence, the arenaceous layers are usually fine grained impure to nearly pure quartzite containing varying amounts of carbonate minerals and sericite. The unweathered rock is light to medium gray, is dense, and seldom shows lamination or other internal structures. Where weathered, these layers are faded to a lighter gray or are coated by a rusty selvage. The weathered surface of some of these rocks is slightly roughened or pitted and may show delicate lamination and cross-stratification—features that are only formed by the etching action of weathering agencies upon the carbonate minerals in the rock. The fact that many of the quartzite beds have faded weathered surfaces that effervesce briskly when cold dilute hydrochloric acid is applied to them indicates the presence of calcite; in other beds the carbonate mineral is mostly a ferroan dolomite. Some of the quartzite beds are gradational upward into the argillite layer. The gradation is most apparent from the color change, but a change to a finer grain size is also noticeable. The medium- to dark-gray argillite part at the top of any bed is usually much thinner than the companion quartzite layer. The contact between an argillite bed and the quartzite bed above is characteristically sharp. Many of the argillitic layers are also carbonate bearing.

In the remaining upper half of the Lower Stevens Lake-Stevens Peak section, the characteristic alternating dark and light layers are still abundant; but zones where one lithologic type dominates are also common. Ferroan dolomite is the most abundant component of the strata, and the zones in which the beds are distinctly carbonate rich stand out because of the rusty red or brown stain or rind on weathered surfaces. These carbonate-rich zones are concentrated in the interval that lies 1,800–2,500 feet above the base of the section (Shenon, 1938, p. 6). For the most part, they consist of thin-to thick-bedded dolomitic quartzite but also contain a few beds that are sufficiently pure to be called dolomite. A fresh fracture of this dolomite is greenish gray and very fine grain and has a dull luster.

The lower part of the Wallace Formation is characterized by unusually well-defined sedimentary features. Most were formed contemporaneously with deposition and include mud cracks, graded bedding, cross-stratification, ripple marks, swash marks, and flow casts. Mud cracks are by far the most abundant sedimentary feature and are exceedingly common wherever the interbedded quartzite and argillite are well defined and relatively thin. At numerous outcrops of such rock, almost every argillite bed, for thicknesses of many feet, contains the crenulated quartzite-filled cracks. The graded bedding, as already described, is a common feature in the same lithologic environment. Cross-stratification is usually apparent only on the weathered surfaces of carbonate-bearing quartzite strata on which the cross-laminae are outlined by etching. This structure was seen only rarely. Ripple marks are well formed on the bedding surfaces of many quartzitic beds.

Minor structures are probably a result of preconsolidation compaction adjustment and associated processes of stabilization. These include interbed crumpling, minute slump structures, and miniature clastic dikes that are common in the upper part of the formation in the thinly laminated argillite containing numerous arenaceous interlaminae. Boudinage, molar-tooth, and ovoid structures (p. 122), which may be related to compaction adjustment, but also to much later deformation, are almost unique to the Wallace Formation and particularly the lower part of it. Minor folds, which are definitely due to postconsolidation deformation, are also common within the lower part of the Wallace Formation.

UPPER PART OF THE WALLACE FORMATION

South of the Placer Creek fault in the southern part of the Wallace and Kellogg map areas, Shenon and McConnel (1939, p. 4 and 5) separated the upper part of the Wallace Formation into three units. These are, from oldest to youngest: a zone of almost all thinly laminated argillite containing little or no carbonate rocks; a central zone of thick-bedded carbonate-rich rocks, most of which are arenaceous; and another zone of thinly laminated argillite very similar to the basal ones. In the section at Striped Peak, Shenon and McConnel measured the basal unit to be about 500 feet thick; the middle unit, 500 feet thick; and the upper unit, 500 feet thick. At Foolhen Ridge, about 7 miles to the southeast, the same units were, 1,000, 250, and 1,500 feet thick, respectively (Shenon, 1938, p. 6). In an adjacent area to the south, Wagner (1949, p. 13) also mapped separately three similar units.

The lower unit near Striped Peak and to the west in the Big Creek drainage consists almost entirely of dark-gray thinly laminated argillite in which are intercalated some lighter gray somewhat arenaceous laminae. The lower unit contains a few quartzitic beds, but at places laminations are not noticeable in the argillite. Except near the base, where it grades into the lower part of the formation, the lower unit is almost free of carbonate-bearing rocks.

The middle unit is made up of medium- to dark-gray usually thin-bedded carbonate-bearing rocks. They range in composition from dolomitic quartzite and argillite to impure dolomite and have a characteristic rusty-red banded appearance on weathered surfaces. An analysis of an arenaceous dolomite from Foolhen Ridge is given in table 2, specimen 106.

The upper unit is so similar to the lower unit that it can only be distinguished because of the intervening carbonate-rich zone.

The middle unit of carbonate-rich rocks was not recognized in the upper part of the Wallace Formation that underlies the ridge slopes on both sides of Beaver Creek in the northwest part of the Mullan area. It probably is present, however, for in the next ridge north of the mapped area a carbonate-rich zone, several hundred feet thick, is well exposed towards the top of the formation. This part of the section may be obscured by overburden along Beaver Creek in the Mullan and Wallace map areas.

At the Beaver Creek locality the most typical rock is a finely laminated argillite, mostly made up of alternating argillitic and arenaceous laminae, about a millimeter in thickness. The colors of the laminae range from dark gray for the argillite to light gray for some of the more quartzitic laminae. Some thin-bedded argillite and an occasional quartzitic layer are intercalated. The quartzitic beds are usually carbonate bearing, as are some of the argillitic rocks. The amount of carbonate-bearing rocks, though, is distinctly less than in the lower part of the Wallace formation.

The finely laminated argillite in the upper part of the Wallace Formation might easily be mistaken for rocks in the Prichard Formation. Most Wallace rocks, however, have minor scale crumples, weather rusty brown if they are carbonate bearing, and are irregularly bedded. In contrast, Prichard rocks have few crumples, weather rusty red, and are regularly bedded.

STRIPED PEAK FORMATION

DISTRIBUTION

The uppermost formation of the Belt Series, the Striped Peak, occurs as erosional and faulted remnants within the map area. It was named (Ransome and Calkins, 1908, p. 44) after Striped Peak, a prominent high ridge on the south edge of the Wallace map area (pl. 3). The peak presumably owes its name to the contrasting colors of the strata exposed in the steep, bare, northeast-facing slope; but the striped effect of the rocks of this formation is not particularly conspicuous. Perhaps a more logical origin of the name comes from the vivid outlining of the nearly horizontal rock ledges by the first snowfalls of winter and the last remnants of snow in the spring, which can be seen so well from the valley of Canyon Creek, a short distance north of Wallace.

The largest exposure of the Striped Peak Formation occupies an area of several square miles and is a westward continuation of the exposure at Striped Peak; it is bounded on the south by the Striped Peak fault. More extensive exposures lie just beyond the map area to the south, but within the drainage basin of the St. Joe River (Wagner, 1949, pl. 1). Small elongate remnants crop out along the south side of the Placer Creek fault about a mile north-northwest of Striped Peak; and a similar poorly exposed remnant lies immediately south of the Osburn fault about 2 miles north of Wallace. In the northwestern corner of the Mullan map area, an elongate block of the formation is bounded on both sides by faults.

THICKNESS

The Striped Peak Formation is preserved only in small remnants within the Coeur d'Alene district or within the neighboring country. The amount of the formation that has been eroded is unknown. An incomplete section measured by Shenon and McConnel (1939, p. 5) along Dam Creek, about 1 mile southeast of Striped Peak, comprises 1,500 feet of strata. The thickest remnant reported (Wagner, 1949, p. 9) in this general vicinity is an estimated 2,000 feet thick and is exposed about 8 miles southeast of Striped Peak along the middle part of Big Creek (a tributary of the St. Joe River as distinct from the Big Creek tributary of the South Fork of the Coeur d'Alene River).

LITHOLOGIC CHARACTERISTICS

Rocks of the Striped Peak Formation are purplish-red, pale-red, and greenish-gray, impure to nearly pure quartzite and lesser argillite. The transition zone from the thinly laminated dark argillitic rocks of the Wallace to the lighter colored rocks of the Striped Peak is relatively thin, and the contact is placed at the beginning of the purer quartzite beds.

For the section at Dam Creek, Shenon and McConnel (1939, p. 15) reported that the lower 1,200 feet is principally composed of alternating beds of pale- to purplish-red and greenish-gray quartzite containing some carbonate-bearing rocks and that the upper 300 feet of strata is mostly laminated purplish-red argillite which includes a bed of impure limestone 13 feet thick.

In the lower 500 feet or more of the formation, the quartzitic rocks are generally lighter colored and are typically pale red or light greenish gray. These colors give way upward to purplish red, maroon, and greenish gray. These darker colors characterize the more argillaceous rocks higher in the section. Partings and thin interbeds of argillite are found throughout the quartzitic part of the section and some quartzitic rocks are interbedded with the argillite of the upper part. The telltale rusty and pitted surface of some beds show that they are carbonate bearing. The rocks are mostly quartzitic. Some beds are sufficiently rich in carbonate to be called arenaceous dolomite, such as specimen 103 given in table 2.

The quartzitic rock is generally flaggy; this is well shown by the slabby talus piles on the upper slopes of Striped Peak. Most beds are from 1 to 4 inches thick; some are as much as 12 inches thick, and an occasional one is 3 or 4 feet thick. The argillite is also characteristically very thin bedded. Some of it is thinly laminated, having interspersions of lighter colored more arenaceous laminae. Ripple marks on the bedding-plane surfaces of many of the arenaceous rocks are as well defined as in most of the older Belt formations. Many of the argillitic beds contain mud cracks which on some surfaces are superimposed upon ripple marks. Cross-stratification is apparent in some quartzite beds, and mud-chip breccia at places occurs in the laminated argillitic rock.

A close similarity between the Striped Peak and the St. Regis is apparent, and individual outcrops of one formation could easily be mistaken for the outcrops of the other. Where the stratigraphic position is not clear, one must rely on the more flaggy nature of the bedding and contrasting color of the rocks for distinguishing the Striped Peak Formation. The overall greater percentage of quartzitic rocks and their usual lighter color also serve to distinguish the Striped Peak.

IGNEOUS ROCKS

Small intrusive bodies and diverse igneous dikes of Cretaceous age and younger intrude the rocks of the Belt Series. They have been divided into four general groups that include: (a) several small monzonitic stocks, (b) diabase dikes, (c) lamprophyre dikes, and (d) a miscellaneous assortment of small intrusive bodies that have been grouped together as other dikes. The last group includes several monzonitic and dioritic, and aplite dikes, which are undoubtedly closely related to the monzonitic stocks, some andesite and latite dikes, and other igneous bodies most of which are so badly altered that their identity is not certain. Although these igneous rocks underlie only a very small part of the area, they are of unusual interest because of the temporal relations of some of them to the ore deposits and their usefulness in establishing the geologic history of the region. Plate 7 shows the distribution of the known igneous rock bodies in the Coeur d'Alene district and the surrounding region. Many more dikes and small irregular bodies undoubtedly cut the Belt strata in the area but are concealed by deep soil and thick vegetation. The greater density of mapped dikes in the mining areas is at least in part a reflection of underground observations but not entirely. The same structural and environmental factors that controlled the localization of the veins may also have localized the areas of emplacement of some of these dikes, particularly the lamprophyre dikes. A large diabase sill exposed just south and east of the mapped area may be Precambrian in age.

The monzonitic rocks have been determined, by the lead-alpha method, to have an age of approximately 100 million years and thus are considered to be Cretaceous in age. The sequence of igneous events is fairly well established. Both the diabase and lamprophyre dikes cut the monzonite stocks; lamprophyre dikes cut major veins and the diabase dikes most likely do the same although the evidence is not as conclusive as for the lamprophyre. The relative ages of the diabase and lamprophyre dikes is unknown, for nowhere are they found in crosscutting relations. Diabase that intruded the Osburn fault has been severely sheared by movement along the fault. To the west the trace of the fault is covered by undisturbed Columbia River Basalt in the vicinity of the city of Coeur d'Alene. These relations indicate that the diabase was intruded prior to the outpouring of these basalt flows, which are considered to be middle Miocene in age. Thus the diabase dikes may be early to middle Tertiary in age. The lamprophyre dikes were probably emplaced during the same interval. In general, the trends of the diabase dikes are similar to that of the main veins whereas the trend of the lamprophyre dikes is at an angle to the main veins and diabase dikes; this may indicate that the lamprophyre dikes are somewhat younger than the diabase dikes, as they are known to be younger than the veins. The mineralogic similarity of the latite and andesite dikes to the monzonitic stocks indicates a common source and probably a common age.

MONZONITIC ROCKS

DISTRIBUTION AND RELATIONS

The monzonitic rocks occur in two clusters, one group of six small bodies in the northeast corner of the Wallace map area and a second group of two larger bodies known as the Gem stocks about 2 miles to the east in the northern half of the Mullan map area. Other members of the Gem stock cluster crop out in a northeasterly direction for 4 miles beyond the map boundary; the group thus extends from Canyon Creek near Gem to beyond Prichard Creek, a distance of more than 9 miles. Monzonitic stocks somewhat similar to those in the Coeur d'Alene district crop out 18 miles to the southwest along the St. Joe River (Wagner, 1949, p. 17) and 12 miles (Gibson and others, 1941, map) and 22 miles (Calkins, 1909, p. 47) to the northeast at the headwaters of Trout Creek and on both sides of the Vermillion River, both tributaries of the Clark Fork. All these igneous bodies appear to be roughly alined, lithologically similar, and from the Gem stocks to the Clark Fork coincide roughly with the axis of the Trout Creek anticline. These apparent coincident features are taken as evidence of their interrelations.

The Gem stocks, though the largest igneous bodies in the district, are relatively small in areal outcrop. The southern body, underlying a part of the ridge between Canyon and Ninemile Creeks and a part of the valley of the East Fork of Ninemile Creek, crops out in an area of only 2.8 square miles. The northern one, underlying a part of the southern and eastern slopes of Sunset Peak and the upper valley of the East Fork of Ninemile Creek, is considerably smaller, and crops out in an area of only 1.0 square mile. Elongate in a northeasterly direction, the Gem stocks range in width from slightly more than a mile near the south end of the southern stock to a few hundred feet at the north end of the northern stock.

All except one of the unnamed monzonitic bodies in the northeast corner of the Wallace map area (pl. 3) lie northeast of the Blackcloud fault. Two of these bodies are in fault contact with this structural feature; the exception is a small crescent-shaped body about 1.5 miles west at the apparent intersection of the Carpenter Gulch and Twomile faults. Another small body, only a few hundred feet across, crops out on the ridge west of Dudley Creek, almost a mile to the north of all the rest and to the north of the Wallace map area. The remaining bodies lie within a triangular area whose base is along the Blackcloud fault and whose apex is about 2 miles to the northeast. The combined outcrop area of all these bodies amounts to somewhat less than a square mile.

Mine workings, which at many places have intersected the contact of Gem stocks with Belt rocks, show that the stocks gradually increase in diameter with depth. Evidence that the monzonitic bodies in the northeast corner of the Wallace map area also increase in diameter with depth was found in the Silverore-Inspiration crosscut (pl. 3, section *B–B′*). This body is at least 2,250 feet wide where intersected by the crosscut 1,500 feet underground and, therefore, is more than twice as wide at this depth as at the surface.

The contacts of the stocks are irregular, both in gross pattern and in detail. The embayments, apophyses, and larger inclusions, the last undoubtedly in part roof pendants, all indicate this fact. In underground mine workings the intricate pattern that exists in the border zone is shown by a maze of dikes and apophyses that extend out from the igneous rock and by numerous xenoliths that occur within the igneous rock near the contact. On a still grosser pattern, it is evident that the Gem stocks are cupolas of the same igneous intrusive. Their outcrop pattern, close lithological similarity, and the findings of an aeromagnetic survey (Dempsey, 1950) are almost incontrovertible evidence of such a fact. Other evidence, that will be examined more fully in the section on structure, suggests that the group of plugs and stocks in the Wallace map area are the upward extensions of the Gem stocks displaced along the Dobson Pass fault.

The intrusive nature of the monzonitic rocks is affirmed by several lines of evidence. Along much of the west side of the Gem stocks the Prichard rocks are intricately folded as if shouldered aside by intruding magma, and at many places the monzonitic rocks crosscut the Belt strata. Other manifestations of magmatic intrusion are the many apophyses exposed in several underground workings and the monzonitic dikes found farther away. The relation shown in the cupola of one of the apophyses exposed in a small cirque near the head of Granite Creek (fig. 16) well illustrates the rock's intrusive nature. Within the cirque are many blocks of the intruded Burke Formation, some 10 feet or more on a side, which were jostled about by the intruding magma into random orientations. The space between the blocks is filled with monzonite and hybrid rock formed through varying degrees of replacement.

The intruding monzonitic magma made room for itself by a combination of methods. Folded Prichard rocks along the northeast side of the stocks indicate that, at least in part, the magma forced the country rock aside. The feldspathization of the sedimentary rocks immediately adjacent to contacts and the partial digestion of inclusions of Belt rock within the igneous rocks show that, in part, the magma intruded by replacement and fusion. Calkins (in Ransome and Calkins, 1908, p. 72) suggested that "overhead stoping" by the magma was the major mode of intrusion. That this stoping was a part of the means by which the stocks were emplaced seems plausible, as even the largest of the xenoliths were moved about as can be seen by their random orientation. These xenoliths do not seem to have been moved far, however, as all appear to be of the same formation as the adjacent country rock. Which factors were the most effective is not known, but it would seem that digestion was the minor one, as indicated by the usually lower silica content of the monzonitic rocks in relation to the Belt rocks.

An aeromagnetic survey made of the Coeur d'Alene district very effectively outlines the monzonitic stocks (pl. 8). The total intensity of the magnetic effect as depicted by contours is shown to have been much greater over these larger igneous masses than anywhere else within the district. The mass effect of the disseminated magnetite within these intrusives smoothed out such irregularities as embayments and apophyses. Moreover, the distance between the flight traverses, one-half mile, and the height of the airplane, about 7,000 feet above sea level, or from 1,000 to 4,000 feet above ground level, both tended to generalize the data and thus the depiction. The extension of the magnetic high southward from the southern Gem stock across the Osburn fault without any break is probably due to the mass effect, rather than to an actual extension of the igneous body across the fault. The fact that the magnetic high, related to the monzonitic rocks in the northeast corner of the Wallace map area, is slightly south of most of the surface exposures of the igneous bodies indicates that the main mass lies there at depth. This is borne out by the large amount of monzonitic rock cut in the Silverore-Inspiration crosscut, which was driven to a point vertically below this high.

The next most significant anomaly, along the south border of the Pottsville map area, could be a reflection of some buried igneous body. Whether the body would be monzonitic or like the diabasic Wishards sill, which lies several miles to the south and has been traced for several miles in an east-west direction, is not known. The anomaly also closely parallels the ridge crest to the east, which might have caused the anomaly. The lesser high with a westerly trend, which lies within the southern part of the Mullan and Pottsville map areas, is over a chloritic zone and may be a reflection of the magnetism within that zone. The several minor north-trending anomalies are along flight traverses and undoubtedly reflect some discrepancies that could not be corrected for in the computation of the data.

The stocks vary in both composition and texture. The major portion of these igneous bodies is monzonite or quartz monzonite, but also included are syenitic and dioritic facies. The syenitic facies is a major component of the southern Gem stock. However, because of a general lack of outcrops within the areas underlain by these igneous rocks and because there seem to be gradations both in composition and texture from one kind of rock into another, the varieties are not separated on the map. The typical rock is medium- to coarse-grained porphyritic monzonite, although in some of the smaller bodies monzonite porphyry, in

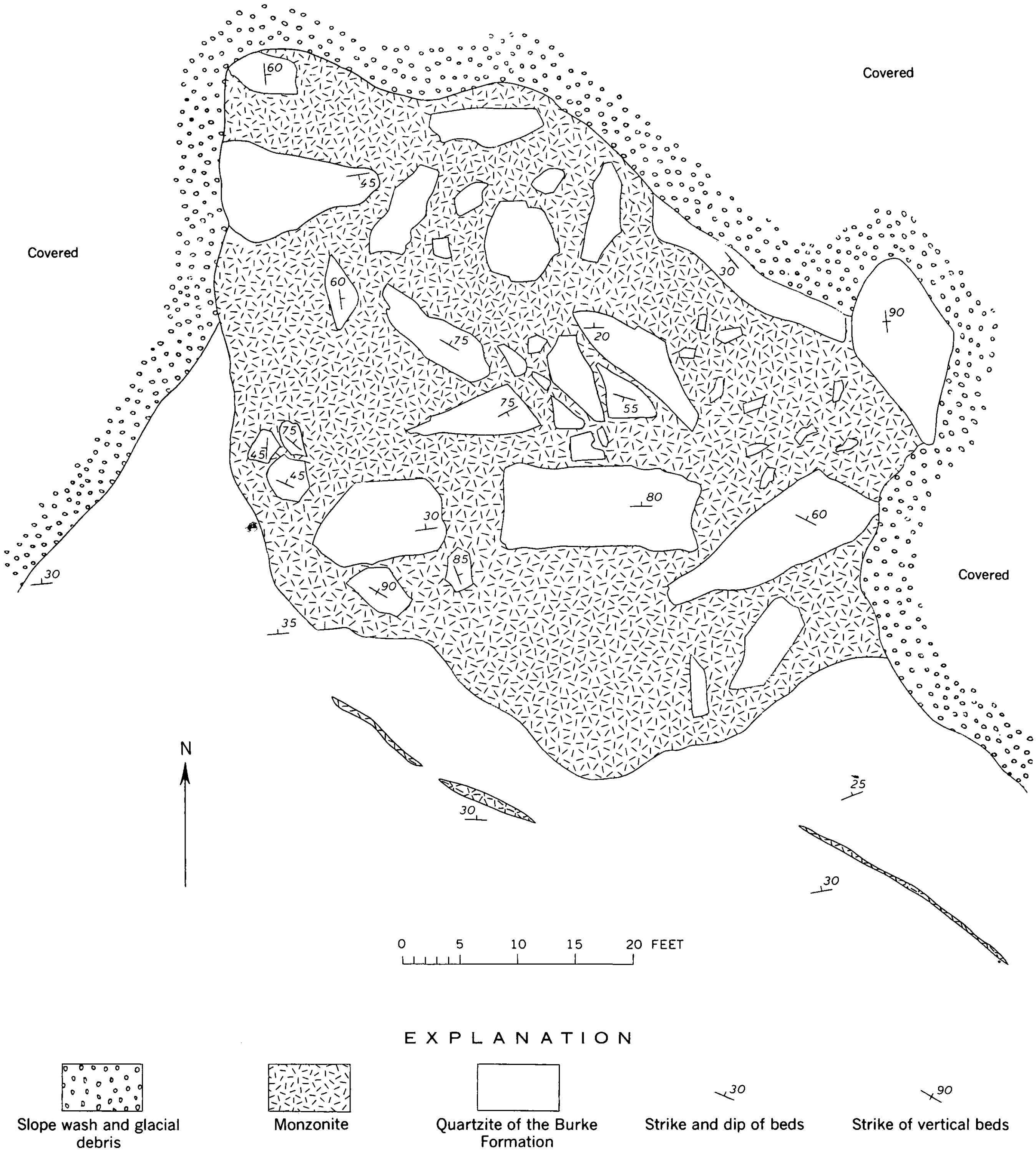


Figure 16.—Brecciated country rock in small monzonite cupola. Jumbled quartzite blocks of the Burke Formation in small monzonite cupola in cirque at head of Granite Creek, Mullan map area.

which the groundmass is considerably finer grained, is fairly characteristic. In addition, the monzonite grades from the various prophyritic varieties into an equigranular, medium-grained rock. A part of the syenite facies is characterized by abundant large feldspar laths.

The usual rock is a light-gray medium- to coarse-grained monzonite or quartz monzonite in which prismatic potassium feldspar phenocrysts, about half an inch in length give it a porphyritic character. The predominant constituents are the feldspars which contain scattered greenish-black hornblende needles and irregular grains of quartz. Other minerals present in minor amounts that can be discerned without the aid of a microscope are quartz, titanite, epidote, pyroxene, and rare flakes of biotite. In the fresh rock, usually found only underground, the light-gray to flesh-colored unstriated potassium feldspar, which bulks large in the groundmass as well as phenocrysts, can be distinguished from the milky white plagioclase. In the weathered surface exposures, however, both the potassium feldspar and the plagioclase usually have the same dull white appearance. In some places, particularly along the northeast margin of the southern stock, the weathered rock has a dull brownish appearance due to numerous minute specks of rust-brown iron oxide along the edges and the cleavage planes of the mineral grains.

The diorite facies, which makes up only a very minor amount of the rock, is restricted to the margins of the stocks, and also constitutes parts of the offshoots and dikes. These generally contain a higher mafic mineral content and are darker. Owing to their higher quartz content, some diorites are classed as granodiorite, which probably results from partial assimilation of the silica-rich wallrock.

Almost a third of the southern stock is syenite, most of which is at the south end, where it underlies almost a square mile from Canyon Creek to Ninemile Creek. Syenite also apparently rims the north side of the same stock, for it has been found as float at several places there, particularly along the northeast side. Croppings and float of similar rock have also been observed at various places at the northern end of the north stock. Porphyritic syenite was observed underground in the Silverore-Inspiration workings, where the crosscut was driven through several hundred feet of it. This syenite underlies the southernmost of the monzonitic stocks in the northeast corner of the Wallace map area. The location of much of the syenite near the peripheries of the stocks is interpreted to represent an earlier pulsation of magma which was later intruded by the main monzonitic facies, but no exposures were found that satisfactorily showed such a relation. The syenite is usually light gray, coarse grained, and porphyritic. Mafic minerals are usually a minor part of this preponderantly potassium feldspar rock. In some places, however, the syenite grades into a variety in which either hornblende, or hornblende and augite, is equal to or more abundant than the feldspar.

An unusual type of porphyritic syenite contains flat tabular potassium feldspar crystals, measuring as much as one-quarter inch in thickness and as much as 2 inches in the other dimensions. In this type of syenite, the feldspar phenocrysts may make up 75 percent or more of the rock. This type is well exposed in the old railroad cut just northeast of the junction of the East Fork of Ninemile Creek with the main stream of Ninemile Creek (pl. 4). Here the feldspar phenocrysts have a markedly preferred orientation. They strike from west to northwest and dip from near vertical to 35° to the north and northeast. A similar, but not so well defined orientation of the feldspar has been noted in many other outcrops of syenite at the south end of the south stock. A preferred orientation of some of the feldspar crystals is evident in the syenite underground at the Silver ore-Inspiration mine; they strike northwest, but they dip southwest.

The inclusions of hornblende- or augite-rich rock in the syenite range from small clots a few inches across to bodies that are several hundred feet in length. They probably are partly assimilated xenoliths of Belt rock. Several thin sections of these rocks are seen to contain granular aggregates of garnet and small remnants of undigested rock, which are predominantly quartz; the quartz occurs both in the groundmass and as scattered remnants in the feldspar crystals. The mafic inclusions are also rich in the accessory minerals, titanite, magnetite, and apatite. In some inclusions, magnetite or titanite make up as much as 5 percent of the rock.

PETROGRAPHY

Although these monzonitic rocks differ in composition and texture, they contain the same suite of minerals. The varied ratio of the different minerals and the change in the size of the grains give rise to the different types. The essential minerals are the potassium feldspars, orthoclase and microcline, plagioclase, in part albite, and smaller amounts of hornblende, augite, and quartz. Accessory minerals include titanite, magnetite, apatite, zircon, and allanite. Epidote, chlorite, sericite, clinozoisite, and actinolite, as well as several of the minerals already mentioned, are probably deuteric or at least partly deuteric in origin. Other minerals found in some specimens are biotite, muscovite, pyrite, and calcite.

Orthoclase and microcline usually make up somewhat less than 50 percent of the monzonite and somewhat more than 50 percent of the syenite. In some varieties microcline predominate, whereas in others orthoclase is more abundant; either may be virtually absent. Both microcline and orthoclase occur in the groundmass and as phenocrysts, although microcline is more common as large crystals, particularly in the syenite. Both minerals range in shape from irregular grains to well-formed crystals. The phenocrysts are typically perthitic and may contain as much as 50 percent exsolved albite in an irregular pattern in veinlets, or parallel to the crystallographic directions of the potassium feldspar. Inclusions of earlier formed augite, hornblende, and feldspar, which commonly occur as oriented remnants in the phenocrysts, and the embaying relation by some of the potassium feldspars indicate that at least part of the potassium feldspar phenocrysts formed very late in the crystallization cycle.

The plagioclase (An_{20}–An_{35}) constitutes 30 percent or more of the monzonitic rock and predominates in the dioritic facies, but amounts to only 10 percent or less in the syenite. The usual subhedral grains generally range from a fraction of a millimeter to as much as a centimeter in size. Many of the larger grains are zoned and the more calcic centers are intensely clouded by alteration. A large proportion of unzoned grains are also clouded by sericitic alteration, although to a much lesser degree. Almost all the grains show good albite twinning. Some of the grains are irregularly indented by potassium feldspar, whereas still others are represented only by remnants within the potassium feldspar.

Hornblende is the most consistently abundant mafic mineral, usually making up at least 5 percent of the rock. In some of the more mafic varieties, however, it predominates. In general, the rocks in the small stocks in the northeast corner of the Wallace map area are more mafic than those exposed in the Gem stocks to the east. In its characteristic occurrence, hornblende forms elongate prisms a few millimeters in length which have a well-formed six-sided section. The prisms have corroded edges and many are only skeletal, the hornblende having been partly replaced by potassium feldspar, magnetite, chlorite, and epidote. In much of the rock a faint green augite is present in minor amounts as remnants or irregular grains. In some of the porphyritic syenite, augite is the only mafic mineral. Some of the augite has been replaced by hornblende, in which the augite can be observed as remnants, and to a lesser degree the augite has been replaced by bladed actinolite, chlorite, or epidote. The grains are usually a millimeter or more in size. Usually, flakes of biotite, partly replaced by chlorite, are scarce.

Modal counts show that quartz composes 5–10 percent of the usual monzonite. Where quartz is more abundant, the rock is quartz monzonite. The quartz content of the syenite is low, amounting to only about a percent. Some of the dioritic facies are also low in quartz; others, which are considered to be grandiorite from the marginal part of the stocks, are higher in quartz but are probably a hybrid type. The quartz occurs interstitially among the other minerals as small irregular grains or as small rounded clots. Larger irregular grains may surround crystals of other minerals. Quartz also occurs in myrmekite on the margins of the potassium feldspar phenocrysts. An undulatory extinction is characteristic for the quartz.

Of the accessory minerals, titanite is the most common; it makes up as much as a percent of some of the rock but generally less. The titanite characteristically occurs as well-formed lance-shaped crystals, generally ranging in size from a fraction of a millimeter to 2 or 3 mm. The next most common accessory is magnetite, which occurs as small irregular grains or as octahedral crystals. A few small hexagonal prisms of apatite were observed in all slides and were numerous in some. Zircon in doubly terminated prisms less than a millimeter in length was observed occasionally under the microscope, and an irregular grain of allanite was seen here and there in some of the thin sections.

In addition to exsolved albite in perthite, small irregular grains of albite can be seen rimming or indenting the margins of the potassium feldspar phenocrysts in some of the syenite and, to a lesser extent, the monzonite. Granular aggregates of pink garnet were observed in some thin sections, but these are probably in hybrid rocks.

Secondary minerals are present everywhere. Sericite in minute flakes clouds much of the plagioclase, particularly the more calcic centers of the zoned plagioclase; sericite is also scattered through some of the potassium feldspar. Minerals present in minor amounts include: clinozoisite in granular aggregates replacing feldspar; epidote in the same form replacing both the feldspar and mafic minerals; and chlorite replacing augite, biotite, and to a small degree hornblende. Pyrite is common in the vicinity of ore deposits, where it replaces hornblende and magnetite. Calcite, occurring in small amounts in veinlets which cut the monzonite throughout, replaces some minerals and is undoubtedly very late.

Replacement and alteration are clearly in evidence throughout the monzonitic rock and are probably mostly due to deuteric effects occurring very late in the magmatic stage. The most striking of these is replacement by potassium feldspar of earlier hornblende, plagioclase, orthoclase, and quartz, remnants of which can be seen poikilitically included within the large grains of orthoclase and microcline or embayed by them. The albite, both in the perthitic arrangement in the phenocrysts and as small grains along and ambaying the large grains of potassium feldspar, and the myrmekitic quartz and orthoclase in a similar arrangement, are all probably related to the same late processes. The accessory minerals are usually seen enclosed within the potassium feldspar phenocrysts; some of the titanite and magnetite grains are common exceptions and these in part probably formed relatively late in the magmatic sequence. Some titanite and magnetite, however, were seen entirely enclosed within pyroxene and hornblende and are considered to have formed early in the sequence.

Some of the secondary minerals, including epidote, chlorite, clinozoisite, and sericite, probably formed after the consolidation of the magma but possibly formed during the deuteric phase. The pyrite and calcite apparently were formed as secondary minerals.

Two age determinations were made of the monzonitic rock. One was made of a sample taken from the Alameda tunnel in the southern stock, and the other was made of a sample of the northern stock from the east slope of Sunset Peak. The age determinations were made by E. S. Larsen, Jr., and others at the U.S. Geological Survey, by means of the lead-alpha method developed by Larsen, Keevil, and Harrison (1952). The determinations are based upon the ratio of radiogenic lead to radioactivity in certain accessory minerals; the minerals sampled were zircon, and zircon and thorite. These age determinations, plus those of four samples from the Idaho batholith, also made by Larsen, are listed in table 4.

TABLE 4.—*Age determinations of the Gem stocks and Idaho batholith*

[From Larsen and others (1958, p. 54)]

Location of sample	Sample No.	Mineral	Ratio	Age (in millions of years)
Gem stocks:				
North stock	ZHCD 62	Zircon and thorite.	1,739α 100 ppm Pb	116
South stock	ZHCD 63	Zircon	292α 11 ppm Pb	94
Idaho batholith:				
Porphyritic quartz diorite, above Yankee Fork, Custer County, Idaho.	L113a	do	825α 30 ppm Pb	90
Do	L113b	Zircon and thorite.	2,200α 100 ppm Pb	102
Quartz diorite, Lowman, Boise County, Idaho.	L81	Zircon	370α 16 ppm Pb	107
Granodiorite, mouth of Vaughn Creek, Elmore County, Idaho.	L288	do	700α 38 ppm Pb	135

These determinations show that the Idaho batholith and the monzonitic stocks in the Coeur d'Alene district were intruded during the Cretaceous Period. The results probably are fairly reliable; the error is ±10 percent (Larsen and others, 1958, p. 37). The Gem stocks were undoubtedly emplaced during the same intrusive episode as the Idaho batholith.

Chemical analyses of five samples from the Gem stocks, and one sample each from three similar small intrusives in the surrounding country—the Herrick stock in the St. Joe country to the south, the Dry Creek stock in the Libby quadrangle to the north, and a latite dike that crops out about 6 miles southwest of the southwest corner of the mapped area—are shown graphically on figure 17. In addition, an average of the analyses of six samples of quartz monzonite from the Idaho batholith is included; bodies of this variety were estimated to underlie about two-thirds of this large batholith (Larsen and Schmidt, 1958, p. 4). The general affinity of these rocks, which apparently are all in the same petrographic province, is evident from these analyses and from the norms depicted. The norms of the rocks from the Gem stocks indicate also the relatively large amounts of albite in the potassium feldspar as well as that included in perthite.

DIABASE DIKES

DISTRIBUTION AND RELATIONS

Diabase dikes are widespread in the Coeur d'Alene district, but are most numerous and most continuous south of the Osburn fault. Most of the dikes trend between west and northwest, and many of the thicker and more continuous ones follow zones of major deformation, although there are conspicuous exceptions to these usual trends and environments. One of the largest and most persistent of these dikes mapped in the area follows the Placer Creek fault for nearly a mile in the southeast corner of the Wallace map area (pl. 3). Another dike, along the Osburn fault, can be seen in several mine workings and is probably fairly continuous, although it cannot be followed on the surface because, like most of the others, it is masked by overburden. A third dike appears to be continuous from the Sunshine mine eastward to the Coeur d'Alene mine, a distance of about 3 miles, and it may extend farther, both east and west. A crescent-shaped diabase dike is probably continuous from the mouth of East Fork of Big Creek westward for several miles where it joins a zone of dikes that follow the general

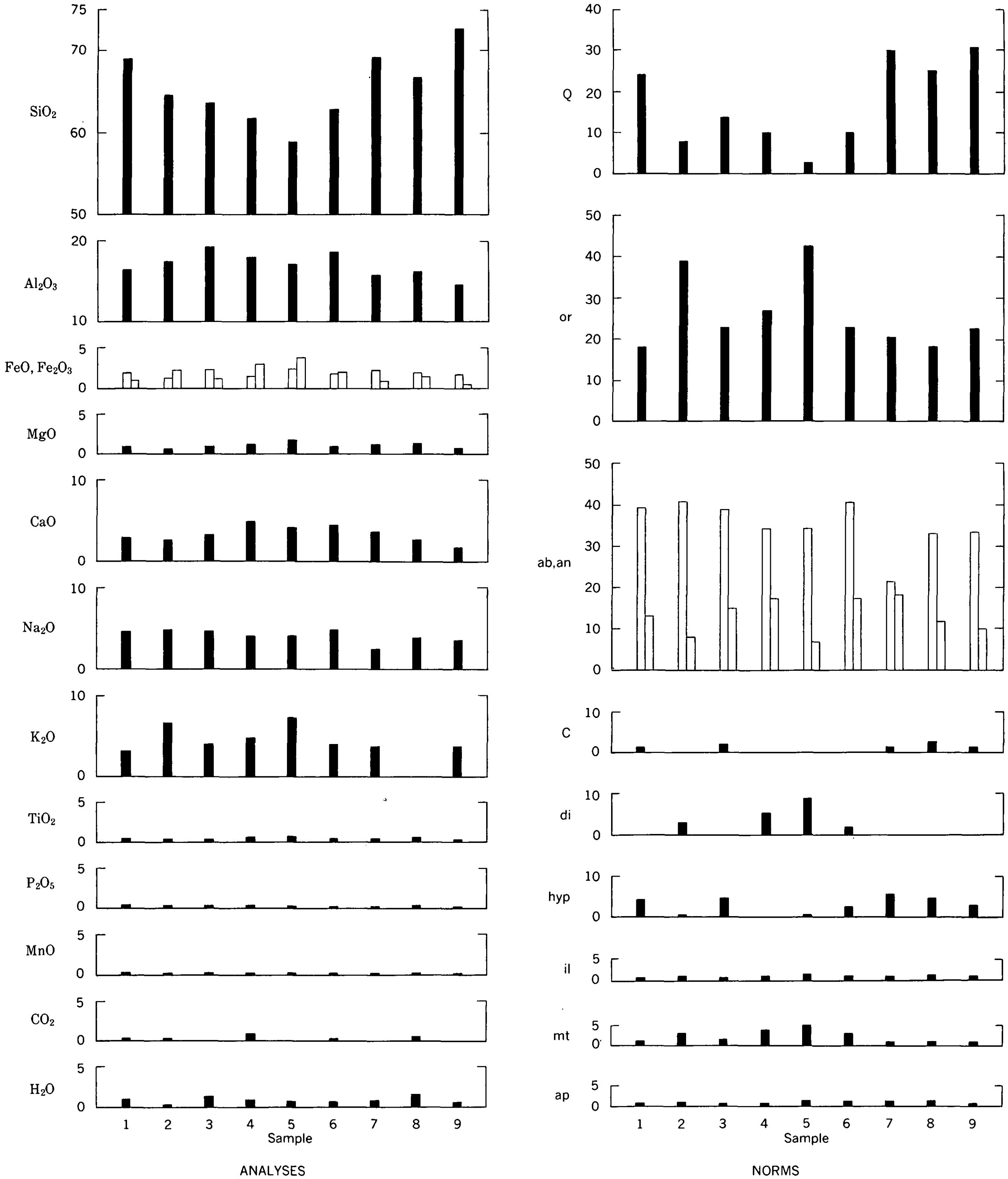


FIGURE 17.—Analyses and norms, in percent, of rocks from the Gem stocks, similar small intrusives in the surrounding country, and the Idaho batholith.

course of the Striped Peak fault westward into the Smelterville map area. Other diabase dikes occur in the vicinity of the Page mine in the Smelterville area and also in the Mullan area. The most prominent diabase dikes north of the Osburn fault follow the Mexican and San Jose faults in the Mullan map area and the Ruth and Blackcloud faults in the Mullan and adjoining Wallace map areas.

Many of the dikes which appear short as mapped are probably just the visible parts of more extensive or continuous bodies, and many others are completely concealed.

A large sill of diabase that lies just south and east of the mapped area deserves mention because of its size, extent, and the possible difference in age between it and the diabase dikes in the Coeur d'Alene district. This is the Wishards sill described by Wallace and Hosterman (1956, p. 587–588), Umpleby and Jones (1923, p. 9), Calkins and Jones (1914, p. 174–175), and Pardee (1911, p. 47). This sill has been traced for more than 30 miles in the upper drainage basin of the St. Joe River and generally ranges in thickness from 50 to 400 feet (pl. 9). Evidences cited to link this large sill with the Purcell sills (described under "Regional geologic setting," p. 11) are its intrusion parallel to the bedding, involvement in regional folding, and the metamorphism of a similar body several miles to the south of it at the edge of the Idaho batholith. The Purcell sills are probably Precambrian in age, whereas the diabase dikes are undoubtedly much younger.

The relative age of the diabase dikes is based mostly upon their relation to the Gem stocks and their distribution and exposure in reference to structural features. A diabase dike cutting the southern Gem stock is exposed in the old railroad cut just east of the junction of the East Fork of Ninemile Creek with the main stream in the Mullan map area (pl. 4), and thus the dike must be younger than the monzonitic intrusives. These diabase dikes generally strike parallel to the trend of the west-northwest major faults that dominate much of the structural pattern of the area. Many diabase dikes are found along major faults and certainly postdate the beginnings of the break and the fracturing, although some of the dikes were crushed and sheared by subsequent movement on the same planes. Diabase exposed at many places along the Osburn fault is intensely sheared and disrupted, which well illustrates dike emplacement prior to the latest movement along this fault; similarly, sheared diabase dikes were observed along other faults. In contrast, the diabase dike that extends between the Sunshine and Coeur d'Alene mines appears to cross faults of considerable displacement without being noticeably offset. For example, this dike as exposed in the workings of the Merger mine on the south side of the Polaris fault projects fairly well to its probable extension in the workings of the Coeur d'Alene mine on the north side of the Polaris fault; yet this fault has an apparent normal dip slip of a thousand feet or more and may have also had a considerable strike-slip component of movement. This relation is germane only to this particular dike and cannot be applied as a generalization of the relation between any other diabase dike and fault.

The diabase dikes are definitely older than some sulfide mineralization, but appear to be younger than the main period of ore mineralization, although supporting evidence is not clear cut. Jones (1919, p. 9) described diabase dike and vein relation at the Highland-Surprise mine in the Pine Creek area, where the vein was offset by a crosscutting fault, but the adjacent diabase dike was not; Forrester and Nelson (1944, p. 9) stated that diabase and lamprophyre dikes tend to "blank out" the veins where they are found in crosscutting relations in the Pine Creek area. Shenon and McConnel (1939, p. 6) cited the presence of a vein containing quartz, calcite, and chalcopyrite in a diabase dike at the Merger mine in the Silver Belt, and another vein containing, in addition to these minerals, pyrrhotite, pyrite, galena, and sphalerite, in a diabase dike exposed along the Osburn fault in the crosscut of

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SAMPLE IDENTIFICATIONS, FIGURE 17

1. Quartz monzonite, South Gem stock (ZHCD–63). H. F. Phillips, P. L. D. Elmore, K. E. White, analysts.
2. Monzonite, North Gem stock (ZHCD–62). H. F. Phillips, P. L. D. Elmore, K. E. White, analysts.
3. Monzonite, Success mine, South Gem stock (Id-Sudg-2a). J. C. Antweiler, analyst.
4. Monzonite, South Gem stock. George Steiger, analyst (Ransome and Calkins, 1908, p. 47).
5. Syenite, South Gem stock. George Steiger, analyst (Ransome and Calkins, 1908, p. 49).
6. Monzonite, Herrick stock (ZHCD–55). H. F. Phillips, P. L. D. Elmore, K. E. White, analysts.
7. Quartz monzonite, Dry Creek stock, Libby quadrangle. George Steiger, analyst (Gibson, 1948, p. 25).
8. Quartz latite, dike 6 miles southwest of southwest corner of Smelterville map area (SEG–50–49). H. F. Phillips, P. L. D. Elmore, K. E. White, analysts.
9. Average of six analyses of quartz monzonite, Idaho batholith (Larsen and Schmidt, 1958, p. 14, samples 10, 11, 14, 15, 16, and 17).

the Silver Dollar mine, as evidence that the dikes were older than the main period of mineralization. At the Silver Dollar, however, R. E. Sorenson (written commun., 1956), who mapped the Silver Dollar when the workings were more open, found that the vein in which the sulfides occurred was in a quartzitic bed in the Prichard Formation rather than in the dike. At the General Mine Co. workings south of Pinehurst, gash fractures in a diabase dike are filled with quartz, pyrite, arsenopyrite, and chalcopyrite with some gold—none in commercial amounts. Veins containing an assemblage of minerals similar to those in the General Mine Co. workings are found at other places in the district; these are considered to have formed later than the main period of mineralization.

Along the course of the Wishards sill, a group of chalcopyrite-dolomite veins occupy steeply dipping eastward-trending fractures, most of which are from a few hundred to a thousand feet vertically above the diabase body (Wallace and Hosterman, 1956, p. 607). This proximity may indicate a genetic relation between the veins and the sill; however, if the sill is Precambrian, its significance in postulating the age relation of diabase dikes within the Coeur d'Alene district is lessened.

The foregoing relations within the Coeur d'Alene district suggest that copper-gold-arsenic deposition may be closely related to the emplacement of the diabase intrusives or at least soon after. On the other hand, the main period of lead-zinc-silver mineralization seems to have occurred before the intrusion of the diabase dikes.

PETROGRAPHY

Most diabase is dark gray to dark greenish gray, although the coarser facies of the thicker bodies may be somewhat lighter and the fine-grained border facies darker—almost the color of basalt. Grain size ranges from medium to fine, depending largely upon the thickness of the dike. The lath-shaped crystals of plagioclase are embedded in a dark mass of pyroxene and a little amphibole. Some iron ore may be distinguished in the coarser grained varieties. The well-formed feldspar laths and the poorly formed mafic minerals are the general features that most easily serve to distinguish the diabase from the lamprophyres in which the mafic minerals are generally more euhedral than the feldspars.

Several specimens of the diabase rocks from the Coeur d'Alene district were restudied in detail by F. C. Calkins and are discussed in an unpublished report on the Silver Belt of the Coeur d'Alene district Idaho by P. J. Shenon. The following lucid petrographic description is from that report and applies to all the diabases. Slight changes have been made to integrate the description into the broader picture of the entire Coeur d'Alene district, but the wording is principally that of Calkins.

The specimens of diabase collected in the Silver Belt show considerable differences in grain size and in degree of alteration. In the coarsest grained specimen from the center of the great dike at the head of Placer Creek, many grains are from 3 to 5 mm long; in one of the finest grained, from Big Creek, few crystals are more than 1 mm long. The finest and coarsest, where they are not greatly altered, have the following characteristics in common: the plagioclase feldspar forms tabular crystals, giving many lath-shaped sections whose dull greenish-white color contrasts with a nearly black matrix. This matrix consists mainly of augite, a mineral which has distinct cleavages but a rather dull luster and which in the diabase never shows good crystal form. Ilmenite, which is black and has a metallic luster, is easily recognized in the coarse rock; it is associated with magnetite.

A thin section of the specimen from Placer Creek, viewed under the microscope, shows the plagioclase to be in large part altered to a saussuritic mixture of sericite and zoisite. The outer parts of some crystals whose cores are much altered are clear, but extinction angles can be measured even in some of the cores. The crystals are shadow zoned, the composition passing gradually from about An_{60} in the cores to An_{20} on the crystal form. Ilmenite, which is black and has a purplish tinge, which suggests that it contains considerable titanium, and a distinct basal parting. It is altered in part to a pale-green amphibole, but much of it is bordered by presumably original amphibole of deeper colors ranging from greenish brown to bluish green. Biotite is present in rather small quantities. Its usual color is olive brown, but some of it is deep green where altered. The ilmenite crystals are conspicuous because of their large size and characteristic skeleton forms, which show trigonal symmetry in favorable sections. They are partly altered to leucoxene. Apatite is abundant in long needles which penetrate all the other constituents. A considerable quantity of quartz, intergrown micrographically with potassium feldspar, fills the interstices between the other minerals. In this specimen the feldspar is chiefly orthoclase, but albite is present in minor amounts. The refractive indices of both feldspars have been checked by comparison with oils.

Two other specimens were taken from the same dike: one from near the margin and one from somewhere between the margin and the center. The marginal facies is fine grained and somewhat porphyritic, having phenocrysts of both plagioclase and augite. The augite phenocrysts are indented by crystals of plagioclase and do not have a sharp crystal form. Hornblende and biotite are scarce, and neither quartz nor alkali-feldspar was found. The section contains one grain of olivine and one psuedomorph of green serpentine after olivine. The rock obviously contains less silica and potassia and more magnesia than the specimen from the middle of the dike. The specimen from the intermediate position is also intermediate in character but is much more similar to the specimen from the middle than to the one from the margin of the dike. The feldspar in its micrographic intergrowths is chiefly albite. The rock from Big Creek has an imperfect ophitic texture and contains little quartz and no micropegmatite. Small lakes of groundmass represent the last material to crystallize.

These diabases are relatively siliceous, but the coarsest rock from the Placer Creek dike is abnormally so. Its character may be the result of a concentration of silica, alkalis, and volatiles in the middle part of the intrusive body while the diabase was still liquid and the outer parts had solidified.

Some of the diabase is altered. A specimen that is more altered than most is from the West Fork of Placer Creek. In this diabase the ferromagnesian minerals are wholly replaced by chlorite and the much-clouded plagioclase approaches albite in composition, however, the diabasic texture is still recognizable, albitic micropegmatite is present, and ilmenite crystals—altering to leucoxene along cleavage cracks—are conspicuous. Another diabase specimen from the Silver Summit property, cut by many veinlets containing quartz, carbonate, chlorite, epidote, pyrite, and amphibole, is a chaotic mixture of these minerals, together with saussuritized feldspar and probably some undertermined zeolites. Yet the diabase contains a little remnant of original hornblende, and many of the large ilmenite crystals that are the most durable identification marks of the diabases and which occur in no other rock in the district.

There is some doubt regarding the proper classification of a specimen from one dike of the group in the Moon Creek fault zone that is mapped as lamprophyre. This dike is the most easterly one of the dike swarm at the side of the highway east of the mouth of Moon Creek (pl. 2). The rock is dark greenish gray and is too fine grained to show any distinctive characteristics. Under the microscope, the most conspicuous feature of the rock is that the plagioclase laths, mostly about one-half millimeter long, are arranged as they are in the diabases. The laths are relatively fresh and show shadow zoning from cores near An_{60} to rims near An_{20}. Presumably, the only original ferromagnesian mineral present is deep-brown fresh-looking biotite, which forms lathlike crystals. Dusty pseudomorphs lying between the feldspar crystals and consisting of calcite, antigorite, and other minerals probably represent augite. A little quartz and albite occur interstitially. Magnetite is fairly abundant in small grains, and thousands of extremely slender needles of apatite occur in the section.

The minerals described form a groundmass for fairly numerous phenocrysts, mostly 1 mm long, which are now wholly replaced by calcite mingled with a green chlorite or serpentine. Some of these pseudomorphs show regular crystal forms that suggest olivine; others are more suggestive of augite. If augite were substituted for most of these pseudomorphs and those in the groundmass, and olivine for a few, the result would be a rock somewhat resembling the marginal facies of the Placer Creek dike. But the habit of the iron ore and the biotite and the regular forms of the phenocrysts are suggestive of lamprophyre rather than diabase.

LAMPROPHYRE DIKES

DISTRIBUTION AND RELATIONS

Lamprophyre dikes are abundantly exposed in mine workings and roadcuts in the Coeur d'Alene district. These dikes are dark-colored fine-grained rocks characterized by phenocrysts of mafic minerals, usually biotite or hornblende, that are commonly distinguishable in the hand specimen. They are most numerous in the part of the district that lies north of the Osburn fault. Some lamprophyre dikes have been found south of this fault, but the number appears to be far fewer than occur in the northern block even though the opportunities for observation in mine workings and on the surface are approximately the same throughout most of the area. The predominant strike of these dikes is between northwest and northeast; a north-northwesterly direction is the more common—a direction that is distinct from the trend of most of the diabase dikes.

The distribution of the dikes on plate 7 probably represents the general pattern, but is only part of the total number. The dikes weather readily and completely, and natural outcrops are rare or absent. The dikes are generally from a few feet to a few tens of feet wide and individual dikes are relatively short as none has been traced continuously for more than a fraction of a mile. Many dikes may be but a few hundred yards in strike length. They tend to branch, split, and occur in groups in an echelon pattern. In addition to occurring as irregular dikes, they also have been found in a few places as small plugs or other small bodies of ill-defined shape. Many of the dikes shown on plate 7 and the surface geological maps are those exposed along roadcuts and in bare canyon walls or projected from mine workings. It is probable that many others occur in the large areas in which no artificial exposures have disclosed them, particularly north of the Osburn fault.

In a description of the lamprophyre dikes in the Coeur d'Alene district, Shannon (1920, p. 478) noted that they were most numerous in the Prichard Formation and became progressively scarcer in the overlying rocks. His observation is in part confirmed by the new mapping. A notable exception to this generalization, however, is the large area of well-exposed Prichard Formation in the region of the Pine Creek mineral belt; here lamprophyre dikes are very rare.

A large number of lamprophyre dikes have been mapped, mostly in underground workings in the great mineral-producing area north and south of the town of Burke in the Mullan map area. Several of these dikes are poorly exposed in cuts along the road across Dobson Pass north of Wallace, where they have been sheared and broken in proximity to the Dobson Pass fault. The best and most readily accessible exposures are along U.S. Highway 10, both the new right-of-way and the cutoff loops of the old road between the mouth of Big Creek on the east and the junction of the South Fork with the main Coeur d'Alene River to the west. A swarm of six dikes cuts the Prichard Formation along the old road 1,500 feet east from the mouth of Moon Gulch. One of these is described as a possible diabase in the preceding section. Several more dikes are well exposed at the east limits of the city of Kellogg on both the north and the south sides of the river, and three others are particularly well displayed in the highway cuts about half a mile west of the Pine Creek road turnoff. All of these dikes are north of the Osburn fault. South of the fault the greatest known concentration of lamprophyre dikes occurs about 4 miles west of the southwest corner of the mapped area in the vicinity of Twin Crags (Campbell, 1960). These dikes cut rocks of the St. Regis Formation.

Most lamprophyre dikes are in a system of fractures that is at an angle to the trend of the major west-northwest system of faults and the similar trend of the veins. The large majority of the dikes mapped underground in the Burke area strike near N. 20° W., and the dip steeply to the southwest. In the Kellogg area the trends of the dikes are somewhat more diverse but tend to be northward rather than westward. Those at Twin Crags also have a strike that is in the north-northwest quadrant and serve to extend the pattern south of the Osburn fault.

The lamprophyre dikes are clearly younger than the monzonitic rocks, for one dike was found that cut the south stock underground at the Alameda and Success mines. They also have been observed to cut veins in the Rex and Black Bear workings. Ransome (in Ransome and Calkins, 1908, p. 35) and Shannon (1920, p. 480–492) also noted that the lamprophyre rocks cut the ore at several deposits, notably in the Hecla, Frisco, Standard-Mammoth, and Marsh mines. The most discussed of these dikes cuts the main Hecla ore body; it was intruded along the ore shoot and replaced part of the ore. At some places it was found on one side, at others on the opposite side or in the middle, and persisted almost through the entire ore body. Another dike, described by Fryklund and Fletcher (1956, p. 231), cuts the Star vein nearly at right angles, and has produced metamorphic changes in the adjacent sphalerite in the vein. Nowhere have ore minerals been found in lamprophyre, and the conclusion has been drawn that all the dikes of this group were formed after the main period of ore-mineral deposition.

PETROGRAPHY

In his study of the lamprophyre dikes, Shannon (1920) described the petrography of specimens from several localities in considerable detail. In 1937 F. C. Calkins (written commun.) restudied some of his original material as well as some new specimens collected during the study of the Silver Belt area and wrote up descriptions of lamprophyre rocks which were included as part of an unpublished manuscript by P. J. Shenon. During the present investigation, many dike localities already described were revisited and other lamprophyre dikes were observed. The synthesis of the petrography that follows incorporates much of the information from these earlier descriptions with data gathered during the present study; no attempt, however, has been made to repeat all the descriptions of individual specimens.

Most of the lamprophyres are dark gray or dark-greenish-gray holocrystalline very fine to medium-fine-grained rocks. Some of the thinner dikes, as well as the selvage of some others, are almost black, and have, in part, a glassy groundmass; a few in which feldspar predominates are a lighter gray. The characteristic porphyritic nature of lamprophyres in which mafic minerals form the phenocrysts is apparent to the naked eye in only some of the lamprophyres; these are the examples of "bright porphyries" that fulfill the etymology of the name. There appears to be every gradation from the bright sparkling porphyries, abounding in larger flakes of biotite or prisms of hornblende, to varieties in which the mafic phenocrysts are so small or so badly altered as to be barely separable from the groundmass even with the hand lens. In fact, some of the dikes that have been classed as lamprophyre appear chiefly nonporphyritic. These are rather dull nondescript rocks that could be mistaken for a very fine grained diabase or a basalt, and their true character commonly is partly masked by alteration. The porphyritic habit of the mafic constituents of almost all the dikes is apparent in thin section, however, and this, together with their characteristic mineralogic composition and textural affinities, relates the questionable dikes directly to the lamprophyre group.

Under the microscope another most distinguishing characteristic is a panidiomorphic texture; the chief constitutents all tend to form their own crystal shape. This texture is most perfectly formed in the more mafic and more obviously porphyritic dikes, particularly those having a fine-grained groundmass in which the feldspar is plagioclase; is less perfectly formed in the more equigranular specimens, particularly the coarser grained ones in which the feldspar is orthoclase; and is nearly obliterated in the highly altered rocks. In all the lamprophyres, however, the tendency for the mafic minerals to form their own crystal shape is apparent whereas in the diabases the mafic minerals are molded around the feldspar laths.

To the naked eye, the lamprophyres are usually divisible into two main groups: in one, biotite phenocrysts are the dominant and easily observable mineral; in the other, hornblende phenocrysts are dominant. A systematic study of thin sections of these rocks shows that most of them may be further subdivided into four groups. These are determined by the proportion of biotite or hornblende, and the combination of each of these minerals with either orthoclase or plagioclase as the essential constitutents. Shannon (1920) called these groups minette (biotite-orthoclase), vogesite (hornblende-orthoclase), spessartite (hornblende-plagioclase), and kersantite (biotite-plagioclase); they may also be considered as melanocratic varieties of syenite and diorite. Shannon also believed that minette and spessartite were the dominant groups, but evidence from the present study is not as conclusive. The orthoclase-bearing varieties appear to be more abundant in the Burke area, and the plagioclase-bearing varieties are somewhat more abundant in the Kellogg area, but the types are far from being mutually exclusive. Kersantite appears to be the least abundant. The validity of such a distinct grouping may be questioned, for several dikes, although they cannot be traced continuously, appear to change from one type to another along strike or in depth.

Biotite or hornblende phenocrysts, which are usually conspicuous in the fine-grained groundmass, are as much as several millimeters across. The biotite is a highly pleochroic brown, characteristically in hexagonal plates, and the hornblende is a green to greenish-brown variety in six-sided prisms. Both minerals are also common as a second generation of smaller grains in the groundmass. A scattering of biotite is usual even in the hornblende-rich rock. A colorless to pale-green pyroxene, either augite or diopside, usually at least partly altered, is an accessory constitutent in many specimens. The pyroxene commonly occurs as larger irregular grains or crystals, and in some rocks is abundant. Pseudomorphs of antigorite or talc dusted with magnetite after phenocrysts of olivine are scattered sparingly through some sections; they do not appear to be restricted to any one rock variety. These mafic minerals most commonly make up a larger percent of the volume of the rock than the feldspars.

The feldspars characteristically make up much of the groundmass. From thin-section inspection that has been corroborated by X-ray diffraction work, the conclusion is that in many specimens the feldspar may be mainly orthoclase, or in others, plagioclase; some specimens, though, may contain both. In others, owing to alteration or fineness of grain, it is difficult to determine what the feldspar is. The orthoclase in the syenitic varieties is usually in irregular grains or bundles of lath-shaped fibers with a rolling extinction. The plagioclase occurs in small laths, usually poorly twinned, which may be zoned from labradorite at the core to oligoclase on the rim. In some specimens the dominant feldspar is now albite, but as some of it encloses remnants of more calcic zoned plagioclase, it probably formed by secondary replacement. The feldspar grains rarely exceed a millimeter in size, and usually are much smaller.

Apatite in colorless stout prisms is an abundant accessory, and magnetite either in irregular or euhedral small grains is somewhat less abundant. A little quartz is present in nearly all specimens and is commonly intergrown in the groundmass or replaces other minerals. In some thin sections a clear grain or aggregate of grains of quartz can be seen that usually have resorption rims and are apparently remnants of the invaded country rocks. Chlorite is almost everywhere a secondary mineral, which largely replaces the pyroxene, and also replaces the biotite and hornblende to a greater or lesser degree. In many specimens the feldspar is partly or almost completely replaced by sericite. Other secondary minerals include calcite, epidote, and zeolites.

Of the many dikes mapped, eight representative lamprophyre dikes and six representative diabase bodies were selected for chemical analyses (fig. 18). The normative mineral composition of these specimens indicates that, although there is a chemical variation among some of the specimens of each group, the lamprophyre dikes form a distinct group which is homogenous within itself and which is different in chemical and mineralogic composition from either the diabase or the monzonite. A considerable variation in the K_2O and Na_2O content in the lamprophyres is reflected in a difference in the essential minerals; and a relatively high magnesia content, plus lime and iron oxides, accounts for the usual large amount of the mafic minerals. The high H_2O content and, in some rocks, CO_2 are typical of lamprophyres, which apparently crystallized from a magma that contained a fairly high amount of volatiles as contrasted to the diabases.

OTHER DIKES

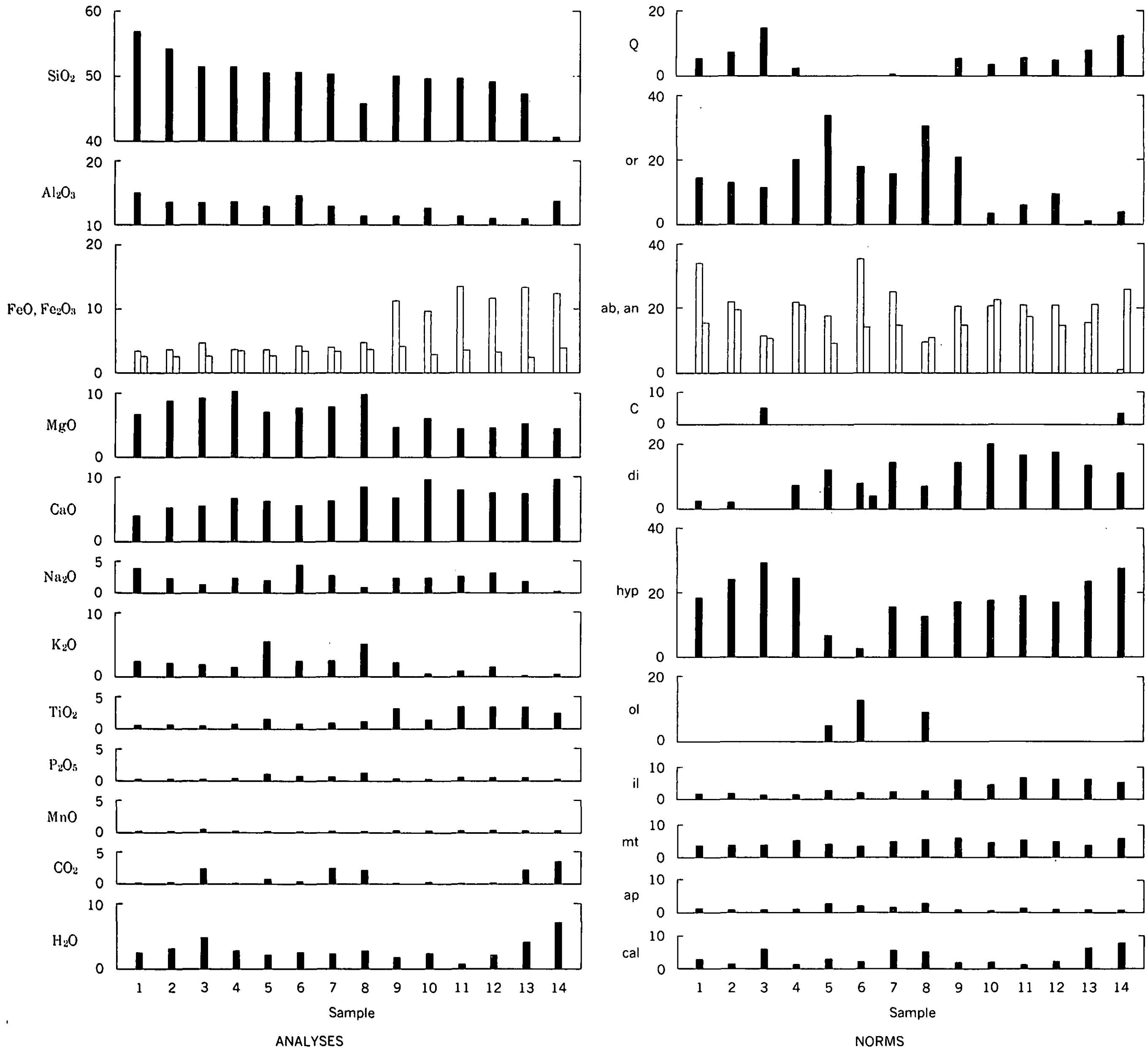
Throughout the Coeur d'Alene district are a scattering of small intrusive bodies that were mapped as a single group of dikes. They included not only some silicic and intermediate types that are in part direct offshoots from the monzonitic stocks but also some dikes of undetermined composition that might be classified with the lamprophyres or diabases should more definitive information be available. Some of these dikes are so badly decomposed that specific identification is impossible; others are known from maps and records of mine workings no longer open; and still others, shown on plate 7, that are beyond the area of our study and not specifically identified were compiled from literature.

In the general vicinity of the Gem stocks are several dikes that range from diorite to monzonite in composition and that are probably direct offshoots from the larger intrusive bodies. The porphyritic monzonite dike exposed in the Interstate-Callahan mine has almost the exact composition of the predominant variety of the stocks. The dike ranges from 10 to 40 feet in width, has an average strike of east-west, and dips 65°–70° N. In the lower part of the mine the dike divides the Interstate vein into two parts, cutting across it at an acute angle. The dike is older than the ore, for veinlets of sphalerite penetrate it, but later faulting along the dike has offset the vein more than 100 feet (McKinstry and Svendsen, 1942, p. 229). The more dioritic varieties are exemplified by the dike exposed in the Fourth of July crosscut on the No. 5 adit level of the Hercules. This dike is also porphyritic, but the plagioclase makes up more of the rock than the potassium feldspar, and hornblende is more abundant. Similar dikes much closer to the stocks occur in the Tamarack, Rex, Nipsic, and Ambergris workings.

A rather unusual monzonitic dike occurs in the ridge just south of Beaver Creek in the northwest corner of the Mullan map area and the adjacent part of the Wallace map area. It is a gray porphyritic rock with a fine groundmass. Microscopic inspection shows that the dike has been largely altered to a mixture of albite, clinozoisite, epidote, and chlorite. The phenocrysts are as much as 2 mm in size and make up almost half the rock. The phenocrysts originally were mostly orthoclase, but are now albite clouded with sericite and clinozoisite. Hornblende, which was in small prismatic needles, made up about 20 percent of the rock and is now almost entirely replaced by a mixture of epidote, sericite, and chlorite. The groundmass is a felted mass of alteration minerals. Small crystals and grains of magnetite are common accessories. Less common are titanite, apatite, and allanite.

Aplite dikes cut the stocks and extend out into the sedimentary rocks. They are characteristically a fine-grained white sugary rock. Mineralogically, aplite dikes differ from the monzonite by having a higher quartz content, containing minor amounts of muscovite, and having almost no mafic and accessory minerals in them. Aplite dikes are equigranular rocks in which the mineral grains are usually less than 1 mm. All the aplite dikes seen were small—less than 12 inches wide. They could be traced for only a few tens of feet. A typical aplite dike cuts monzonite above and to the west of the Success mine. In it, potassium feldspar in irregular microperthitic grains makes up about half the rock; plagioclase (An_{25}) in clouded grains and quartz are present in nearly equal amounts, and a few percent of muscovite in irregular shredlike flakes makes up the remainder. Calkins (in Ransome and Calkins, 1908, p. 46) reported that the stocks are cut by some pegmatite dikes. The only one observed was a small dikelike body, associated with quartz veins, which occurred in Belt strata near the edge of the southern stock.

A few light-colored dikes that approach latite or andesite in composition were found in the western part of the area. At least some of these dikes appear to be lamprophyres, but they are somewhat less mafic than lamprophyres in the strict sense of the definition.



SAMPLE IDENTIFICATIONS

[Analysts: H. F. Phillips, P. L. D. Elmore, K. E. White]

1. Hornblende lamprophyre, Rex mine (AB G-8-49).
2. Hornblende lamprophyre, 1000-foot level, Star mine (VF-17-53).
3. Hornblende lamprophyre, 2500-foot level, Star mine (VF-32-53).
4. Hornblende lamprophyre, Montgomery Gulch (B-28-52).
5. Biotite lamprophyre, near Success mine (AB G-88-48).
6. Hornblende lamprophyre, Italian Gulch (B-33-52).
7. Hornblende-biotite lamprophyre, Red Monarch mine (AB G-138-49).
8. Biotite lamprophyre, Alameda tunnel (AB G-20-49).
9. Diabase, Trout Creek, Superior quadrangle, Montana (34-C-54).
10. Diabase, San Jose fault northwest of Grouse Peak (AB G-163-49).
11. Diabase, Wishards sill, east portal, Chicago, Milwaukee, St. Paul and Pacific Railroad tunnel, Montana (52-W-15).
12. Diabase, Osburn fault, Superior quadrangle, Montana (195-C-54).
13. Diabase, General mines, southeast of Pinehurst (ABC-26-51).
14. Diabase, Nancy Lee mine, Superior quadrangle, Montana (191-C-54).

FIGURE 18.—Analyses and norms, in percent, of diabase and lamprophyre dike rocks.

METAMORPHISM

REGIONAL METAMORPHISM

All Belt sedimentary rocks have gone through some mineralogical adjustment since they were laid down. Part of this change took place during a diagenetic phase, and part resulted from a relatively weak regional metamorphism. The adjustment may have been a continuing process, but the authors believe that it had two high points of activity; one during the compaction and lithification of the sediments, and the other when the accumulation of sediments was the greatest and when pressure and temperature were at their maximum. No clean-cut separation of all the minerals formed during diagenesis from those resulting from regional metamorphism is believed possible. Some minerals are attributable to both phases; others, though, are more clearly the result of one set of conditions.

The quartz, although originally mostly detrital, has undergone some change. The more rounded shape of the larger primary grains is evident at places where the secondary quartz overgrowth, which has grown in optical continuity, is clouded by inclusions. The usual quartzite, however, consists of an interlocking mosaic of irregular quartz grains. This evidence shows that much of the quartzite must have been recrystallized, probably owing to metamorphism. It is impossible to differentiate sericite that is diagenetic in origin from that due to the dynamic or load effect of regional metamorphism. As of the present writing, though, it is safe to say that in rocks like those of the Belt Series, in which recrystallization is so far advanced, almost all the clay components are now changed to sericite and chlorite, much of which has a preferred orientation and formed under stress during the period of regional metamorphism.

The original carbonate minerals appear to have remained relatively stable throughout the diagenetic and regional metamorphic changes. At least the general fineness of the mineral grains is indicative of such stability in the carbonate-rich beds. On the other hand, the accumulation of ferroan dolomite or ankerite into a speckling of small clots that in part replace the quartz in many of the quartzitic beds probably took place during the time of regional metamorphism. The widespread occurrence of this phenomenon indicates that the carbonate minerals were original constituents of the sediments. The carbonate minerals were most likely disseminated throughout the rock in discrete grains until the period of metamorphism, when they were concentrated into the clots which are so apparent now because of the rusty speckling on weathered surfaces that their oxidation has caused.

The chlorite and biotite in the Prichard and Burke Formations, far removed from the stocks, are indicative of the maximum effect of the regional metamorphism, and show that it was mild. In these two formations the chlorite and biotite occur in small clots and stringers or are more concentrated in certain laminae. Their replacement relation to sericite, crystalloblastic texture, and restriction to the two older formations show their metamorphic origin. The chlorite found in great concentration in the St. Regis Formation may be largely diagenetic in origin.

Other minerals are clearly secondary as shown by their relatively large size, good crystalline habit, and inclusions of magnetite, ilmenite, tourmaline, and pyrite; they may have been formed in large part during the diagenetic phase. Pyrrhotite found in place of pyrite in the Prichard Formation at places around the Gem stocks is probably genetically related to the heat of the intrusives rather than to regional metamorphism.

Other dynamic forces have superimposed changes upon the rocks that are mostly later than the adjustments brought about by other processes. In some shear zones the texture of the rocks has been changed to what is best described as phyllitic. In one such phyllite, in the shear zone exposed in the saddle just east of East Grouse Peak, Mullan map area, shiny black flakes of ottrelite, which must have formed during the time of greatest stress, are large enough to be easily seen with the naked eye.

CONTACT METAMORPHISM

Metamorphism of the sedimentary rocks around the Gem stocks is manifested in several ways. The first and most widespread effect is an aureole of recrystallized rocks surrounding the stocks. Immediately adjacent to the intrusives, however, sedimentary rocks have been feldspathized over a distance measurable only in inches or, at most, a few feet. The great host of partly digested inclusions within, but close to, the margins of stocks are rimmed with similar feldspathized borders. Sericite, chlorite, epidote, and similar minerals that are widespread throughout the stocks as deuteric alteration products are also evident within this feldspathized selvage. A later hydrothermal alteration, characterized by silicate minerals, which apparently preceded the formation of the ore deposits by a relatively short time, might also be considered part of the metamorphic effects. Not including the hydrothermal alteration, three different kinds of metamorphism have left their imprint through distinct changes of the sedimentary rocks surrounding the monzonitic stocks. Only the first of these, however, is considered as thermal metamorphism in the strict sense.

Thermal metamorphism of the Belt rocks was the primary and most pervasive process. Two general types of change took place, depending primarily on the presence or absence of a significant amount of carbonate minerals associated with the quartz and sericite that comprise the predominant components of the Belt strata. The mineralogy of the metamorphosed carbonate-bearing rocks is different from that of the less reactive noncarbonate-bearing rocks, and the effects of thermal metamorphism appear to extend much farther from the contact. Most of the metamorphosed carbonate-bearing rocks are restricted to the northeast corner of the Wallace map area and the adjacent part of the Mullan map area, where small stocks invaded the lower part of the Wallace Formation. The larger Gem stocks to the east intruded into argillite and quartzite of the Prichard and Burke Formations and the contact metamorphic changes and variations in non-carbonate-bearing rocks are best seen along their periphery. At no place were outcrops continuous from the igneous contact to the outer rim of the metamorphic aureole, and the conclusions reached are based upon isolated outcrops and float. On the basis of many such observations, the general nature of the metamorphism was determined.

The aureole of contact metamorphism in the non-carbonate-bearing series of rocks around the stocks is very irregular and ranges from a few hundred to more than a thousand feet in width. Apophyses of the stocks, which are plentiful in mine workings but which may not be evident at the surface, may be the cause of some of the irregularities. Other irregularities, though, must be due to more vulnerable areas wherein the rock was more highly fractured and transfer of heat and materials was more rapid. Rocks in deep embayments and even in the largest inclusions, like those exposed along the East Fork of Ninemile Creek, were similarly metamorphosed.

The simplest changes in the sedimentary rocks, now preserved only at the outer edges of the metamorphic aureole, is the recrystallization of the sericite to muscovite and a coarsening of grain, which is also particularly evident for quartz and which is accompanied by some fading in color. Such rocks have a special sheen. In darker rocks, such as the argillite of the Prichard Formation, this change on the outer edge of the aureole may be evident only along bedding partings or other fractures. Where the metamorphism was more intense, biotite replaced part of the muscovite; where it was most intense, andalusite, sillimanite, garnet, clinozoisite, and hornblende become common. Some metamorphosed rocks were converted to hornfels, many others to schistose rocks. In the latter the mica plates are commonly parallel to or subparallel to the bedding; however, in some schistose rocks, the micas are oriented parallel to a cleavage direction. Thus the pressure of intrusion was apparently of little importance in the forming of this schistose foliation. In some of the more intensely metamorphosed rocks the platy or bladed minerals form clots or clusters; such rocks are best described as spotted schists.

The mineralogic changes in most of the non-carbonate-bearing rocks are minor, which indicates little or no addition, or loss of material during metamorphism. The quartz usually recrystallizes to form larger grains whose size depends upon the grain size in the original rock and nearness to the contact. Purer quartzite near the stocks has a sugary appearance, and many of the individual grains are between 0.5 and 1.0 mm in size. Upon recrystallization, the boundaries of the grains become somewhat more irregular and sutured, shadowy extinction disappears, and not uncommonly the larger grains include muscovite or biotite. The sericite in recrystallizing becomes much coarser; the smaller sizes are between 0.02 and 0.05 mm, but in the coarsest rocks the sericite can grow into muscovite flakes several millimeters across. The individual mica grains lose their ragged, feathery appearance and become platy and regular in outline.

Some of the accessory minerals in the sedimentary rocks have disappeared, some have altered, and some have remained unchanged during metamorphism. In many rocks the ilmenite-magnetite group has disappeared entirely, whereas in others it is unchanged. What appear to be remnants of these black opaque minerals occur within biotite flakes or are surrounded by clots of biotite. This fact suggests that some of these remnants furnished the iron to form authigenic biotite. Part of the ilmenite may have been transformed into exceedingly small prisms of rutile or into scattered grains of titanite seen in some sections. No trace of the pyrite so prevalent in the lower part of the Prichard Formation remains in the metamorphic aureole. In some of the metamorphosed rocks, tourmaline, having a bluish-gray to almost black pleochroism characteristic of the mineral in the sedimentary rocks, remains unchanged and in the usual minor amounts. In other rocks, however, it has been altered to a pleochroic variety that is almost colorless to a honey yellow at greatest absorption. Apparently, this absorption is due to a loss of iron, changing the tourmaline from the variety schorlite to dravite. The exceedingly fine carbonaceous dust is gone from most of the argillaceous rocks; the disappearance of this material partly explains the bleached apperance. Zircon remains in the same abundance and in the same subrounded crystalline form; many such grains are included in newly formed minerals.

Biotite, the most prevalent new mineral formed, is found from the border of the stocks almost to the outside periphery of the aureoles. In some of the more argillaceous sedimentary layers, it may make up as much as 50 percent of the rock. Biotite duplicates the muscovite in shape and size, although the larger plates of biotite tend to be more irregular or ragged. The optical properties of the biotite, especially the pleochroism, indicate a variation in composition; the pleochroism ranges from almost colorless, yellowish tan, or yellow to a reddish brown, very dark brown, or dark greenish brown.

The new minerals, formed where the rock is more intensely metamorphosed, resulted from the interaction between the original minerals and fluids that probably, at least in part, originated in the magma. Common new minerals are clinozoisite, andalusite, sillimanite, garnet, and hornblende. They usually occur within patchy bands or zones, commonly parallel to the bedding; some, though, are crosscutting. Andalusite is found in irregular grains, and in thin sections it usually displays a faint red pleochroism. Sillimanite occurs in short needles in plumose arrangements, in wavy bands, or in felted masses in part invading quartz. Clinozoisite occurs in colorless fine-grained aggregates. It is more widespread than the other minerals, as it is also found in irregular patches far removed from the stock. Hornblende, a pale-green variety, which is relatively rare, occurs in patches of irregular grains. Small veinlets, usually of a single mineral such as quartz or clinozoisite, are locally abundant.

Contact metamorphism is most extensive in the carbonate-bearing rocks; some effects of it were found almost half a mile from the nearest intrusive outcrop. The only place, however, where the carbonate-rich rocks of the Wallace Formation are in intrusive contact with the monzonitic rocks is in the northeast corner of the Wallace map area, where a prong of one small stock and an elongate dikelike body cut across lower beds in the Wallace (pl. 3). The rocks between these two intrusives show the effects of contact metamorphism to a greater or lesser degree, and eastward of the dikelike body recrystallized rock has been traced more than 2,000 feet. The aeromagnetic survey (pl. 8) discounts the possibility that these igneous bodies spread more abruptly with depth and thus make this zone of contact metamorphism seem wider than it really is. This map indicates that the main monzonite mass lies to the south and that the prong and dikelike body are apophyses from it.

The new minerals formed in the carbonate-rich rocks, in addition to the recrystallized quartz and mica, are a colorless to pale-green diopside, brownish to green biotite, brown to greenish hornblende, and clinozoisite. The diopside occurs in very small irregular grains and, less commonly, in short stubby prisms, whose abundance apparently depended upon the carbonate minerals in the original rock. In some thin sections only a few scattered grains are to be seen, whereas in others nearly half of an individual lamina is diopside. In some strata hornblende is present in very fine needles, irregular grains, or skeletal crystals. Fine flakes of biotite are common throughout and the clinozoisite occurs as scattered granular aggregates. Quartz still remains the predominant mineral.

Recrystallization has increased the grain size of these rocks only slightly, resulting in a dense hornfels, some of which appears horny or flinty. The most noted change is in color; the grays have been replaced by various hues of green with a yellowish to grayish cast. The rocks have a banded appearance, which results from the concentration of the green minerals diopside, biotite, and hornblende in certain layers.

The zone of feldspathization around the stocks is generally restricted to only a few inches or at most a few feet measured at right angles to the contact. From observations underground, however, the zone has been found to be extremely irregular because of the numerous apophyses of the igneous rock and the many xenoliths of the sedimentary rock within the stocks near the contact. In some places the apparent width of the zone may be 100 feet or more.

Within this relatively thin feldspathized selvage zone, plagioclase locally predominates over the potassium feldspar, and where the plagioclase is not predominant, it is usually more abundant than in the igneous rock as a whole. Like the plagioclase in the stocks, it is oligoclase. The orthoclase is usually perthitic and much more abundant than the microcline. Much recrystallized quartz remains. Green hornblende and in some places a pale-green augite accompany biotite as mafic constitutents of this feldspathized zone, and in the more completely changed rocks the hornblende and augite replace the micas altogether. Diopside and hornblende are common constituents of feldspathized carbonate-bearing rocks. The accessory minerals sphene, magnetite, and apatite are commonly present; in some thin sections the sphene makes up several percent of the rock. Remnants of garnet remain, but andalusite and sillimanite are entirely gone.

The same deuteric changes noted within the igneous rocks are found within the feldspathized zone. In the vicinity of mineral deposits, a still later alteration is superimposed upon the contact-metamorphosed rock. Pyrite is common and usually replaces only the mafic minerals. In turn, the pyrite is rimmed and partly replaced by late magnetite. Chlorite, epidote, and clinozoisite are most abundant. In some places, carbonate minerals have replaced a part of the original minerals. An aggregate of greenish-brown biotite grains and chlorite replacing the hornblende have been noted in some of the thin sections containing carbonate minerals. In thin sections, the texture of these rocks is ragged and patchy, and the outline of the grains is irregular.

GEOMORPHOLOGY AND SURFICIAL DEPOSITS

The Coeur d'Alene district lies within the western part of the Northern Rocky Mountains physiographic province (Fenneman, 1931, p. 186), which occupies much of central and northern Idaho and adjacent parts of Montana. This province is a continuous mountain mass wherein individually distinct ranges are nonexistent. The streams usually are deeply entrenched in steep-walled narrow valleys. In contrast, the eastern part of the province, which occupies much of western Montana and parts of south central Idaho, consists of definite elongate ranges separated by intermontane basins.

Within the Coeur d'Alene district the upland parts consist of long, sinuous ridges that commonly maintain a fairly uniform altitude (fig. 19), although the average height gradually decreases westward from the Bitterroot divide. At a few places the usual narrow crests broaden into small flats. A view of the horizon (fig. 20) from almost any high vantage point shows a pronounced accordance among the tops of the ridges in and around the district; a few scattered peaks stand out

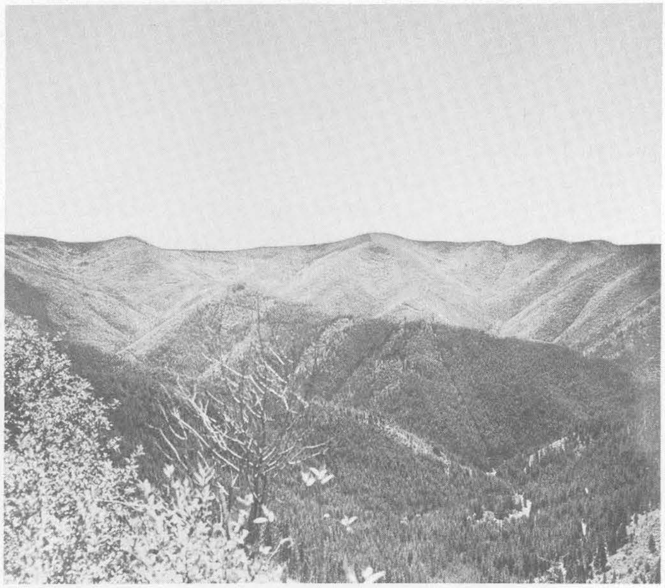


FIGURE 19.—Looking south of Rock Creek at even crest of ridge between South Fork of Coeur d'Alene River and Placer Creek.

only several hundred feet above the general level. The valley of the South Fork of the Coeur d'Alene River westward from Wallace is the only relatively large area of low flatland; at places the valley floor is almost a mile across. Most of the tributary valleys are steep walled and V-shaped, although the floors of some widen appreciably in their lower courses.

The present landscape in the Coeur d'Alene Mountains appears to have resulted from the dissection of a mature land surface. The geomorphic history, however, is not simple; on the contrary, it is multicyclic. At least two principal periods of aggradation and numerous subperiods of short duration are interspersed through the general history of downcutting. All this is evident from the flats and notches, some of which are gravel floored, on the subsidiary ridges below the accordant summits of the main high crests.

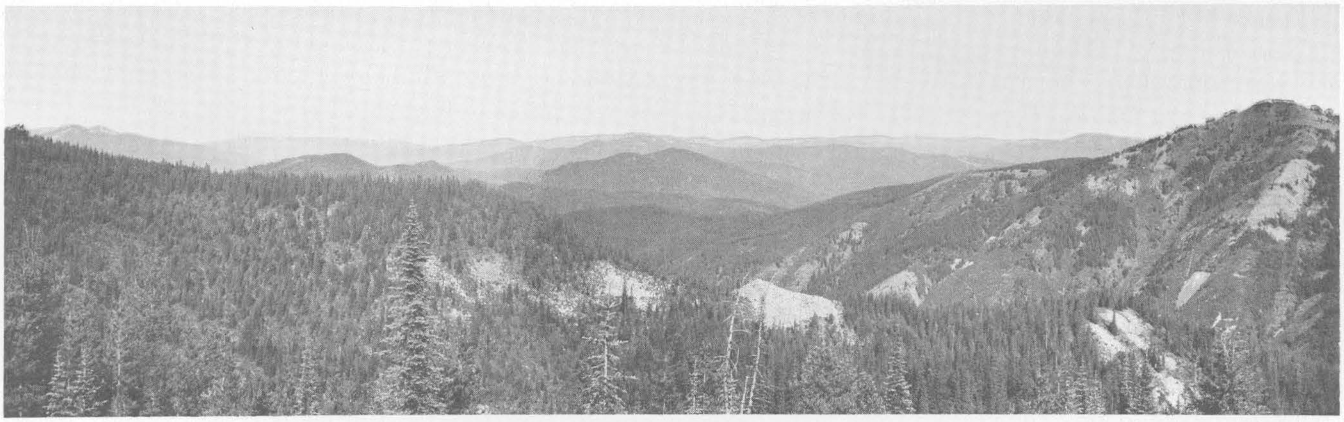


FIGURE 20.—Looking northwest across Canyon Creek view; shows accordant summits of ridges.

The two principal periods of aggradation can be related to outside influences: the first to the damming of the ancient Coeur d'Alene River in middle Tertiary time by Columbia River Basalt flows which then built up the plateau to the west, and the second to the damming of the main stream valley at the Purcell Trench by lobes of continental ice and the material they deposited. A continuing but interrupted uplift of this mountainous area in comparison to the country to the west is indicated for all time since the beginning of the dissection of the summit-capping mature land surface. In addition, alpine glaciers in Pleistocene time modified the landform by the cutting of cirques in the higher ridges and deposition of debris in the valleys below.

The assignment of definite ages to many of the events in this geomorphic history is impossible, particularly when only the evidence found within the district is considered. The geologic event of most recent date within the mapped area which can be used to limit the beginning of the general cycle of erosion was the intrusion of the monzonitic stocks in Cretaceous time. Thus, in order to date even tentatively post-Cretaceous events in the area, much evidence gained from investigations outside the district has been drawn upon.

Structural features have only indirectly controlled the surface configuration in the Coeur d'Alene district and the region that surrounds it. Deformation preceded the sculpturing of the present landscape sufficiently long ago that none of the original irregularities are reflected by the topography today; no fault scarp or fold can be traced by its surface expression. However, major faults such as the St. Joe to the south, the Osburn fault within the district, and the Hope to the north have undoubtedly controlled the position of major drainage channels for at least part of their courses. The valley of the South Fork of the Coeur d'Alene River closely follows the trace of the Osburn fault throughout the district. The superposition is not perfect, but is too close to be fortuitous. The courses of parts of Ninemile and Beaver Creeks and the low divide between them are apparently the direct result of the ease of erosion along the Dobson Pass fault. The Placer Creek fault lies athwart the drainage pattern, but even so several tributary gulches follow closely along its trace, and ridges usually contain a saddle where the fault crosses. Many additional faults have similar surface expression; for many others, however, little or no similar evidence can be found.

SUMMIT EROSION SURFACE

An accordance among the crests of the main mountain ridges in northern and central Idaho and adjacent parts of Montana was recognized by early workers (Lindgren, 1904, p. 14; Ransome and Calkins, 1908, p. 75; Umpleby, 1912), who were so impressed by it that they concluded that the present topography had most likely resulted from the dissection of a plateau or an uplifted peneplain. Other later workers who have been concerned with the geomorphology of this region also recognize a summit erosion surface, but disagree as to when it was formed. They likewise disagree on the time when dissection of this erosion surface began; various times ranging from Cretaceous to late Tertiary have been postulated. In a region of this size, about 45,000 square miles, a geologic event such as an uplift need not occur everywhere at the same time. In fact, it is fairly clear from geologic evidence that different parts of this region had different geomorphic histories.

Pardee (1950, p. 366–369), who studied the area to the east, believed that much of western Montana was reduced to a peneplain by late Tertiary time and since then has been significantly modified by faulting and warping to form a series of elongate mountain ranges separated by intermontane basins. The accumulation of "lake beds" within these basins probably ended in late Miocene or early Pliocene time by general reelevation. This was accompanied by greatly accelerated local crustal disturbances which produced the present ranges. To the south, Capps (1941, p. 4–6) found that what was apparently a mature land surface in west-central Idaho was subjected to elevation and extensive block faulting which produced a series of north-trending structural valleys. A probable Pliocene age is indicated for these disturbances because the Columbia River Basalt of middle Miocene age was involved in the faulting, and Pleistocene glaciation postdates the basalt. There is no evidence that a mature erosion surface has formed since the faulting took place. To the southeast in central Idaho, Ross (1934, p. 83–86; 1937, p. 87–91; 1947, p. 1140–1146) reported the presence of two old erosion surfaces, one of early Tertiary age that predates the Challis Volcanics (Eocene?, Oligocene, and Miocene?), and the other which was carved across deformed Challis. The post-Challis surface consists of gently rolling uplands that cap many high ridges and that are in sharp contrast to the nearly precipitous slopes of the deeply incised canyons that bound these ridges. In a report on the erosional history of the mountainous country of northern Idaho, Anderson (1929) listed several erosion surfaces, the oldest of which he called the "summit peneplain." The evidence he cited for this peneplain is the general levelness of the crests of the main ridges throughout the region and the flats that still remain on some of the crests. He believed that the leveling of this old surface had been accomplished by the end of the Cretaceous Period.

The Coeur d'Alene district lies within the mountainous region of northern Idaho discussed by Anderson, and the general accordance among the tops of the ridges and the shape of their crestal areas that he describes can be gained from a study of the topographic maps. These crests are usually gently rounded in marked contrast to the steep slopes that lead down into the present valleys. Good examples of these crests are the divide between Canyon Creek and the South Fork of the Coeur d'Alene River, the ridge continuing westward from Stevens Peak, and the ridge bounding Big Creek on the west. In the district, the ridge tops have an average altitude of somewhat more than 6,000 feet near the east edge of the mapped area and about 5,000 feet near the west edge. Prominences such as Stevens Peak (6,844 ft), Sunset Peak (6,423 ft), and Kellogg Peak (6,296 ft) stand out only several hundred feet above the general level of the ridge crests. Viewed from a distance, these high points blend in with the rest of the crestal areas to give an appearance of gentle low relief. Small flats such as that at the head of Rock Creek and to the north of Striped Peak are not uncommon features of the crestal areas. Their greatest dimension can be measured in hundreds to a maximum of several thousand feet, and they usually lie along the lower part of the crests. Only one occurrence of a surficial deposit on this summit surface was found within the district. Calkins (in Ransome and Calkins, 1908, p. 56) reported a few well-rounded quartzite cobbles, about 3 inches in diameter, at an altitude of about 5,800 feet on the east side of Gorge Gulch near its head. Campbell (1960) listed a similar small deposit on a high divide north of Superior, Mont., about 30 miles east of the Coeur d'Alene district.

The amount of the summit erosion surface preserved within the Coeur d'Alene district is small, but in the adjacent area to the south, Anderson (1929, p. 751) noted that much larger parts are preserved in the upper reaches of the St. Joe River drainage basin. From what remains within the Coeur d'Alene district, the local maximum relief of the old surface appears to have been somewhat more than 1,000 feet. This relief and the general morphologic shape of the old surface indicate that it had passed well into the old-age stage when interrupted.

One of the more important geologic events useful in interpreting the geomorphic history of the Coeur d'Alene district was the outpouring of the Columbia River Basalt which built up along the mountain front to the west. By the close of this volcanic episode the bordering foothills had been buried or left as islands standing above the plateau, and in the mountainous area the westward-draining valleys had been filled to the level of the plateau. In the vicinity of Spokane and to the east and southeast, the basalt flows overlie or are interbedded with the Latah Formation, a sedimentary group of rocks laid down in ponded areas formed behind dams of basalt (Pardee and Bryan, 1926, p. 4–10). The position of the Latah Formation, along the margin of the mountainous area (Kirkham and Melville, 1929), and the location of the known major feeder dikes indicate that the basalt mostly flowed from the west and south. The fossil flora found within the Latah Formation was considered to be of middle Miocene age by Brown (1937, p. 163), and thus the Columbia River Basalt along the eastern part of the plateau is of a like age. Eroded remnants of the basalt remain about 5 miles east of the general mountain front in the valley of the Coeur d'Alene River and at a like distance at the head of Wolf Lodge Bay of Coeur d'Alene Lake about 10 miles to the north (Anderson, 1940, pl. 2). Along the St. Joe River, the next major stream to the south, remnants of basalt remain perched on the valley walls for 35 miles upstream (Wagner, 1949, p. 24), or about due south of Osburn. Embayments of basalt into the mountains equally as deep as that of the St. Joe valley are evident in other old major drainage channels to the south. The pattern of embayments clearly shows that the mountainous country in which the Coeur d'Alene district lies was in existence in Miocene time and that the drainage system was much the same as it is today. Thus the summit erosion surface that caps this mountainous area was formed well before middle Miocene time. On the other hand, the summit surface must have been formed after Late Cretaceous time, as the monzonitic stocks of this age that lie within the Coeur d'Alene district were deroofed while the surface was being formed. Thus the formation of the summit erosion surface appears to have ended sometime during early to middle Tertiary time.

SUBSUMMIT EROSION SURFACE

Many of the long ridges that extend from the summit divides separating the main valleys have shoulders cut in them at altitudes generally ranging from 4,500 feet in the vicinity of Pine Creek to 5,000 feet near the Montana border. These ridges have been interpreted to be remnants of an ancient erosion surface about 1,000 feet below the erosion surface on the summits. These nearly flat-topped areas are evident from many vantage points particularly on the tributary ridges south of the South Fork of the Coeur d'Alene River and are also obvious on the topographic maps. To the north of the river and to the west of Ninemile Creek these areas are not as well formed. Good examples that are conspicuous on the topographic maps are those on the ridge between Sonora and Military Gulches up Canyon Creek east of Burke, on the ridge near the head of Anderson Gulch southeast of Wallace, and on the ridge lying between the South and West Forks of Big Creek.

The subsummit erosion surface is apparently widespread in this region. Pardee (1911, p. 43) found remnants of an old base level at altitudes of about 5,000 feet on the ridges above the St. Joe River. In a review of the geomorphology of northern Idaho, Anderson (1929, p. 753) noted that an erosion surface about 1,000 feet below what he called the summit peneplain was widespread in the southern Coeur d'Alene Mountains (St. Joe Mountains) and in the adjoining Clearwater Mountains.

At the close of this period of base leveling the region must have been one of subdued relief. It apparently consisted of relatively broad main valleys, in some places as much as several miles across, which were separated by ridges having a maximum relief between 1,000 and 2,000 feet. Temporarily the region was at an old-age stage in the erosion cycle. The dating of this erosion surface can only be approximated. Its intermediate position between the summit erosion surface and the aggraded gravel deposits built behind the dam, formed by the outpouring of Columbia River Basalt to the west, indicates a middle Tertiary age.

BROAD VALLEY STAGE

Older gravels that cap ridges and remnants of higher terraces and fill what remains of old abandoned channels were deposited in a period of aggradation apparently caused by the damming effect of the outpouring of the Columbia River Basalt to the west. In addition, some bedrock-floored sloping benches on spur ridges that extend into the valley of the South Fork of the Coeur d'Alene River are nearly in accordance with the tops of the higher gravel remnants and probably belong to the same stage of the geomorphic history. From these many remnants of gravel deposits and benches, one can easily reconstruct an aggraded valley which was much wider than the one of today. Calkins (in Ransome and Calkins, 1908, p. 76) referred to this phase in the geomorphic history as the broad valley stage, and believed it most plausibly could be explained as being a result of the damming by the basalt flows.

The older gravels occur in scattered remnants above both sides of the main valley from the vicinity of Wallace to and beyond the west edge of the mapped area; similar deposits also have been found on the upper slopes in the Pine Creek drainage. This broad valley stage appears to be widespread, for remnants of a similar old valley feature—ridges capped by gravels that are about 1,000 feet above the present valley bottoms—are well preserved in the St. Joe drainage (Anderson, 1929, p. 754). Anderson believed, however, that this old valley surface was too high above the remnants of the basalt flows to be related to their damming effect.

Within the Coeur d'Alene district the uppermost surfaces of these older gravels generally range in altitude from 4,100 feet northeast of Wallace to 2,900 feet on the ridge west of Pinehurst, or from 1,100 to 800 feet above the present valley level. By plotting the high points of the old gravel, the gradient of this old valley surface is seen to be similar to the gradient of the present valley, which is also in an aggraded condition westward from Wallace (fig. 21). If this gradient is projected westward along a gentle slope to the remnants of the basalt plateau perched on the sides of the Coeur d'Alene River valley, it is seen to be well alined with their tops, which are at altitudes between 2,500 and 2,700 feet, and thus the gradient gives strong credence to their mutual relation.

The path of the old channel of the main stream prior to the broad valley stage is different from that of the present South Fork of the Coeur d'Alene River. From just north of Wallace the old channel is nearly coincident with the trace of the Osburn fault zone west to and beyond the community of Osburn or north of the present valley, but westward from Big Creek to beyond the edge of the mapped area the old buried channel lies south of the present valley. Both Calkins (in Ransome and Calkins, 1908, p. 56) and Dort (1954, p. 75) have pointed out that at places bedrock ribs separate the gravel-filled channel from the present valley. Thus the old channel is fairly well outlined. The easternmost good examples of an intervening rib between the present valley and the old gravel-filled channel is about 1 mile east of Osburn. Here the old channel is to the north of the valley, where the older gravels have been mapped down to an altitude of about 2,900 feet, and the top of the intervening rock rib is at an altitude of more than 3,300 feet. West of Big Creek, gravel fill in the old channel occurs almost down to the present stream level, whereas just to the north in the same spur, ridge rocks of the Prichard Formation occur some 400 feet higher. Sloughing of the gravel downslope is likely here, and the old chan-

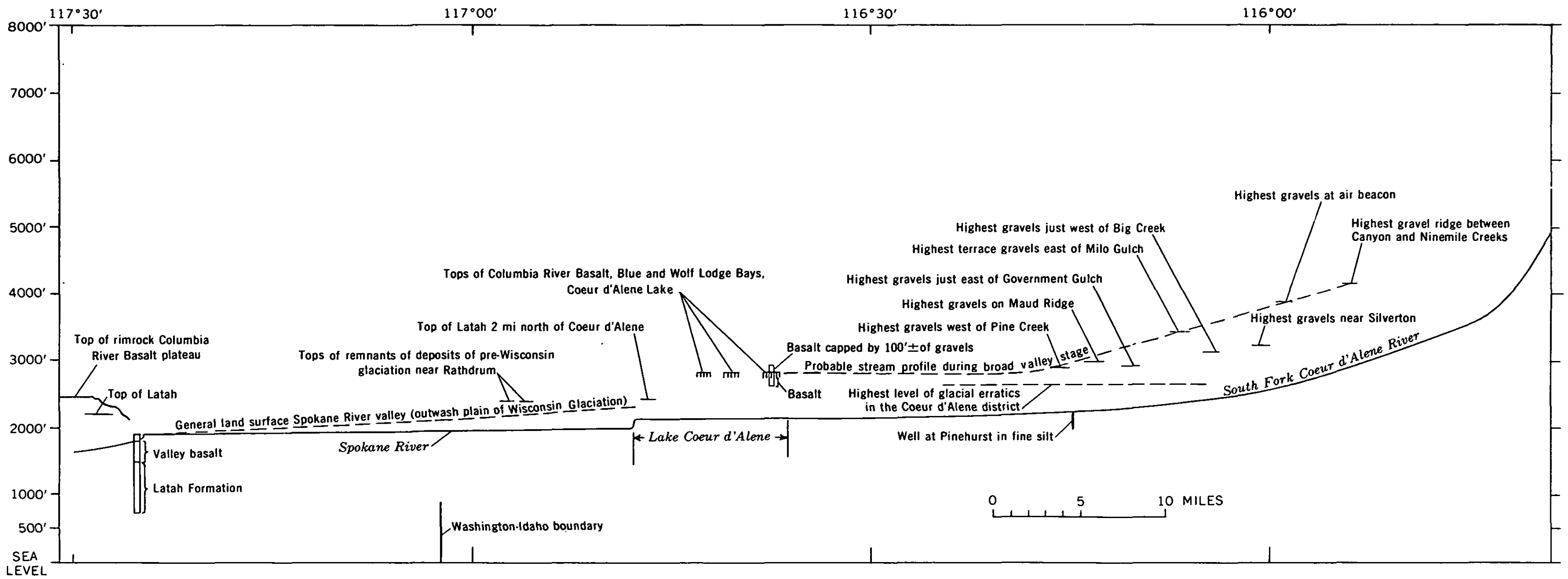


FIGURE 21.—Profile of the South Fork of the Coeur d'Alene River and the Spokane River west to Spokane, Wash., to which the probable stream profile during the broad valley stage is compared.

nel may not be as deep as indicated. Similar relations are also well illustrated east and west of Pinehurst. Here Kingston Ridge stands between the two channels about 550 feet above the eroded surface of the old buried channel.

Prior to the outpouring of the Columbia River Basalt, the drainage system in the Coeur d'Alene district apparently was incised to a depth comparable to the present one. The outcrop pattern of the older gravels 1 mile east of Osburn indicates that the bottom of the old channel came to within about 200 feet east of the level of the present valley. In the vicinity of Pinehurst, the old channel is at least as deep as the present valley. West of Pinehurst the main channel was much deeper, as a well drilled almost at river level near Spokane penetrated 1,090 feet of flat-lying beds of the Latah Formation before contacting the granitic gneiss basement (Pardee and Bryan, 1926, p. 9) (fig. 21).

LOWER BENCHES AND TERRACES

Remnants of benches and terraces below the broad valley stage are evident at many places along the main valleys within the Coeur d'Alene district. Hershey (1912, p. 519–524) described five such terraces in the vicinity of Kellogg at intervals of 30, 60, 200, 600, and 1,150 feet above the level of the present valley. Only the upper three terraces are well formed; the top one probably represents the broad valley stage. No attempt has been made to correlate these and other remnants at similar or different altitudes. Some are rock-cut benches having little or no surficial material remaining on them. These thin remnants of terraces along the east edge of Canyon Creek from 1 to 2 miles northeast of Wallace and the terraces bounding both sides of the valley of the South Fork of the Coeur d'Alene River eastward from Mullan were probably built up during a glacial episode and are described later.

OLDER GRAVEL DEPOSITS

All the surficial material except the alluvium in the valleys and those deposits considered to be of glacial origin has been mapped as a single unit, called the older gravels. These older gravels range in age from Tertiary to Quaternary. Although they lie at widely different altitudes, the location, outline, and mutual relation of most of the gravel occurrences indicate that they were laid down as part of the old channel fill that was deposited during the broad valley stage. The remaining gravels are younger and cap terrace remnants, most of which are not more than a hundred feet or so above the present valley levels.

Several of the older gravel deposits have been cut by bulldozer trenches in which the material can be seen to be relatively unconsolidated. Most of the deposits consist of gravel containing variable amounts of sand but also include some lensy patches of silt and clay. Rude stratification is evident at some places. Most of the gravel is rounded to well rounded and is predominantly quartzitic in composition, although all the rock varieties found within the drainage of the South Fork of the Coeur d'Alene River may be found within the deposits. The gravels show the effects of weathering, particularly the less quartzitic rocks which can be broken with ease. Calkins (in Ransome and Calkins, 1908, p. 56) noted that similar older gravels exposed in placer mining in the Murray district just north of the mapped area were in part stained orange by iron oxides. The gravels in the lower terraces, apparently much younger in age, differ only in being less consolidated and less decomposed.

GLACIAL FEATURES AND DEPOSITS

Studies in the Northern Rocky Mountain region around the Coeur d'Alene district defined several glacial stages during Pleistocene time (Alden, 1953). To the west of the district, lobes of the Cordilleran ice sheet advanced sufficiently southward down the Purcell Trench to dam the drainage of the Coeur d'Alene River at least twice near the Idaho-Washington boundary; the last advance probably took place during the Wisconsin (Anderson, 1940, p. 14–15; Alden, 1953, p. 142–146). Within the district, however, most evidence is indicative of only one period of glaciation, most likely the Wisconsin. The evidence consists of many small cirques, glacially striated bedrock, and remnants of drift in the valleys below the cirques.

The cirques, with only two exceptions, are all on north-facing slopes of the higher main ridges and at the heads of already established drainage channels. From his study of glaciation in the district, Dort (1954, p. 45) found that a minimum valleyhead altitude of 5,500 feet was necessary before erosion by ice was sufficient to form recognizable cirques. In general, the size and degree of erosion of a cirque increased with an increase in altitude above the 5,500-foot minimum. Only from the very highest cirques adjacent to the main divide between the South Fork of the Coeur d'Alene River and the Clark Fork on the east edge of the district was the ice flow sufficient to alter significantly the shape of the valley below. The greatest change is evident at the head of Canyon Creek, where the glacier from the head of the valley joined with glaciers from Upper and Lower Glidden Lakes areas and possibly the next gulch to the west and flowed more than 4 miles downstream to a point a short distance below the Burke substation, or to an altitude of almost 4,000 feet. Down to this point the profile of the valley has been changed to a U-shape and the floor is mantled by glacial debris, most of which is till. The glaciers in the cirques at the heads of the East and West Forks of Willow Creek apparently flowed far enough to coalesce, but it is doubtful that the combined glacier reached the valley of the South Fork of the Coeur d'Alene River. Glacially striated bedrock and small accumulations of drift are common below the lip of most of the rest of the cirques, but in only a few places are these deposits present for more than a few hundred feet down the valley.

The floors of several cirques are swampy or occupied by small lakes dammed by bedrock barriers. All the cirques sharply truncate what were once more subdued slopes but do not appear to be eroded headward much beyond the former line of the ridge crest. Two cirques are on east-facing slopes where their catchment basins, like those that face north, were somewhat protected from the sun's rays. One is on Tiger Peak and the other on Snowstorm Peak. A remnant of till in St. Regis Pass (pl. 5) indicates that ice flowed over the divide from a glacier in the St. Regis drainage and into the drainage of the South Fork of the Coeur d'Alene River. Evidence that trancept ice also flowed westward across the divide is to be found at the head of Canyon Creek just east of the mapped area.

Surficial material of glacial origin occurs within or just below almost every cirque, and sometimes farther down the valleys. Those deposits, however, which are small or only scattered in patches, are not shown on the maps. Both till, the material dropped directly by the glacier, and gravel transported by glacial streams have been found. Where observed in stream gullies or roadcuts, these glacial deposits appear quite fresh; there is no decomposed gravel. Many of the cobbles and boulders, particularly in the till, show sharply grooved striae.

By far the most extensive deposit of till covers the floor and lower walls of the upper part of the Canyon Creek valley; the width of this deposit is as much as half a mile. The surface of this material has an uneven, hummocky appearance and has barely been changed by stream erosion. Where seen in roadcuts, the till is poorly sorted and consists of unconsolidated material ranging in size from rock flour to large boulders. Some of the large quartzite boulders which are scattered on the surface are as much as 10 feet in largest dimension. Striae have been observed on the boulders. A cut along the road going up Sonora Gulch exposes several feet of horizontally bedded sand and silt at an altitude of about 4,200 feet, the upper limit of the till. The sand and silt were undoubtedly deposited in ponded water along the side of the Canyon Creek glacier.

Typical of the till occurring below the lips of many of the cirques is that exposed in several cuts along the switchback road that goes up Gorge Gulch to the upper workings of the Hercules mine. This till contains a high percentage of cobbles and boulders, many of which are only slightly rounded. Striae and soling are evident on some of these cobbles and boulders. The till appears to be a relatively thin veneer, ±20 feet thick, resting on the west slope of the gulch.

The sloping terraces east of Mullan are probably at least in part capped by glaciofluvial drift. This is particularly true for surficial deposits near the mouths of Willow Creek on the south side of the valley and the Little North Fork on the north side. Sorting is extremely poor in most of this drift because clay-size material is mixed with sand and gravel. Some of the boulders are as much as 20 inches in diameter. Most material larger than coarse-grained sand appears subrounded to rounded, but some of the cobbles and boulders are soled or are striated. Most of this material was probably washed down Willow Creek and the Little North Fork by glacial streams.

From a point about a mile below Gem, glaciofluvial material rims the east wall of Canyon Creek valley for almost 3,000 feet. The lower adits of the Formosa and Verda May prospects both cut this deposit. The first adit extends through 140 feet before intersecting bedrock, and the second adit, 200 feet. The material exposed in the workings usually consists of a quartzitic gravel and sand containing scattered thin lenses of sandy silt. Much of the gravel is cobble size or finer, although boulders as much as 4 feet in diameter are exposed in a pit dug for road metal. This deposit extends 75 feet above stream level.

Glacial erratics have been found at many places scattered along the lower valley walls westward from the vicinity of Kellogg. Hershey (1912, p. 521) was the first to describe them and found many scattered westward as far as Coeur d'Alene Lake. Glacial erratics include granitic and gneissic rocks and scattered pieces of basalt; all are alien to the district. None of the glacial erratics are similar to the monzonitic rocks of the Gem stocks. They generally range in size from a few inches to several feet and are commonly irregular in shape. Dort (1954, p. 93–102), who made an exhaustive search for the erratics, and plotted their position, found that they occurred up to an altitude of 2,650 feet (fig. 21); he also found clusters of them near this altitude on the west side of promontories that projected into the main valley. These erratics were probably rafted by ice upon a glacier-dammed lake whose shoreline reached a maximum altitude of about 2,650 feet. Evidence that a lobe of the Cordilleran ice sheet advanced sufficiently southward down the Purcell Trench to form a dam in the vicinity of the city of Coeur d'Alene, Idaho, has been found by Anderson (1927, p. 18). The variety of rock types present as erratics indicates that both sides of the Purcell Trench north to Pend Oreille Lake and beyond were source areas.

Modification of almost all of the glacial features by weathering and erosion has been insignificant, a fact which suggests that these features formed lated in the Pleistocene Epoch. Glaciation of a probable contemporary age in neighboring regions is considered to belong to the Wisconsin (Alden, 1953, p. 97–165; Flint, 1957, p. 331). Hershey (1912, p. 519), who suggested that an earlier period of glaciation had taken place in the Coeur d'Alene district, based his contention mainly upon evidence found beyond the boundaries of the district, and Dort (1954, p. 69–91) believed that the older gravels were mostly glacial outwash laid down during an earlier period. The older gravels, however, probably date back to the time of the extrusion of the Columbia River Basalt. Some glacial features, though, may antedate the latest glaciation. Glaciofluvial material in terraces along the main valley just east of Mullan and a narrow terrace remnant on the southwest side of the lower valley of Canyon Creek may have been deposited during an earlier glacial episode. The erratics which were ice rafted as far east as Kellogg were probably dropped at about the same time as this terrace material. The terminal moraine of the last lobe of the Cordilleran ice sheet (Wisconsin) forms the shore at the south end of Pend Oreille Lake, although an earlier lobe advanced more than 20 miles farther to form the ancient Coeur d'Alene Lake (Anderson, 1927, p. 14–19). It was on this earlier lake that the erratics were rafted eastward to the district. The arm of this lake that occupied the valley of the South Fork of the Coeur d'Alene River must have extended to the vicinity of Wallace. The glaciofluvial deposits remaining along lower Canyon Creek and east of Mullan were probably built up while the lake was at a maximum and the streams flowing into it were aggrading their courses.

ALLUVIUM

Westward from the vicinity of Wallace, the South Fork of the Coeur d'Alene River is an aggraded stream, as indicated by the extent of the alluviated valley flats. This is also true for part of the lower courses of several tributary streams west of Wallace, particularly Pine Creek. Coeur d'Alene Lake, almost 20 miles to the west of Pine Creek, is the base level behind which the alluvium has been accumulating. It has probably been near the present level since the last glacial stage when the main drainage channel was dammed again by glacial debris. Just below Wallace the thickness of the alluvium is probably not more than a few tens of feet, for just east of the city the stream flows almost on bedrock through a narrow constriction. At the west end of the district, however, the alluvium is much thicker. A well drilled near the center of the valley flat at Pinehurst penetrated almost 300 feet of unconsolidated material, containing mostly silt and well-preserved wood fragments, without penetrating bedrock (fig. 21).

Upstream from the level of aggradation, the streams are usually narrow and have only a thin veneer of alluvium flooring their bottoms. At places, however, the valleys widen perceptibly because of rapid erosion of highly fractured rock along major fault zones. A good example is the wide section of the valley of the South Fork of Coeur d'Alene River east of Mullan, where it is carved out of the wide shear zone along the trace of the Osburn fault. Conversely, in places the main valley is narrow but aggraded. Such situations appear to result from the superposition of the stream along a new channel at some time prior to the period of major aggradation. The best example of this is at the west end of the district, where the South Fork flows within a narrow channel north of Kingston Ridge; formerly the South Fork had flowed in a wider valley south of this ridge.

The alluvium observable in the valleys consists almost entirely of unconsolidated sand and gravel, in part capped by a thin film of gravelly soil. Most of the gravel is well rounded but becomes less well defined in the upper courses of the tributary streams. Evidence gained from the well drilled at Pinehurst indicates that much of the buried alluvium toward the west end of the district probably consists of finer sediments that were deposited in ponded water.

With the beginning of mining, tailings from the mills were dumped into the streams and were then deposited as thin veneers that covered large tracts of some of the wider valley flats. The principal accumulations of these tailings were on the flat along Canyon Creek northeast of Wallace, on the valley floor of the South Fork east and west of Osburn, and also west of Kellogg. These accumulations consisted mainly of jig tailings a quarter of an inch or smaller in size, and some accumulated behind temporary dams. The jig tailings contained an appreciable amount of metals, and these accumulations where thick and rich enough were reworked in the 1940's. The localities where this mining took place now have the appearance of desolate placer ground. The tailings now dumped into the streams are from flotation mills and, being finer, are flushed downstream to a dam several miles west of the district, where most of them are trapped, pumped out, and deposited on a large flat.

STRUCTURE

The Coeur d'Alene district lies at the intersection of a broad arch that extends at least from Kimberly, British Columbia, south to the St. Joe River in Idaho and the Lewis and Clark line (Billingsley and Locke, 1939, p. 36) represented by the Osburn and related faults. The rocks of the district were intensely deformed in a complex pattern which can be referred to as a structural knot.

Virtually all the bedded rocks were tilted and most now dip at angles greater than 45°. Dips less than 10° are scarce, but near-vertical dips are common and many beds are overturned. The rocks were sheared and faulted, and phyllites and even some schists formed by processes of dynamic metamorphism in many parts of the district.

The general pattern of folds and faults in the district and in the surrounding region is shown in plate 9. This pattern is dominated by the Osburn fault, a very extensive structural feature that strikes west-northwest and has a large strike-slip displacement. Most of the folds and faults south of the Osburn fault trend parallel or subparallel to it, but north of the Osburn fault both the major folds and faults trend more nearly north. This north trend is paralleled by elongation and alinement of the monzonite stocks. This intersection of north-trending and west-northwest-trending faults and folds is one of the most pronounced features and possibly one of the most significant structural patterns of the district in relation to mineralization.

FAULTS

Faults are the dominant structural features of the Coeur d'Alene district; understanding them is the key to the geologic history and the localization of the ore deposits. Myriad faults cut the region into a complex pattern of blocks, and for every fault shown on the accompanying maps, there are hundreds of others, most of only slight displacement, that can be seen only in underground workings. The positions of veins are controlled by fractures: some fractures have served as channels for ore-bearing solutions, others have acted as dams to hydrothermal solutions, and still others, formed after the veins, have offset the veins and even centers of mineralization. The pattern of folds has been greatly altered by faults; even the largest folds have been segmented by major faults, and some segments have been separated for many miles. Large folds have also been dragged and sharply flexed by movement along faults. Faults have strike lengths as much as tens of miles and net slip displacements as much as several miles. The overall structural pattern is complex, but certain general patterns characterize different parts of the area.

Between the Osburn fault and the Placer Creek fault, which roughly parallels the Osburn about 3–4 miles to the south, are many other faults that trend northwest diagonally across the block and form connecting links between the Osburn and Placer Creek faults. Most of these faults dip steeply southwest; some are reverse, some are normal, and some are strike slip.

The area north of the Osburn fault is characterized by north and west-northwest structural trends; the two sets are in part separate and in part overlapping. Some faults in each set are normal, some are reverse, and some are strike slip. The north-trending Dobson Pass fault roughly bisects this area and is unusual in having a dip of 30° W. and normal displacement of at least 14,000 feet of apparent slip. West of the Dobson Pass fault, the Carpenter Gulch and Blackcloud faults also dip to the west but have reverse displacement. East of the Dobson Pass fault north and northwest-trending faults are the most persistent, but a second set trends more nearly west or west-northwest. Most of the faults in the north-trending system have steep dips; some have reverse displacement whereas others have normal displacement. The west-northwest-trending faults are more numerous, but they are generally less persistent than the others, and the displacement along most is less than that along the larger north-trending faults. Dips are also steep, and faults of reverse, normal, and strike-slip displacement make up this system.

The variety of faults that disrupt the rocks in the Coeur d'Alene district can be grouped as follows: (a) Low-angle reverse faults, (b) early steep-dipping reverse and normal faults, (c) strike-slip and related normal faults, and (d) late normal faults. The low-angle reverse faults probably formed relatively early in the history of faulting, and the strike-slip faults probably formed relatively late. Reactivation of some faults, perhaps with reversal or change of the orientation of net slip, is probable. The major period of mineralization probably succeeded the formation of low-angle reverse faults as well as some of the steep reverse and normal faults and was probably also related to the early phases of strike-slip deformation. Later phases of strike-slip deformation cut and displaced veins and zones of mineralization.

Fault gouge and sheared, crumpled or highly fractured rocks are associated with all the faults having large enough displacement to warrant mapping. Most faults, even of minor displacement, are first recognized underground by a zone of gouge and sheared rock. There is probably a correspondence between the width of a zone of gouge and sheared rock along a fault and the amount of displacement, but the width of gouge and sheared rock also depends upon such things as rock type, configuration of fault plane, ratio of normal to shearing stress, and rate of deformation. In quartzite, the strain along a fault of given displacement is characterized by a relatively narrow zone of gouge bordered by a zone of breccia which grades outward into a stockwork of small shears and joints. In argillite, along a fault of similar displacement, the strain produced a relatively wider zone of gouge bordered by a zone of contorted and crumpled rock. The entire fault zone in argillite is mapped most commonly as being wider than the entire zone in quartzite, yet in quartzite the border of the disturbed zone is more difficult to define, and jointing of the quartzite far from the fault plane may be recognized only with difficulty as being part of the deformation related to the fault. In a few specific places, where quartzite borders one side of a fault and argillite the other, the width of the recognizable fault zone is slightly narrower than if it were bordered on both sides by argillite.

A few faults of large displacement have very narrow zones of gouge and sheared rock where seen underground. More commonly, wide zones of disturbed and crumpled rock occur along some faults on which there is relatively little apparent displacement. Many of the veins are in such fracture zones having little displacement but having a wide zone of sheared rock.

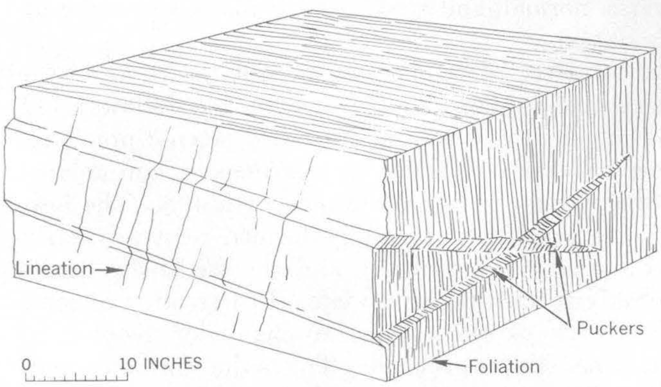


FIGURE 22.—Block diagram showing relation of puckers, foliation, and a type of lineation that crosses pucker fold axes nearly at right angles.

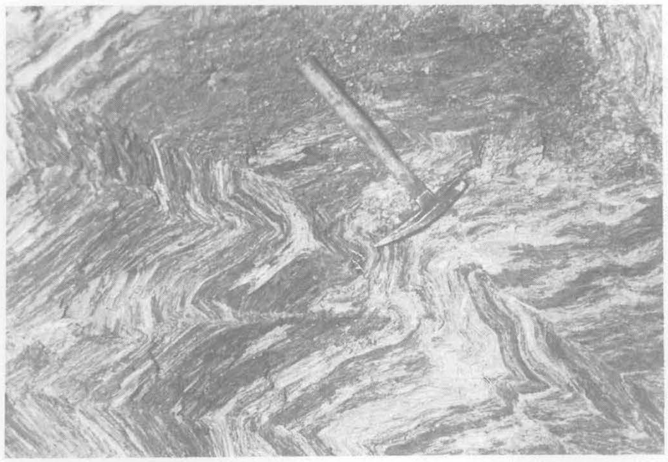


FIGURE 23.—Puckers in phyllitic rock in the lower part of the Wallace Formation, National tunnel.

Bedding-plane slippage and puckering are additional types of faulting or shearing that are common in the district. The amount of deformation attributable to them, however, is difficult to appraise. Puckers was a term used by Hills (1953, fig. 66*A*, p. 108) for Z-shaped flexures which form in secondary shear zones crossing foliated rock; the folia are sharply bent during the puckering, but are not broken (figs. 22 and 23 and Wallace and Hosterman, 1956, p. 600). In many places the sum of displacements along numerous small bedding-plane faults must account for a large amount of distortion of the rocks, but because the displacement is parallel to the bedding, the amount of total strain is seldom determinable. Similarly, in phyllitic masses, puckers commonly represent a large amount of shearing, but as original structures are obscured, the net effect can seldom be recognized. For example, in the Gold Hunter tunnel a rough totaling of the offsets on individual puckers indicated more than 1,000 feet of shearing strain.

In the following descriptions of the individual faults an attempt has been made to define their continuity, to describe their geometry, and to give what evidence is available on the history and mechanics of their formation. The nature of the formation and displacement for many faults is uncertain. The Osburn and several other major faults are discussed first. The remainder of the descriptions are subdivided according to the special map area in which the faults occur. Some faults are continuous across more than one map area, and their descriptions have been separated according to where the major part of the fault lies or where it is best exposed. Many other faults, which are shown on the maps, are not described. These have had only small displacement along them or are only poorly delineated.

MAJOR FAULTS

OSBURN FAULT

The Osburn fault has been mapped almost continuously from Fernan Lake near the city of Coeur d'Alene, Idaho, eastward for more than 105 miles airline to a point about 7 miles due east of Superior, Mont. (pl. 9). Only a small segment, about 1½ miles long, immediately east of the Kootenai-Shoshone Counties line is not shown on published maps, but the structural feature can be projected across the gap with confidence. The fault is best known and apparently has its maximum displacement in the Coeur d'Alene district. Anderson (1940, p. 28) reported that the fault appears to "decrease in magnitude" west of the Fourth of July summit about 12 miles southeast of Coeur d'Alene, and that the extension of the fault west of that city is lost to view under basalts of the Columbia Plateau and the gravels in the Purcell Trench. The Osburn fault is a major structural feature at the easternmost point to which it has been mapped in the vicinity of Superior, Mont., but Campbell (1960) believed that the displacement along it at this point is considerably less than in the district. Campbell and Hobbs, who made a reconnaissance by airplane east of the St. Regis-Superior area in Montana, reported that the fault can be recognized by physiographic features for many miles east of that area.

The Osburn fault is the major structural feature in the area that includes the western part of the Lewis and Clark line. This line was described by Billingsley and Locke (1939, p. 36) as a northwest-trending tear fault of continental scale. It consists of a series of discontinuous ruptures within an ill-defined linear zone that can be traced northwest from south-central Montana almost to Spokane, Wash., a distance of more than 500 miles. Within the Coeur d'Alene district the Osburn fault makes up a single zone of faulting along which most of the movement within the Lewis and Clark line took place. Anderson (1940, p. 28–29) indicated that immediately to the west in Kootenai County a greater amount of adjustment occurred along the Burnt Cabin fault, which diverges from the north side of the Osburn fault with a slightly more northwesterly trend. From a point about 8 miles east of the district, the Osburn fault splits into two major strands and continues southeastward as separate north and south branches a mile or more apart for almost 15 miles before apparently joining again (Wallace and Hosterman, 1956, p. 589–591 and pl. 48). No means of determining the amount of movement along these branches was found, but it appears to have been large along both of them. Campbell (1960) believed that to the southeast in the St. Regis-Superior area the largest displacement along the Lewis and Clark line has followed the Boyd Mountain fault, which diverges from the south side of the Osburn fault at a slightly greater angle to the southeast.

The Osburn fault generally trends west-northwest. A straight line drawn through the westernmost and easternmost points mapped strikes about N. 70° W., but locally different segments of the fault have strikes ranging from N. 55° W. to due west. Nevertheless, the trace of the fault is remarkably linear over its known length, and a straight line more than 100 miles long can be drawn from which no part of the Osburn fault trace diverges more than 3.5 miles. Individual segments of the fault a few miles or more long are very straight, and the broad divergences from the regional strike show only in gross pattern. Between Mullan, Idaho, and Superior, Mont., the trace of the fault is bowed gently concave to the south, and between Mullan and Coeur d'Alene, Idaho, the trace is bowed somewhat irregularly concave to the north.

Within the five special map areas of the present study, smaller scale departures from a linear straight line pattern are noticeable. In the Pottsville map area the strike of the fault is N. 88° W. and at the town of Mullan it changes rather sharply to N. 77° W., a direction that is maintained nearly across the entire Mullan map area. Where the fault crosses Canyon Creek, near Wallace, there is a noticeable two-fold bend in the fault trace so that the segments to the east and west are not alined even though they have the same strike. This bend in the fault trace approximately coincides with the point of junction of the Dobson Pass fault, a possibly significant relation. West of Osburn in the Wallace, Kellogg, and Smelterville map areas, the dip of the fault is at a relatively lower angle and the irregularities of the surface trace of the fault are due to the ups and downs of the topography rather than to any sharp changes in the strike of the fault plane.

Along the entire length of the Osburn fault, its position is prominently marked by physiographic features. Perhaps the most striking ones that reflect the location of the fault are saddles or notches which have been eroded in ridges where these are crossed by the fault. In some places, as in the vicinity of Osburn and east from Mullan, the fault has controlled the course of the valley of the South Fork of the Coeur d'Alene River and lies hidden under alluvium. More typically, the fault is not followed by major drainage channels, an apparently anomalous relation but one that results from a complicated Cenozoic history. Tributary drainage, on the other hand, is invariably channeled along the highly fractured zone of the fault.

The dip of the fault ranges from about vertical, or possibly very steep to the north, to about 55° S. Westward from Osburn both surface and underground evidence indicate a dip to the south. At the Bunker Hill mine in the Kellogg tunnel, for example, the fault dips at an angle of about 55° S. Eastward from Osburn the dip steepens and at Mullan the relative positions of the fault at the surface and in the main crosscut of the Morning mine indicates a steep dip to the north. Anderson (1940, p. 28) reported that the fault probably has a south dip in Kootenai County, Idaho, to the west of the Coeur d'Alene district, and Campbell (1960) reported that at the Nancy Lee mine near Superior, Mont., 40 miles to the east, the relation of surface to underground position of the fault and the orientation of individual gouge zones seen underground indicate a dip of about 80° S.

The width of the zone of fractured and sheared rock along the fault varies considerably from place to place, but in most places where the zone has been cut underground its width is more than a hundred feet. This zone contains numerous gouge seams, and quartzitic rocks within it are intensely brecciated and the more argillitic rocks are foliated and crumpled. The width of the zone, although dependent to a large extent upon the competency of the rocks bordering the fault at a particular point, is undoubtedly also greatly affected by the geometry of the fault zone with respect to stress distribution. For example, at a bend in the fault plane stresses may be relatively greater and so extreme brecciation may result. In the main crosscut of the Morning mine, near Mullan, the Osburn fault zone is 800 feet wide, but within this general zone of disturbance a more intensely sheared and brecciated part, 400 feet wide, undoubtedly accommodated most of the displacement (fig. 24). In still finer detail within the 400-foot-wide zone, four separate zones of clay gouge, 10–60 feet thick, are the major loci of movement along the fault. Contrasted to this, only 1.5 miles to the west where the Osburn fault is cut by workings of the Alice mine, Ransome (in Ransome and Calkins, 1908, p. 170) reported: "About 350 feet from the portal the tunnel cuts through the Osburn fault here marked by 1–2 feet of soft dark clay gouge accompanied by much shattered quartzite. In fact, the Burke beds are broken or shattered for at least 150 feet from the gouge."

The reason for this difference in the width of the fault zone and intensity of brecciation and crushing at points so near to one another on the same linear segment of the fault is not obvious. Argillitic rocks of the Wallace Formation border the south side of the fault and quartzitic rocks border the north side at both localities, although at the Morning mine the quartzite beds are impure and are part of the St. Regis Formation, whereas at the Alice mine the quartzite beds are relatively pure and are considered to be part of the Revett Quartzite. The difference in competency of the quartzite beds may be partly responsible for the difference in the effect of faulting, but it seems unlikely that this difference accounts for such a wide variance. In the main crosscuts of the Golconda and Granada mines about 1.5 and 2 miles, respectively, west of the Alice mine, the intensity of deformation along the fault compares more nearly to that in the Morning crosscut. At the Golconda mine the fault zone is made up of several strands of gouge plus breccia and foliated rocks in a zone more than 300 feet wide (fig. 25). At the Granada, the zone south of a cave-in which blocked the crosscut, the fault zone is more than 150 feet wide and the rocks are complexly foliated, fractured, and pulverized as in the Golconda crosscut. Argillite of the Wallace Formation borders the south side of the fault at both the Golconda and Granada mines. Impure quartzite of the Burke Formation lies north of the fault at the Golconda mine, and quartzose argillite of the Prichard Formation lies north of the fault at the Granada mine.

In the main adit of the Silver Dollar mine near the west edge of the Wallace map area, the Osburn fault consists of a zone nearly 200 feet wide that is composed of numerous fault strands, including about 80 feet of gouge and breccia, where the adit is tightly lagged. In the main crosscut at the Bunker Hill mine in the Kellogg map area, the fault zone is reported to be composed of only a few feet of gouge plus some phyllitic rock and breccia, but the details of the fault zone are now hidden by a lining of concrete. At the Morning, Alice, Golconda, and Granada mines, the attitude of the fault is nearly vertical or it dips steeply to the north, whereas at the Silver Dollar mine a major fracture in the fault zone dips 80° SW., and at the Bunker Hill mine the dip is about 55° SW. Farther west in the vicinity of the Page mine, however, the dip is greater than 70° S. The variations in dip from place to place probably result from local variations in the dip of the fault plane, as exposed in a single crosscut. Dips that can be measured over a considerable depth are generally steep.

STRIKE SLIP ALONG THE OSBURN FAULT

Hershey (1916, p. 2–5) was the first to suggest that many miles of a right-lateral strike slip had taken place along the Osburn fault; Umpleby and Jones (1923, p. 11–13) and Umpleby (1924) gave additional

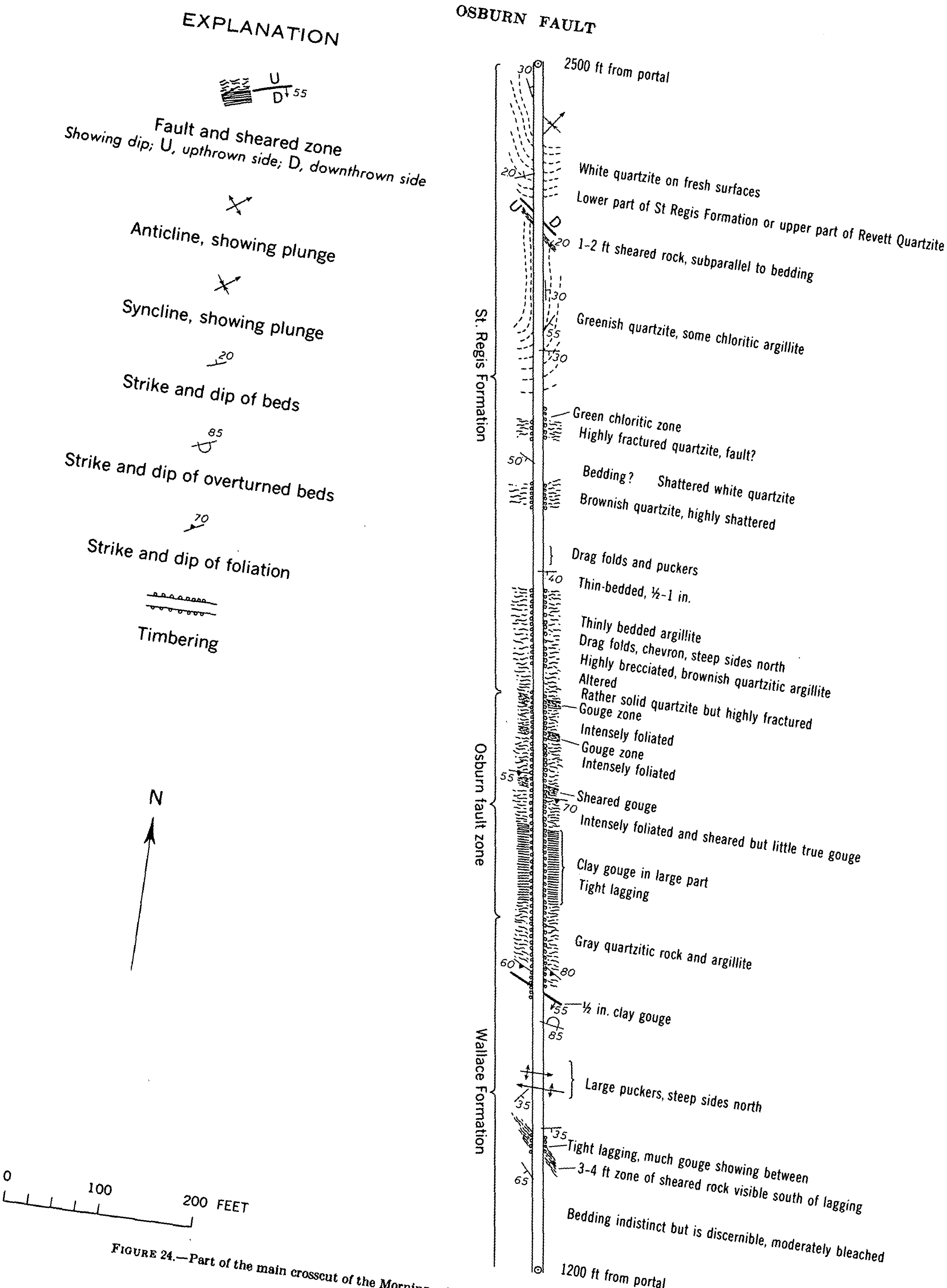


FIGURE 24.—Part of the main crosscut of the Morning mine in the vicinity of the Osburn fault.

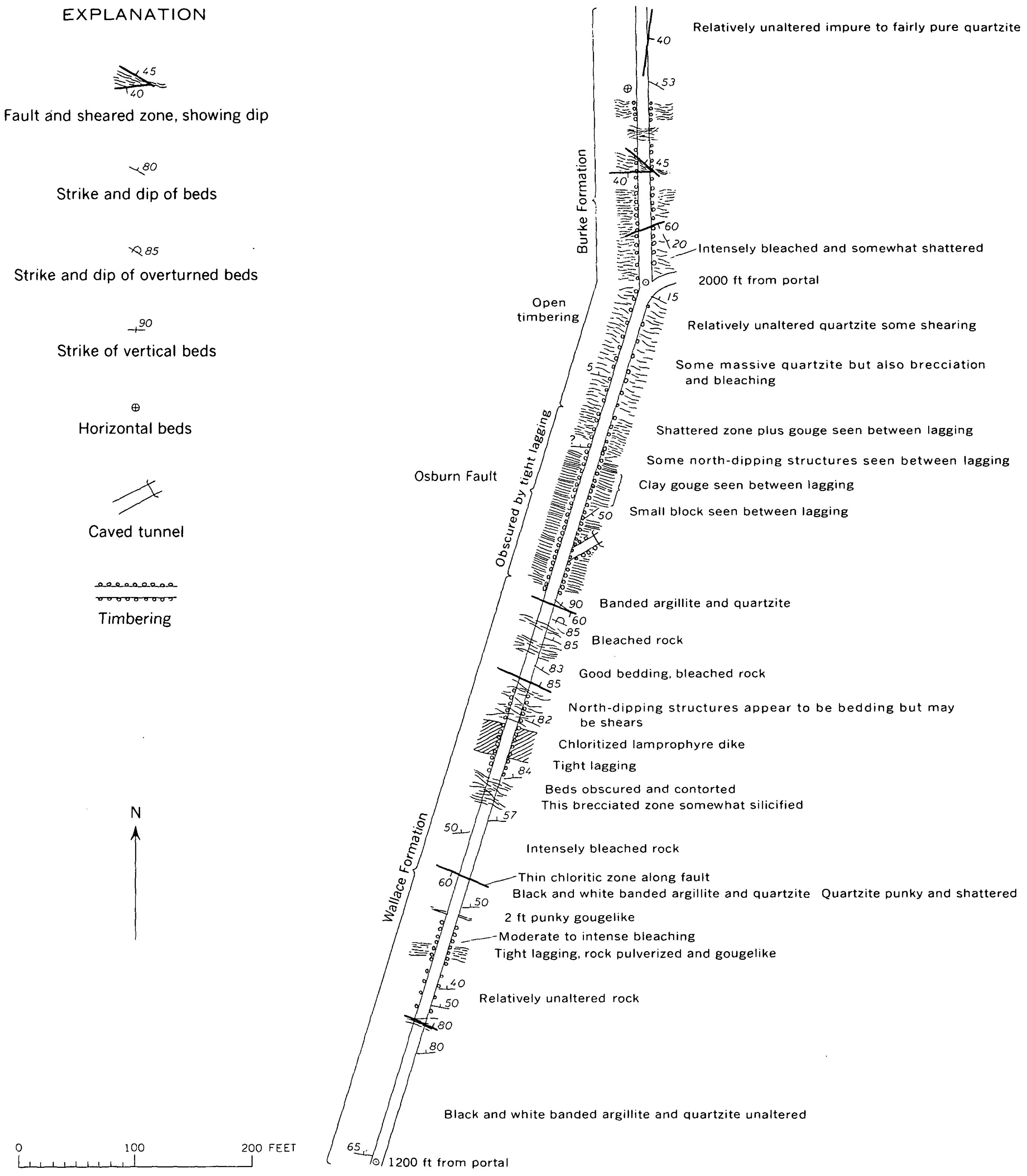


FIGURE 25.—Part of the main crosscut of the Golconda mine in the vicinity of the Osburn fault.

evidence to support this thesis. The present conclusion, based upon review and analysis of old and new evidence, is that a large right-lateral strike-slip movement did occur. The maximum amount of displacement is probably about 16 miles. No single line of evidence is conclusive proof of such a large movement, and other interpretations fit some of the structural and lithologic relations found in the field, but no other interpretation so adequately fits all these relations. Evidence also has been found to suggest that the ore deposits originated relatively early in the formation of the Osburn fault structural pattern and indicates that a large part of the 16 miles of displacement took place later than the formation of most of these ore deposits. The evidence for lateral displacement is impressive; the evidence for the date of movement is subject to other interpretations.

The thesis of large strike slip has never been accepted by all concerned with the geology of the Coeur d'Alene district. The interpretation of a large strike slip and its time relation to time of ore deposition is obviously of great economic importance as well as geologic significance, and because of this relation the evidence is discussed here in considerable detail and various interpretations are weighed one against the other. The principal lines of evidence for strike-slip displacement, the amount of movement, and the time of movement are tabulated below and are discussed in the paragraphs that follow.

1. Offset of large upwarped blocks more or less delineated by areas of outcrop of the Prichard Formation.
2. Offset of major folds and faults and dissimilarity of structural features on opposite sides of the fault.
3. Differences in lithology of formations on opposite sides of the fault.
4. Large-scale drag features.
5. Offset of similar features along parallel or subparallel faults.
6. Position of major mining areas on opposite sides of the Osburn fault and the pattern of ore and gangue mineral distribution within the district.

Some of the ideas expressed here have previously been stated orally by geologists of various companies. Roger McConnel, Chief Geologist of the Bunker Hill Co., in particular, has presented similar concepts on several occasions, but it is difficult to know exactly with whom or at what time a particular shade of interpretation has originated.

OFFSET OF LARGE UPWARPED BLOCKS

The areas of outcrop of the oldest formation in the district, the Prichard, are shown on plate 9. These represent the general shape, but not the overall extent of large areas of general upwarp. Umpleby and Jones (1923, p. 12) recognized two of these unwarped blocks on opposite sides of the Osburn fault which they considered to be segments of a single broad elliptical-shaped anticline that had been separated by about 12 miles of right-lateral slip. The core of each anticline occupies an area of several tens of square miles, and each has a reverse fault of northwest strike and southwest dip along its east margin.

The southernmost of the two anticlinal blocks, here called the Pine Creek anticline, borders the Osburn fault on the south side. The northern border of this core area, as outlined by the outcrop of the Prichard Formation, extends from 1.5 miles east of Pinehurst westward for about 7 miles to near Cataldo Mission about 4 miles beyond the west edge of the Smelterville map area. Its shape of outcrop is crudely that of a segment of an ellipse whose long axis extends roughly from Pinehurst southeastward for about 6 miles. The Government Gulch fault, which includes the Page fault at its north end, is a reverse fault that lies along the east margin of the core block.

The northern upwarped area of Prichard Formation borders the Osburn fault on its north side from near Kellogg eastward for about 8 miles to near Revenue Gulch in the vicinity of Wallace (pl. 9). This is here called the Moon Creek anticline. The core of the Moon Creek anticline also has the shape of a segment of an ellipse whose long axis extends roughly from Osburn northwestward for about 7 miles. The Carpenter Gulch fault is a reverse fault along a part of its east edge.

The similarity of shape, size, and trend of these two domelike anticlines, the fact that each is bordered on the east by a reverse fault of similar trend, and the fact that they both border the Osburn fault for nearly equal distances strongly suggest that they are segments of a single large, elliptical-shaped domelike structural feature, which has been displaced by strike slip but by little or no dip slip. The east margin of Prichard outcrop area in the core of the Pine Creek anticline is now 12 miles west of the equivalent east margin in the Moon Creek anticline. The offset of the axes of the two domelike segments similarly represents about 12 or 13 miles of strike slip, although the exact intersection of the axes and the Osburn fault cannot be precisely delineated. The west margins cannot be matched accurately, because the west margin of the Moon Creek anticline has been complicated by the Kellogg and Blue Star faults (pl. 9).

Other areas of outcrop of the Prichard Formation lie to the west of the Coeur d'Alene district in Kootenai County, where Prichard rock borders both the north and south sides of the Osburn fault (Anderson, 1940, p. 12) from Coeur d'Alene Lake eastward to about the east edge of Kootenai County. The east edge of this Prichard terrain is similarly offset by strike-slip displacement, but the displacement is only about one-half that indicated by the separation of the Moon Creek and Pine Creek anticlines. The upwarps of Prichard terrain within the area to the west of the district are sufficiently different north and south of the fault to preclude a good match of the two sides, and the amount of apparent strike-slip offset probably has no relation to the exact amount, although the type of offset is corroborative evidence of right-lateral displacement. A. L. Anderson (1940, p. 28) reported that the displacement of the Osburn fault decreases in magnitude westward in Kootenai County; this observation is consistent with the evidence indicating less movement.

No other outcrops of Prichard Formation are known to border the south side of the Osburn fault or to be within 10 miles of it, for a distance of more than 80 miles to the east of Kellogg. As one goes eastward along the south side of the fault, younger stratigraphic units are found exposed at the surface. Thus from Coeur d'Alene Lake eastward for more than 100 miles along the Osburn fault, the Pine Creek anticline on the south is the only unwarp that is at all comparable with the Moon Creek anticline on the north. The fact that there is only one such structural feature in the general area adds to the credence of the interpretation of strike slip.

The facts that the length of outcrop of the Prichard Formation along the fault is about equal in the Moon Creek and Pine Creek anticlines and that the two outcrops of the Prichard Formation are comparable in areal extent are taken as evidence that there has been little differential uplift of either block and that net slip along the fault has been mainly along the strike. Elsewhere along the fault, as in Mineral County, Mont., evidence indicates oblique slip (Wallace and Hosterman, 1956, p. 590–591).

Another large area of outcrop of Prichard rocks lies north of the Osburn fault and east of the Moon Creek anticline within the core of a broad but separate upwarp that extends from the vicinity of the Gem stocks north and northeast for about 20 miles into the Trout Creek quadrangle (Gibson and others, 1941, pl. 1; Hosterman, 1956, pl. 57). This is referred to as the Burke-Trout Creek anticline, and is bounded on its west side by the normal Dobson Pass fault, which dips 30° W. Displacement along the Dobson Pass fault is estimated to be about 4 miles, and the small monzonitic plutons in the Dudley Creek area might be offset cupolas that once extended upward from the Gem stocks. If this interpretation is valid, the total right-lateral offset along the Osburn fault east of the Dobson Pass fault must be 4 miles greater than the 12 miles suggested west of the Dobson Pass fault.

OFFSET OF MAJOR FOLDS AND FAULTS AND DISSIMILARITY OF STRUCTURAL FEATURES ON OPPOSITE SIDES OF THE FAULT

Hershey (1916, p. 2) stated: "* * * I tried vainly to fit together the country on opposite sides of the fault. Anticlines are in line with synclines and the apparent displacement varies from less than 1,000 to more than 10,000 ft." Umpleby (1924, p. 602) added: "* * * even allowing for such vertical displacements, it is impossible to fit the opposite sides together into anything like a regular arrangement."

These and many other geologists have recognized a great difference in structural features and trends on opposite sides of the Osburn fault within the district. Plate 9 illustrates the structural discontinuity at the Osburn fault. The striking difference in the gross structural pattern is a nearly right angle change of structural trends on opposite sides of the fault. North of the Osburn fault, in the area between the Carpenter Gulch fault and the Glidden Pass anticline, most of the folds and faults trend north; directly opposite on the south side of the fault, the folds and faults trend west-northwest, approximately parallel to the Osburn fault. In detail, however, this abutment of structural features is not directly at the Osburn fault but, rather, is more nearly along secondary structural features that nearly parallel the Osburn fault ½–1 mile to the north. The Paymaster fault is the most conspicuous of these features. Because of their adjacent position and their trend, these secondary structural features are probably a part of the major Osburn strike-slip system.

As Hershey and Umpleby have indicated, the structure within the zone of influence of the Osburn fault is, in many places, extremely complex and distorted beyond resolution, and the matching of structural details immediately across the fault is impossible. However, if the structural detail within a strip about a mile on each side is ignored and only the gross pattern of folds is considered, a duplication of pattern on opposite sides of the fault can be recognized. The distinctive features that can be recognized on both sides of the fault are a pair of major anticlines and the intervening syncline. North of the Osburn fault and east of the crest of the Burke-Trout Creek upwarp, the Burke anticline, Granite Peak syncline, and Glidden Pass anticline make up a succession of folds that are truncated at right angles by the Osburn fault. South of the Osburn fault and east of the crest of the Pine Creek anticline, the Big Creek anticline, the Lookout downwarp, and the Lookout upwarp make up a west-to-east succession of companion folds (pls. 9 and 10*F*). Structural complexities were superimposed upon these folds during deformation, and they are now in an echelon arrangement. These complexities have masked the similarity of the folds to each other or the similarity between the two sets. The northwest ends of these folds south of the fault are truncated by the Osburn fault at a very low angle in contrast to the ends north of the fault. These three-unit sets of large folds, each set lying east of a major upwarped block, probably had composed one set of major folds. This interpretation requires the presence of a nearly right angle bend in the trends of the folds at about the line of the Osburn fault. A remnant of such a bend is preserved at the south end of the Granite Peak syncline, where its east flank is warped to the east just north of the Deadman shear zone, which truncates the fold. The Mill Creek syncline (pl. 4) and Deadman syncline (pl. 5) may also represent a single fold whose axis has been warped into a nearly right angle bend (pls. 5 and 10*F*).

The only set of companion folds—the Big Creek anticline, Lookout downwarp, and Lookout upwarp—lies in a truncated position on the south side of the Osburn fault in the 105-mile interval between Coeur d'Alene, Idaho, to the west and Superior, Mont., to the east. In fact, along this continuously mapped segment, no other major fold on the south side is completely truncated by the Osburn fault. This one set of folds seems to be unique, particularly when coupled with the major Pine Creek upwarp immediately to the west. Only the gross pattern, of course, can be compared. The Dobson Pass fault and many others that diverge to the north from the Osburn fault, together with anticlines and synclines that are secondary to the major folds, are features that have complicated any detailed matching of the two sides. There are also differences in the gross structural characteristics of the major folds north and south of the fault. Although these folds have about the same amplitude and wavelength in the two areas, they are relatively less complicated and disturbed in the Burke-Glidden Pass area north of the Osburn fault than they are south of the fault.

Wallace and Hosterman (1956, p. 598) described the apparent low-angle truncation of the Boyd Mountain anticline by the Osburn fault, and recognized the possibility that the Lookout upwarp might be the western extension of the Boyd Mountain anticline. This implies that the Osburn fault has sliced off a northward bow in a Lookout-Boyd Mountain anticline. Because the axis of the Lookout upwarp (pl. 10*F*) has a southward bow, this fold is truncated at the west and east ends by the Osburn fault. If one presumes the strike slip has been of a right-lateral type extending for about 16 miles, then the sliced-off northward bow of a Lookout-Boyd Mountain anticline should be found north of the Osburn fault about 15 miles east of the district in the vicinity of Haugan and Deborgia, Mont. The Rock Creek anticline does occur in proper position, but no recognizable features relate it to the Lookout-Boyd Mountain anticline. In fact, the east end of the Rock Creek anticline is tight and overturned, whereas the Boyd Mountain anticline, to which the Rock Creek anticline might have been joined at one time, is broad and open up to the plane of truncation by the Osburn fault. Therefore, this relation is only permissive evidence of strike slip.

Offset of faults provides another line of evidence, but, in general, matching of possible segments of individual faults across the Osburn fault is less certain than matching gross structural features such as large upwarped areas or groups of folds which by their very nature are much more surely recognized and less likely to end abruptly. The possible correlation of the Carpenter Gulch fault north of Osburn with the Page-Government Gulch fault southeast of Pinehurst is suggested above. These are reverse faults of relatively shallow dip and comparable stratigraphic displacement. Whether the Carpenter Gulch fault extends as far south as the Osburn fault is not known for certain. On the map (pl. 3) the Carpenter Gulch fault is shown ending about 2 miles north of the Osburn fault, but could easily have escaped notice in the intervening and monotonously similar rocks of the Prichard Formation. The Blackcloud fault north of the Osburn fault may be a possible correlative of the Alhambra fault south of the Osburn fault. Hershey (1916, p. 5) suggested that the White Ledge fault (presumably as mapped by Calkins, 1908) might also be the correlative of the Alhambra fault. If the interpretation that the top of the Ninemile-Canyon Creeks area has been offset along the Dobson Pass fault is correct, all three, the Blackcloud, Alhambra, and White Ledge (or more likely the Paymaster fault on current maps) might represent parts of the same fault, or perhaps at least the same zone of faulting. This latter suggestion, although possible, is no more than speculation based on a rather tenuous extrapolation of the strike-slip theory.

DIFFERENCES IN LITHOLOGY OF FORMATIONS ON OPPOSITE SIDES OF THE OSBURN FAULT

A change in facies for both the St. Regis Formation and the Revett Quartzite has been noted to the east of the Coeur d'Alene district in Mineral County, Mont. (Wallace and Hosterman, 1956, p. 580–583). The zone of transition from one facies to the other trends approximately north to northeast, at about right angles to the Osburn fault. This transition between lithologic facies takes place much farther east on the north side of the Osburn fault than it does on the south.

As described in the section on stratigraphy, the upper part of the St. Regis Formation in the east half of the district consists of green argillite in contrast to the much thicker lower part that consists of interbedded purplish-red quartzite and argillite. On the south side of the Osburn fault, within 5 miles east of the Montana-Idaho State line, the green facies has completely replaced the purple facies and is the only type of rock found between the underlying Burke-Revett quartzitic rocks and the overlying rocks typical of the Wallace Formation. Opposite this locality of the all-green St. Regis Formation and north of the Osburn fault, the St. Regis Formation consists mostly of faulted segments that generally are poorly exposed. Nevertheless, it is evident that these rocks include some of the western purple facies. Along the upper reaches of Twelvemile Creek, more than 20 miles east of the State line, an apparent complete section of the formation consists predominantly of the somewhat more argillitic purple facies. Within the district such a marked lithologic difference on opposite sides of the Osburn fault is not so noticeable, but the St. Regis Formation is consistently thicker south of the fault.

The Revett Quartzite on both sides of the Osburn fault in the Coeur d'Alene district is almost entirely a light-colored vitreous quartzite, but south of the Osburn fault and eastward from about the Montana-Idaho State line into Mineral County, the Revett contains major amounts of impure quartzite and argillite (Wallace and Hosterman, 1956, p. 580–581). North of the Osburn fault in Mineral County, the Revett Quartzite still consists predominantly of light-colored vitreous quartzite as far east as Camels Hump Mountain 25 miles from the State line. Farther east in the St. Regis-Superior area, Campbell (1960) found that impure quartzite typified the Revett Quartzite both north and south of the Osburn fault. The evidence suggests that the light-colored vitreous quartzite facies extends eastward for many more miles on the north side of the fault than on the south side.

LARGE-SCALE DRAG FEATURES

Large-scale drag features indicative of strike-slip movement along the Osburn fault are not numerous but have been noted at several places. Wallace and Hosterman (1956, p. 597–598 and fig. 74) described one of the most clear cut of such features, the Flat Rock syncline, which forms the southeast end of the west-northwest-trending and overturned Savenac syncline. This syncline is in the vicinity of the north branch of the Osburn fault some 25 miles southeast of the district (pl. 9). This cross fold has been interpreted as a large-scale drag feature that has resulted from relative westward movement of the block south of the south branch of the Osburn fault. In addition to the cross folding of the Savenac syncline, a well-formed axial-plane cleavage in this syncline has been folded, and the north branch of the Osburn fault is bent almost concentrically with the cross fold. The axis of the Flat Rock syncline plunges about 35° SW., which suggests that the block south of the south branch of the Osburn fault may have moved up as well as westward. This possible vertical component is open to question, however, as the orientation of the trace of the bedding in respect to the fault surface and the direction of net slip at the beginning of the movement is unknown, but there is little doubt that the Flat Rock syncline indicates a right-lateral strike-slip component. A minimum of 1.5 miles of strike slip would be required to produce the Flat Rock syncline.

Umpleby (1924, p. 610) reported: "Where cut off by the Osburn fault in the Senator Stewart mine (Kellogg area), the plane of the New Era fault is bent from a westward dip, and its strike turns sharply to the northeast, showing drag phenomena on a tremendous scale and indicating a relative westward shifting south of the Osburn fault."

OFFSET OF SIMILAR FEATURES ALONG PARALLEL AND SUBPARALLEL FAULTS

Strike slip can be clearly shown along some faults that are parallel or subparallel to the Osburn fault, because of less displacement and fewer complexities to obscure the similarity of units, contacts, or fold axes on opposite sides.

The Thompson Pass fault (Ransome and Calkins, 1908, pl. 2; Hosterman, 1956, pl. 57; this report, pl. 9), which is subparallel to and about 7 miles north of the Osburn fault, crosses the Burke-Trout Creek anticline, the Granite Peak syncline, and the Glidden Pass anticline almost at right angles. The offset position of the axis of the Granite Peak syncline on opposite sides of the Thompson Pass fault most clearly shows the amount and direction of movement; the right-lateral strike slip is more than 2 miles. The block south of the fault also has been raised almost a mile relative to the block north of the fault, and thus the direction of net slip plunges about 20° ESE. Although the position of the Glidden Pass anticline is somewhat ill defined north of the Thompson Pass fault, this fold is also segmented by strike slip along the fault. The trend of the Burke-Trout Creek anticline is indistinct near the Thompson Pass fault and may be part of the curved anticlinal axis two miles southeast of the town of Murray (Hosterman, 1956, pl. 57; this report, pl. 9). The axis of the Burke-Trout Creek anticline north of the Thompson Pass fault is sharply bowed near the fault, and intersects the fault about a mile east of the point at which the axis of the possible southern correlative of the Burke-Trout Creek anticline intersects the fault. If the two folds had originally been parts of the same fold the offset is compatible with right-lateral displacement elsewhere. It should be noted, however, that the trend of the Burke-Trout Creek anticline some distance north of the fault is almost in alinement with the main segment of the Burke-Trout Creek anticline to the south. No explanation is offered for this relation, but complexities of structure not yet revealed by field mapping are suspected.

Approximately 6 miles north of the Thompson Pass fault, Hosterman (1956, pl. 57) found the Trout Creek anticline to be offset about a third of a mile along a right-lateral fault trending northwestward.

The Deadman shear zone, a major fault north of the Osburn fault in the Pottsville map area, may have a large component of strike slip. The Granite Peak syncline, which is at least 10 miles long, ends abruptly at the Deadman shear zone, and on the opposite side the Deadman syncline, a tight isoclinal fold, lies at almost right angles across the truncated end of the Granite Peak syncline (pl. 5). This right-angle relation is difficult to explain by dip slip along the Deadman shear zone, and horizontal displacement is suspected as a partial solution. It is conceivable that the Deadman syncline slid, shutterlike, across the end of the Granite Peak syncline.

The Placer Creek fault extends across the south edge of the district about 3–4 miles south of the Osburn fault. Near the west margin of the mapped area, the Pine Creek anticline appears to have been segmented by movement along this fault. The axis of the probable southern segment of the anticline meets the fault slightly more than a mile west of the intersection of the axis of the Pine Creek anticline on the north. The axis of the Pine Creek anticline is somewhat sinuous near the fault, but this situation may be a result of generally low dips, in which case a relatively minor difference in actual orientation of bedding planes may cause a large difference in strike. The suggestion that the fold axis is offset by right-lateral movement along the fault is substantiated by an apparently similar offset in the belt of mineralization of the Pine Creek area. This relation is described further in the section below entitled "Position of major mining areas on opposite sides of the Osburn fault."

In the larger Pine Creek upwarp, the easternmost exposure of Prichard Formation adjacent to the Placer Creek fault on the north side is east of the easternmost exposure of Prichard Formation adjacent to the fault on the south side. Similarly, the contact between the Burke and Prichard Formations has apparently been offset about one-third mile along the Spring fault in the headwaters of Humboldt Gulch. Neither of these pieces of evidence is more than permissive, for the displacement along either fault could have just as well been brought about by dip slip.

Umpleby (1924, p. 610) reported that in the Bunker Hill mine the Jersey fissures, two parallel veins that strike northeastward, are cut off by the Upper and Lower Cate faults and that the southern segments are displaced relatively westward.

Campbell (1960) reported that in the St. Regis-Superior area, Montana, the Boyd Mountain fault, which probably branches off from the south side of the Osburn fault and diverges southeastward from it, may have had right-lateral strike slip of many miles. The contact between the Wallace Formation and the overlying Spruce Formation (in part equivalent to the Striped Peak Formation) is offset approximately 13 miles on opposite sides of the Boyd Mountain fault. At least some of this offset could be a result of dip slip; moreover, the offset may not be an accurate measurement of strike slip, as the contact on the south side is subparallel to the fault. Perhaps, however, the total amount of strike slip reported by Campbell is significant. The 13 miles of strike slip on the Boyd Mountain fault, if added to the 4 miles of strike slip along the Osburn fault to the north, is almost equivalent to the suggested total strike slip along the Osburn fault in the Coeur d'Alene district.

POSITION OF MAJOR MINING AREAS ON OPPOSITE SIDES OF THE OSBURN FAULT AND THE PATTERN OF MINERAL DISTRIBUTION

Base-metal mineral deposits have been found on both sides of the Osburn fault from Coeur d'Alene Lake on the west to beyond Superior, Mont., on the east—a distance of about 100 miles. The only major ore deposits, however, are those within the Coeur d'Alene district, and these are concentrated in two separate areas. One area, centered around Kellogg, lies south of and adjacent to the Osburn fault; it includes the Pine Creek deposits on the west side of Kellogg and the Silver Belt deposits on the east side. The other area lies north of and adjacent to the Osburn fault in the Mullan-Burke area. These two areas are so disposed that the west edge of one barely overlaps the east edge of the other, and their centers are about 16 miles apart. Only a few scattered mineral deposits have been found in the areas directly opposite each of these great ore-producing areas across the Osburn fault. The geometry and location of these two areas in which the principal ore deposits are restricted agree with other evidence of major strike-slip dislocation. This line of reasoning is based on acceptance of the thesis that the ore bodies were deposited in one large structural knot that subsequently split into two segments and was offset by right-lateral movement along the Osburn fault. Other data support an offset along the Osburn fault and strengthen this thesis. Contributing to the evidence is the dissimilarity of mineral deposits on opposite sides of the Dobson Pass fault, along which the movement probably took place contemporaneously with that along the Osburn fault. (See discussion on Dobson Pass fault, p. 83.)

A similar but crude zoning of metallic and gangue minerals is evident within these two separate areas in which the ore deposits are concentrated. In the Mullan-Burke area most of the deposits lie to the east of the Gem stocks, and eastward from the stocks metal distribution changes from relatively high zinc content, through relatively high lead content, to relatively high copper content. A similar but also irregular zoning exists south of the Osburn fault. The ore bodies in the Pine Creek area are higher in zinc than other deposits south of the Osburn fault; the Bunker Hill mine area contains a higher percentage of lead; and in the Silver Belt to the east copper is relatively abundant. Distribution of the gangue minerals is also suggestive of this correlation between the two areas on both sides of the Osburn fault. South of the Osburn fault in the Pine Creek area, pyrrhotite is characteristic of the gangue; in the Bunker Hill mine area and in the Silver Belt, siderite is a characteristic gangue mineral; and in the area bordering the south side of the Osburn fault from about Wallace eastward to and beyond the Montana State line, ankerite typifies the gangues. North of the Osburn fault, a similar pattern from west to east can be defined. Approximately bordering the Gem stocks, and no more than 1.5 miles from it, pyrrhotite and magnetite are common gangue minerals. In a crude semicircle about 4 miles in radius centering at Mullan and lying north of the Osburn fault, siderite characterizes the gangue; and to the east of the Montana State line, ankerite increases in abundance as a gangue mineral. Although the distribution is far from perfect and some discrepancies exist, the zoning of the ore and gangue minerals suggests that the two great producing areas were once adjacent.

CONTRADICTORY EVIDENCE

Most of the evidence strongly supports the theory of large-scale strike slip along the Osburn fault, but some evidence seems contradictory or at least poses questions not yet explained satisfactorily. For example, one would expect to find many more drag features indicative of strike slip than those already described. Folds having steeply dipping axes reflecting drag caused by strike slip are not numerous. In fact, most folds along the Osburn fault have more nearly horizontal axes, a fact that is indicative of dip-slip movement. Evidence of strike-slip movement, which might be expected to have occurred along many lesser associated faults, is generally lacking. For example, north of the Osburn fault, known strike slip is limited to a few larger faults such as the Deadman shear zone and the Thompson Pass fault. If large-scale strike slip did occur, the absence of drag features and any sympathetic movement along smaller faults would indicate that shearing stress was confined to only a few fault planes and well-lubricated planes of movement. If the component of normal stress along the fault plane was great in proportion to the component of shearing stress, the blocks adjacent to the fault could scarcely avoid sympathetic deformation.

The group of small intrusives, which includes the Gem stocks and which was apparently emplaced prior to the large movement along the Osburn fault, crops out in a linear arrangement trending north-northeast (pl. 7). This linearity does not appear to be disrupted by the indicated strike slip along the Osburn fault. At least the Herrick stock south of the Osburn is in good alinement with the Gem stocks and the additional stocks to the north.

Adjustments to a large strike-slip movement along the Osburn fault might be expected along many of the faults within the district, and some of these adjustments might have been relatively large. If this were true and if the ore deposits were formed prior to the major strike-slip movement, such faults that are at fairly large angles to the veins could be expected to have offset segments of some deposits for considerable distances. Yet, the only fault of this type along which there was apparently considerable movement is the Dobson Pass fault. Otherwise, segments of veins along faults are not offset by more than a few hundred feet at the most and are usually offset much less.

A regional anomaly raises still another problem. In the Lake Basin fault zone near Billings, which lies along the eastern extension of the Lewis and Clark line in south-central Montana, the fault pattern is almost certainly a result of left-lateral strike slip in a deep-seated zone. Similarly, the Nye-Bowler lineament, extending from the Beartooth Range to the Pryor Mountains, is characterized by left-lateral movement. Here, then, is left-lateral strike slip along the eastern part of the Lewis and Clark line and right-lateral strike slip along the western part of the line.

SUMMARY AND EVALUATION OF EVIDENCE

The evidence indicates that there has been about 16 miles of right-lateral displacement on the segment of the Osburn fault between the points of junction with the Dobson Pass fault and the Montana-Idaho State line. On the segment of the Osburn fault west of the junction with the Dobson Pass fault to and beyond the vicinity of Pinehurst, the right-lateral strike slip seems to have been about 12 miles. The difference in the amount of displacement on these two segments probably is principally the result of dip slip along the Dobson Pass fault, which has effectively lengthened the block north of the Osburn fault. Although the Osburn fault must have been in existence prior to the formation of the ore deposits, most if not all of the strike slip along the fault probably occurred after the ore had formed.

The authors' evaluation of evidence, both direct and indirect, is summarized and graded into three categories of certainty as follows: (a) Strongly indicative—implies little possibility of alternate hypothesis, as evidence appears virtually complete and definitive, (b) indicative—implies one hypothesis, although there is some possibility of an alternate hypothesis, as evidence is incomplete, and (c) suggestive—implies greater possibility of alternate hypothesis, but available evidence favors the hypothesis under test. A similar summary is also given for the contradictory evidence.

Supporting evidence that pertains directly to the Osburn fault itself and that is strongly indicative of strike slip includes: offset of the Pine Creek anticline from the Moon Creek anticline and large-scale drag along the Osburn fault zone as represented by the Flat Rock syncline. The supporting evidence that is indicative of strike slip includes: offset of the Page-Government Gulch fault system from Carpenter Gulch fault; offset of major folds; offset of lithology of the St. Regis Formation and Revett Quartzite to the east of the district; drag represented by bend in the New Era fault; offset of major mining areas; and offset ore and gangue mineral zoning. The last two are also indicative of strike slip which occurred after the ore had formed. The supporting evidence that is suggestive of strike slip includes: offset of the Moon Creek anticline from the Burke-Trout Creek anticline along Dobson Pass fault; offset of the Alhambra fault from Blackcloud fault; difference in thickness of the St. Regis Formation within the district; general structural dissimilarity of adjacent blocks on opposite sides of the Osburn fault; and large-scale drag features in the west end of Lookout anticline and Lookout syncline. The last line of evidence is suggestive of lateral drag on a regional scale although not specifically strike slip along the Osburn fault.

Supporting indirect evidence that pertains to parallel or branching faults and that is indicative of strike slip along the Osburn fault includes: offset of the Granite Peak syncline and Glidden Pass anticline along the Thompson Pass fault; offset of the Pine Creek anticline and Yreka vein system along Placer Creek fault; truncation of Granite Peak syncline by Deadman shear zone; and offset of the Wallace-Striped Peak (Spruce Formation) contact along the Boyd Mountain fault. Similar indirect evidence that is suggestive of strike slip includes: offset of the Burke-Trout Creek anticline along the Thompson Pass fault; and offset of the Prichard-Burke contact along the Spring fault.

Contrary evidence suggesting that right-lateral strike slip did not occur along the Osburn fault includes: apparent left-lateral movement in the Lake Basin fault zone and in the Nye-Bowler lineament; lack of numerous drag features; strike slip restricted to relatively few faults; lack of evidence of large-scale adjustments along many faults; and linearity of the trend of stocks.

DOBSON PASS FAULT

The Dobson Pass fault extends northward for at least 10 miles from a point near Wallace, Idaho, where it probably abuts the Osburn fault at about right angles (pl. 4). The road over Dobson Pass, after which the fault is named, crosses the fault 14 times in 5 miles between Ninemile Creek and Beaver Creek, and the fault can be seen in roadcuts at most of these crossings. The fault has also been intersected in the workings of the Panhandle mine, in the east crosscut of the Ninemile Mining Co., and was cut in the shaft and on the 800 level of the Dayrock mine (pl. 4). These locations plus additional surface evidence allowed the position and attitude to be determined rather accurately over much of the fault's length. The Dobson Pass fault, however, is obscured near its south end by a cover of gravel deposits.

Except for one major change in strike the fault appears to be remarkably planar without much curving or distortion, although the surface trace of the fault is highly irregular as a consequence of the fault's low angle of dip and the uneven topography along its course. From the Osburn fault to Beaver Creek the strike of the Dobson Pass fault is nearly north, but north of Beaver Creek the strike turns sharply to a N. 40° W. trend. The dip is nearly 30° W. wherever it can be determined with a fair amount of accuracy.

The rocks in the hanging wall of the fault are shattered and broken and to some extent sheared for many hundreds of feet away from the fault. This shattering is particularly true of the quartzitic rocks of the Revett and St. Regis Formations to the north and south of Blackcloud Gulch. At some places this shattering has been intense, and a bulldozer cut below the Panhandle workings exposes Revett Quartzite so shattered that the rock can be pulverized in the hand. Brecciation also occurs in the workings of the Dayrock mine across Ninemile Creek but becomes less pronounced to the west. In the footwall, the rocks of the Prichard Formation in the vicinity of the fault are contorted and folded, and the monzonite is shattered and sheared.

Undoubtedly, the fracturing of the monzonite and possibly some of the folding and crumpling of the sedimentary rocks are related to movement along the fault. The sedimentary rocks in the footwall block, however, have been intruded by the monzonite stocks, and at least some of the distortion in this block may be attributed to the forceful emplacement of the monzonite. The monzonite intrusion has had no recognizable effect on rocks in the immediate hanging wall, which at the time of intrusion were more remote from the stocks.

On the west slope of Dobson Gulch the Striped Peak and Prichard Formations are in contact across the fault (pl. 4). The Striped Peak rocks, however, are in a downfaulted wedge-shaped block. Discounting this block, the Prichard Formation would be in contact with the upper part of the Wallace Formation, and the stratigraphic displacement would amount to at least 14,000 feet. The net slip, however, is not known with certainty, but several lines of evidence suggest the amount and type of displacement. The Dobson Pass fault clearly cuts the Gem stocks, and the movement has brought the Wallace and St. Regis Formations in the hanging wall into contact with monzonite in the footwall. If the low westward dip of the fault is projected up to the east, it can be seen that the tops of the Gem stocks may have been cut by the fault. Of probable significance, therefore, are the small bodies of monzonite that crop out from 1½ to 3 miles west of the trace of the Dobson Pass fault. There is strong evidence that these monzonite bodies are the sheared-off tops of cupolas of the Gem stocks, which have been displaced about 3½ miles westward. Furthermore, if the structure is reconstructed so that these cupolas lie above the Gem stocks, the broad anticline in Wallace terrain west of the Dobson Pass fault is superimposed approximately over the Burke anticline. This reconstruction also moves the Dayrock mine block into a position very nearly above the Star-Morning mines block. An original juxtaposition of the Dayrock mine block and the Star-Morning mines block could be one explanation for the similarity between the lead-rich Dayrock ore and Star-Morning ore and for the dissimilarity between the Dayrock ore and the zinc-rich, silicate-gangue ore in nearby prospects and mines in the footwall of the Dobson Pass fault.

In the Dayrock mine, the rocks in the hanging wall are intensely bleached, whereas the sedimentary rocks that are exposed in the footwall are dark colored, and though highly sheared, do not appear to have been similarly altered by hydrothermal solutions. The same conditions have been found at other places along the trace of the fault. This relation of bleached rocks above and unbleached rocks below such a low-angle fault seems most logically to have resulted from movement along the Dobson Pass fault which took place after the bleaching had occurred.

The Ohio vein in the Dayrock mine has been dragged out along the plane of the Dobson Pass fault and sheared off; this is clear evidence that movement had occurred along the fault after the formation of the ore. The drag relation is well shown by the change of attitude of the vein near the fault. Beyond 100 feet from the fault, the vein strikes N. 80° W. and dips about 60° S., but as the fault is approached the strike changes to northeast and the dip to 30° W. Offset of the veins in the Dayrock mine by the Zanetti, Upper and Lower Murray, and Haff faults, which probably are genetically related to the Dobson Pass fault, is also strongly suggestive of movement that occurred along the main fault after the ore had formed.

Veins close to the monzonite stocks in the footwall block contain high-temperature silicate minerals in the gangue, but the Dayrock mine veins, which are just within the hanging wall, contain no silicate minerals and are more typical of deposits much farther removed from the stocks. This relation suggests that the Dayrock veins have been transported a considerable distance by the movement along the Dobson Pass fault, although the direction of the movement is subject to alternate interpretations.

The Dobson Pass fault is probably younger than the Ruth and Blackcloud faults. It clearly truncates the Ruth fault, which is also cut into several segments by the Zanetti, Upper and Lower Murray, and Haff faults, which as already stated are probably related to and contemporary with the Dobson Pass fault. East of and in the footwall block of the Dobson Pass fault the Mexican-San Jose fault has an attitude very similar to that of the Ruth fault to the west. Both the Ruth and San Jose faults have been injected by diabase dikes. The two faults may be correlative segments that have separated by movement along the Dobson Pass fault. No possible continuation of the Blackcloud fault has been found to the east of the Dobson Pass fault, but the Alhambra fault south of the Osburn in the Kellogg map area has been proposed as a possible continuation that has shifted many miles along the Osburn fault.

The Dobson Pass fault may best be described as a normal fault, but the movement along it does not appear to be due to gravity. The angle of dip is far too small for gravity alone to be the cause of movement, unless the fault has been rotated since it was formed, but there is no evidence for such rotation. Hubbert (1951, p. 362) has shown that gravity faults should have a dip of about 60°. Some mechanism other than gravity, therefore, must be called upon to explain normal faulting at such a low angle of dip.

The Dobson Pass fault is probably related genetically to the Osburn fault. The abrupt ending of the Dobson Pass fault at the Osburn fault and the lack of a known continuation to the south suggest that the two formed simultaneously.

The footwall of the Dobson Pass fault appears to have been pulled out from under the hanging wall. If the movement of the footwall block were in sudden, abrupt jerks, as is common of displacements that produce earthquakes, the inertia of the blocks in the hanging wall would provide the opposing stress that would allow the footwall block to move relatively eastward. By this mechanism, no overall tension is applied to the hanging-wall block and no tensile stress is required for the hanging-wall block to be pulled off the footwall block. Nevertheless, considerable jostling of the hanging-wall block would seem probable and might well account for the intricate fracturing of the hanging-wall block near the Dobson Pass fault.

The west side of the Gem stocks may possibly have dipped at a low angle to the west, and thus may have provided a strength discontinuity or parting plane which helped localize the Dobson Pass fault. An anomaly shown on the aeromagnetic map (pl. 8) suggests that the monzonite is at relatively shallow depths west of the Dobson Pass fault. This anomaly, however, can be interpreted in two ways—a shallow extension of the main mass of the stock, or the faulted top of the stock dropped down along the Dobson Pass fault. Perhaps both interpretations are true.

The possibility of the Dobson Pass fault being a thrust fault must also be considered. Although this cannot be ruled out, the interpretation of the fault as being normal is preferred by the authors. R. P. Full (1955) and others have suggested that the parallelism of the Dobson Pass fault to the north-trending folds, some flanks of which are overturned to the east, and the low angle of dip characteristic of thrust faults (Hubbert, 1951, p. 362) are indicative of its being a thrust fault. In this interpretation the Dobson Pass fault could be considered genetically related to the early period of folding and thrust faulting during which folds were overturned to the east and faults such as the Carpenter Gulch and Blackcloud were produced. The truncation of the Dobson Pass fault by later strike slip along the Osburn fault would be consistent with this interpretation, and although no offset segment of the Dobson Pass fault can be identified, it is conceivable that one of the reverse faults of the Bunker Hill-Silver Belt area might be the rotated segment of the Dobson Pass fault.

The age and geometry of the rocks in the hanging wall of the Dobson Pass fault and the regional geologic structure are difficult to reconcile with reverse movement, and are the most convincing evidence in support of normal displacement. The rocks in the hanging-wall block of the fault form the east limb of a large anticlinal feature and include the youngest rocks of the area. Small patches of the highest beds—Striped Peak Formation—occur along the fault and dip eastward into it. The rocks below the fault belong to the Prichard and Burke Formations, which regionally dip southwest, and form the west limb of a large anticline. The relations are such that if the fault were a thrust, a deeply infolded synclinal feature from which the uppermost formation could be displaced would lie in the footwall block approximately 5 miles to the west of the present exposure of the Dobson Pass fault. The following facts make a thrust interpretation almost untenable: (a) There is no evidence of a deep syncline either as an offset segment south of the Osburn fault or anywhere to the north where its extension might be expected to show, (b) the restoration of such a postulated thrust to its position before thrust would undoubtedly result in gross discrepancies across the Osburn fault, and (c) evidence of movement along the Osburn fault requires a larger amount of slip east of the Dobson Pass fault than west of it—a condition opposite to that required for reverse movement along the Dobson Pass fault. It might be argued that the hanging-wall block of Wallace and Striped Peak Formations was thrust in from west of the Moon Creek high, but this interpretation is highly speculative.

PLACER CREEK FAULT

The Placer Creek fault, in many respects, appears to be similar and closely related to the Osburn fault. Although generally paralleling the Osburn at a distance of between 3 and 4 miles to the south, the course of the Placer Creek fault is somewhat more irregular and the displacement is less. The Placer Creek fault is probably the second most important strike-slip fault in the mapped area. Like the Osburn, it spans the length of the Coeur d'Alene district and has been mapped westward into Kootenai County by Anderson (1940, p. 28) and eastward into Montana by Wallace and Hosterman (1956, p. 596). The Placer Creek fault is particularly well delineated along the upper part of the valley of Placer Creek, the locality from which it gets its name (pls. 7 and 9).

The strike of the Placer Creek fault averages N. 70° W., but it differs in trend from place to place; one segment of the fault strikes N. 80° E. for about 3 miles in the Smelterville and Kellogg map areas. The fault passes through the Smelterville and Kellogg map areas south of the center and then angles southward to the southeast corner of the Wallace map area, and then continues eastward beyond the south edge of the Mullan and Pottsville map areas. The course of the fault can be fairly well located by conspicuous notches where it crosses ridge crests, by valleys and gullies that follow its trace, by sharply truncated quartzite members of the Prichard and Revett Formations, or by zones of shearing exposed in roadcuts. This fault is similar to the Osburn in its physiographic expression and unlike many of the others, which have little if any surface expression.

The fault is cut in the tunnel and 200 level of the Castle Rock prospect in Placer Creek (southeast corner of the Wallace map area). At this locality the fault dips about 75° S. (pl. 3). Although no other exposures of the fault plane have been seen, a similar dip is postulated for the full extent of the fault because of its generally straight course and consistent relation to topography. Where cut in the Castle Rock tunnel, the fault separates Revett Quartzite in the footwall from dark and light banded rocks of the lower part of the Wallace Formation in the hanging wall. A dark-gray clay gouge that ranges from 2 to 18 inches in thickness marks the fault plane. In addition to the gouge, the Revett Quartzite in the footwall is sheared and brecciated, but the interbedded quartzite and argillite of the Wallace Formation in the hanging wall show remarkably little disruption.

The quartzite in the footwall is silicified and cut by numerous stringers of quartz, carbonate minerals, and sulfides. Most of the footwall block near the fault shows evidence of alteration and the introduction of material. In contrast to this, the Wallace beds above the fault are fresh and unaltered. The dark gouge also appears to be virtually unaltered even in its finely pulverant state. These relations are suggestive of major movement along the fault after the alteration.

In the valley of Placer Creek about 2 miles south of the town of Wallace, the location of the Placer Creek fault is marked by the contact of a prominent resistant Revett Quartzite ridge with less resistant Wallace Formation to the south—the movement on the fault has been sufficient to cut out the St. Regis Formation. Between 1 and 2 miles to the west of Placer Creek, the surface trace of this fault is marked by a diabase dike that was intruded along it for more than a mile (pl. 3).

In the Smelterville map area (pl. 1) the position of the Placer Creek fault can be accurately located in several places, and its characteristics can be at least partly determined. Immediately east of Highland Creek, two zones of quartzite beds in the Prichard Formation are terminated by the fault. Another well-established point along the fault is near the mouth of Nabob Creek, where a vitreous quartzite zone is present on the south side of the fault but not on the north. A zone of shearing from 10 to 15 feet wide marks the position of the fault on the east side of the West Fork of Pine Creek valley and a similar zone is exposed immediately west of the large patch of older gravels between Sourdough and McLaren Gulches.

The quartzitic zones in the Prichard Formation, so conspicuous in the Pine Creek area, have been offset by right-lateral movement along the fault. The horizontal stratigraphic separation between the quartzite beds in Highland Creek and those near the mouth of Nabob Creek is about 1.8 miles. Forrester and Nelson (1944, p. 9), who did detailed mapping in the Pine Creek area, stated that the offset quartzite beds show a minimum vertical displacement of 500 feet. They each side of the fault suggests this this figure may be each side of the fault suggests that this figure may be far too small. The stratigraphic position of the quartzite bed near Nabob Creek on the south side of the fault is not known, so it cannot be used as a key bed to calculate the displacement along the fault.

The Pine Creek anticline has been offset by the Placer Creek fault. On the north side of the fault the fold axis terminates in the Denver Creek valley. A poorly defined anticline extends southeastward from the mouth of Nabob Creek on the south side of the fault and may be the faulted segment of the Pine Creek anticline. If these two folds were once joined, the axis must be offset about 1 mile.

The Yreka vein system north of the Placer Creek fault in the Pine Creek area is remarkably straight from the Hypotheek mine on the northwest to the Highland-Surprise mine on the southeast. South of the fault a zone of mineralization extends from the New Hilarity mine southeastward to the Constitution mine. The vein type and mineralogy are similar in these two sections, which are probably segments of the same zone. If so, the movement is of the same type as that indicated by the offset of the anticlinal axis, but the offset of the vein system is nearly 2 miles.

Most of the evidence suggests a strike-slip movement along the fault in which the north side moved east relative to the south side. There is no irrefutable evidence, however, concerning the amount of the net displacement of the fault in the Pine Creek area. Some evidence contradictory to strike slip is the relation of the quartzite near Nabob Creek south of the fault to the proposed Pine Creek anticline axis. The uppermost quartzite cut on the north side of the fault is considerably east of the anticlinal axis, yet the quartzite south of the fault crosses the anticlinal axis. If one assumes that these two folds were originally parts of one fold, it is possible to postulate a dip-slip movement along the fault. In this type of movement the quartzite south of the fault would be a repetition of the quartzite bed near the fold axis at the upper portal of the Nabob mine rather than a continuation of the faulted quartzite bed in Highland Creek.

FAULTS IN THE SMELTERVILLE MAP AREA

BLUE STAR FAULT

The Blue Star fault is exposed only where it crosses Blue Star Ridge near the mouth of Pine Creek, but the fault is interpreted as being continuous along a westward trend for more than 4 miles. The trace is covered by alluvium in the valleys of the South Fork of the Coeur d'Alene River and Pine Creek. On Blue Star Ridge the fault separates quartzite of the Burke or Revett Formations from argillite of the Prichard Formation, and along the northeast flank of Blue Star Ridge the rocks are intensely fractured and sheared, and a large lamprophyre dike occupies the fault zone. The dip of the fault is 50° S., and the apparent displacement is reverse, although it may have a large component of strike slip as discussed in the section entitled "Kellogg fault."

SPRING FAULT

The Spring fault in the Smelterville map area has been traced from the east edge of the gravel deposits on French Gulch Divide eastward to an intersection with the Katherine fault on the ridge crest between Government Gulch and Grouse Creek. The Katherine fault, which is discussed separately, is probably the southeast extension of the Spring fault. The separate names are retained, however, because of their common usage in the area where each fault is known. West of Pine Creek the position of the Spring fault has been inferred on the basis of topographic expression and a poorly exposed quartzite zone of the Prichard Formation that has been offset by the fault. Immediately east of Pine Creek the fault has been exposed in the Corby mine adit for about 470 feet of strike length. Workings of the General mine in the Little Pine Creek valley have intersected the fault at several places on the adit level and in the 200-level crosscut. Eastward, from the General mine to the vicinity of Corrigan Ridge, the position of the fault is indicated by an alinement of slight topographic depressions, by anomalous bedding attitudes of the Prichard rocks in the opposite blocks, and by a zone of shear and gouge poorly exposed in a shallow trench near the crest of Maude Ridge. In the vicinity of Corrigan Ridge and eastward, rocks of different formations have been offset into juxtaposition in opposite walls, and the fault has been mapped along these anomalous contacts. The 600 level of the Page mine also cuts the fault at an altitude of about 2,300 feet.

The fault is about 3¼ miles long, and its strike and dip are remarkably constant throughout that distance. The only actual exposures of the fault are in the three mines previously mentioned. In each mine the fault strikes about due east and dips 70°–75° S. The most prominent shear plane in the cut on Maude Ridge strikes east and dips 80° S.

The zone of sheared rock and gouge along the fault is fairly narrow, a fact that probably explains the lack of marked topographic expression of the fault. In the adit of the Corby mine about 2 feet of gouge and an equal amount of intensely sheared rock are exposed along the fault. At its widest place in the General mine the fault zone is composed of 20 feet of sheared rock and several thin gouge seams.

The apparent displacement has not been equal along the fault, for near the east end the Prichard Formation has been faulted against the St. Regis Formation, but at the west end Prichard rocks are in both walls. This relation can be explained by differential dip slip along the fault, or right-lateral strike slip. Because the fault transects folded rocks, the apparent displacement at any point depends upon the relation of strike and dip of the bedding to the fault plane. No direct evidence was found to support one or the other of these interpretations, but the Spring fault's remarkable straightness and parallelism to the Osburn fault suggest that the Spring fault is one of the late strike-slip faults. Slickensides on the argillite beds in the hanging wall of the fault in the Corby adit are normal to the strike of the fault and plunge down the dip of the shear planes. These slickensides probably indicate only one of the latest directions of movement along the fault. In the same adit similar striae are also present on a diabase dike that has intruded along the faults.

The Spring fault intersects and offsets the Page-Government Gulch fault on the ridge between Silver and Grouse Creeks. The steeply dipping Spring fault thus appears to be distinctly later than the reverse Page-Government Gulch fault.

A diabase dike is present in the hanging wall of the Spring fault in the Corby, General, and Page mines workings. The dike also crops out on the surface along the trace of the fault above the Corby and General mines. The distance between the dike and main shear zone of the fault varies from place to place. The dike is immediately adjacent to the fault plane at the portal of the Corby adit but is 10–20 feet in the hanging wall in the east end of the mine. The dike is consistently several feet in the hanging wall of the fault in both the General and the Page mines. As previously mentioned, the dike rock is slickensided in places and has also been slightly offset along faults subsidiary to the Spring fault on the 200 level of the General mine. The dike appears to have intruded into a shear zone along which later movement was concentrated in the footwall of the dike.

Mineralization has not been found along the Spring fault itself, although the diabase dike in the General mine contains many quartz, ankerite, and arsenopyrite veinlets of the gold-arsenopyrite variety.

PAGE-GOVERNMENT GULCH FAULT

Several faults lying between the Placer Creek and Osburn faults that have a general northwest trend and are similar in other characteristics are probably segments of the same structural feature here called the Page-Government Gulch fault. This group of faults is offset along faults having a more westerly trend. The northernmost segment of this group, the Page fault, is well delineated on the surface and has been cut on several levels in the Page mine. This fault trends slightly west of north and dips 35°–40° W. It is barely half a mile long and terminates abruptly against the Osburn fault to the north and an unnamed west-trending fault near the Spring fault to the south. The remaining segments, which have been traced through the upper courses of Government Gulch and across the divide into Highland Creek drainage, are called collectively the Government Gulch fault. Except near the Placer Creek fault at the south end, the surface trace of these segments can be followed rather closely owing to abrupt changes in the attitude of the beds of the different formations on opposite sides of the segments.

The Page-Government Gulch fault is a reverse fault whose stratigraphic displacement generally ranges from 4,000 feet at the Page mine, where the upper part of the Prichard Formation has been thrust up against St. Regis beds, to 1,500 feet, where lower beds of the Revett Quartzite adjoin the middle or upper layers in the same formation along the Government Gulch fault south of the Spring fault. The stratigraphic displacement provides only a rough measure of movement because folding and other structural complexities have affected the beds, but it does give a minimum figure—the actual amount of movement may have been much more.

The Page fault forms the west boundary of the main ore shoot at the Page mine from the surface down to the 2,100 level, 1,600 feet vertically below the collar of the shaft. Below this level, the ore shoot pinches out before reaching the fault, and the barren vein has not been followed to its intersection with the fault. Information on the fault was obtained from mine maps and from discussions with personnel of the American Smelting and Refining Co., the property owner, as none of the levels that exposed the fault were accessible at the time of this study. The evidence is conflicting as to the relation of the fault and the vein. In places, vein matter was reported to have spread out against the fault as though dammed beneath an impervious fault gouge which formed before ore emplacement. At other places a clean cutoff of the productive vein against the fault and some consequent drag that may have resulted in the spreading of ore against the fault is reported.

Whether the time of major movement along the Page fault occurred prior to or after ore emplacement cannot be determined from the evidence found underground. The sheared condition of the vein at the fault contact at some places is clear evidence that there has been some movement after ore emplacement, but the amount is unknown. The interpretation that the Page fault formed prior to ore emplacement and that it is a reverse fault is consistent with the structural evolution of the district and also seems logical if one considers the relation of this fault to others that cut it.

DIVIDE FAULT

The Divide fault in the southern third of the Smelterville map area was named and described by Forrester and Nelson (1944, p. 10). The fault has been traced for about 4 miles from its intersection with the Placer Creek fault at a point a short distance northwest of the mouth of Trapper Creek southeastward to the edge of the map area. A part of the Divide fault is the same structural feature mapped by Jones (1919) as the Pine Creek fault, a name which is still in common use in the district.

The general trend of the fault is N. 45° W., and although the true dip was nowhere seen, the trace of the fault indicates that it is nearly vertical. Several saddles that lie in a practically straight line, regardless of their altitude, have formed along the trace of the fault where it crosses ridge crests.

The direction and amount of net displacement along the fault are questionable. Nelson and Smith (1943) in their map of the Pine Creek area showed the west side of the fault as being the downdropped block. The Prichard-Burke contact on the southwest side of the fault has been displaced to the northwest relative to its position east of the fault. Such a shift is in conformity with the depression of the western block but could also result from right-lateral horizontal shift or a combination of both. Nelson and Smith (1943) showed a section through the fault near this faulted contact that indicates a stratigraphic throw of about 1,500 feet, but much more than this amount would be necessary to produce the observed offset by normal fault movement alone. Forrester and Nelson (1944, p. 10) mentioned that the stratigraphic throw appears to increase greatly along the northwestern parts of the fault. Their statement was based on the relation of the quartzite bed north of the fault near the mouth of Trapper Creek to a normal Prichard-Burke contact near the junction of Hunter Creek and Trapper Creek shown on the geologic map (Nelson and Smith, 1943) available to them. A large stratigraphic throw would indeed be indicated by such proximity of these features, because the quartzite bed is about 8,000 feet below the upper Prichard contact. During the present study, however, this Prichard-Burke contact was interpreted as a fault contact rather than as a normal contact. This different interpretation has somewhat reduced the necessity for such a great change in throw along the fault, although it still appears that there has been some differential dip-slip movement.

TRAPPER CREEK FAULT

The Trapper Creek fault near the south border of the Smelterville map area parallels Trapper Creek on the west side of its valley for most of its length. Near the junction of Hunter Creek and Trapper Creek, the fault swings sharply across Trapper Creek and intersects with the Divide fault. The fault strikes approximately N. 15° W. for most of its length but turns to a N. 35° E. strike at the north end. The dip of the fault is nearly vertical. Although the fault is exposed in only a few places, its surface trace can be followed easily because of the fault contact relations between the Prichard Formation and Burke and Revett Formations.

A stratigraphic separation of nearly 5,000 feet is apparent on this fault, for the Prichard-Burke contact has been faulted against the upper part of the Revett Quartzite. The sense of the displacement has been similar to that of the Divide fault, the west side down relative to the east side. The amount and direction of absolute net displacement along the fault is not known, but the contacts are so far displaced that a combination of some lateral displacement and dip slip seems most probable.

ROSS FAULT

The Ross fault extends from the Divide fault at Trapper Creek northwestward to the valley of the West Fork of Pine Creek. Although the evidence is not conclusive, the fault probably continues across the valley of the West Fork, runs up Ross Gulch, and then curves into Sourdough Gulch, where a conspicuous zone of shear marks its trace. The fault is difficult to follow in the field as argillitic rocks of the Prichard Formation make up both walls for most of its course. Between Trapper Creek and the West Fork of Pine Creek the fault was located mainly on the basis of discordant attitudes of bedding on opposite sides. The fault is exposed in the rock quarry next to the road in the West Fork of Pine Creek, where it is a vertical intensely sheared zone. Here, the bedding to the north of the fault is vertical, and to the south dips 35° NE.

The fault trends about N. 65° W. except at the northwest end, where the strike changes to N. 5° W. at the intersection with the Placer Creek fault. The attitude of the fault at the rock quarry and the straight course of the trace indicate its general attitude as near vertical. The upper quartzite zone of the Prichard Formation is in contact across the fault with argillitic rock lower in the section on the divide between Trapper Creek and the West Fork of Pine Creek. This shows that the south side is the downdropped block. The amount of stratigraphic displacement is not known, but must be several hundred feet or more.

FAULTS IN THE KELLOGG MAP AREA

KELLOGG FAULT

The fault that crosses Milo Gulch near the southern city limits of Kellogg is named the Kellogg fault. This fault can be followed with certainty from its junction with the Osburn fault northwestward to the vicinity of Kellogg, a distance of about 2 miles. The fault, however, probably continues an additional 4 miles to the northwest within the mapped area; most of this distance is within the Smelterville map area. Because of generally good alinement and other similarities, the Burnt Cabin fault (Anderson, 1940, p. 29 and pl. 2) is probably a northwest continuation of the Kellogg fault for an additional 30 miles. Where the fault is exposed in the Kellogg map area, the lithologic contrast of the rocks on opposite sides makes the trace evident. On the Smelterville sheet, similar quartzitic rocks on both sides of the fault mask the trace, but such evidence as lineaments on aerial photographs, fairly clear topographic expression at places, some structural discontinuities, and a spring have been used to locate the fault.

The attitude of the fault is not definitely known, but bends in the fault trace in the area of irregular relief southeast of Kellogg indicate a southwest dip. Displacement along the fault has brought beds of the lower quartzitic zone in the Prichard Formation against Revett Quartzite, a fact that indicates many thousands of feet of movement. The major amount of the movement along the Kellogg-Burnt Cabin fault may have been strike slip. If so, the fault could be considered a branch of the Osburn fault that accommodated some of the strike slip to the east. The block bounded on the north by the Kellogg and Blue Star fault and on the south by the Osburn fault may possibly be a part of the Moon Creek upwarp that has been displaced relatively westward several miles along the Kellogg and Blue Star faults. This possible relation is well illustrated on the map of the regional structure (pl. 9) as most of this intervening block consists of rocks of the Prichard Formation. Supporting evidence for this relation is the attitude of the rocks on opposite sides of the Kellogg fault. The general dip of the strata in the block between the Kellogg and Osburn faults is northeast, which is similar to dip on the east side of the Moon Creek upwarp, but in the adjacent block north of the Kellogg fault the rocks are on the west flank of the Moon Creek upwarp and have a general southwest dip.

ALHAMBRA FAULT

The Alhambra fault crosses the middle part of the Kellogg map area. The general strike of the east half of the fault, in the Crescent-Alhambra mines area, is N. 80° W. but the fault trace is not straight, as the west half swings to a strike of about N. 50° W. At its extreme west end the fault is interpreted as bending sharply north into the Osburn fault zone. In the Crescent mine the attitude of the Alhambra fault ranges from a dip of 60° S. to nearly vertical in separate exposures, but has an average dip of 60° S. between the Hooper tunnel level and the 3,200 level (pl. 2). The Alhambra fault has been drifted along for almost 7,000 feet on the main level of the Alhambra mine. The fault has also been followed for about 1,500 feet on the Hooper level and for more than 4,000 feet on the 3,200 level (altitude 340 ft above sea level) of the Crescent mine. On the surface the Alhambra fault forms the contact between the Revett Quartzite and St. Regis Formation on the south side and the Wallace Formation on the north side for the more than 3 miles of known strike length between the Crescent mine area on the east and Milo Creek on the west.

Underground, the Alhambra fault consists of an anastomosing and branching set of fractures in a zone 50 or 60 feet wide. In places the footwall of the fault zone is defined by a band of black sticky gouge ½–2 inches wide overlain by 1–4 feet of light-colored gouge. Commonly, as for example on the 3,100 level of the Crescent mine, there is a relatively continuous strand of the fault near the hanging wall of the zone, but none of such individual strands contains more than a few inches of gouge and 6–8 inches of breccia and sheared rock. The brittle quartzite of the hanging wall tends to be more shattered than the less quartzitic rocks of the footwall. The rocks in both the hanging wall and footwall of the Alhambra fault are locally folded and, in places, cut by small faults. Several small folds in the footwall are crossed by the Hooper tunnel, and similar folds are exposed where the mine workings penetrate the hanging wall. The axial planes of the folds and the cleavage planes are nearly parallel to the Alhambra fault.

Tetrahedrite, abundant pyrite, and some galena and chalcopyrite are in stringers and pods irregularly distributed along the fault. One large ore shoot and several small shoots have been mined along the Alhambra fault zone in the upper levels. The ore occurs in the gouge and as stringers and replacement bodies in the fractured Revett Quartzite of the hanging wall. In many places on the 3,100 level of the Crescent mine, the gouge in the hanging-wall seam is dark gray as a result of pulverized sulfide minerals in the gouge. Some assays of the dark-gray gouge have revealed high silver content.

Uraninite has also been found in fractures near the footwall of the fault. The uraninite vein is cut by siderite veins and provides a key to the timing of structural events. The uraninite has been determined to have a Precambrian age, and its presence along the fault is evidence of initial Precambrian formation of the Alhambra and related faults and folds. The fault then must have been reactivated at a later time to permit access of the siderite and sulfide minerals, and must have been reactivated or continued active after the later mineralization so that some of the sulfide minerals were crushed and pulverized to gouge.

Displacement along the fault has been reverse and must have amounted to at least several thousand feet, bringing Revett Quartzite in contact with Wallace Formation. The Blackcloud fault, north of the Osburn fault in the Wallace map area (pl. 3), may represent the offset segment of the Alhambra fault. The reverse nature of the two faults and their positions relative to the Moon Creek and Pine Creek highs are evidence to suggest a possible correlation.

Calkins (in Ransome and Calkins, 1908, pl. 11) interpreted the Alhambra fault as bending sharply southward at its east end to join with the Big Creek fault. P. J. Shenon and R. H. McConnel (written commun.) have also supported this interpretation, principally on the basis of surface mapping and the existence of the slight bend in the strike at the east end of the fault where exposed underground in the Hooper tunnel workings. The same interpretation has been retained on the map of the Kellogg map area (pl. 2) accompanying this report, mostly for lack of definitive evidence to the contrary. However, an alternate interpretation supported by additional evidence gained from underground workings is shown in figure 26*B*. In this interpretation the throughgoing Alhambra-Big Creek fault complex would have the larger displacement, and the eastern part of the Alhambra as shown in figure 26*A* would be merely a branch having much less displacement. The north-south segment in figure 26*A* may be absent or may be a fracture of only minor displacement.

FAULTS IN THE VICINITY OF BUNKER HILL MINE

A large number of faults have been mapped in the Bunker Hill area, and the more important ones are shown on plate 2. The concentration of faults in this area illustrates the complexity of structure in the vicinity of a major mine and also reflects the greater amount of information available in areas where extensive underground openings permit observation of the structural features. Most of the faults shown on the surface map of this area have been projected from underground workings.

Although many of these faults have been observed in the workings of the Bunker Hill mine and their continuity and general geometric characteristics determined, the relative displacements along them, the sequence of their formation, and their ages relative to the time of ore emplacement are largely still open to speculation. In the mine area, these faults cut rocks of the Revett Quartzite and the St. Regis Formation that have been intensely deformed and, in many places, altered by hydrothermal solutions to such an extent that it is difficult to establish the identity of the rock units. The distribution of the formations as shown on the Kellogg map area is probably as detailed as it is possible to depict, and is roughly correct. The additional structural complexities of folding, shearing, and minor faulting, however, cannot be adequately interpreted and consequently are not illustrated. Because of these additional structural complexities and the alteration, the amount of displacement and the direction of movement along faults are also largely indeterminate.

Of this group of faults, the Cate is perhaps the dominant structural feature. It definitely appears to have formed prior to ore emplacement and to have been a major control on the localization of the ore deposits in the mine area. Several of the major faults shown on the map and innumerable small shears and slip planes are hanging-wall or footwall splits from the Cate fault and may also have formed prior to ore emplacement, although some show evidence of movement that occurred subsequent to ore emplacement.

STRIPED PEAK FAULT

The Striped Peak fault is one of the longer faults within the general map area. It has been followed continuously across the southern part of the Kellogg map area for 6 miles, and extends at least an additional 20 miles to the southeast in the St. Joe district (Wagner, 1949, p. 31 and pl. I). The fault is named after Striped Peak, which lies at the south edge of the Wallace map area; near this prominence, the trace of the fault is well delineated by the marked contrast in lithology on opposite sides of the fault.

The fault has not been seen underground, and no exposures of the fault plane at the surface are known. Its trace, though, is plainly marked by pronounced discontinuities of rock units, by differences in the attitudes of the bedding on opposite sides of the fault, by the occurrence of a diorite dike within the fault zone, and by saddles were the fault crosses ridges. The general strike of the fault is about N. 70° W. Slight bends in the trace of the fault due to topographic irregularities indicate a steep dip to the south.

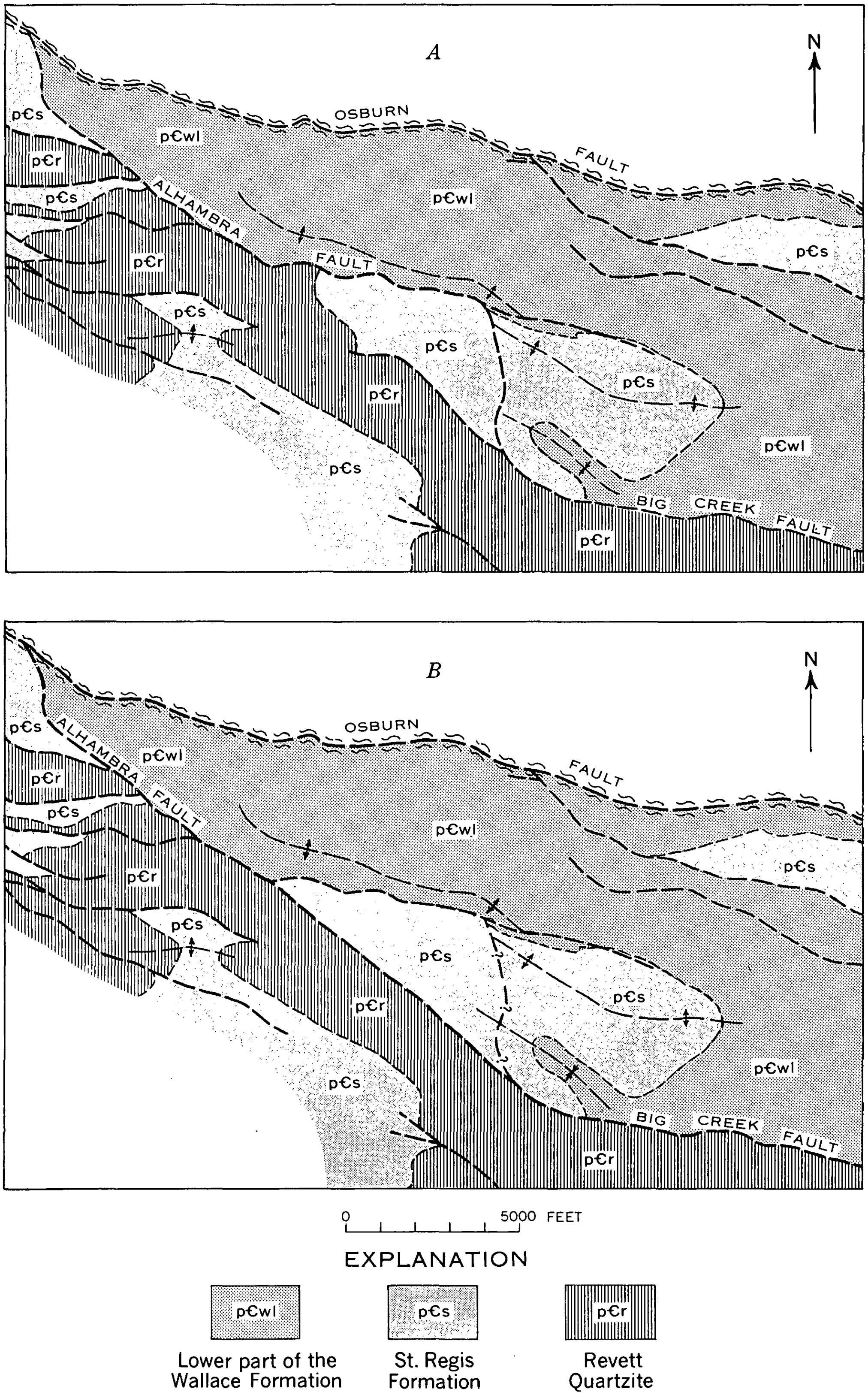


FIGURE 26.—Alternative relations between the Alhambra and Big Creek faults in the vicinity of the Crescent and Sunshine mines, Kellogg map area. *A*. Interpretation of faults as shown on surface map, plate 2. *B*. Alternate interpretation to eliminate differences in stratigraphic throw between the "hook" area (lower right center) and the east and west ends of the Alhambra-Big Creek fault complex.

The amount and direction of movement along the Striped Peak fault are not clearly defined. South of the map area near Striped Peak, the Striped Peak Formation lies north of the fault against Wallace Formation on the south. Such a relation suggests reverse movement with a dip-slip component of more than 1,000 feet. However, the rock-unit contacts in the Kellogg map area and to the southeast in the St. Joe district are displaced along the fault in a direction that indicates normal dip slip and that is opposite to the direction of movement in the Striped Peak area. Either the fault had a counter-buckling movement in the central part or the anomalous relations have resulted from a combination of dip- and strike-slip displacement. The latter interpretation is favored by the authors on the basis of general structural pattern in the area.

SILVER HILL FAULT

The Silver Hill fault, named from its proximity to Silver Hill near the south edge of the Kellogg map area, has been followed for about 3½ miles along strike. The only good exposure of the fault is along the East Fork of Pine Creek in the southeast corner of sec. 1, T. 47 N., R. 2 E., where a cut bank of the stream has laid bare a shear zone of crushed Revett Quartzite at least 10 feet wide. From that point eastward and across the divide into the drainage area of the South Fork of Big Creek, there is good topographic expression of the fault. Lithologic differences on opposite sides of the fault also help locate the trace of the fault at places.

The surface trace of the fault strikes nearly due east on the Big Creek side of the divide, swings to N. 70° W. where it crosses the East Fork of Pine Creek, and turns back again to about due east near the west edge of the Kellogg map area. The dip of the shear zone that is exposed along the East Fork of Pine Creek is nearly vertical, and the topographic expression of the fault indicates a vertical attitude or steep south dip along the entire mapped length. The outcrop pattern of the formations on opposite sides of the fault indicates both right- and left-lateral displacement, but these anomalous relations appear to be due to cross faults and lesser folds superimposed on the major fold. The major net displacement is dip slip; the south side is downdropped relative to the north. The outcrop pattern shows that the amount of movement is different from place to place.

FAULTS IN THE WALLACE MAP AREA

CARPENTER GULCH FAULT

The Carpenter Gulch fault was named by Calkins (in Ransome and Calkins, 1908, p. 64) from exposures near the mouth of Carpenter Gulch about 5 miles north of the Wallace map area. He described the fault as follows:

> The Carpenter Gulch fault is an overthrust with a rather gentle dip, which has been traced for about 12 miles. From the northern boundary of the district (47°40′) the fault trends nearly due south to a point about one-half mile southwest of bench mark 4630, at the head of Moon Creek, where its direction changes rather abruptly to about S. 35° E., and this direction is maintained to a point near Twomile Creek, beyond which the fault cannot be followed. The fault is well expressed in the topography and can be traced for the most part with considerable accuracy. The mapping shows that the dip is west and south at a moderate angle and that it is steeper at the north than at the south. Its throw is probably about 2,000 feet along most of its course as traced. West of the mouth of Prichard Creek it has thrust Revett beds over Wallace; west of Twomile Creek it brings Prichard over Burke, the two formations being strongly discordant in dip and strike.
>
> It is on the knob west of the mouth of Carpenter Gulch, however, that the fault is best exposed. The top of this knob is Revett Quartzite, which is underlain on the southeast slope by St. Regis beds. The two formations are seen in place within about 50 feet of one another at one point. They differ but slightly in attitude, and although there is some brecciation along the contact there is no evidence of great disturbance in the fault zone.

Recent geologic mapping has extended the Carpenter Gulch fault south to Twomile Creek, where this fault joints the Twomile fault. At the junction of the two faults a small plug of monzonite is exposed and is bounded on the west side by the Carpenter Gulch fault. The nature of the junction of the two faults is not certain, and it is entirely possible that the Carpenter Gulch fault continues southeast of Twomile Creek. Most faults, however, are very difficult to trace in Prichard terrain, and the continuation of the fault farther southeast is questionable. The Shirttail Gulch fault may be a continuation of the Carpenter Gulch fault, although it dips at a much steeper angle than the Carpenter Gulch fault. Perhaps the Twomile fault has offset the Shirttail Gulch fault from the Carpenter Gulch fault.

The Carpenter Gulch fault is the only structural feature on the north side of the Osburn fault that might be correlated with the Page-Government Gulch fault system south of the fault (Smelterville map area). Both faults border similar upwarped masses of Prichard Formation, and both are low-angle reverse faults, which are rare in the district. The Carpenter Gulch fault, of course, is not known to extend to and to be truncated by the Osburn fault, but if the Page-Government Gulch faults and the Carpenter Gulch fault do not represent segments of a single fault, they may well represent separate members in a zone of overthrusting along the northeast side of the Moon Creek-Pine Creek upwarp.

BLACKCLOUD FAULT

The Blackcloud fault extends from near the mouth of Blackcloud Gulch in the Mullan map area, after which the fault is named, northwestward for about 4 miles into the Wallace map area. The fault is intersected at several points in the Silverore-Inspiration tunnel in the Wallace map area (pl. 3). In places, the fault's position has been determined principally by mapping the distribution of float from the Wallace and Revett Formations which border the fault. Northwest of the Silverore-Inspiration workings, the position of the fault is marked by a contact between monzonite and Revett Quartzite and by lineaments seen on aerial photographs. The fault is lost at its northwest end in a terrain of Revett Quartzite.

In the Silverore-Inspiration workings the fault zone contains a band of rubbery gouge ranging from 6 to 14 inches in width and numerous small subsidiary shears. In the underground exposures the fault plane dips at angles of from 25° to 45° SW. Deflection of the surface trace by topography also attests to the relatively flat dip of the fault. The fault is a reverse fault, and within the Silverore-Inspiration workings Prichard Formation in the hanging wall overlies St. Regis Formation in the footwall indicating at least 4,000 feet of stratigraphic displacement.

No ore minerals are known to have been found along the Blackcloud fault, but in the Silverore-Inspiration workings a diabase dike follows or is near the fault for several hundred feet. Two monzonite stocks in the footwall of the fault are truncated along the fault plane, and several dikes and sills of monzonite in the hanging wall of the fault are exposed in the Silverore-Inspiration crosscut. The metamorphic aureole adjacent to the dike is clearly truncated by the fault, therefore, the fault must have been active after the monzonite intruded.

The Blackcloud fault is truncated at its east end by the Dobson Pass fault and thus may be a relatively early fault. Some of the north-trending faults related to the Dobson Pass fault, such as the Upper and Lower Murray faults, may also offset the Blackcloud fault, but the trace of the faults could not be followed exactly enough to determine this relation. It has been suggested that the Alhambra fault in the Kellogg map area may be an offset continuation of the Blackcloud fault. If the postulated right-lateral strike-slip faulting along the Osburn fault had not occurred, the Moon Creek anticline would be beside the Pine Creek anticline, the Carpenter Gulch fault would be in alinement with the Page-Government fault, and the Blackcloud and Alhambra faults would be in approximate alinement although not joined. According to this concept the Blackcloud fault would be a relatively early fault, and if the mineralized Alhambra fault is truly correlative, the Blackcloud fault might also be locally mineralized.

MOON CREEK FAULT

The Moon Creek fault or fault zone is best exposed along the highway east of Moon Creek in the Kellogg map area (pl. 2), where the fault zone has been intruded by several lamprophyre dikes. The fault zone trends northwest and, as indicated by the attitude of the dikes, dips at angles between 50° and 55° SW. The Moon Creek fault is interpreted as continuing southeastward and intersecting the Osburn fault, but throughout most of its length the trace is covered by alluvium. Normal displacement of as much as 4,000 feet is indicated along the southeastern part of the fault by an apparent offset of a quartzite zone of the middle part of the Prichard Formation. At its northwest end the fault has displaced a quartzite bed by only a few feet.

TERROR GULCH FAULT

The Terror Gulch fault crosses from the drainage of Terror Gulch southwestward across the headwaters of Little Terror Gulch into Prospect Gulch. The fault has been recognized principally because it displaces the conspicuous quartzite beds of the middle part of the Prichard Formation. The stratigraphic throw along the fault is about 1,000 feet. The dip appears to be steep, but the direction of dip is unknown.

TWOMILE FAULT

The Twomile fault, named after Twomile Creek, is known only from surface exposures and is apparent because it transects the trends of formations and has brought Prichard and Burke Formations on the northwest side into contact with Burke and Revett Formations, respectively, on the southeast side. The fault trends about N. 65° E., and deflection of the surface trace by topography shows that it dips to the southeast. Displacement has been reverse and may amount to 2,000 feet.

The Twomile fault ends against the Blackcloud fault and may end against the Carpenter Gulch fault. This pattern, plus the fact that the Twomile fault is also a reverse fault, suggests that all three faults may have formed contemporaneously, the Twomile fault representing a cross fault that accommodated differential displacement along the Blackcloud and Carpenter Gulch faults.

WESTERN UNION FAULT

The Western Union fault is known principally from exposures in the workings of the Western Union property, after which the fault is named. The fault is the major structural feature prospected by the workings.

The fault can also be recognized at the surface by offset of the upper and lower contacts of the Burke Formation. Relatively little gouge occurs along the fault, and the fault zone is principally a zone of crumpled argillite and brecciated quartzite. The fault strikes N. 65° W., dips 70° S., and has apparent normal displacement of about 400 feet. Galena, pyrite, and quartz are reported to occur along the fault in a vein as much as 2 feet wide.

ST. ELMO FAULT

The St. Elmo fault is exposed about 680 feet from the portal of the St. Elmo crosscut, after which it is named. It can be traced on the surface as a contact between the St. Regis and Wallace Formations, the beds of which are overturned. The fault strikes about N. 45° W. and dips about 60° S. In the St. Elmo crosscut there is a gouge zone 2 feet wide along the fault.

In the St. Elmo workings a vein of quartz with some sulfide minerals about 2 inches wide follows the hanging wall. There has been moderately intense bleaching of the rocks for several hundred feet in the hanging wall of the fault and less intense bleaching in the footwall near the end of the crosscut. Most of the movement along the St. Elmo fault probably occurred prior to mineralization, as some quartz containing sulfides follows the fault and as the gouge along the fault has been hardened by mineralizing processes, but there is also evidence for about 60 feet of movement which occurred after mineralization. Although the direction of movement along the fault is not clearly defined, it is probably reverse, and the total amount is probably not great.

MINERAL POINT FAULT

The Mineral Point fault, named after the Mineral Point claim of the Coeur d'Alene Mines Corp., is exposed in the St. Elmo crosscut about 1,500 feet from the portal and was mapped on the surface. The fault is about 2 miles long, strikes approximately N. 60° W., and dips between 50° and 60° S. In the St. Elmo crosscut a zone of gouge and sheared rock at the fault is from 3 to 10 feet wide.

Displacement along the Mineral Point fault is normal, and the net slip is about 500 feet. This is based on the fact that the beds on the south side of the fault are the type found in the middle and upper parts of the St. Regis Formation, whereas those on the north side of the fault are the type found in the lower part of the St. Regis or in the transition zone between the St. Regis and the Revett Quartzite. The beds on the south side of the fault show normal drag. The presence of drag ore in the fault zone shows that movement subsequent to ore emplacement has occurred, but unbroken veinlets in the fault zone indicate that there was also movement prior to ore emplacement.

ARGENTINE FAULT

The Argentine fault is exposed in the Vulcan crosscut about 2,600 feet from the portal and also in a drift from the main crosscut driven westward to the Argentine claim. The fault strikes about N. 60° W. and dips 50°–70° S. There is a gouge and shear zone 3–6 feet wide along the fault. The footwall is principally unaltered rocks of the St. Regis Formation, but the hanging-wall block comprises rocks of the St. Regis and Wallace Formations that, because of alteration, are difficult to distinguish clearly, and some of the rocks shown as St. Regis Formation on plate 3 may be Wallace Formation. The fault has normal displacement and the total throw is about 1,000 feet.

POLARIS FAULT

The Polaris fault can be traced eastward from its junction with the Osburn fault, three-fourths of a mile west of Big Creek, for about 7 miles to the divide between Lake and Placer Creeks (pls. 2 and 3). East of this divide the fault is wholly within Wallace beds and cannot be traced on the surface with any confidence.

The Polaris fault is well exposed in several of the mines. In the Silver Dollar and Silver Summit crosscuts, the fault consists of a zone of gouge a few inches wide, several feet of sheared rock, and in the hanging-wall block a zone of crumpled rock as much as several hundred feet wide. On the adit level of the Coeur d'Alene mine the gouge and sheared rock along the fault is more than 10 feet wide. In the Vulcan crosscut the merging Polaris and Argentine fault zones have broken the rocks into a series of slices. The gouge and sheared rock along the faults in this zone of slicing generally range in thickness from 2 to 5 feet. The fault strikes about N. 50° W., and its dip is 50°–65° SW.

The Polaris fault has an apparent normal throw of possibly as much as 5,000 or 6,000 feet, but there may also be a strike-slip component of displacement of indeterminate amount and direction. Veins south of the Polaris fault, in workings of the Merger mines and the Coeur d'Alene mines on McFarren Gulch, strike northeast and dip southeast, and the vein zone appears to be truncated by the Polaris fault. About 1,000 feet southeast along the Polaris fault another vein of the Coeur d'Alene mines is found north of the fault and it also strikes northeast and dips southeast. If these veins north and south of the fault represent segments of one vein zone, the offset may represent strike slip as well as normal displacement along the fault. No productive ore bodies have been found along the Polaris fault itself, but many veins along fractures in the hanging and footwalls of the fault contain ore, and movement subsequent to mineralization along the fault has offset ore bodies.

As discussed under the subsection entitled "Structural evolution" (p. 125) the Polaris fault appears to be one of a group of faults that trend diagonally across the block between the Placer Creek and Osburn faults, and it may accommodate some of the strike-slip adjustment in the block between the Placer Creek and Osburn faults.

FORT WAYNE FAULT

The Fort Wayne fault is exposed in the American Silver tunnel in McFarren Gulch and has been correlated with a fault cut in the Rainbow tunnel in Shields Gulch. The American Silver tunnel follows the fault for more than 900 feet and is tightly lagged for most of that length. In one place where the fault zone could be examined, 1 foot of white gouge occurs above which is a foot of brecciated quartzite. Small veinlets and pods of quartz occur along the fault. Along part of the American Silver tunnel the fault separates the St. Regis Formation in the footwall from the Wallace Formation in the hanging wall, but along the remainder of the tunnel, the Wallace is on both sides of the fault. In the Rainbow tunnel, the St. Regis is on both sides of the fault. The fault strikes about N. 60° W. and dips 60°-70° S. Displacement is thus normal and must not amount to more than a few hundred feet.

KILLBUCK FAULT

The Killbuck fault is best exposed in the Vulcan tunnel about 700 feet south of the Polaris fault. This fault is unusual in that it dips to the northeast at about 65°, whereas all other major faults in the vicinity dip southwest. It is characterized by a zone of gouge and sheared rock up to 3 feet wide and is the largest of numerous shears that crisscross a zone of crumpled and intricately folded rocks more than 400 feet wide. This zone of deformation, of which the Killbuck fault is a part, lies between a block of overturned south-dipping beds to the north and upright north-dipping beds to the south. Very possibly some differential strain in the formation of the overturned Big Creek anticline was accommodated in this zone. Displacement is normal and net slip has probably not been more than a few hundred feet.

SILVER STANDARD FAULT

The Silver Standard fault is known by its surface trace, and is also exposed in the Rainbow tunnel about 1,900 feet from the portal. On the surface this fault is rather clearly defined throughout much of its length as a contact between different lithologic units. In several places saddles in ridges and small draws and gulches are topographic expressions of the position of the fault. The fault is more than 4 miles long and extends from Placer Creek northwest to McFarren Gulch. On the southeast the fault joins at a very low angle with the Big Creek fault and on the northwest it joins or is truncated by the Silver Summit fault. The fault strikes about N. 60° W. and dips 65° S. The apparent normal displacement along the fault is about 800 feet.

SILVER SUMMIT FAULT

The Silver Summit fault is exposed in the Silver Summit crosscut, where it strikes N. 45° W. and dips 70° SW. It probably extends from a junction with the Big Creek fault at its southeast end for about 3 miles to the northwest. Shenon and McConnel (1939, pl. 1) showed the fault as feathering into several smaller branches at its northwest end. In one place in the Silver Summit crosscut the fault is represented by a gouge zone 4 feet wide and in another place by a zone of gouge 10 feet or more wide.

Shenon and McConnel (1939, pl. 1) also interpreted the Silver Summit fault to be a left-lateral fault, displacing the axis of the Big Creek anticline horizontally for about 1,500 feet. The displacement along the Silver Summit fault is indeed anomalous in relation to the right-lateral strike slip along the Osburn and other faults. The Silver Summit fault may represent a complementary shear plane in the general right-lateral strike-slip fault system.

BIG CREEK FAULT

The Big Creek fault, named after Big Creek in the eastern part of the Kellogg map area, is exposed in the Western Star adit near Big Creek, and in a long crosscut on the adit level of the Metropolitan mine. Both of these intersections are approximately 2,700 feet above sea level. The Big Creek fault has also been cut by the 3,100-level crosscut of the Sunshine mine—400 feet below sea level. Near its east end the fault is exposed in a tunnel on Cranky Gulch, a tributary of Placer Creek, about 2 miles south of Wallace. The fault can be traced throughout most of its length by the difference in lithology on both sides of it, but between the East Fork of McFarren Gulch and Shields Gulch, exposures are so poor that the exact location of the fault has not been determined. The surface expression of the fault is well shown where it crosses Big Creek in the vicinity of the Metropolitan mine (pl. 2). Massive beds of Revett Quartzite, which are well exposed in the valley walls south of the fault, dip

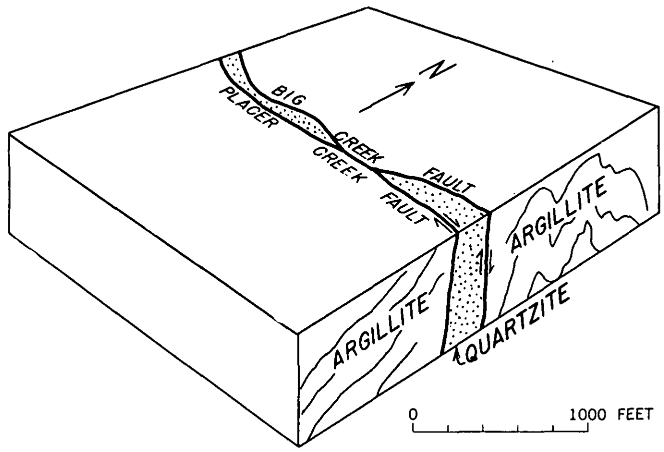


FIGURE 27.—Relation between the Big Creek and Placer Creek faults in the vicinity of the Castle Rock property, Wallace and Mullan map areas.

gently southward away from rocks of the Wallace and St. Regis Formations that form the south limb of the Big Creek anticline north of the fault. The fault line is marked in part by straight well-defined gullies tributary to Big Creek. West of Big Creek the fault has been interpreted as turning north rather abruptly to the Crescent mine area, where it is shown joining with the west-trending Alhambra fault. This connection of the two faults is open to serious question, and is discussed under the subsection entitled "Alhambra Fault."

The fault appears to have a dip of 70° S. where exposed in the Western Star and Metropolitan workings, but a projection from these exposures to the point at which the fault is cut in the 3,100 level of the Sunshine mine gives an average dip of 60° S. Near the east end in the valley of Placer Creek (pl. 4) the dip is nearly vertical. The fault's general trend is about N. 70° W., but in detail is irregular. The Big Creek fault contains a gouge zone generally ranging from 1 to 3 feet wide. The Revett Quartzite in the hanging wall commonly is highly shattered. The fault is sharp and clean cut where it is cut by the Metropolitan crosscut on the 3,100 level of the Sunshine mine, and Burke Formation in the hanging wall is brought in contact with basal St. Regis Formation in the footwall. Apparent reverse dip slip is about 5,000 feet near the Metropolitan mine. No vein matter has been found in the fault zone.

The east end of the Big Creek fault in and near the valley of Placer Creek nearly parallels and is only a few hundred yards north of the Placer Creek fault for more than a mile before the Big Creek fault ends against the Placer Creek fault. The combined displacement along the two faults has placed a thin wedge of Revett Quartzite and St. Regis Formation between rocks of the Wallace Formation. The Revett Quartzite and St. Regis Formation may possibly have been faulted against the Wallace Formation first by reverse movement along the Big Creek fault; then the Placer Creek fault may have become active as a strike-slip fault, truncating the Big Creek fault at a low angle and actually paralleling it for some distance. These movements could account for the wedgelike tablet of Revett Quartzite and St. Regis Formation that is far removed from the main mass of such rock and bounded by Wallace Formation on both sides of the fault (fig. 27). It seems inconceivable that such a thin tablet of quartzite could have been injected for thousands of feet as a wedge that pierced a rock mass of the St. Regis and Wallace Formations. The presence of such thin wedges of rock so far out of place is considered to be strong evidence for strike slip and for two or more distinct episodes of structural adjustment.

FAULTS IN THE MULLAN MAP AREA

PURITAN FAULT

The Puritan fault, so named in the workings of the Tamarack mine, has been traced northward from its convergence with the Standard fault to beyond the north edge of the Mullan map area, a distance of about 4 miles. This is the same fault that McKinstry and Svendsen (1942, p. 228) described as the Wallace fault in the Interstate-Callahan mine. At its south end, the Puritan fault strikes about N. 20° W. and dips 55°–60° NE. From this attitude it changes to a north strike and vertical dip at the north edge of the map area. In the Tamarack workings it is a normal fault, the Burke Formation being dropped down on the east, but to the north it is probably a reverse fault because of the position of monzonite in the hanging wall. North of the monzonite, offset of the contact between upper and lower parts of the Prichard Formation indicates normal displacement along the fault. Thus, normal displacement may be characteristic of all parts of the fault. If normal displacement has brought monzonite in the hanging wall into contact with metasedimentary rocks in the footwall, the western contact of the monzonite must dip eastward. The exact amount of displacement is unknown, but at the place where the fault cuts across the west end of the north Gem stock, the movement is sufficient to bring Prichard Formation that has not been affected by contact metamorphism into fault contact with massive monzonite.

The fault has been mapped from mine workings for most of its known length, as its surface trace is somewhat uncertain for long distances. At its south end, the Puritan fault has been traced along most levels of the Tamarack mine and, in addition, is cut on the 200 and 1,200 levels some distance from the veins. Presence of the fault is confirmed on the 1,500 level of the Interstate mine, which closely follows the fault for 900 feet and cuts it 2,000 feet farther north. Some 4,000 feet beyond this cut it is cut in another place on the 1,000 level of the Idora mine (just north of the Mullan map area), about 200 feet from the portal. Marked changes in places in the attitude of bedding and shattered rock in a roadcut are the only evidence to mark its surface trace in the intervening distance. Beyond the map area on the north side of Beaver Creek, bulldozing has exposed a probable extension of the Puritan fault.

The Puritan is one of the few large faults along which any mineralization occurs. At the Tamarack mine, ore minerals occur along the fault over a vertical distance of more than 1,000 feet and were locally in great enough concentrations to be mined. In the lower part of the mine the ore deposits are in the footwall, but in the upper part they are in a different group of veins in the hanging wall. Any movement subsequent to ore emplacement is considered to have been small.

STANDARD FAULT

The Standard fault is most evident at the surface where it crosses Canyon Creek, owing to the obvious discordance in the attitude of the bedding between the upper part of the Prichard Formation on the east and rocks of the Burke Formation on the west. This relation continues along the same trend for 1,000 feet to the south, and the fault can be followed beyond this point because of marked changes in dips of rocks of the Burke Formation, which form both walls. The fault, however, must die out to the south within 4,000 feet of Canyon Creek, as no evidence could be found to indicate that the break continued into the cirque at the head of the gully which was eroded along it. North of Canyon Creek, few surface indications of the fault could be found, but its position is well known underground by the many exposures in the Standard-Mammoth mine and also on the 1,200 and No. 5 tunnel levels of the Tamarack mine. The position of the fault in the underground workings indicates that the Standard fault joins the Frisco fault at its north end. No trace of the Standard fault has been found beyond the Frisco fault, so it must end at their junction either abruptly or by merging with the Frisco fault. Thus the Standard fault is estimated to be about 12,000 feet long.

The strike of the Standard fault averages about N. 30° W. along an irregular trend. Throughout the Standard-Mammoth workings the fault plane consistently dips 75° NE., and the dips are similar in the Tamarack mine. The movement has been reverse with the maximum vertical displacement at Canyon Creek at least 500 feet and probably somewhat more to the north. Where exposed in the No. 5 tunnel of the Tamarack, the fault contains a gouge zone 12 inches wide, and across a zone 8 feet wide the rock is sheared and shattered. Ransome (in Ransome and Calkins, 1908, p. 119–121), who named the fault, reported that it contained 5 inches of dark clay gouge and 10–12 feet of sheared quartzite in the hanging wall. He also stated that the evidence strongly suggested that the fault was older than the ore deposits and thus acted as a dam at the east end of the Standard-Mammoth lode.

FRISCO FAULT

The Frisco fault is named after the Frisco mine. The veins in this mine end against the fault on the east. North of the Frisco mine the fault is exposed in the No. 4 adit of the Black Bear mine and also near the portal of the main adit of the Black Bear Fraction. In all these workings the Frisco fault shows as a conspicuous structural feature with 6–18 inches of gouge, several small subsidiary faults, and shears for several feet in one wall or the other. To the north, across Canyon Creek, the fault is located between areas in which the bedding attitudes are markedly different, and the hydrothermal alteration of the rocks to the east contrasts strongly with the unaltered rocks to the west. A pit has been dug into the sheared zone along the fault on the crest of the ridge between Canyon Creek and the East Fork of Ninemile Creek. The fault is also exposed underground where it is crossed by the No. 5 adit and 200 level of the Tamarack mine. To the north, the Frisco fault appears to end against the Puritan fault near the knob just south of the portal of the Interstate-Callahan 1,500 level. South of the Frisco mine no evidence could be found to show that the Frisco fault continues beyond the Star fault. Thus its length is about 2½ miles.

The average strike of the Frisco fault is N. 5° E., but the strike of its different segments ranges from N. 20° E. to N. 10° W. In the Frisco workings the fault has an average dip of about 85° W., but in the Black Bear Fraction the dip is 80° E., and at the Tamarack mine it is 70° and 65° E. At the south end, movement along the fault is apparently not much more than 100 feet but must be many times that on the north owing to the large duplication of rocks of the Burke Formation.

In the Frisco mine the south (Frisco) vein strikes about N. 65° W. and ends abruptly against the fault, but the north vein curves from almost parallel to the south vein to almost parallel to the Frisco fault, suggesting that the north fissure was formed contemporaneously with the fault.

Several broad zones of bleached rock, which trend northwest across the Burke area, end abruptly at the Frisco fault. In the area adjacent to the west of the Frisco fault, only a small amount of bleached rock is found. Termination of the bleaching against the fault could result either from damming of the hydrothermal solutions which were responsible for the alteration or from movement along the fault subsequent to bleaching that would displace the bleached rocks out of sight in one direction or another on the west side. The favored interpretation is that the Frisco fault acted as a dam to the bleaching solutions, as the probable movement along the fault was scarcely enough to displace from view on the west side such an extensive zone of bleaching as that found on the east side.

The mutual relation of the Standard, Frisco, and Puritan faults is peculiar. The manner in which they join—the Standard against the Frisco, the Frisco against the Puritan, and the Puritan against the Standard—suggests that they are almost contemporaneous. It would seem more logical, however, that the wedge of upper Prichard rocks had been brought into its present position by reverse movement along the Standard and Frisco and was later isolated by subsidence of the block to the east of the Puritan.

FRACTION AND GEM FAULTS

The Fraction and Gem faults west of the southern part of the Frisco fault are apparently supplementary to the Frisco fault. They have similar attitudes, and the direction of movement has been the same along all three. They have been cut at several places in the Gem and Frisco mines, and their strikes converge so that it appears certain that they join south of these mines. Furthermore, only one fault was found along a projection of their trends to the south in the adjacent Betty Lou workings. Farther south, this fault must end, as no trace of it could be found south of the Star fault. The Fraction and Gem faults can be traced only a short distance north of Canyon Creek. The Gem fault has ore deposited along its course for a short distance. This fact shows that this fault, and probably others of this group, formed prior to ore emplacement.

OREANO, MART, AND PHOENIX FAULTS

The Oreano, Mart, and Phoenix faults, together with several other northwest- to west-trending faults, lie north of Canyon Creek between the Standard and O'Neill Gulch faults. The Oreano and Mart faults are well exposed in the 1,000 level or Oreano tunnel of the Sherman mine, and the Mart fault has also been cut on most other levels of the Sherman mine. The Phoenix fault is followed by the Sherman No. 5 tunnel or 600 level for about 800 feet and is also intersected in the western part of the Hercules No. 5 level.

Most faults of this set dip steeply to the southwest. The Oreano dips 60°–80° SW., the Mart 65°–80° SW., and the Phoenix 80°–85° SW. A poorly defined fault zone that bounds the east end of the Sherman ore body dips about 80° E.

Underground, the Oreano fault consists of a zone of gouge and sheared rock as much as 2 feet wide; the Mart, of a zone about 1 foot wide; and the Phoenix, of a zone as much as 3 feet wide.

The Oreano, Mart, and Phoenix faults have apparent normal displacement, but three faults of this group that cut the Hercules No. 5 level are reverse faults. The displacement along any one of the faults has probably not amounted to more than a few hundred feet.

The Mart fault bounds the west end of the Sherman ore bodies and appears to be a fault that formed prior to vein formation as there is no evidence of drag along the fault. A vein has been found west of the Oreano fault in approximate alinement with the Sherman veins, and the minerals in it include quartz, hematite, and pyrite but no lead or zinc minerals. The faults may have acted as dams to the ore-bearing solutions.

O'NEILL GULCH FAULT

The O'Neill Gulch fault, named by Calkins (in Ransome and Calkins, 1908, p. 64) after a valley tributary to Canyon Creek, is one of the dominant north-trending faults in the northern part of the Mullan map area. The fault is at least 5 miles long. No other fault in the area is so well expressed by the topography. The streams in Granite, Gorge, and O'Neill Gulches follow closely along the fault's surface trace, and saddles mark the places where it crosses divides. The northern three-fourths of the fault trends generally north, but in O'Neill Gulch there is a change in strike so that the south end trends about N. 30° W. The dip of the fault as observed in the Tiger-Poorman workings (Ransome and Calkins, 1908, p. 173) is 75° E., and the dip is similar in part of the Hecla workings. Southeast of the point at which the strike changes to N. 30° W., the dip appears to be more nearly vertical. The fault was also cut by the Ajax workings, but the dip could not be determined because of the tight lagging necessary to control the soft material in the fault zone. Ransome (in Ransome and Calkins, 1908, p. 173) noted that in the Tiger-

Poorman mine the fault "is marked by a zone of sheared and crushed quartzite, in places several feet wide and containing one or more seams of plastic gouge."

The north-trending segment of the fault has had reverse displacement. At Canyon Creek, where the bedding is almost as steep as the fault, a large section of Burke Formation is duplicated, and some rocks of the upper part of the Prichard Formation are exposed at the surface. The displacement at this place must be measured in thousands of feet. At the head of Granite Gulch, though, the displacement is at most only a few hundred feet. Along the southern part of the fault, which trends N. 30° W., the apparent stratigraphic throw amounts to more than 3,000 feet. Hydrothermally altered rocks of the Burke Formation are in contact with unaltered but sheared rocks of the Revett Quartzite and the St. Regis Formation along the southern part of the fault.

Ransome (in Ransome and Calkins, 1908, p. 173) noted that the Tiger-Poorman vein ended against the O'Neill Gulch fault and stated: "The ore ends against the first gouge seam and is slickensided. It is quite possible, however, that this slickensiding is due to continued movement along a fissure which was already in existence when the ore was deposited."

In the subsection entitled "Possible relation of Granite Peak, Deadman, and Mill Creek synclines," the possibility is suggested that the southern part of the O'Neill Gulch fault represents a rupture of the west flank of the Granite Peak syncline as the original fold was contorted into a drag-fold-like flexure. It is also suggested that the undistorted character of the Star-Morning vein suggests that mineralization succeeded the formation of the O'Neill Gulch fault. If this relation were true, an area of several square miles around the south end of the O'Neill Gulch fault should have contained many open fractures suitable for ore deposition at the time mineralizing solutions pervaded the block.

RUSSELL AND GERTIE FAULTS

The Russell and Gertie faults are east of and parallel to the O'Neill Gulch fault. They dip 85° W. or counter to the O'Neill Gulch fault but are like it in having reverse movement, as they cut out about 500 feet of the stratigraphic section of Burke Formation exposed at the surface. Reverse movement is also substantiated by the direction of drag indicated by the bedding at the faults. The Gertie is the more persistent of the two and therefore the one along which the movement was most likely greater. If the unnamed fault next to the east, which parallels these two, has a similar dip, it is normal in character.

BANNER, COUGAR, ELITE, AND OMAHA FAULTS

The Banner, Cougar, Elite, and Omaha faults are representative of a set of numerous relatively small faults in the northern part of the Mullan map area that form a pattern of cross breaks between and adjacent to the more persistent faults trending north. The faults strike northwest or west, and the majority dip 60° or more to the south or southwest. The displacement along most of them has been normal.

Both the Elite and Cougar faults are conspicuous where cut in the Gertie workings. For part of its length on the surface, the Cougar fault is marked by a difference in lithology on opposite sides, but the only surface evidence of the Elite fault is sheared rock on the dumps of two prospects along it. Normal displacement along the Cougar fault must be about 1,000 feet, and displacement along the Elite fault, although of the same type, probably is considerably less.

This set of northwest-trending faults may be contemporaneous with or later than the major north-trending faults. Several of the faults end against north-trending faults, but no offset segments have been found as might be expected if the north-trending faults formed later. The Banner and Cougar faults and a crossfault between the O'Neill Gulch and Standard faults might appear in areal plan to be offset segments of a single fault, but the direction of dip is not the same on all three, nor is the type of displacement. The north-trending and the northwest-trending faults may well be a single system of block faults that principally represents vertical adjustments.

STAR FAULT

The Star fault is principally known from exposures underground in the Independence, Morning, Star, and Black Bear Fraction workings. It is about 3 miles long and extends from Mill Creek almost to Canyon Creek. It strikes northwest in the Morning mine and Star mine areas, but in the Black Bear Fraction the strike changes to northeast. The dip is steep, ranging from 80° S. to 80° N. on different segments of the fault. The fault characteristically has a zone of gouge and breccia from 10 inches to 2 feet wide. Rocks are bleached in the vicinity of the fault, and phyllites have formed in many places in its walls.

The Star fault is of particular interest because of its proximity to the Morning-Star vein, which it actually follows for more than 100 feet of strike length in the Star mine. In the Morning mine the Star fault is south of and subparallel to the vein, but in the western part of the Star mine the fault leaves the vein zone and diverges to the north. In the Black Bear Fraction, where the strike changes from northwest to northeast, some of the strain has been taken up along bedding-plane faults that diverge from the Star fault.

Displacement is probably not more than a few hundred feet, but the relations to the ore body and to lamprophyre dikes in the Star mine provide clues to the sequence of geologic events. Movement along the fault has obviously occurred subsequent to ore emplacement, and has been of a strike-slip type as indicated by the offset of a vertical north-trending lamprophyre dike well exposed on several levels of the Star mine. The fault has sheared the ore body, and gouge seams form an anastomosing pattern in the segment where the fault follows the vein. The near coincidence of the faults and vein suggests that there has been recurrent movement along a zone that was first fractured, then mineralized, then once fractured again. Whether the first movement was strike slip, as was apparently the later movement, cannot be determined. If the Star fault is a partial correlative of the Cincinnati fault of the Pottsville map area and if the Cincinnati-Deadman shear zone has had strike-slip displacement of many thousands of feet as has been postulated, then the small amount of strike slip along the Star fault would suggest that it came into being as a divergent fracture late in the formation of the Deadman-Cincinnati fault system.

FANNY GREMM FAULT

The Fanny Gremm fault, in the vicinity of the Morning mine, is cut both in the Fanny Gremm tunnel, after which it is named, and in the Sunshine Premier tunnel. It has a near-north strike and is a cross fault between the Star and Commander faults. The fault appears to be dipping steeply to the west. In the Fanny Gremm tunnel the fault is marked by a zone of intensely foliated rock almost 50 feet wide and a zone of gouge 2 feet wide.

Displacement is reverse, but the amount, probably at least several hundred feet, is difficult to determine because the fault nearly parallels the bedding. One of the few places where a clear relation of faulting to foliation can be seen is along the Fanny Gremm fault. The strike of foliation in the area around the Morning and Independence mines is northwest almost parallel to the Commander and Star faults, but near the Fanny Gremm fault the foliation is irregular and contorted (fig. 28). Obviously, foliation had begun to form before the formation of the Fanny Gremm fault and movement along this fault has contorted the foliation. The crosscutting relation of the fault to cleavage has clearly provided the optimum conditions for distortion of foliation, whereas the effects of a later movement along a fault that parallels foliation might not be so clear. Perhaps the Star fault and the Fanny Gremm faults formed contemporaneously.

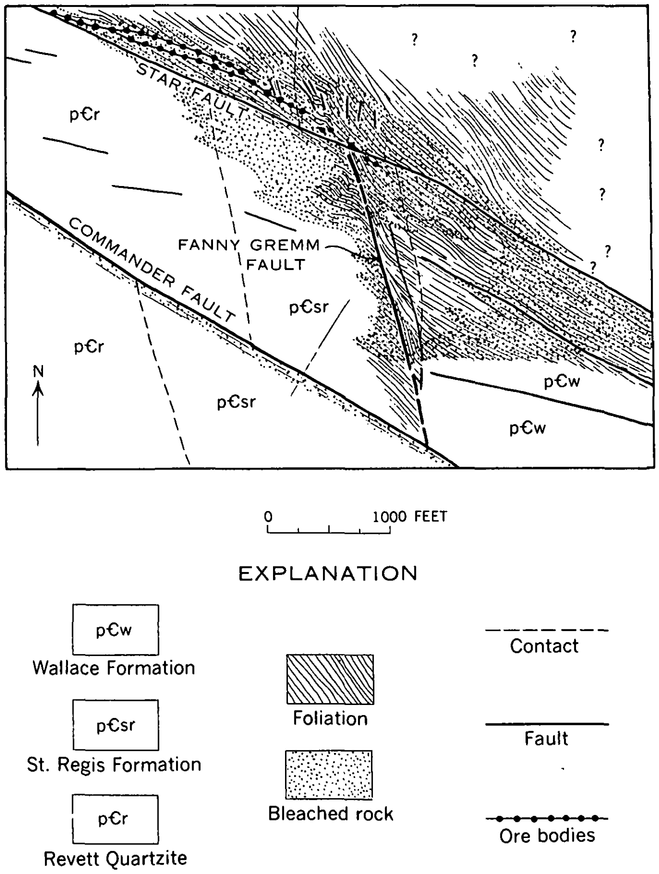


FIGURE 28.—Relation of foliation, bleached rock, and faults in vicinity of Morning mine. Note irregularities of foliation trend near Fanny Gremm fault and difference in distribution of foliation and bleached rocks.

COMMANDER FAULT

The Commander fault, named after the American Commander workings in Mill Creek, extends from its junction with the Paymaster fault near the mouth of Paymaster Gulch northwest for about 3 miles to the point where it is truncated by the Star fault. The Commander fault is cut in the Morning crosscut and at several places in the 1,200 level of the Star mine. On the surface a contact between the Wallace and St. Regis Formations marks the fault trace in Mill Creek, and in Grouse Gulch lineaments on aerial photographs, and alined gulches express the position of the fault. Near West Grouse Peak the fault forms a contact between St. Regis Formation and Revett Quartzite. The fault dips about 80° NE. along its eastern part but dips southwest where exposed in the Black Bear Fraction tunnel.

In the Morning crosscut, the fault zone is composed of highly cleaved and brecciated rock and gouge 15–20 feet wide. In the hanging wall of the fault, the rocks are relatively unaltered quartzite, but in the footwall the rocks are so intensely bleached and foliated that bedding is obscured for a distance of 30 feet or more from the fault. In the Star workings the fault is principally bounded by Revett Quartzite, and the fault zone is considerably narrower, but along it are zones of gouge and breccia that are several feet wide.

The north side is upthrown more than 2,000 feet as indicated by the offset of the St. Regis-Revett contact on the divide between Grouse Gulch and Mill Creek, but on the eastern part of the fault, the south side appears to be upthrown. The strike of beds changes from roughly east in the apex of the wedge between the Commander and Paymaster faults to a north direction farther to the west within the wedge; the net offset along the fault is difficult to determine.

Some iron oxides occur along small fractures near the west end of the fault, but no ore minerals have been identified within it. The confinement of bleaching to the footwall block of the fault suggests offset subsequent to bleaching, but the gouge and sheared rock along the fault may also have acted as a confining wall for the hydrothermal solutions.

MEXICAN-SAN JOSE FAULT

The Mexican and San Jose faults are parts or branches of the same fault zone, but the two ends have been named separately. The Mexican fault is named after a claim on the northeast side of Bell Gulch, where the fault is exposed at the surface. The San Jose fault is named after a drift in the Star 1,200-level workings that follows the fault. Both faults are exposed in the West Star No. 3, in the West Star No. 2 west, and in the West Star No. 2 workings. West of these workings the Mexican fault can be traced at the surface as it separates rocks of the Prichard Formation from those of the Burke Formation, and it is cut by the West Bell crosscut. The Mexican fault continues west across Canyon Creek and terminates against the Dobson Pass fault. East of the West Star workings, the surface position of the San Jose fault is uncertain in places, but contacts between the St. Regis and Revett Formations that transect the trend of bedding are evidence of the fault's position for part of the strike length. The combined length of the two faults is almost 3 miles, and although the San Jose fault strikes N. 50° W. for part of its length near West Grouse Peak, the overall trend of the fault is west. The dips of the fault range between 60° and 75° S., but the dip of the branch that is considered the east end of the Mexican fault may be somewhat flatter. Where the faults have been exposed underground, there is from 1 to 12 inches of gouge and as much as 6 feet of sheared and shattered rock. Where the Revett Quartzite is cut by the fault as in the San Jose drift, there is less sheared and foliated rock and relatively more jointing and subsidiary fracturing.

Both faults have had apparent normal displacement, but the net slip was very likely of different amounts along different segments of the fault. Along part of the fault, the middle part of the Burke Formation is against the lower part of the Prichard Formation, a fact that indicates several thousand feet of movement; elsewhere, St. Regis Formation is against St. Regis Formation, and Burke is against Burke, a fact that indicates relatively little movement.

A fine-grained relatively fresh diabase dike lies between the two faults in the West Star workings and continues eastward along the San Jose fault. In the West Star No. 2 West workings a considerable amount of galena was found in a zone that appears to lie between the two faults. The mineralized zone is as much as 10 feet wide and is in a sheared zone about 50 feet north of, but subparallel to, the San Jose fault. The west end of the mineralized zone bends and is truncated by and joined to the San Jose fault.

As previously stated, the Mexican fault ends on the west against the Dobson Pass fault. A possible extension of the fault west of the Dobson Pass fault may be the Ruth fault, which has many aspects similar to the Mexican-San Jose fault zone. Not only are the dips and displacements similar, but diabase dikes occupy both faults, and if the Dobson Pass fault has 3–3½ miles of normal dip slip as postulated, the dike along the Ruth fault may represent a faulted segment of the dike along the Mexican-San Jose faults.

WONDER FAULT

A fault exposed in the Wonder crosscut at 1,200 feet from the portal is named the Wonder fault. On the surface its position on a ridge west of West Grouse Peak is confirmed by sheared and foliated rock exposed in a prospect pit. A lineament observed on aerial photographs and nonalinement of bedding strikes have helped to locate the fault's position along its course.

The fault dips about 55° S. and apparent displacement has been normal. The contact between St. Regis and Revett Formations has not been offset more than a few hundred feet.

PAYMASTER FAULT

The Paymaster fault, named after a claim through which it passes on the east side of Mill Creek, is about 8 miles long and lies parallel to and one-half mile north of the Osburn fault. The fault is probably truncated at its west end by the Dobson Pass fault, and it extends eastward to the vicinity of Gentle

Annie Gulch in the Pottsville map area, beyond which it has not been clearly delimited.

The fault is cut by the Square Deal, Morning, and Gold Hunter tunnels (pls. 4 and 5). In the Square Deal tunnel the fault zone is more than 50 feet wide and is cut about 200 feet from the portal. Another zone of intensely sheared and shattered rock cut 300 feet from the portal is probably a subsidiary fault. One major strand within the fault zone dips 60° S., but other fractures are at many other orientations. Quartzite borders both sides of the fault in the Square Deal tunnel. In the Morning No. 6 crosscut, the Paymaster fault is probably the structural feature cut about 5,600 feet from the portal. Here, a zone about 15 feet wide consists principally of highly brecciated rock, bordered on both sides by Revett Quartzite. No striking discordance of bedding was found on opposite sides of this zone. In the Gold Hunter crosscut the fault is cut about 3,300 feet from the portal, where it consists of a zone 10 feet wide of sheared and shattered rock, including 4 feet of gouge. The formations on opposite sides are not clearly distinguishable. For much of the distance eastward in the Pottsville map area, the Wallace Formation forms the north boundary of the fault and St. Regis Formation the south boundary, and it is fairly certain that the position of the Paymaster fault must coincide with the contact between these two formations from Mill Creek near Mullan eastward to Gentle Annie Gulch in the Pottsville map area. East of Gentle Annie Gulch—where the beds strike nearly parallel to the fault, are steeply dipping, and are intensely sheared—the course of the fault is less certain. Much of the displacement along the Paymaster fault may be dispersed along bedding or shear planes, and the fault as a dominant structural feature may lose much of its identity. In the Idaho Silver workings in Daisy Gulch, for example, a large fault separates the Wallace and St. Regis Formations, and another major fault occurs 500 feet to the north. Neither of these, however, fits the position or character of the Paymaster, although they may be strands of the fault. The main Paymaster fault has been placed to the north of the Idaho Silver workings and entirely within the Wallace Formation on the basis of alinement, shearing, and alteration of the rocks and the presence on the east side of Daisy Gulch of a pronounced fault zone in a prospect trench. Westward between Grouse and Dexter Gulches in the Mullan map area, the Paymaster fault can be traced by lineaments on aerial photographs. From Dexter Gulch westward, the position of the fault is more obscure but probably extends to the Dobson Pass fault, even though its extreme west end is covered by gravel. A possible westward extension of the Paymaster fault is a fault that is similar in trend but alined south of it and west of the Dobson Pass fault.

Eastward from Grouse Gulch, the dip of the fault ranges from very steep south to vertical. This attitude is derived most conclusively from the relation of the surface to underground position and is substantiated by topographic expression. Westward from Grouse Gulch, the one exposure, in the Square Deal tunnel, and the topographic expression support the interpretation of a less steep southerly dip.

Displacement along the fault appears to be reverse, the south side upthrown relative to the north side. This is indicated by offset of the Burke-Revett contact in and near Dexter Gulch; by the presence of Revett Formation south of the fault against St. Regis Formation north of the fault in Ruddy and Trowbridge Gulches; by offset of the Revett-St. Regis contact near the Morning crosscut; and by the presence of St. Regis Formation south of the fault against Wallace Formation north of the fault along most of the eastern half of the fault. A few hundred to 1,500 feet of dip slip would account for most of the relations described. A relatively large drag fold in the Revett Quartzite on the west side of Grouse Gulch is consistent with the interpretation that the displacement is reverse. The Paymaster fault, however, occupies a special position in the gross structural pattern, and this fact arouses suspicion of more than simple dip-slip movement along the fault. The Paymaster fault appears to be the northern boundary of a tectonic block lying between it and the Osburn fault. This block is characterized by a myriad of faults and numerous tabular plates and isoclinal folds almost parallel to the Osburn and Paymaster faults. The surface trace of the Paymaster fault forms a cord across a concave-northward segment of the Osburn fault between Canyon Creek and the Montana line. In this position some right-lateral strike-slip adjustment probably took place along the Paymaster fault if it were in existence during the main period of strike slip along the Osburn fault. However, the offset by the Paymaster fault of individual formational contacts seems to preclude any right-lateral strike slip.

The fault is the boundary for bleaching along part of its eastern half, and if this is interpreted as being a result of displacement that occurred subsequent to bleaching, the fault may be a relatively late structural feature. Bleaching appears to be far more common along the south side and immediately adjacent to the fault than along the north side. No ore minerals have been found along the Paymaster fault, and it may have formed after the principal period of mineralization.

GOLCONDA FAULT AND OTHER FAULTS IN THE GOLCONDA MINE AREA

The Golconda fault, named after the Golconda property which it crosses, is recognized on the surface by a lineament on aerial photographs, by a difference in lithology on opposite sides, by a gouge zone exposed in a logging road about 400 feet east of the creek in Trowbridge Gulch, and by a spring in another logging road 200 feet farther east. Underground, in the main crosscut of the Golconda mine and near the east end of a drift driven eastward from the main crosscut, a conspicuous fault, which is probably the Golconda fault, is exposed. The Golconda fault extends from Canyon Creek slightly more than 2 miles eastward to Ruddy Gulch. The dip, as determined from the relative position at the surface and underground, is steep to the north, and its apparent displacement is normal.

Underground the fault consists of a zone of intensely sheared, foliated, and pulverized rock more than 30 feet wide. A chloritized dike is along the south side of the fault in the main crosscut. South of the fault, the Prichard and Burke Formations are exposed underground, but north of the fault in the east drift, massive white Revett Quartzite is cut.

From the Golconda fault southward to the Osburn fault, faults and zones of shearing are so numerous that it is difficult to correlate one with another where cut at different points underground. Many have a foot or more of gouge, and large blocks of rocks are shattered and sheared. Some correlations between faults on different levels make the Golconda fault appear to dip south rather than north, but evidence favors a steep north dip. The Golconda vein lies within a shear zone that dips south and within which the rock and ore is intensely sheared and in many cases is contorted or ground to a gouge. In addition to shear zones that lie subparallel to the ore body and to the Golconda and Osburn faults, there are many faults that crosscut the ore body. The trend of these faults ranges from northwest to northeast, and individual faults dip 40°–60° E. or W. Almost invariably the vein has been displaced in such a way as to indicate normal displacement along these faults; owing to the south dip on the vein, a rule of thumb is that if a crosscutting fault dips east, a drift on the vein must be turned to the left along the fault to find the continuation of the vein. Conversely, a right-hand turn must be made in a drift where a westward-dipping fault is encountered.

The intense deformation of this area has probably been caused principally by movement along the Osburn fault. Only one fault of the many in this block between the Golconda and Osborn faults, however, may have had right-lateral strike slip similar to the movement along the Osburn; the rest have apparent normal or reverse displacement or possible left-lateral strike slip.

Bleaching is intense along the Golconda fault and some of the other faults in this area, but much of the block, although highly sheared, is unbleached. The Golconda vein was formed along a fracture that trends more east or northeast than the Golconda and Osburn faults and that dips 50°–60° S. This attitude of an apparently reverse fault could be related mechanically either to the system of strike-slip faults or to earlier reverse faulting. It is obvious, however, that some movement occurred after ore emplacement along many faults in this block.

WHITE LEDGE FAULT

Calkins (In Ransome and Calkins, 1908, p. 63) named the White Ledge fault after a tabular mass of light-colored quartzite that borders the fault for part of its length. The narrow quartzite rib is conspicuous in the valley walls of Mill Creek half a mile north of Mullan, where it is somewhat shattered and crisscrossed by numerous small secondary quartz veinlets. Present interpretation is that the quartzite body is bounded by faults on both the north and south sides, but that the northern fault is a minor one. The southern, more pronounced, fault is now considered to be the White Ledge fault, although Calkins originally referred to the northern member as the White Ledge fault. The White Ledge fault is crossed by both the Morning crosscut and the Gold Hunter crosscut (pls. 4 and 5). In the Morning crosscut, several shattered and sheared zones are in the vicinity of the projection of the White Ledge fault. The largest fault zone is more than 20 feet wide and is bounded by 3 feet of gouge on one side, but the remainder of this zone is tightly lagged. For several hundred feet north of this fault zone in the Morning crosscut, the rocks are foliated and highly puckered, and the axes of pucker folds generally plunge 25°–35° E. In the Gold Hunter crosscut there is no major fracture zone at the projected position of the White Ledge fault. The most pronounced fracture zone in the vicinity is a set of branching faults in quartzite that include zones of gouge from 1/4 inch to 3 inches wide. These small fractures dip 65°–85° S. A fault near the Hunter Creek property on Deadman Gulch in the Pottsville map area may be part of the White Ledge fault, but it appears to have a northeast strike. The fault, thus, is not clearly defined along its eastern part, where the tablet of Revett Quartzite is perhaps brought into place as much by an isoclinal fold as by faulting. From Mill Creek west, however, the displacement must increase to 1,000 feet or more, for in that area the tablet of Revett Quartzite is lying near the axis of a syncline. West of Grouse Gulch the dip of the fault flattens, and the strike changes to about N. 65° W., so that the fault strikes into and probably joins the Paymaster fault. The total length of the fault is about 3½ miles.

The parallelism between the White Ledge fault and the Osburn fault would lead one to suspect strike-slip displacement, but no such evidence was found. The mapped displacement of the contact between the St. Regis and Revett Formations in Grouse Gulch is largely an interpretation.

In the Morning crosscut, rocks near the White Ledge fault are hydrothermally altered and bleached. No ore minerals have been found along the fault.

CARLISLE FAULT

The Carlisle fault near the north edge of the Mullan map area strikes N. 20° W. and dips 75° SW. The movement along it is reverse and has amounted to about 2,000 feet. On the main haulage level of the Carlisle mine, the fault is bounded by a zone of clay gouge and sheared rock 6–36 inches wide and has been drifted along for almost 1,400 feet. Sulfide minerals, associated mainly with quartz but also with some siderite, are found in short lenticular-shaped bodies that may either be in the hanging wall or in the footwall of the fault. Although there has been some movement that took place after mineralization occurred, the relatively unshattered condition of the quartz and sulfides indicates that this movement has been minor.

RUTH FAULT

The Ruth fault can be traced almost continuously from a junction with the Blackcloud fault in the Wallace map area eastward into the Mullan map area, where it ends against the Upper Murray fault. Its surface trace for most of this distance is marked by a large diabase dike; the fault is exposed underground at three places in the Ruth workings and toward its east end in the Marshall No. 1 tunnel. In both of these underground workings the diabase dike that is as much as 25 feet wide is exposed. The fault is also exposed in a bulldozed road above the California No. 4 tunnel. In the blocks between the north-trending Upper Murray, Lower Murray, Haff, and Dobson Pass faults, there are segments of a cross fault of trend similar to the Ruth fault but not alined with it. These segments are probably parts of the Ruth fault that have been displaced by the north-trending faults. The segment between the Lower Murray and Haff faults contains a diabase dike, which is evidence to support the idea that it is part of the Ruth fault that is so persistently followed by such a dike to the west. Segmentation of the Ruth fault by the Upper Murray, Lower Murray, Haff, and Dobson Pass faults suggests that the Ruth fault was formed relatively early and has been broken by juggling of blocks in the hanging wall of the Dobson Pass fault. Thus the Ruth fault apparently intersects the Dobson Pass fault at a point near where the Mexican-San Jose fault intersects it from the east.

The strike of the Ruth fault including the eastern segments is between west and N. 50° W., and dip is 60°–80° S. The fault has apparent normal displacement, and rocks of the Wallace Formation are against rocks of the St. Regis Formation at the point of greatest offset.

ZANETTI, UPPER AND LOWER MURRAY, AND HAFF FAULTS

A group of north-trending normal faults—including the Zanetti, Upper and Lower Murray, Haff, and an unnamed one to the east—lies just west of the Dobson Pass fault at Blackcloud Gulch. The group was intersected in the Dayrock and California mines and associated workings, and its dips range from nearly vertical to 50° W. Faults in the group are probably contemporaneous with one another, and their accumulated movement has amounted to much more than 1,000 feet. As two of them, the Upper and Lower Murray, displace the Ruth fault, they probably formed at a relatively late stage of the deformation. A logical conclusion is that they are related to the movement along the Dobson Pass fault. Some of them cut either the California or Dayrock ore bodies, which they have offset.

TORNADO AND DEFIANCE FAULTS

Both the Tornado and Defiance faults are exposed in the Rock Creek crosscut, a long exploratory adit that was driven south from near the mouth of Rock Creek on the south side of the South Fork Coeur d'Alene River. These underground structural features have been correlated with sheared and bleached zones exposed in prospect pits on the surface and serve to locate the approximate positions of the faults, although the exact positions are not known.

Dips on the faults as seen underground are between 65° and 75° S. Each fault has a chloritized zone, presumably an altered dike, following it. The Tornado fault, bordered by argillite of the St. Regis Formation, consists of a zone of gouge and sheared rock 40 feet wide; and the Defiance fault, also bordered by St. Regis Formation, consists of many small shear planes in a zone 15 feet or more wide. The amount of displacement along the faults has not been determined, as St. Regis rocks are on both sides of each fault.

Both faults appear to limit bleached zones. The footwall of the Tornado fault is bleached, but the hanging wall is unbleached. The opposite is true for the Defiance fault—the hanging wall is bleached, but the footwall is unbleached. No ore minerals have been found in these faults, but ladder veins of quartz and some calcite are present in the chloritized dikes along the faults.

BLUE JAY FAULT ZONE

The Blue Jay fault zone is exposed underground in the Rock Creek crosscut and also in prospect trenches on the spur between the forks of Rock Creek and in trenches both west and east of Rock Creek. The fault trace as shown on the geologic map (pl. 4) is along the north side of a broad zone so severely sheared and altered that it is difficult to delineate individual faults. Innumerable shear planes and gouge-filled seams suggest movement, but there is no way of identifying those in which significantly more movement occurred. The entire zone is nearly a mile wide, but there has been a decided concentration of shearing in a zone a few hundred feet wide just south of the fault as shown on the map. The footwall of the fault zone appears to dip about 55° S.

The fault zone follows the core of a tightly folded syncline, and the shearing may have in part resulted from the folding. The hanging wall block is intensely bleached, and many small veinlets and pods of quartz, siderite or ankerite, and small amounts of sulfide minerals are dispersed throughout the sheared and foliated zone. The veinlets have about the same attitude as the faults and foliation. At the surface, near the west end of the fault zone, there is a vein 8–10 inches wide and a few tens of feet long composed of scattered small pods of galena and sphalerite in a matrix that appears to be in part a silicified and carbonatized bed and in part an irregular replacement body.

The zone of bleaching along the fault appears to widen upward and, in gross pattern, may spread outward from the fault along the general position of the St. Regis-Wallace contact and into the Wallace Formation, which forms the core of the syncline. Furthermore, the marked tendency of the Wallace Formation to crumple and shear near the axes of folds prepared it for greater penetration of the solutions that altered the rocks.

The amount of movement within the broad area between the D–6 fault and the footwall of the Blue Jay fault zone is very difficult to determine because of a lack of distinctive marker beds. The location of the contact between the St. Regis and Wallace Formations is definitely known in but two places where it is delineated by the distinctive greenish part of the St. Regis. The mapped location of the rest of the contact is an interpretation and projection based on the folded structural features within the area. The distribution of rock types within this area might be explained at least in part by a series of faults or by distributed shear throughout the zone.

The amount of movement along the Blue Jay fault zone footwall is likewise unknown. The apparent offset of the green part of the St. Regis Formation may be misleading as to the actual amount of displacement. The fault parallels the strike of the rocks along the north limb of a syncline, and a relatively slight vertical movement may cut out the key green member of the St. Regis Formation for a long distance. Furthermore, intense alteration of the rocks along the fault may have obliterated outcrops of this recognizable zone.

D–6 FAULT

The D–6 fault extends at least 3½ miles across the headwaters of Rock, St. Joe, Gold, and Boulder Creeks. The fault may extend much farther to the west and join one of the faults west of Placer Creek, but from Rock Creek west the Wallace Formation borders both sides of the fault and the fact that the soil cover is deep makes the fault doubly difficult to follow. To the east, the fault dies out in a series of folds on the east side of Boulder Creek. The Reindeer fault, which crosses the heads of the East and West Forks of Willow Creek farther to the east, is alined with the D–6 fault but is modestly displaced in a direction opposite to that of the D–6 fault. The D–6 fault is not exposed underground, but prospect trenches and natural exposures clearly reveal its position. The fault forms the contact between the Wallace and St. Regis Formations throughout much of its length and trends at a slight angle to minor fold axes in the rocks on each side. The fault dips about 70° S.

Near the east end of its mapped extent the stratigraphic throw of the fault, as determined from the offset of the green part of the St. Regis Formation, is about 600 feet. Toward the west end, the displacement is probably larger, but no direct measurement is possible. The estimates of displacement make no allowance for a horizontal component of movement, which cannot be determined.

Bleached rocks are confined almost entirely to the north or footwall side of the D–6 fault, which effectively limits the bleaching, although some bleached rocks have been found south of the fault. The fault is so steep that it is difficult to imagine that the damming of solutions alone could account for the limiting effect of the fault on bleaching. Displacement that occurred after the rocks were bleached would be an alternate explanation, but the amount of displacement is small relative to the large volume of bleached rocks involved to the north of the fault. The restriction of the bleaching is more logically related to the intense shearing and small-scale deformation of the rocks north of the fault as compared to the rocks to the south of it.

FAULTS IN THE POTTSVILLE MAP AREA

FRENCH GULCH FAULT

The French Gulch fault strikes almost due north for about 2 miles from a point near the junction of French Gulch and Canyon Creek. The fault is exposed only in the Oom Paul No. 1 tunnel. Along most of its length the fault forms the contact between the upper part of the Prichard Formation and the Burke Formation. Inasmuch as parts of the beds of the upper part of the Prichard are similar to the Burke rocks, the position of the fault is questionable in places.

Underground, the fault consists of a zone of clay gouge 3 inches wide, sheared rock 1 foot wide, and a stockwork of many small fractures 40–50 feet wide in the west wall of the main fault strand. The dip of the main strand is about 80° W. Displacement is normal and may amount to as much as 1,000 feet. The rocks are bleached along the fault, but no ore minerals are known to be present.

HUMBOLDT GULCH FAULT

The Humboldt Gulch fault is a north-trending fault that crosses Canyon Creek near the mouth of Humboldt Gulch. Its extension north of Canyon Creek is indefinite because it almost parallels bedding and nearly coincides with the sedimentary contact between the Revett and Burke Formations. The fault is located on the basis of anomalously steep and locally overturned beds and several exposures of intensely sheared rocks. South of Canyon Creek the fault can be identified with much more certainty. A contact between Burke and Revett Formations on the west and St. Regis Formation on the east can be clearly traced by float across the ridge between Sonora Gulch and Canyon Creek, and on the crest of this ridge intensely sheared and altered rock occupies the saddle through which the fault passes. Markedly different strike and dip of the rocks on both sides of the fault is further evidence of its existence. At the south end the fault appears to die out where the Wallace–St. Regis contact crosses Sonora Gulch, and there is no apparent offset of the contact.

The fault strikes N. 5°–10° W., and the dip must be steep, for there is no topographic deflection of trend. The fault zone has not been seen, but bleached rocks, principally as float, occur near the fault along much of its length.

SONORA FAULT

A fault exposed in the Sonora tunnel and known to offset formational contacts mapped on the surface on the southwest side of Sonora Gulch has been named the Sonora fault. A fault cut in the National crosscut about 1,300 feet from the portal and in the Copper King crosscut about 3,000 feet from its portal is probably the southeastward continuation of the Sonora fault, but no actual continuity can be demonstrated on the surface.

In the Sonora tunnel two pronounced faults, one striking N. 45° W., the other N. 25°–30° W., appear to diverge to the northwest; the northeasternmost of the two is referred to as the Sonora fault. Both faults dip at angles of about 60° SW. and are characterized by gouge zones as much as 1 foot wide in some places and by zones of shattered rock 1–2 feet wide in other places. The rocks in the triangular block between the two faults near their junction are sheared and shattered and contain sparsely disseminated pyrite, chalcopyrite, and galena.

Two pronounced fault zones are crossed in the Copper King crosscut, one about 2,400 feet from the portal, the other about 3,000 feet from the portal. Both have nearly the same strike and dip, and because of an unknown amount of possible offset along the Imperial fault, either fault might be an extension of the Sonora fault as mapped in Sonora Gulch (pl. 5). Each fault in the Copper King crosscut consists of a zone of shattered rock 10–20 feet wide and gouge zones as much as 2 feet wide. Individual fractures in the fault zone dip steeply southwest. In the National crosscut a fault, which is probably the Sonora, consists of a zone of highly sheared rocks, about 1–2 feet wide, which have abundant slickensides but little claylike gouge. Numerous other fracture planes border the fault and form a zone of fractures almost 100 feet wide. The principal fault strand dips about 80° SW.

The Sonora fault has also been cut in the drift driven west from the main National crosscut, at a point about 2,400 feet northwest of the main crosscut, and about 1,400 feet northwest of and below the main crosscut of the Copper King. Maps of this drift supplied by Day Mines, Inc. show that the Sonora fault has a dip of 55°–65° SW. and that the Sonora fault truncates the National fault. Sulfide minerals are sparsely disseminated near the junction of the two faults. These data may be interpreted as indicating a somewhat closer spatial relation of mineralization to the Sonora fault than to the National fault.

The Sonora fault is probably a reverse fault. In Sonora Gulch the displacement along the fault brings the St. Regis Formation in the hanging wall into contact with the Wallace Formation in the footwall, and in the drainage area of Deadman Gulch the proposed extension of the Sonora fault has Wallace Formation on both sides at the surface, and St. Regis Formation on both sides in the National mine workings. The displacement, thus, is not great but may amount to several hundred or even a thousand feet along some parts of the fault.

In addition to the Sonora fault as just described, there is evidence of possible faulting, as yet not delineated, along the west flank of the Granite Peak syncline west of the Sonora fault. In the headwaters of Sawmill Gulch, the contact of the St. Regis and Revett Formations at the land surface is 800 or 900 feet east of the contact between the same formations where exposed 1,000 feet below in the Imperial tunnel. A relative eastward displacement of the rocks near the surface is suggested since the dips recorded underground average about 60° E. (pl. 5).

The displacement might have been accomplished by a sharp flexure, including overturning of the beds, or by a flat thrust fault. The many overturned beds found in the northeastward-facing cirque at the head of Sonora Gulch suggest to the authors that the answer may be a sharp flexure including reversal of dips. South of the divide in Deadman Gulch, however, certain discordances that are evident cannot be accounted for only by overturning of beds, and a series of north-striking faults are interpreted as displacing the contact at the surface between the St. Regis and Revett Formations.

Nearly the entire thickness of the St. Regis is represented in the west flank of the Granite Peak syncline south of the Sonora Gulch-Deadman Gulch divide. Throughout this formation in this part of the fold the beds trend north and have steep or overturned dips. In contrast to this structural attitude, the Wallace Formation east of the interpreted fault that separates the two formations is structurally a part of the east limb of the Granite Peak syncline with beds that dip 40°–60° W. or are overturned to the east. These beds thus appear to abut the steep or overturned beds of the St. Regis Formation, and that part of the Wallace Formation that should appear in the west limb of the syncline is absent. The attitude of bedding in the Wallace is well displayed in the Copper King crosscut that lies only a few hundred feet east of the contact between the two formations.

No major throughgoing fault is exposed that seems to account for all the anomalies. One large fault exposed in the Copper King crosscut 600 feet south of the Sonora fault appears to form the northern part of the contact between the St. Regis and Wallace Formations. This fault and others exposed in the Copper King crosscut, in surface trenches, and suggested by surface mapping, appear to strike northwest across the questionable contact. It is entirely conceivable that the northwest-trending faults represent part of late deformation, and that the interpreted fault was produced in earlier compressional phases of deformation when the folds were overturned and some thrust faults were formed. Whatever the exact position and trend of the interpreted fault, there is little doubt that the beds of the west flank of the Granite Peak syncline have been overturned and have been displaced thousands of feet upward relative to the truncated beds of the east flank.

Several square miles of this area west of the contact between the Wallace and St. Regis Formations lies along a projection of one of the zones or belts of ore deposition, and deformation has been so intense in the block that some fractures within it may have been suitable for mineral deposition.

CHAMPION FAULT

The Champion fault is a well-defined fault that strikes northwest and is exposed in three tunnels in Military Gulch. In two tunnels, the portals of which are on the west side and near the mouth of Military Gulch, the fault is characterized by two gouge zones bordering a massive quartz vein and numerous small shears cutting diagonally across the vein. In the Coeur d'Alene Champion tunnel on the east side of Military Gulch, the fault consists of gouge 1½ feet wide and a zone of breccia and fractured rock 2–3 feet wide. The gouge zone dips approximately 65° SW. in the Coeur d'Alene Champion tunnel, and in the other tunnels different individual fractures dip 60°, 75°, and 85° SW. In the Half Moon tunnel at the south end of Glidden Lake (pl. 5), a fault zone consisting of 10–15 feet of shattered and pulverized rock and 1–1½ feet of claylike gouge also probably represents the Champion fault.

Displacement along the Champion fault may be principally strike slip. In the Coeur d'Alene Champion tunnel, well-formed slickensides along minor fractures adjacent to the main fault strand plunge 5°–15° NW. The contact between the St. Regis and Revett Formations was offset about 2,000 feet by right-lateral movement along the Champion fault. The contacts are gradational and are not precisely delimited. This is one of very few faults in the district along which small structural features indicate near strike-slip movement.

Mineralization along the fault is limited to massive quartz in veins and lenses as much as 4 feet wide. No sulfide minerals were found. The quartz veins clearly followed a fracture, and the fracture then was reactivated after the quartz vein formed.

IMPERIAL FAULT

The Imperial fault strikes west-northwest across the Granite Peak syncline in the headwaters of Sawmill Gulch, Sonora Gulch, and Deadman Gulch and is named after the Imperial tunnel in which it is exposed. The fault trace is conspicuous on aerial photographs in the eastern part of the cirque at the head of Sonora Gulch, where it is recognizable on the ground for several hundred feet as a structurally discordant contact between the Wallace and St. Regis Formations. In the western part of the cirque the fault forms the boundary between overturned St. Regis beds to the south that dip to the southwest, and normal St. Regis beds to the north that dip to the south. In the headwaters of Sawmill Creek the fault separates different formations, and its trace is also marked by intensely foliated and bleached rocks. To the east, the Imperial fault appears to be responsible for offset of the St. Regis Formation on the east limb of the Granite Peak syncline.

The dip of the fault is nearly vertical, as there is little topographic deflection of its trace, although comparison of surface trace and the point of exposure in the Imperial crosscut suggests a steep dip to the north.

Displacement has been nearly coincident with dip slip and ranges from a few hundred to 1,000 feet; the north side is upthrown relative to the south side. Contacts on both the west and east flanks of the Granite Peak syncline north of the fault are shifted outward from the synclinal axis as compared with the same contacts south of the fault.

The apparent continuity of the trace of the fault suggests that it may offset the Sonora fault, but this cannot be demonstrated. No fault of similar trend has been traced west of the Gertie fault, at which the Imperial fault is interpreted as ending (pl. 4). The Imperial fault may have formed relatively late in the structural history, perhaps almost simultaneously with the Gertie fault.

NATIONAL FAULT

A large fault crossed by the main tunnel of the National mine about 3,950 feet from the portal on Deadman Creek is referred to as the National fault. The strike of the fault has been traced in underground workings for about 2,400 feet northwest of the National crosscut but has not been traced on the surface. The fault maintains a fairly consistent strike of N. 55° W. along its entire length. The dips of individual fractures and gouge seams within the fault range between 70° SW. and vertical. The fault is characterized by a zone of plastic claylike gouge about 1 foot wide and a zone 5–30 feet wide of shattered, crushed, and sheared rock chiefly in the hanging wall of the gouge seam.

Rocks on both sides of the fault are impure quartzite plus some argillite and probably belong to the lower part of the St. Regis Formation or upper part of the Revett Quartzite. The rocks are partly bleached on both sides of the fault. Displacement along the fault must not have been great because rocks on opposite sides of the fault are from about the same stratigraphic horizon. Along several minor fractures near the National fault, slickensides plunge at a low angle, and one minor fault offsets a set of quartz stringers in strike-slip fashion, suggesting the possibility of some strike slip along the major fault, but there is no other supporting evidence. The fault has been interpreted as being truncated by the Sonora fault at its west end in the Copper King and National workings, although in its surface projection it appears to intersect the Imperial fault.

The abundance of minor fractures of random orientation in the hanging wall of the gouge seam suggests that the hanging wall was subjected to tensional stresses while it dropped relatively downward in normal-type displacement.

In the drift along the National fault, as along the Sonora fault, galena, pyrite, and chalcopyrite were found sparsely disseminated and in discontinuous stringers. The sparse mineralization is apparently confined rather close to the junction of the two faults.

DEADMAN SHEAR ZONE AND THE CINCINNATI FAULT

A zone of sheared rock several hundred feet wide exposed at the portal of the National tunnel (fig. 29) on Deadman Creek has been named the Deadman shear zone. Southeast of the National tunnel the shear zone strikes about N. 60° W. and its position is

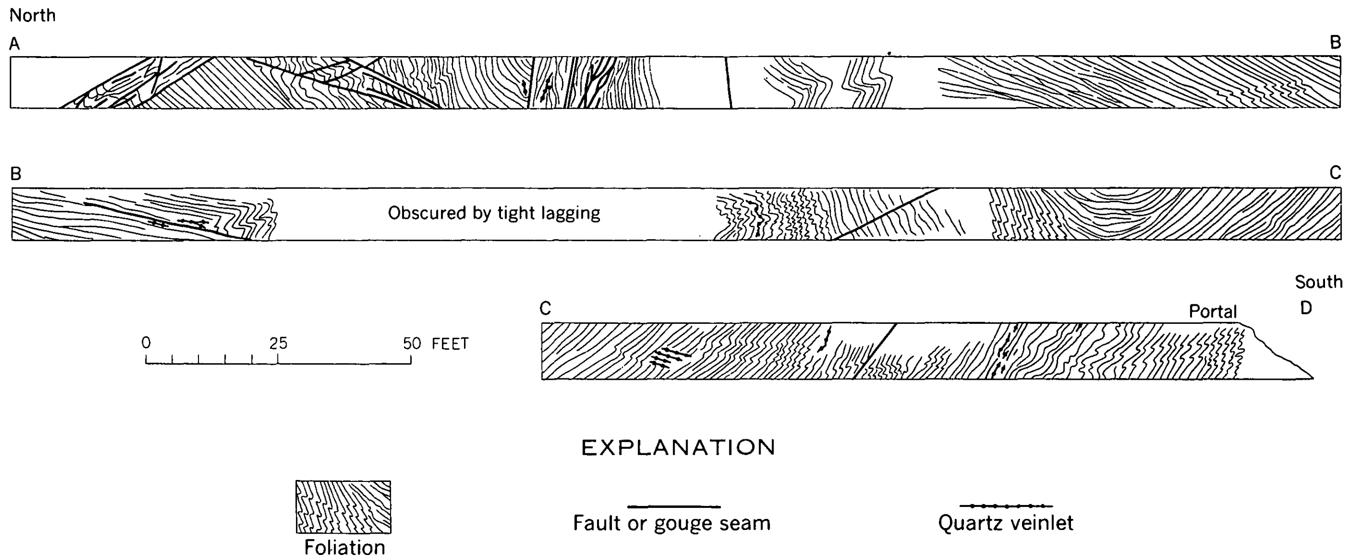


FIGURE 29.—East wall of a part of the National tunnel where it cuts the Deadman shear zone. Bedding has been obliterated by foliation in this shear zone. Various types of distortions of foliation are illustrated including puckers, drag of foliation along faults, and a large synclinal fold in foliation. Rocks are probably part of the Wallace Formation.

marked topographically by conspicuous saddles in the two major ridges that it crosses between Deadman and Gentle Annie Gulches and between Gentle Annie and Daisy Gulches. Southeast of Daisy Gulch the topographic expression is less pronounced, but the shear zone can be located in prospect trenches, roadcuts, tunnels, and natural exposures. The shear zone appears to join the Osburn fault zone a mile or two east of the Little North Fork, but from O'Brien Gulch eastward the entire zone between the two faults is sheared and foliated, and individual faults are difficult to delimit.

West of the National tunnel the fault splits into two main branches, one striking about N. 60° W. and the other about S. 80° W. The branch striking N. 60° W. is well exposed in a prospect trench about 300 feet east of the portal of the Pilot tunnel, where the rocks are intensely brecciated and pulverized, and many gouge seams form a fault zone 200 feet or more wide. The rocks exposed in the Pilot tunnel near its portal are sheared and foliated because of their proximity to the fault. From the Pilot tunnel west, there is little evidence of a fault, as exposures are poor, and the fault is extrapolated to an offset of the contact between the Revett Quartzite and St. Regis Formation near the crest of the ridge.

The branch striking S. 80° W. has been named the Cincinnati fault after the Cincinnati prospect which it crosses. It is not certain that the Cincinnati fault continues westward, but fault segments of similar strikes exposed in the National mine, the Copper Plate tunnel, and the Cincinnati tunnel are probably parts of a single fault. Strong supporting evidence includes the discontinuity of St. Regis and Wallace Formations along this line, topographic expression in the form of a conspicuous saddle east of the Cincinnati tunnel, and a sharp draw along the interpreted fault trace. Another fault, the Copper Plate fault, exposed in the Copper Plate workings and in two small prospects east of the Copper Plate, appears to strike northwest across the line of the Cincinnati fault, but how the two faults are related is not known.

The dip of the Deadman shear zone is difficult to determine. It crosses ridge and gulch with no apparent deflection, which suggests a near-vertical attitude, but the zone is so wide that exact points for reference are difficult to identify. Individual gouge seams in the National mine range in dip from 30° N. to 20° S., but one of the strongest gouge seams dips 85° N. Foliation within the zone dips north and south, and in some places is vertical. The Cincinnati fault appears to dip 45°–55° S.

Displacement has been such that the north-trending Granite Peak syncline, which extends for 10 miles or more to the north, is sharply truncated by the fault, and the Deadman syncline, a nearly east-west fold, now occupies a position directly across the truncated south end of the Granite Peak syncline. The type of displacement that would most likely produce this result seems to be right-lateral slip, in which the north side would be upthrown relative to the south side. On figure 30 it is suggested that the Deadman syncline and the Mill Creek syncline are segments of the Granite Peak syncline that have been flexed and sheared off by strike slip and moved westward relative to their present positions. This interpretation would suggest continuity of faults in some sort of pattern extending westward from the Deadman shear zone along the east limit and possibly around the northern limit of the Mill Creek syncline. The fault pattern as mapped along this general line is very irregular, and it may be that the zone of rupture along which the shifting of the synclinal segments was accomplished had been buckled and broken (fig. 30). Certainly the axes of Deadman and Mill Creek synclines are at a sharp angle to one another. Another possibility is that the Deadman shear zone does extend almost linearly to the northwest, is continuous with at least part of the O'Neil Gulch fault and with other northwest-trending faults to the west, and may even join the Standard fault. However, the continuity of the Revett Quartzite in the west flank of the Granite Peak syncline southward to the Cincinnati fault is evidence unfavorable to this interpretation, and the interpretation of strike slip along the Cincinnati and other faults is preferred.

SNOWSTORM FAULT

Ransome and Calkins (1908, p. 150–152) described the Snowstorm fault as it was exposed in the Snowstorm mine, and they illustrated the manner in which rocks of the Revett Formation are faulted against rocks of the St. Regis Formation along this reverse fault. The position of the fault in the vicinity of the Snowstorm mine is plotted on the accompanying maps (pl. 5) principally from unpublished maps of the Snowstorm mine prepared by Calkins. Only a few hundred feet of the lowest tunnel were open at the time of the present investigation. To the east, discontinuity of formational contacts and missing parts of the stratigraphic section on the west side of the Little North Fork are clear evidence of a fault alined with the Snowstorm fault, but its trace in the valley of the Little North Fork valley suggests a dip more nearly vertical than the 60° N. dip that was recorded for the Snowstorm fault by Calkins. The westward extension of the Snowstorm fault is obscure. Three faults have been found in the headwaters of Gentle Annie Gulch, and one on the north edge of sec. 30, T. 48 N., R. 6 E., has trend, alinement, and displacement that suggest correlation with the Snowstorm fault, but continuity between the two has not been demonstrated.

Ransome and Calkins (1908, fig. 17) showed that the Snowstorm fault is a reverse fault and stated that displacement cannot be less than 700 feet. They also stated (ibid., p. 151): "The fault shows no mineralization and contains about 10 feet of clay gouge. These facts would ordinarily be taken to indicate that the fault is later than the ore. In this district, however, such a conclusion cannot safely be drawn and the realtive age of fault and ore must remain for the present undetermined."

FRIDAY FAULT AND OTHER FAULTS IN THE LUCKY FRIDAY MINE AREA

In the Lucky Friday mine and in the main crosscut of the Gold Hunter mine, particularly south of the White Ledge fault, the rocks are cut by numerous faults and a great deal of shearing is represented by crenulated and puckered phyllites and schists. This disturbed zone is similar in many ways to the one between the Golconda and Osburn faults in the vicinity of the Golconda mine. The feature here called the Friday fault is one of the most conspicuously exposed faults in the Lucky Friday crosscut. The Friday fault consists of a zone of gouge 18 inches wide having highly contorted phyllites on both sides. No definable fault was found in the Gold Hunter crosscut along its projection from the Lucky Friday mine, but the rocks are extremely phyllitic and contorted over a zone more than 200 feet wide. Near the portals of both the Gold Hunter and Lucky Friday tunnels, the rocks have been questionably identified as altered Wallace Formation, whereas farther north some of the rocks more nearly resemble altered St. Regis Formation. The Friday fault has been interpreted as forming the contact between the two formations, but if more certain identifications of the formations were possible, it might well be found that the fault and contact of the two formations are not coincident. The fault plane as exposed in the Lucky Friday tunnel dips about 60° NE. Some of the other fractures of this network of faults between the White Ledge and Osburn faults dip north, but others dip steeply south. Most of these fractures strike northwest, and the Lucky Friday vein is cut into a myriad of segments by slight movement along dozens of these faults that cut diagonally across the vein. Offset of the vein along these faults suggests that some had normal and others had reverse displacement, and the block has the overall appearance of a complex stockwork of fractures.

The proximity of this block of intensely fractured and deformed rocks to the Osburn fault suggests a genetic relation between the two features. The fact that the faults of the stockwork clearly cut the Lucky Friday vein indicates that considerable movement occurred along the Osburn fault after ore emplacement. Unfortunately, the direction of this movement cannot be demonstrated by the evidence at this locality.

The Friday fault is interpreted as continuing west beyond Mill Creek Gulch on the basis of three lines of evidence: (a) It forms the contact at the surface between rocks of slightly different lithologic composition, here assumed to be Wallace and St. Regis Formations, (b) sheared rock is exposed in several roadcuts and one natural outcrop, and (c) one of several faults exposed in the Morning crosscut near the projection of the Friday fault is tentatively correlated with it. Whether or not a single plane of fracture is continuous along the entire length of the Friday fault is problematical, but as it is mapped, the fault is at least representative of many faults and shear zones, some large and some small, that trend subparallel to the Osburn fault in the structural block between the White Ledge and Osburn faults.

S-BRIDGE FAULT

A fault zone exposed in a railroad cut near the Carbonate Hill mine at the upper end of the S-Bridge over Willow Creek has been tentatively correlated with a conspicuous zone of shearing cut by the main crosscut of the Atlas mine. West of Willow Creek the fault is located by a zone of phyllite and bleached rock exposed on the ridge crest and by sheared rock in prospect adits about 100 and 200 feet above the railroad grade. Underground, the fault zone consists of about 5 feet of gouge and sheared and crumpled rock, and individual slip planes dip about 80° S. A vein of white carbonate mineral, 12 inches wide, lies along the hanging wall. As rocks of the St. Regis Formation are on both walls of the fault, displacement has not been determined.

REINDEER FAULT

The Reindeer fault trends west for about 2 miles across the headwaters of Willow Creek and is exposed underground in the Reindeer Queen mine. On the surface its position is clearly marked where it truncates greenish argillite of the upper part of the St. Regis Formation and a small block of Wallace Formation. In the Reindeer Queen mine the fault comprises a zone of gouge and brecciated rock about 20 feet wide, and a flat fault zone containing considerable gouge and breccia appears to branch to the south from the Reindeer fault.

Maximum displacement as indicated by offset of the distinctive green beds in the St. Regis Formation on the divide between the east and west forks of Willow Creek amounts to about 700 feet, the north side of the fault being downthrown relative to the south side; however, along the eastern part of the fault there is almost no displacement of the green beds. Near its west end the fault appears to form the south limit of a zone of intense bleaching, although some of the rocks immediately south of the fault are slightly bleached. Veins containing quartz, siderite, and some copper minerals are along the eastern part of the fault. The Reindeer fault and vein are similar to the fractures and accompanying copper veins at the St. Lawrence, Monitor, and Hansy properties about 10 miles to the southeast (Wallace and Hosterman, 1956, p. 607).

ATLAS FAULT

The Atlas fault is a conspicuous fault cut in the main crosscut of the Atlas mine. This fault has been followed for 700 feet in a drift to the east from the main crosscut. The fault strikes N. 60°–80° W. and on the main tunnel level is about 400 feet south of the Atlas shaft. The fault dips 80°–85° N. and has been exposed on the 800 level; it is probably the same fault that is exposed on the 2,400 level. The fault consists of a set of anastomosing shears, the largest of which is a zone of gouge and sheared rock 5 feet wide. At one point approximately south of the shaft a seam of black gouge, 1–3 inches wide, is in the fault zone. In the main crosscut, rocks north of the fault are bleached, but immediately south of the fault they are not. Displacement is difficult to determine, but on the 800 level the rocks south of the fault may be Revett Quartzite, and the rocks north of the fault may be of the lower part of the St. Regis Formation; such evidence would suggest normal displacement. Contrary to this evidence, large-scale drag of beds suggests a relative upward and westward movement of the hanging wall, or north block.

The age relation of the fault to mineralization is uncertain. Another fault system that extends from the Atlas shaft southeastward for at least 1,200 feet in echelon pattern with the Atlas fault displaces massive siderite veins. Individual strands of this fault limit the extent of chloritized and bleached rocks. Inasmuch as the siderite and chloritized rocks contain some galena, it might be inferred that the whole fault system, possibly including the Atlas fault, formed after the sulfide was deposited.

FOLDS

The Coeur d'Alene district lies along a broad northward-trending anticlinorium in the center of which the older rocks of the Precambrian Belt Series are exposed. On a map compiled by Paul Billingsley (1952), rocks equivalent to the Prichard Formation are shown extending in a belt along the anticlinal axis to Kimberly, British Columbia, and the tectonic map of Canada shows an anticlinal axis extending north to lat 51° N. The folds shown in plate 9 are parts of this major anticlinal arch.

A set of large folds in the northeastern part of the Coeur d'Alene district trend north or northeast, but the larger folds in the southern part of the district trend west-northwest. The change in trend takes place at about the Osburn fault, which seems to terminate the major fold axes. Some of the major folds are many miles long and are characterized by a wavelength of 2 or 3 miles from crest to crest and an amplitude of from several thousand to possibly several tens of thousands of feet from trough to crest. A more equidimensional domelike anticline constitutes the principal structural feature underlying an area of many tens of square miles in the west half of the district and is represented by the Pine Creek and Moon Creek anticlines, two halves of the original fold. In addition, many minor folds occur upon the larger folds, particularly in overturned flanks.

Some of the folds south of the Osburn fault are tight and overturned, but in the north-trending system north of the Osburn fault all the folds are relatively open, and overturning of some parts of these folds is generally a local phenomenon.

The major folds probably formed the earliest structural framework of the Coeur d'Alene district. Steeply dipping tabular veins cut the folds and yet show no evidence of having been bowed or otherwise deformed during folding. The age of uraninite found in some of these veins has been determined to be about 1,250 million years; thus the folds must have been formed before that time. The axis of the folds were bowed and broken during later deformation that culminated in the large offset along the west-northwest-trending Osburn fault.

BURKE ANTICLINE

From the vicinity of Burke (pl. 9) north for more than 4 miles to a monzonite stock on Granite Gulch (Hosterman, 1956, pl. 57), the rocks are upwarped and form a north-trending structural feature named the Burke anticline. This anticline appears to be a southern extension of the Trout Creek anticline that extends from Prichard Creek north for 20 miles or more to the Clark Fork River. Even though the two folds can logically be considered as being coextensive along strike, the exact manner in which they join is uncertain, and separate names are given to them.

In the vicinity of Burke, the Prichard Formation crops out in the core of the Burke anticline and marks a high point on the crest of the fold. Here the anticline has the characteristics of an irregular dome with the axes plunging both north and south and with a minor linear cross fold that parallels the Oreano fault to the northwest. To the north, in Granite Gulch, the Burke anticline is more regular, the axis is tilted back to a low south plunge, and the axial trace is paralleled by the O'Neill Gulch fault.

Towards the south end of the fold an axial trace is shown on the map (pl. 4) for only a short distance just west of Burke because the crest of the fold is so irregular that it can scarcely be depicted adequately by a single line. However, approximately east of a line from Mace northeast and extending along Granite Gulch, the beds generally dip 35°–60° E., and west of this line the beds generally dip 20°–45° W. The anticline thus appears to be slightly asymmetric. The Granite Peak syncline parallels the anticline to the east, but the west flank of the Burke anticline is in part obscured by the Gem stocks. South of Canyon Creek the fold steeply plunges south and becomes obscured in a maze of cross faults and divergent dips. The axis of the anticline projected across this confused interval to the south is in alinement with the Mill Creek syncline of the Mullan area. These relations are explained more fully in the subsection entitled "Mill Creek syncline."

Hosterman (1956, pl. 57) believed the Burke anticline to end against the monzonite stock in Granite Gulch, although it may swing sharply west and be coextensive with a north-trending anticline that intersects the Thompson Pass fault 1½ miles southeast of Murray. The structural feature in the headwaters of Vendetta Gulch (just north of the Mullan map area), where the Burke anticline is presumed to bend west, is not known sufficiently well to make this correlation of folds definite, and the monzonite stock on Granite Gulch further obscures the possible continuity.

A correlation has been suggested (p. 78–79) between the Burke-Trout Creek anticlines north of the Osburn fault and the Big Creek anticline south of the fault. The separation of about 16 miles between them possibly results from strike slip along the Osburn and related faults.

LOOKOUT UPWARP AND THE LOOKOUT, GOLD CREEK, AND STULL ANTICLINES

The Lookout upwarp, or anticlinorium, south of the Osburn fault, is a large composite structural feature (pl. 10). It consists of several parts that are shown separately on the 1:24,000-scale maps (pls. 4 and 5) and are, from west to east, the Stull anticline, Gold Creek anticline, and Lookout anticline. The Lookout upwarp extends from near the Golconda Mill between Wallace and Mullan east to a point in Montana near Lookout Pass, a distance of at least 9 miles.

The Stull anticline is best delineated on the geologic map (pl. 4) by the outcrop pattern of the contact between the St. Regis and Wallace Formations.

The fold plunges to the west, and its crest is irregularly crenulated and faulted as can be seen in the Western Silver Lead tunnel. The plunging nose of the fold is obscured under alluvium near the Golconda Mill and presumably a fault that trends west-northwest under the alluvium near the Golconda Mill cuts the north flank of the fold. Sheared and foliated rock in a roadcut next to the mill and mineralized fractures on the ridge east of Stull are evidence of the fault.

The Gold Creek anticline is almost exactly alined with the Stull anticline, but the two folds cannot be directly connected across the intervening gap. The Rock Creek tunnel crosses the gap, and in the position where the axis is projected the beds dip uniformly north. However, two anticlinal zones are cut, one south of the Tornado fault and one south of the Defiance fault, and these probably represent the axis of the major upward somewhat crenulated and broken by faults.

The eastern part of the Lookout upwarp is well defined for about 3 miles and is named Lookout anticline on plate 5. It is overturned to the north, and the axial plane of the fold dips about 45° S. Overturned dips as low as 20° are recorded in the north flank. The axial trace of the fold lies about 2,000 feet north of Lookout Pass, and bedding attitudes in roadcuts along U.S. Highway 10 clearly show the anticline's position. The long crosscut of the Atlas mine between Willow and Boulder Creeks provide the best section of the fold. North of the S-Bridge fault where exposed in this crosscut, many of the beds are overturned, although the determination of overturned or upright attitude of many steep-dipping beds cannot be demonstrated with certainty. In general, the rocks near the portal of the Atlas tunnel are of the Wallace Formation; the rocks next to the south are of the green upper part of the St. Regis Formation, followed by the gray rocks of the lower part of the St. Regis. The strata in the first 1,500 feet or more of the Atlas tunnel, southward from the portal, are thus clearly in the north flank of an anticline, even though some isoclinal drag folding is evidently involved.

LOOKOUT DOWNWARP AND THE LOOKOUT, BLUE JAY, WALLACE SYNCLINES

The Lookout downwarp, south of the Lookout upwarp, is a large composite structural feature. It consists of several parts that are shown separately on the 1:24,000-scale maps (pl. 10) and are, from west to east, the Wallace syncline, the Blue Jay syncline, and the Lookout syncline.

The Lookout downwarp or synclinorium extends from near Wallace east to Brimstone Creek, several miles east of the Montana-Idaho State line.

The axial trace of the Wallace syncline passes through the eastern part of the city of Wallace, and trends about N. 35° W. (pl. 4). The position of the axis is fairly well defined by attitudes of beds observed along the flume on the ridge between Canyon Creek and the South Fork of the Coeur d'Alene River. The axis of the adjacent Wallace anticline is well exposed in a single continuous cut along the south side of the South Fork of the Coeur d'Alene River opposite the mouth of Canyon Creek. Both folds are possibly slightly asymmetric so that the east-dipping flank is slightly steeper than the west-dipping flank. The Wallace anticline, although a relatively large fold, should perhaps in gross relations be considered a secondary upwarp within the trough of the Lookout syncline. Between the areas of outcrop of St. Regis Formation in the Stull anticline and in the Big Creek anticline, the terrain is entirely of Wallace Formation, which delineates the overall pattern of the Lookout syncline.

In the vicinity of Rock Creek between Mullan and Wallace the Blue Jay syncline is the major fold between the Blue Jay fault and the D–6 fault, but a complex of smaller folds combine to form the upwarped south limb of the syncline against the D–6 fault (pl. 4). This complex, folded area may constitute part of the broad crest of the Wallace anticline. The folds in this area are in large part interpolated between widely scattered outcrops, because the entire block between the Blue Jay and D–6 faults is intensely sheared and foliated and largely bleached. The flanks of these folds generally dip more than 50°, and there is little evidence of asymmetry. The folds plunge to the west. The gross pattern of the folds between the Blue Jay fault and the D–6 fault appears to be similar to that represented by the Wallace anticline and Wallace syncline. A general downwarp predominates, but rather large anticlines are present within the trough of the downwarp. Continuity between the Blue Jay and Wallace synclines, however, and between the Wallace anticline and the corresponding anticline in the Rock Creek area has not been demonstrated, and where the fold axes can be identified they are relatively irregular. In St. Joe Creek the Blue Jay syncline is along the crest of the main anticlinal upwarp, and locally minor folds plunge to the southeast rather than to the west as does the regional structure.

The downwarp is poorly defined between Gold Creek and a point a mile east of Willow Creek, but from there eastward for about 5 miles, to and beyond Lookout Pass, the Lookout syncline is a relatively regular clearly defined fold (pl. 5). Although the companion fold to the north—the Lookout anticline—is overturned and nearly isoclinal, the flanks of the Lookout syncline are relatively symmetrical. The ends of the Lookout syncline are more open than the central part near Lookout Pass, where dips average about 70° (Wallace and Hosterman, 1956, pl. 48). The fold dies out to the east in a homoclinal south-dipping structural feature.

MOON CREEK ANTICLINE

Most of the area north of the Osburn fault in the Wallace and Kellogg map areas is occupied by a broad domelike anticline, whose core is outlined by the contact of the Prichard and Burke Formations. Except for minor crumples and some crosscutting faults, the fold is relatively uncomplicated. The minor crumpling, as shown by dips and strikes and the irregularities of the quartzite units, is most pronounced near the Osburn fault and the Carpenter Gulch fault. The dip of the beds ranges widely—from as low as 20° to overturned—and the variation in dip is related more to the minor irregularities of the bedding rather than to the general anticlinal structure, as shown by the pattern of formational outcrops.

BIG CREEK ANTICLINE

The Big Creek anticline is the most persistent fold in the Silver Belt area south of the Osburn fault and extends from near the junction of Experimental Draw and Cranky Gulch with Placer Creek in the southeast corner of the Wallace map area westward to the Government Gulch area in the Kellogg map area. The anticline's north flank is bounded largely by the Polaris fault and its south flank by the Big Creek fault, the fold actually lying between these two major breaks. The axial plane of the fold dips about 70° S. and has a general west-northwest trend. The north limb, particularly near big faults, is considerably crumpled and, in places, is broken by relatively small normal faults along which there are some valuable ore deposits. Thus, near Big Creek there are many minor crumples just south of the Polaris fault, and at the Sunshine mine valuable ore deposits occur along normal faults that have relatively small displacements. Some of the beds in the north limb of Big Creek anticline are overturned; the beds in the south limb have gentle dips and are much less distorted than those on the north limb.

EAST FORK ANTICLINE

The broadest fold south of the Osburn fault is called the East Fork anticline from the expression of the structure in the valley of the East Fork of Big Creek, where the anticline is well shown both in outcrop and by map pattern (pl. 3). In section the fold is fairly symmetrical with a nearly vertical axial plane. The fold abruptly widens to the west and loses its identity in the western half of the Kellogg map area. Eastward the fold turns slightly to the south and crosses the southern boundary of the Wallace map area, beyond which the fold has not been mapped. The north limb of the East Fork anticline is cut off by the Placer Creek fault and the south limb by the Striped Peak fault.

PINE CREEK ANTICLINE

The largest fold in the Smelterville map area is the Pine Creek anticline. The fold axis was traced from near the Hypotheek mine southeastward to Denver Creek, where it has been offset by the Placer Creek fault. A possible extension of the fold on the south side of the fault was traced from near the mouth of Nabob Creek southeastward for about 1½ miles.

The trend of the fold axis is about S. 40° E. from the Hypotheek mine to a point a short distance southeast of the fork in Pine Creek. There the axial trace swings northeastward into a broad arc that turns southeastward to the point where it is terminated by the Placer Creek fault. The trend of the possible offset segment of the fold south of the fault is also southeastward.

There is little symmetry along parts of the fold, for the dip of the limbs varies considerably from place to place. Generally, however, dips are less than 45°, and the fold is fairly open. Along parts of the fold the crest is not well defined, and the axial trace has been somewhat arbitrarily located.

Much of the south flank of the northern segment of the fold has been faulted out by the Placer Creek fault, and little is known of the details of the minor structural features in it. The northeast flank is a uniformly dipping homocline which beyond the Page-Government Gulch fault is broken into numerous blocks by faults that disrupt its symmetry. Minor folds are superimposed on the main anticline and are most apparent in that part of the section occupied by the more quartzitic beds.

The productive lead and zinc deposits of the Pine Creek area are all contained within the northeast limb of the anticline. These mineral deposits are replacement veins controlled by echelon shear zones that nearly parallel the anticlinal axis but lie from ½ to ¾ mile north of it.

The anticline is well formed in the Denver Creek area, where it is terminated by the Placer Creek fault. Across the fault at that point there is no indication of the continuation of the anticline. An anticlinal fold does exist on the south side of the fault nearly a mile to the west, but it is poorly defined, and its exact position and extent have not been accurately determined. Thus, although the fold is definitely known to be offset by the Placer Creek fault, and the direction of movement is known from other evidence to be right lateral, the exact position of the offset segment of the Pine Creek anticline south of the fault is uncertain.

GRANITE PEAK SYNCLINE

The Granite Peak syncline in the Pottsville map area is one of the major folds of the Coeur d'Alene district. From the south end where the syncline is truncated by the Deadman shear zone, it extends 7 miles north through Granite Peak at the north edge of the Pottsville map area to the Thompson Pass fault, which transects and offsets the fold. The offset segment north of the fault is fairly distinct for an additional 3 or 4 miles north of the fault. Thus, the total length is at least 10 miles. From the crest of the Burke anticline on the west to the crest of the Glidden Pass anticline on the east is a horizontal distance of about 5 miles, and from the trough of the Granite Peak syncline to the crest of bordering anticlines is, in places, a vertical distance, as measured on a single stratigraphic horizon, of more than 7,000 feet.

The Granite Peak syncline is asymmetric, the west flank in most places being steeper than the east flank. North of Canyon Creek (pl. 5 and Ransome and Calkins, 1908, pl. 2) beds in the west flank generally dip 45°–70°, whereas beds in the east flank most commonly dip 15°–40°. South of the Imperial fault at the head of Deadman Gulch, a network of faults in part obscures the trough and west flank of the fold. West of this network of faults the west limb of the syncline is overturned, but to the east the east limb dips gently to the west. As discussed in the section on the Sonora and related faults, there is a suggestion that an unidentified, flat thrust fault may be present in the vicinity of the Imperial and Alcides tunnels. The overturned attitude of the west flank of the fold south of the Imperial fault suggests that the displacement responsible for the network of faults in the trough of the syncline in part produced this thrust or reverse-fault relation. The east flank of the fold, usually having low normal dips, is also overturned in the vicinity of the Snowstorm mine, where it bends away from the north trend to an orientation nearly parallel to the Osburn fault. The overturned part of the east flank is immediately adjacent to and north of the Deadman shear zone and underlies an area of about 2 square miles. This is an unusual structural relation, as the implication is that there has been movement involving overriding from northeast to southwest; all other overturned folds and reverse faults in the district seem to be related to movement involving overriding from southwest to northeast. An explanation of this overturned block may be its proximity to and distribution along the Deadman shear zone, and its position at the sharp bend of the fold trends. A local reverse buckling might well be expected in such an environment.

The only minor folds associated with the Granite Peak syncline are near the north edge of the Pottsville map area along the Idaho-Montana State line. The usual open, uncomplicated nature of the Granite Peak syncline is demonstrated by the fact that the Wallace Formation generally has many small drag folds, but the Granite Peak syncline has very few. Foliation found in the fold can generally be related to faults, rather than to compression during folding.

The sharp truncation of the Granite Peak syncline by the Deadman shear zone and Cincinnati fault is one of the most pronounced structural discontinuities of the entire district. The Deadman syncline lies almost at a right angle across the truncated end of the Granite Peak syncline. Such a pattern could hardly have been produced by the in-place formation of the Deadman syncline as a cross fold superimposed on the Granite Peak syncline. Such an origin of the Deadman syncline would have produced high and low points along its axis along which other formations would be exposed; however, the syncline has no such exposures and is solely confined to the Wallace Formation. The preferred interpretation is that the Deadman syncline has been horizontally moved by strike slip along the Deadman-Cincinnati fault system into its present relation to the Granite Peak syncline (fig. 30).

DEADMAN SYNCLINE

The Deadman syncline is northeast of Mullan and extends northwestward from Daisy Gulch for about 2½ miles to and beyond Gold Hunter Gulch (pl. 5). The syncline lies between and nearly parallel to the Deadman-Cincinnati fault system and the Paymaster fault. It is a tight, in places nearly isoclinal, fold. Dips 75°–90° are common in both flanks of the fold where exposed in Deadman Gulch. The fold axis appears to be nearly horizontal, as strike attitudes in opposite flanks are nearly parallel, and within the fold no formation other than the Wallace is exposed.

Three minor folds almost parallel to the main one are present in the southern flank of the Deadman syncline in Deadman Gulch, and the Wallace Formation is generally crenulated and buckled in many small drag folds that are particularly numerous near the trough of the major fold axis. The rocks are also highly foliated near the trough of the fold.

Intense foliation all but obscures the bedding at the east end of this fold in the acute wedge where the Deadman shear zone, Paymaster fault, and Osburn fault converge. The west end of the fold appears to be truncated at a low angle by the Cincinnati fault, but Wallace Formation continues to crop out between the Cincinnati and Paymaster faults west to Mill Creek where Wallace rocks also form the core of the Mill Creek syncline. This pattern of outcrop of Wallace Formation suggests that the Mill Creek syncline is the northwestward continuation of the Deadman syncline, even though the two folds have different trends, and a specific axial trace can not be followed between the two folds.

MILL CREEK SYNCLINE

The Mill Creek syncline is the dominant fold in the vicinity of the Morning and Star veins north of Mullan (pl. 4). Its axis is in Mill Creek valley, and the fold largely controls the attitude of bedding in an area extending from the Paymaster fault northwest almost to Canyon Creek and from the O'Neill Gulch fault west at least to West Grouse Peak. In a general way, the structural feature from West Grouse Peak west to Canyon Creek might also be considered part of the west flank of the Mill Creek syncline as the general dip is eastward, although faults have dissected the area into many blocks and locally beds diverge from a simple north trend and east dip.

Continuity of the Mill Creek and Deadman synclines is suggested by the continuity of Wallace outcrop between the two troughs, although the detailed features are so intricate that an exact continuity of the two axial traces cannot be demonstrated.

The axial trace of the Mill Creek syncline itself is not easily defined and on the map (pl. 4) is shown as a specific line only for a short distance, but the outcrop pattern of the formations involved in the fold more clearly show the extent of the structural feature.

The fold thus underlies an area of several square miles. The flanks dip at angles that average 65° or more, and the fold plunges at least 60° SW.

POSSIBLE RELATION OF GRANITE PEAK, DEADMAN, AND MILL CREEK SYNCLINES

Figure 30 shows a concept of the possible formation of the Granite Peak, Deadman, and Mill Creek synclines. This concept accounts for some seemingly anomalous relations of the three synclines one to another and of the Mill Creek syncline to the Burke anticline.

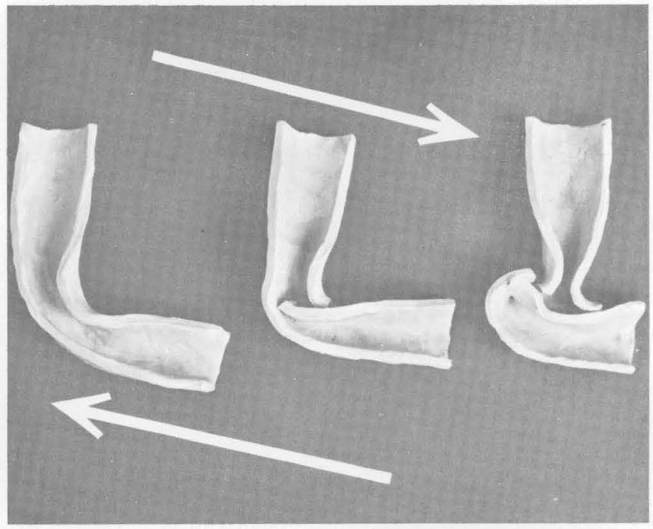


FIGURE 30.—Clay models of three stages in the formation of the Granite Peak, Deadman, and Mill Creek synclines.

The stage at the left in figure 30 shows a single continuous syncline that has begun to be warped in a rotational stress couple. Note that the east flank is overturned and dips to the northeast at the elbow of the flexure. This, perhaps, is the stage at which the beds were first overturned in the Granite Peak syncline between the Snowstorm fault and Deadman shear zone.

In the stage shown at the center, the east flank of the syncline is being broken and sheared westward as the drag-fold-like flexure of the synclinal trough progresses. This stage represents the beginning of the Deadman shear zone. Breaking of the overturned east flank at this stage allowed it to virtually retain the attitude it had in the first stage—that is, the bow to the east and the overturned attitude of bedding. The southern segment of the syncline continued to be moved westward, and the west end curled to the north around the west flank of the northern segment as in the stage at the right. This sharp change in trend is the principal feature that differentiates the Mill Creek and Deadman synclines. The south end of the O'Neill Gulch fault perhaps came into existence at this stage, when the west flank of the synclinal trough was ruptured. The beds in the west flank of the Granite Peak syncline are overturned in the structural knot formed around the south end of the O'Neill Gulch fault.

As the Mill Creek syncline was shifted around to the north undoubtedly the Burke anticline was affected. Perhaps this effect is represented by the irregular doming that distinguishes the south end of the anticline from the northern, more regular, part of the fold. This concept of genesis of the structural features also accounts for the manner in which the Burke anticline gives way along a southward projection of its axis to the Mill Creek syncline.

If this concept is true, the orientation of the Star-Morning vein, virtually parallel to other major veins to the north, is evidence that the vein formed after the major buckle of the fold axis had been formed, for the vein appears not to have been similarly buckled or twisted. Because the vein is at only a slight angle to the Osburn fault, it would seem logical that the vein is in a strike-slip fracture rotated only enough to exert a slight component of tensile stress across the fracture and to thus open the fracture at the time when mineralizing solutions were permeating the crust. This interpretation would be consistent with the general concept that mineralization occurred within the period of strike-slip deformation and succeeded most warping of the fold trends, but preceded a large part of the strike slip along the Osburn fault.

The evidence most contradictory to this interpretation of long-distance transport of the Mill Creek syncline is that no major fault has been found between it and the Burke anticline to the north. The Star crosscut transects the area and should have exposed the fault if indeed it exists. There seems to be little alternative to the interpretation of large-distance transport of the Deadman syncline, however; it is clearly in a discordant relation to the Granite Peak syncline. It may be that the Mill Creek syncline is not far from its original position and that only the Deadman syncline has been displaced.

If this concept of the buckling of the synclinal axis and timing of mineralization is true, it would seem likely that the structural knot a few square miles in areal extent in the vicinity of the southern end of the O'Neill Gulch fault would contain a variety of open channels excellent for mineral deposition. This block includes the overturned and faulted west flank of the Granite Peak syncline and the adjacent east flank of the Mill Creek syncline. The suggestion has been made elsewhere that such suitable hosts must also lie over deep linear feeders in order to be in a position to receive ore-bearing solutions. Eastward projections of the mineralized belt containing the Star-Morning ore body and the mineralized belt containing the Hecla ore body would fall very close to parts of this structurally suitable area. It would follow that some of the potentially mineralized features in this block should have near-north trends parallel to the O'Neill Gulch fault. The structural setting would in some ways be similar to the Bunker Hill mine area.

FOLIATION AND CLEAVAGE

In the following discussion, "foliation" is considered to be the more general term: a family name that includes any planar structure that gives the rock the characteristics of a bundle of "leaves." "Cleavage" refers more specifically to the property of a metamorphic rock to split along close-spaced plane surfaces. In large part the two terms refer to the same features.

Two types of foliation or cleavage are distinguished: (a) those that are related to folding and regional metamorphism, and (b) those that are related to later faulting. Throughout most of the rocks of the district there is a preferred orientation of sericite grains, but only locally is foliation so well defined that the rocks are appropriately referred to as slates or phyllites. Most writers refer to the fine-grained rocks of the Belt Series as argillite, which indicates that foliation is poorly defined. Locally, however, where folds are tight, foliation is well defined, particularly near the axes of the folds. Where a fold is overturned, the rocks of the overturned flank are also well foliated.

Superimposed upon this foliation formed during regional metamorphism is a foliation related to faulting. In the vicinity of almost all the larger faults, the rocks are sheared, although not to a degree that gouge and breccia have been produced. Rather numerous small shear planes give the rock a foliated appearance. Undoubtedly, foliation and cleavage resulting from regional metamorphism has controlled, to some degree, foliation related to later faulting.

Figure 31, *A–F* shows some typical relations between foliation, cleavage, and bedding in rocks of different lithologies and after different intensities of deformation. All are shown as being in the same relative

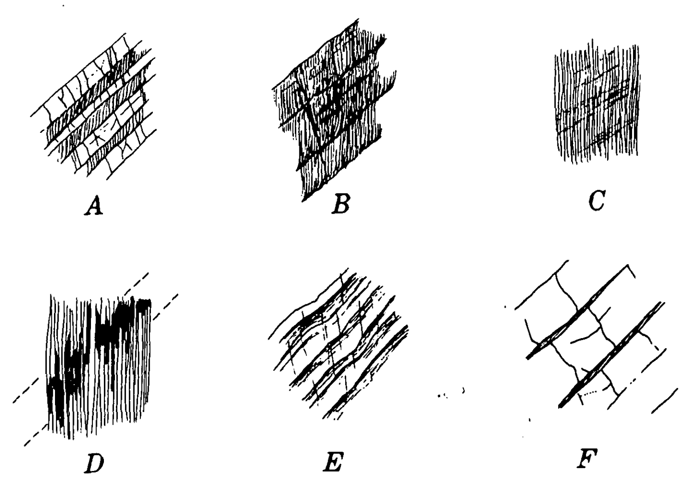


FIGURE 31.—Typical relations between foliation, jointing, and bedding; *A–F* are discussed in text.

position on the left flank of an anticline, and bedding in each case dips to the left. Foliation, cleavage, and jointing are more nearly vertical.

Figure 31*A* shows relatively thin interbeds of quartzite and argillite in which the contrast between composition and competency is great. Distinct strength discontinuity is localized along the bedding plane, and interbed shearing has taken place. There are no continuous shear planes cutting diagonally across several beds. Sericite in the finer grained beds is reoriented subparallel to the axial plane of the fold. Interbed shearing commonly drags the slaty folia nearest the bedding plane into the plane of bedding more than those in the center of the argillitic layer and thereby produces an S-shaped pattern in the section of individual folia. The joint planes in the quartzite are more nearly at right angles to the bedding than are the cleavage in the argillite.

Figure 31*B* illustrates foliation and cleavage formed in fine-grained rocks relatively free of quartzitic beds. In this rock, a few widely spaced bedding planes serve as planes of parting, and there has been some bedding-plane shearing causing some folia to be warped into an S-shaped pattern. In places the bedding is obscured, and the ability of bedding to serve as a parting plane has been destroyed. Some planes of parting cut across the slaty cleavage and probably represent planes of later shearing.

Figure 31*C* illustrates well-defined foliation and cleavage in fine-grained rocks in which thin compositional or color laminations are visible. Bedding planes in this example do not serve as parting planes or as planes of strength discontinuity. Even where such slaty cleavage is well defined, cleavage surfaces are generally irregular. Bedding laminations may be undistorted or may be intricately crenulated. The foliation and cleavage are generally nearly parallel to the axial plane of the fold.

On figure 31*D* the black segments represent parts of a quartzitic bed that has broken into thin plates along foliation planes. Commonly, the quartzitic plates are wrapped in an envelope of fine-grained or argillitic rocks in such a way that foliation may be mistaken for bedding in a simulated alternating sequence of argillite and quartzite. In a larger section, however, the bedding actually crosses the foliation at an angle, and the slabs of quartzite represent fragments of a single thick quartzite bed. The mechanics by which the slabs of quartzite have been interlaced with argillitic rock cannot be demonstrated in most cases, but certainly shearing and slipping along foliation planes are involved. The amount of displacement along individual foliation planes has been so great as to suggest that the foliation is related more closely to faulting than to folding. The slip along the foliation planes may be parallel to the strike in some places, but this was not determined. Perhaps foliation originally formed as a result of folding and then provided easy paths for relief of stresses that accompanied later faulting.

Figure 31*E* illustrates interbedded quartzite and fine-grained argillitic rocks with incipient cleavage or jointing that crosses compositional boundaries indiscriminately. Such ruptures are not necessarily related to reorientation of mineral grains and are probably to be considered fracture cleavage.

Figure 31*E* illustrates cleavage and jointing in a rock mass in which quartzite in thick beds is by far the most abundant rock type and argillitic rocks form only thin beds, in some places discontinuous, between the beds of quartzite. In such examples, most of the interbed shearing during folding tends to be accommodated in the thin argillitic beds. The foliation and cleavage produced in the argillite by this shearing is nearly parallel to bedding planes; nevertheless, with careful scrutiny some folia can generally be found that form a low angle with bedding and cross from the lower to the upper bed of quartzite. Locally, cleavage may have an orientation almost like that on figure 31*A*.

DISTRIBUTION AND ORIENTATION

The most intensely deformed parts of the Coeur d'Alene district are characterized by well-defined foliation and cleavage in most of the argillitic rocks and in some of the quartzitic rocks. Foliation is especially conspicuous in (a) the Big Creek anticline in the Wallace and Kellogg map areas, (b) the north overturned flank of the Lookout anticline in the Pottsville map area, (c) the block bounded approximately by the Paymaster and Osburn faults and extending westward to the Dobson Pass fault and eastward to the Deadman shear zone in the Mullan and Pottsville map areas, (d) the Deadman shear zone and Deadman synclinal block south of the shear zone in the Pottsville map area, (e) the Mill Creek synclinal block in the Mullan map area, and (f) a block between the D–6 and Blue Jay fault zone in the Mullan map area.

Foliation and cleavage are strongly defined near almost all the larger faults. Almost everywhere within 500 feet of the Osburn fault zone argillitic beds have conspicuous foliation, and the foliation itself is folded and contorted. Some shear or fault zones are characterized more by highly sheared and foliated rocks than by gouge or breccia. The Deadman shear zone is a good example of this.

In that part of the area where fold axes and faults trend N. 60°–70° W., foliation and cleavage have a relatively consistent strike in that direction; they most commonly dip to the southwest at high angles or are vertical. In the north half of the Mullan map area, however, where faults and folds trend more nearly northward, foliation and cleavage also assume the same general trend and dip steeply westward or are vertical.

Campbell (1960), and Wallace and Hosterman (1956, p. 599–601) reported intensely foliated bodies of rock in adjacent areas of Montana, east of the Coeur d'Alene district. For the most part, they found the intensely foliated blocks in a zone a few miles wide along the north side of the Osburn fault zone.

STRUCTURAL RELATIONS AND GENETIC IMPLICATIONS

At least two generations of foliation and cleavage have formed, one related to the major period of folding and regional metamorphism and the other to later faulting, but the two cannot be distinguished in every place. It is important, however, to understand that the two generations exist, because foliation and cleavage genetically related to folding can be used as a key to the recognition of overturned beds, whereas foliation related to later faulting cannot.

Some foliation is clearly associated with faults, and in mine workings it can be seen that foliation is well defined near most fault zones where fine-grained rocks are present. In a few places, where the original top and bottom of strata can be determined by sedimentary features, the foliation has an orientation counter to what would be expected if the foliation were related to folding. Such examples are evidence that the period in which the foliation occurred is separate in time from the major period of folding and is possibly related to a period of later faulting.

Such well-foliated rocks as sericitic phyllite and schist characterize some large shear zones. The Deadman shear zone, for example, is several hundred feet wide and more than 3 miles long, and undoubtedly a great deal of the displacement along this shear zone has been accommodated by a cumulative movement along the close-spaced foliation planes of the sericite phyllite and schist (fig. 29).

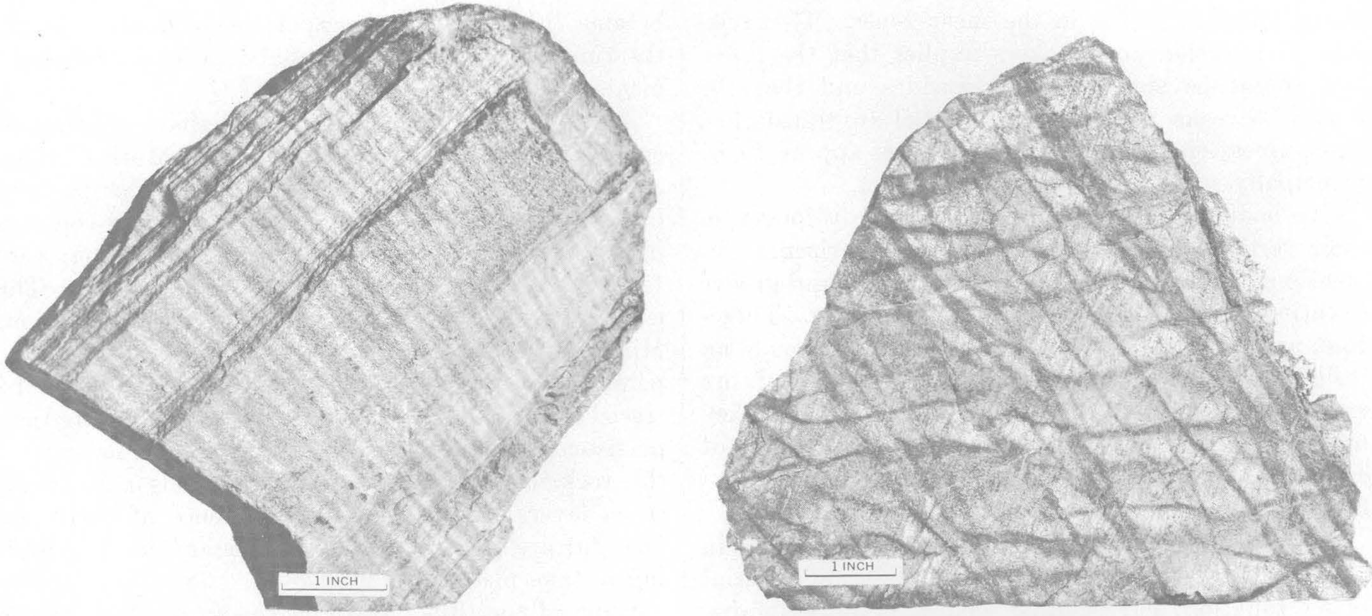
On figure 3*A* incipient foliation and cleavage can be seen to have formed in both the light-colored quartzite bed and in the dark-colored argillite bed. In adjacent beds the presence of foliation or cleavage, mud cracks, and thin laminations provide some clues as to the origin of foliation and cleavage. In the quartzite bed, the foliation and cleavage planes are widely spaced and are separate, distinct fractures. In the fine-grained rock, foliation and cleavage are represented by a multitude of minute poorly defined planes having spacing so close in places as to be comparable in scale to the grain size of the fine-grained rock.

Particularly to be noted is the parallelism of the incipient foliation and cleavage of the argillitic rock and the mud cracks filled with light-colored quartzitic material. The mud cracks, once perpendicular to the bedding, give clear evidence of strain that has rotated their trace in the plane of the outcrop about 45° with respect to bedding.

It is noteworthy that none of the distinct joints in the quartzitic beds displaces fine-bedding laminae within the quartzite; this relation suggests that the joints are ruptures perpendicular to tension. Furthermore, if the joints had formed early in the period of strain, it seems likely that some rotation or differential displacement of the blocks would have resulted. Therefore, although the foliation of the fine-grained rock formed in a continuing process of strain, the joints in the coarser grained rock were apparently formed very differently and not merely as one type of shearing rupture.

Foliation has been bent and crumpled in numerous places. Wallace and Hosterman (1956, p. 597) described a particularly significant example of this. In the Flat Rock syncline, axial-plane foliation has been bowed into a broad synclinal feature by drag along the Osburn fault; this shows that movement along the Osburn fault was later and distinct from the regional folding and metamorphism to which the foliation is related. A similar situation can be seen in the National tunnel (fig. 29), Pottsville map area, where highly foliated rocks in the Deadman shear zone have been folded into a broad synclinal feature and myriad smaller puckers have formed throughout the body of foliated rocks. In the Morning mine area, foliation is crumpled near the Fanny Gremm fault (fig. 28). Clearly then, there has been considerable movement along faults that postdate the foliation.

In most places in the district, highly foliated rocks are bleached, but this is not so everywhere. On figure 28 the pattern of bleaching and foliation in rocks of the Morning mine area is shown. Rocks in relatively close proximity may be foliated and unbleached, foliated and bleached, or relatively massive and unfoliated and bleached. If bleaching is related to the intrusion of the Gem stocks, the bleaching should have occurred much later than the foliation, which is probably related to Precambrian folding and regional metamorphism. Fryklund (oral commun.,



A. Ridge and groove lineations extend from upper right to lower left and are formed by intersection of nonparallel cleavage planes. Subdued pucker lineations extend from upper left to lower right and are small folds or crenulations in the cleavage planes.

B. Two sets of pucker lineations in the cleavage planes are outlined by light and dark shading. The one extending from upper left to lower right is more pronounced than the other, which extends from upper right to lower right.

FIGURE 32.—LINEATIONS IN FOLIATED ROCKS OF THE WALLACE FORMATION

1959), however, reported that bleaching was Precambrian and could have preceded cleavage.

LINEATIONS

In a great many highly foliated rocks of the Coeur d'Alene district, a district lineation can be seen on foliation surfaces (fig. 32). This lineation is principally made up of grooves and ridges, representing the intersection of many foliation planes (S-planes) that are at slight angles to one another. Thus, a typical cleaved surface of a rock specimen is not a simple plane but is a composite of numerous planes that are all nearly, but not quite, parallel. Individual planes of foliation are seldom perfectly planar, but are, instead, slightly undulatory. Elongated mineral grains, mineral streaks, and fragments of more competent rocks are commonly oriented with their long axes parallel to this lineation. The rock fragments are parts of more competent beds that have been brecciated, and the mineral grains are crushed and broken so that the mineral streaks are actually clusters of minute fragments. Sericitic folia wrap around these more competent nodular masses, and this contributes to the irregularity of the foliation surfaces.

Almost everywhere in the district, ridge-and-groove lineation on foliation surfaces is approximately parallel to the dip of the planes of foliation. Typically, for example, a foliation surface strikes N. 70° W., dips 85° SW., and the lineation plunges 80° SW., raking slightly to the west of the dip of the foliation plane.

The mode of origin of the ridge-and-groove lineation on foliation surfaces is not clearly understood, but most of the lineation is probably a "b" type—perpendicular to movement along the cleavage planes. The interpretation of this mode of origin is supported by the segmentation of some competent beds into pencillike structures with the pencils oriented parallel to lineation. Some pencils are rounded, presumably by rotation around their long axes. This mode of origin would be consistent with the large strike slip that probably took place along some shear zones. It is peculiar, however, that there are no crenulations or small or large drag folds whose axes are nearly vertical as would be expected if a nearly vertical shear zone, in which folia are parallel to the shear, were subjected to strike-slip movement.

A close genetic relation between a certain lineation and puckers has been suggested by Wallace and Hosterman (1956, p. 600). They noted that lineations appear to maintain a nearly right-angle relation to puckers; so, where the fold axes of puckers plunge at a low angle to the east, lineation plunges at a steep angle to the west; and where the fold axes of puckers plunge steeply to the east, lineation plunges at a low angle to the west. Most of the pucker folds represent displacement along a normal fault (fig. 22); such movement would be accompanied by dip slip along foliation planes in the shear zones. This relation of lineation and puckers implies that the lineation might be similar to slickensides and that the mineral streaks are smeared parallel to translation. Some lineations along foliation planes appear to be principally slickensides, but most are not.

Ore bodies of the district are commonly longer in their vertical dimensions than in their horizontal dimensions, and the orientation of ridge-and-groove lineations are, on the average, about the same. Therefore, an understanding of lineation might provide an insight into the time and structural setting of ore emplacement, and the lineations might provide a key to predicting local variations in the orientation of ore bodies. Unfortunately, the present investigation has not permitted an exhaustive study of lineation.

Other types of lineations have also been noted in the Coeur d'Alene district. The intersection of axial plane foliation and bedding planes produces a distinct lineation, and small drag folds and crenulations of bedding approximately parallel this orientation. These lineations are clearly related to folding; they serve as a guide to the orientation of axis of the major, or controlling, folds, which generally parallel the fold axis, or "b" tectonic axis.

Some faults, particularly those with relatively small displacement, have fracture surfaces that display slickensides. Fractures displaying horizontal slickensides have been observed on the walls of the Star vein and along the Highland-Surprise vein. In both of these places, the slickensides are within 25° of horizontal and are along fracture planes that cut the veins. In larger fault zones slickensides have been found in almost random orientations, and probably each set represents the local adjustment of an individual small block within the fault zone during the last phase of adjustment.

One fault paralleling the National vein in the National tunnel, east of the main crosscut, has mullion structures which plunge about 25° W. The mullions are grooves a foot or more across and several inches deep. The Champion fault, in the northern part of the Pottsville map area, also has nearly horizontal slickensides.

MINOR STRUCTURES

Minor structures occur throughout the Belt Series but are particularly characteristic of the Wallace Formation. They include minor folds, boudinage structures, and similar disruptions of bedding, segregation structures that have been called ovoids, structures of probable stylolitic origins, and quartz veinlets. Some of these evolved long after the rocks became lithified; others may have originated during the time of compaction and stabilization of the sediments.

Almost every outcrop of the Wallace Formation exhibits crenulation or minor folding. Much of these are interbed crumpling formed during compaction, but a great number of minor folds that are common in the lower part of the Wallace Formation were formed during a later period of deformation. The radii of such folds generally range from 1 to 15 feet. Minor folds affect more than one bed but are not persistent vertically; not even the largest can be traced for more than a few tens of feet. Nor are they persistent along the strike. The physical makeup of the rock, the alternation of argillaceous and arenaceous layers, and perhaps the presence of carbonate material are probably factors necessary for the folding to take place.

Some of the thin interbedded quartzite beds in the lower part of the Wallace Formation, usually an inch or less in thickness, show good boudinage structure. A more complex pattern of disruption of thin beds where there is an alternation of lithologic types is also characteristic of this lower part of the formation. Such structures are most evident where carbonate-bearing material is etched out on weathered surfaces (fig. 8). They are akin to what Gibson (1948, p. 16) described as molar-tooth structures, and these along with boudinage structures may have started to form during the time of compaction but are most likely a disruption formed during a later period of deformation.

Some of the more carbonate-rich layers near the middle of the lower part of the Wallace Formation display an unusual structure whose origin is not clear. They consist of what are probably segregations that because of their shape have been called ovoids (fig. 33). These ovoidal structures are alined parallel to the bedding in thin alternating strata and consist of what probably was once a single, more limy layer. The ovoids most commonly range in size from 1 to 3 inches in maximum diameter where viewed in sections at right angles to the bedding. They consist of an ovoid core of nearly pure light-gray calcite surrounded by a rim of fine-grained quartzose material. Some of the ovoids are flattened parallel to the bedding, whereas others in deformed rock may have their axes of elongation inclined toward the direction of foliation. Upon exposure to the weather the calcite core it etched out, leaving the quartzose rim in relief. Some ovoids clearly disrupt the enclosing rock and therefore seem to have formed during a period of

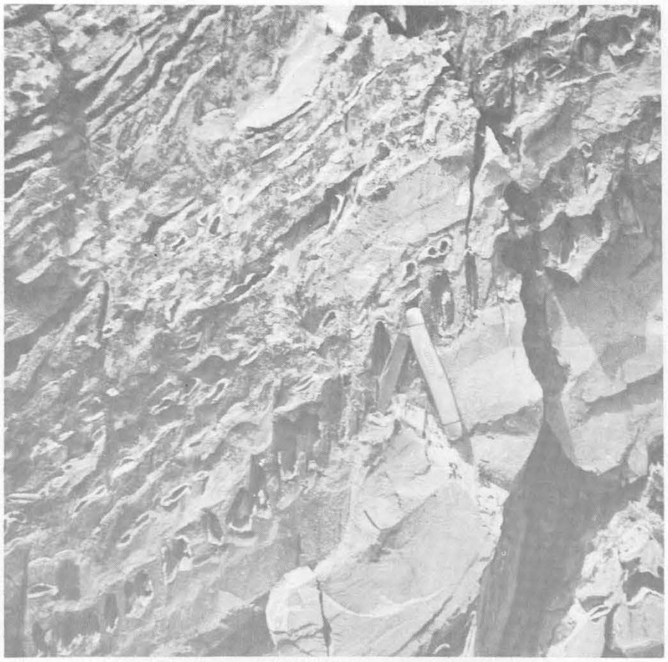


FIGURE 33.—Ovoids from which most of the calcite core has been etched out, from the lower part of the Wallace Formation at the head of Gold Creek. The ovoids in the row near the knife are elongated parallel to the foliation.

deformation, but their formation is also clearly related to some chemical reaction.

Sharp mounds and ridges and corresponding depressions which have no particular orientation have been found on the surfaces of some float. These features are probably of stylolitic origin and are most likely caused by deformation.

Highly deformed thick-bedded pure quartzite in the district is usually laced by an anastomosing system of quartz veinlets. These are undoubtedly of local origin and were formed from quartz in the rock which had taken into solution and redeposited to form the veinlets. They are most typical of the Revett Quartzite but are also found associated with more quartzitic beds in other parts of the Belt Series.

RECOGNITION OF OVERTURNED STRATA

To interpret the geologic structure of the Coeur d'Alene district it is necessary to recognize strata that have been overturned. The features most useful for recognizing overturned strata in the Coeur d'Alene district are discussed by Shenon and McConnel (1940), and results of an exhaustive study of the general problem are given by Shrock (1948). These features are reviewed here to point up the criteria used in determining tops and bottoms of strata, and are thus the basis for part of the structural interpretations made in the present study. Six criteria were most useful in the recognition of overturned strata: (a) mud cracks, (b) ripple marks, (c) cross-stratification, (d) graded bedding, (e) bedding-plane irregularities, and (f) foliation.

Mud cracks are particularly abundant in the Wallace Formation, and sections in which dark argillite and light quartzite are interbedded commonly contain mud cracks in the argillite filled with quartzite of the overlying bed. The top of the mud cracks, and thus also of the argillite bed, is the surface that joins the overlying quartzite bed. In most places, the mud cracks are considerably distorted from their original simple wedge shape. They are commonly crinkled and bent from a position perpendicular to bedding. These crinkles make it difficult to be certain which end of the filled crack was the original top or wide part of the wedge (fig. 4). Bending of the mud crack a position perpendicular to the bedding follows a geometry of distortion similar to that of slaty foliation; that is, the trace of a mud crack on a plane perpendicular to a fold axis is roughly parallel to the axial plane of the fold (fig. 3A). In many places where deformation has made the original top of the mud crack wedge difficult to distinguish from the bottom, the angle of the trace of the mud crack with the trace of bedding can be clearly determined and provides a key to the upright or overturned attitude of bedding.

Sections of mud cracks are generally more reliable for determining original attitudes of bedding than are mud cracks exposed on bedding planes. On bedding planes, whether the bottom surface or the top, mud cracks are generally represented by ridges because the quartzite filling the cracks is more resistant to erosion and thus stands above the surrounding argillite.

Oscillation or wave ripple marks, whether exposed in section or in plan, as mold or original surface, provide an excellent criterion for determining the original tops of beds in which they are found. In the best preserved examples, the crests of the ripple marks form a sharp angle, but the troughs are broad and rounded. Ripple marks are unreliable where troughs and crests are equally sharp or equally rounded. Current ripple marks in which an asymmetry is characteristic may also be unreliable. Deformation may obliterate an original difference between the crests and troughs of a set of ripple marks. In a few places the troughs may be distinguished from the crests by the presence of magnetite in the troughs. In some places, particularly in rocks of the Wallace Formation, the ripple marks have been distorted by rock deformation. The most common type of distortion that accompanies the thickening of the ripple-marked bed is characterized by compression of the ripple marks and over-steepening of the ripple slopes. Some ripple marks have apical angles as acute as 60°. In others, a thinning of the beds tends to lower the height of the ripple mark and thereby flatten the slope of the sides. If distortion is too great, the usefulness of the ripple as a criterion for determining tops of beds may be destroyed.

Cross-stratification (cross-lamination, crossbedding, or false bedding) is most common in quartzite beds, particularly in the Revett Quartzite. Individual laminae in the cross-laminated unit join the overlying bed at a relatively high angle but curve so as to be almost parallel to the lower bed where they join it. The difference between the angles at which the cross-laminations join the bedding above and below the cross-laminated unit is thus the key to determining the original tops and bottoms of beds. This criterion is most reliable where the bedding planes on both sides of the cross-laminated layer are visible. In some beds, there is little or no perceptible difference in the angle of junction of the cross-lamination with the overlying and underlying bed, and they are of no use in determining original tops and bottoms of beds.

Graded bedding, the gradation in grain size of an individual sedimentary unit of continuous deposition from coarser at the bottom to finer at the top, is perhaps the most widely used criterion for recognizing original tops of beds of the Belt Series. The gradation results from the more rapid settling of the larger and heavier grains in contrast to the smaller grains. If grains of mixed sizes are allowed to settle in water, the larger ones settle to the bottom first, and the finer grains come to rest at progressively higher levels. For this mechanism to operate, of course, all the grains of different size must start settling at about the same time; it is therefore essential to find a bed that has had a sedimentation history of this sort. In beds that have a sharp boundary both on the bottom and top, and have a gradation of grain size from coarser at the bottom to finer at the top, it is clearly evident that the sedimentary process describes above has been operative. If turbulence or other disturbing influences have been operative, the boundaries of the sedimentary unit may appear indistinct, and it may be difficult to recognize the limits of the sedimentary unit in which all grains of assorted sizes had a common starting time of settling. Multiple laminae may grade from a coarser grain size in a lower sedimentary unit to a finer grain size in a higher one; but even though a particular set of such laminae may represent the mechanism of sorting described above, it is extremely difficult to be certain that these laminae are not merely a function of the grain sizes available at different times.

In the Belt Series there is rather little variation in grain size, the gradation is commonly from medium- to fine-grained quartzite to finer quartzite, or to argillite. It is difficult to distinguish differences in grain size in many places without a hand lens, but the quartzitic part of the unit can generally be distinguished. The quartzitic part in unaltered rocks is also almost everywhere lighter gray in color than the argillitic part, but with moderate bleaching the argillic part becomes even lighter than the quartzitic part, and in such cases it is possible to confuse them. If the two are confused, of course, the stratigraphic section would appear to be inverted.

Bedding-plane irregularities commonly indicate overturning of beds. The bottoms of some of the quartzitic units are irregular, but their tops are smooth. Where sand has settled on an unstable argillaceous ooze, a certain amount of deformation of the surface of the ooze has resulted. Contrasting with this, the sand layer provided a relatively stable base on which a succeeding layer of argillaceous material was deposited, and the top of the sand layer remains smooth and undistorted. In addition, the top of an argillaceous lamina that represents the end of a short period of deposition may have been channeled and then filled during the subsequent brief period of sedimentation, and is, in effect, a minute disconformity. These and other similar conditions make an irregular bottom but an even top on quartzite laminae and beds. The resulting difference provides a key, if used with discretion, for determining the sequence of the beds.

Foliation has also been useful in determining tops and bottoms of strata. As has been emphasized, one must first be certain that the foliation under question is genetically related to the folding that tilted the beds rather than to later faulting. The most reliable foliation for this purpose is foliation confined to a single bed and thus obviously related to the bedding movement and not to a throughgoing fault. Some of the techniques by which foliation can be used as a guide to determining overturned beds are highlighted as follows:

1. Foliation is roughly parallel to the axial plane of the controlling folds. As beds must warp symmetrically across the axial plane, the upright or overturned attitude of the beds can be recognized by imagining a foliation plane as the axial plane of a fold and by imagining bedding bent so as to form a fold symmetrical with respect to this plane.
2. If foliation and bedding dip in the same direction and foliation has an angle of dip less than that of

bedding, the beds are overturned; if the opposite is true, the beds are upright.

3. S-shaped foliation traces indicate the direction of interbed slipping; the ends of the S point in the direction that the adjacent beds slipped. Interbed slippage related to folding is such that the beds stratigraphically higher slip toward the crest of the anticline. Thus, if the bed apparently of lower stratigraphic position as observed in the outcrop has slipped updip, the beds are overturned.

In addition to these techniques for recognizing individual beds that have been overturned, the gross stratigraphic succession can be conclusive evidence of the overturned or upright attitude of beds.

STRUCTURAL EVOLUTION

A variety of data on the nature and origin of the individual structural features in the Coeur d'Alene district is presented in the preceding sections, but no attempt is made to establish the general evolutionary sequence. A concept of the sequence, depicted as stages in the formation of the structural pattern of the district, is illustrated on plate 10. Although these diagrams are hypothetical, they attempt to portray a unified evolutionary history that will accommodate the varied, and even apparently anomalous, data that have accumulated. Because of the speculative nature of much of this information and the difficulties of dating and correlating the rock formations and structural elements, a completely integrated and definitive history of the structural evolution of the district may never be possible. At the present writing, however, the evidence is strongly suggestive of the order of events, and certain broad aspects of the pattern fit our interpretation; this concept should serve as a beginning toward ultimate solutions. Time markers in the geologic history are so few that the sequential arrangement of structural events must be based more on the relative ages of rocks than on the established time scales. The principal rocks or events to which significant dates can be applied are (a) the Belt Series of Precambrian age, (b) uraninite in certain veins in the Sunshine mine within the Silver Belt, ±1,250 million years old (Precambrian), (c) the Gem stocks, ±100 million years old (Cretaceous)—similar to the Idaho batholith in age, and (d) glaciation of Pleistocene age. Other geologic units or events that are more tenuously associated with the geologic history, or not so well known include (a) remnants of sedimentary rocks of Middle Cambrian age, which cap fault blocks in nearby areas, (b) features of Laramide orogeny in the Northern Rocky Mountains, (c) Columbia River Basalt and interbedded rocks of the Latah Formation of Miocene age in the plateau country to the west, and (d) deformation of continental deposits to the east in the Northern Rocky Mountains and of Columbia River Basalt to the west for the late Tertiary. Age determinations of the lead in galena in the deposits of the Coeur d'Alene district indicate the lead to be Precambrian which is anomalous, as some of these deposits crosscut the Gem stocks.

OLDEST KNOWN STRUCTURAL FEATURES

Rocks that are known to be pre-Belt in age are not exposed within 100 miles or more of the Coeur d'Alene district. However, gneissic rocks that may be pre-Belt in age crop out almost 30 miles to the west on the west side of Coeur d'Alene Lake. Anderson (1940, pl. 2) referred to these as "gneissoid rocks" of Jurassic or Cretaceous Age, but the evidence relating to their age is inconclusive. Their structural grain, fold axes, and foliation have a general north trend, whereas the structural grain of Belt rocks that crop out east from the east shore of Coeur d'Alene Lake has a west-northwest trend. This difference in trends is an anomaly, indicating that the two groups of rocks have undergone different structural histories, and suggests that the gneissic rocks may be either younger or older.

Some features of the Belt geosyncline provide evidence of the structural pattern in pre-Belt time. The generally north-trending Belt geosyncline has a conspicuous southeastward embayment which is in alinement with the Lewis and Clark line. This suggests that the Lewis and Clark line, as a structural zone of weakness, may have existed at least as early as Belt time. The Belt Series in the Coeur d'Alene district, however, seems to be thinner than in nearby areas to the east and north (fig. 2), which suggests that this trough did not extend westward across the geosyncline.

The uraninite of Precambrian age occurs in Belt Series rocks in steeply dipping undistorted veins in the northern overturned flank of the Big Creek anticline in the Silver Belt area. Thus, the structural evolution within the immediate vicinity of the district must have advanced through the stage depicted on plate 10*C* before these uraninite-bearing veins had formed. The first regional deformation of the Belt Series was distortion into a north-trending group of large gentle folds, which were basinwide in scope (Deiss, 1935). In the region outside of the Coeur d'Alene district, rocks of the Belt Series had only been gently warped and partially eroded prior to the deposition of the next younger rocks—the late Precambrian or Middle Cambrian sequence. Thus, the relatively intense deformation that preceded the emplacement of the uraninite veins in the Coeur d'Alene district appears to have been an anomalous local phenomenon. This view is strengthened by the near conformability between rocks of the Belt Series and the next younger rocks in the localities nearest to the district where these relations are found. These localities are in the Pend Oreille district, 35 miles to the northwest, and in the St. Regis-Superior area, 45 miles to the southeast, where rocks of Middle Cambrian age overlie the Belt Series.

RELATION OF FAULTS TO FOLDS

Most of the pattern of faults can be seen to have formed after the major period of folding; there is clear and abundant evidence that folds have been broken and displaced along many faults. Displacement along some faults, which has been largely strike slip, has caused apparent offset of fold axes. Displacement along other faults, which has been largely dip slip, also clearly cuts folds, but the type of movement is not everywhere clearly defined.

Four kinds of faults, which may be genetically distinct, are recognized. They are reverse faults, steep dip-slip faults, strike-slip faults, and late normal faults. The time relations of these faults are uncertain except that the reverse and steep dip-slip faults are probably relatively early, and the strike-slip and late normal faults are relatively late. Some of these faults must have originated in Precambrian time, whereas others undoubtedly did not come into existence until Tertiary time. Repeated movement along many faults can be demonstrated from their relation to veins and dikes. However, the differentiation of the amount and type of displacement at different times is not known with certainty along any fault in the district, and it is commonly difficult to be certain of the net slip, even without resolving net slip into separate steps.

REVERSE FAULTS

The Page-Government Gulch fault group and the Carpenter Gulch and Blackcloud faults are the most certain reverse faults representing compressional stresses; the Alhambra fault may also belong to this set. As shown on plate 10*A* these faults probably formed by the same stresses that brought about the major folds, and they are localized where the folds are tighter and are in part overturned. Each fault dips 35°–65° SW., and all but the Alhambra fault trend over most of their lengths at fairly large angles to the Osburn fault. The Page-Government Gulch fault group is offset along the Spring and related faults. If, as believed, the Spring and related faults are members of the strike-slip system, the Page-Government Gulch group must be earlier. Moreover, the Page-Government Gulch fault group and the Carpenter Gulch fault appear to be segments of a single fault zone that have been offset by later strike-slip movement along the Osburn fault. The supporting evidence is that both have similar trends and dips, the movement has been similar along both, and both border the east side of an upwarped area. Similarly, the Blackcloud and Alhambra faults may be offset segments of the same reverse fault zone, although the supporting evidence is not as clear cut. The reverse faults formed relatively early, as indicated by the fact that they are segmented and are irregular and bowed, apparently as the result of later deformation. Other reverse faults that may be related to this group of faults include the Big Creek, St. Elmo, Fort Wayne, a poorly defined fault zone on the west flank of the Granite Peak syncline, and several unnamed faults in the Atlas mine area. Later movement along the St. Elmo fault is indicated by the fact that a vein is offset along the fault.

The Page and Alhambra faults display different relations to the associated veins but appear to have had somewhat similar histories. In the Page mine the Tony vein ends abruptly at the Page fault, and on some levels drag relations show that some movement occurred after the ore had been emplaced. At other places the relations indicate that the fault may have acted as a dam to ore solutions; moreover, no proven extension of the vein has been found west of the fault, although this area has not been completely explored. This would indicate that the fault was in existence prior to mineralization and that some movement occurred along the fault after ore emplacement. The Alhambra fault zone contains both uraninite and sulfide veins, and in places the sulfide minerals are pulverized within gouge seams. From this evidence the authors conclude that the Alhambra fault has been in existence since Precambrian time and that there have been repeated movements along it, the last movement occurring after the sulfide minerals had been emplaced.

STEEP DIP-SLIP FAULTS

The northern parts of the Mullan and Pottsville map areas are characterized by faults of steep dip, some of which have had reverse displacement along them, and others normal displacement. Some of these strike north, and others west to north. The dip of these faults is so steep, usually more than 70°, that it is probably improper to consider the reverse faults compressional features and the normal faults tensional features; rather, they all should be considered to represent virtually vertical adjustments. The north-trending faults are generally the more conspicuous and throughgoing ones, and are roughly parallel to the axes of the major folds; those with a more westerly trend are nearly at right angles to the folds. Conceivably, these faults could be genetically related to the period of major folding and could have initially formed as separate sets of longitudinal and transverse faults. However, many of the faults in this area appear to offset axes or flanks of folds. A good example is the Imperial fault, which is transverse to the Granite Peak syncline, and thus the displacement of the fold is quite evident. Similarly, the Paymaster, Mexican-San Jose, Commander, O'Neill Gulch, and Sonora faults appear to cut folds; but for the Gertie, Russell, Cougar, Elite, Omaha, Oreano, and Mart faults, little or no evidence has been found to indicate their temporal relation to the folds.

Two of the more north-trending faults in the Mullan map area, the Gem and Carlisle, contain sulfide ore deposits along them, and thus must have existed prior to the main period of mineralization. Others, including the O'Neill Gulch, Standard, Mart, and Frisco faults, on the basis of their bounding relations to veins, also apparently existed prior to the main period of mineralization. Slickensided ore or pulverized sulfide minerals in the gouge show that some movement has occurred along these faults since ore emplacement, but the amount of movement is undeterminable.

South of and in the vicinity of the Osburn fault many of the faults are subparallel to fold axes, and thus it is difficult to analyze their relation to folding. Some of the faults that are subparallel to the Osburn fault have already been mentioned as possibly belonging to the group of earlier reverse faults, of which the Alhambra is the most evident. Others, such as the Polaris, Mineral Point, and Argentine faults, along which there has been apparent normal displacement, may have originated as longitudinal faults, but no evidence for or against such a belief can be cited. The D–6 and Reindeer faults seem to be later than the folds, for they transect folds at a low angle. The Divide and Trapper Creek faults in the southwest corner of the mapped area also transect fold elements. In the block between the Osburn and Paymaster faults deformation has been so intense that any initial phases of faulting are impossible to recognize, and it can only be said that folding, shearing, and crushing must have been going on simultaneously in the late phases of deformation.

STRIKE-SLIP FAULTS

In the formation of the regional pattern of folds and faults (pl. 10), the folds appears to have been warped during strain that culminated in the major strike-slip faults. Apparently, these initial folds and some faults were nearly linear elements that trended north to northwest across the region, and which at a

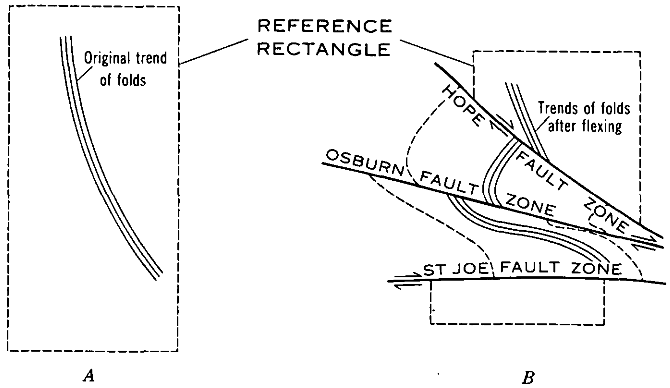


FIGURE 34.—Nature of regional strain that accounted for flexing of fold trends and culminated in right-lateral strike-slip faults.

later time were flexed into a sharply bowed pattern akin, on a small scale, to the orocline of Carey (1955). Only after the axes of the original folds had been bent did the Osburn and related strike-slip faults evolve as throughgoing breaks that offset the folds.

The system of strike-slip faults dominates the regional structural pattern from Superior, Mont., on the east to Coeur d'Alene Lake on the west, and from south of the district north to Pend Oreille Lake (pl. 9). Figure 34 diagrammatically suggests the nature of the strain inferred for this region. The dotted lines bound a reference rectangle that depicts the distortion in plan view. The distortion inferred includes: (a) right-lateral strain that shifts the northern part of the rectangle southeast relative to the southern part, and (b) movement of the north edge closer to the south edge with accompanying flexing of the part of the area between the Hope and St. Joe faults.

Within this region the major strike-slip faults include, from south to north, the St. Joe, Placer Creek, Silver Creek, Boyd Mountain, Osburn, Burnt Cabin, Thompson Pass, and Hope faults. Within the district in the five map areas other faults that appear to have had important strike-slip components of displacement along them include the Champion fault, Deadman shear zone, and Cincinnati, Kellogg, Blue Star, Polaris, Silver Summit, and Spring faults. Several earlier faults of other types such as the Alhambra and Star appear to have been reactivated by strike-slip stresses. Several faults that would appear from their position in the fault pattern to belong to the strike-slip system, but for which evidence seems to be against strike slip, include the Paymaster, Friday, White Ledge, and Golconda faults.

Several major folds in the Coeur d'Alene district and adjacent areas are truncated at the Osburn fault and displaced by movement along it. Movement along the Thompson Pass fault has clearly offset the Granite

Peak syncline and Glidden Pass anticline. The Deadman shear zone and Cincinnati fault sharply truncate the Granite Peak syncline, and along these breaks the Mill Creek and Deadman synclines are interpreted as being displaced from original continuity with the Granite Peak syncline. The Pine Creek anticline also appears to be offset along the Placer Creek fault. Within the Savenac syncline, in western Mineral County, Mont., the axial-plane foliation as well as the axial plane has been warped into a drag relation along the Osburn fault. From this last evidence it is apparent that tight folding preceded some of the strike-slip faulting.

Although the north branch of the Osburn fault in western Mineral County, Mont., the Deadman shear zone and Cincinnati fault, and the Placer Creek fault have good evidence of strike-slip along them, they are sinuous and, thus, may be representatives of an early phase of strike-slip shearing (pl. 10*C*) that were distorted during continued strike-slip deformation. The Polaris, Silver Summit, and perhaps some other faults in the Silver Belt area probably formed as strike-slip faults when the Placer Creek fault buckled and could not longer accommodate strike-slip displacement. The Deadman shear zone and Cincinnati fault also may have formed relatively early, and appear to have been warped by continued strike-slip deformation due to the separation in the structural continuity of the Deadman and Mill Creek synclines from the Granite Peak syncline.

The evidence of dislocation and disruption of other features along the faults of the strike-slip system gives additional support to the belief that these faults formed relatively late in the tectonic history. Strike slip along the Osburn fault after deposition of the ore deposits probably separated the two major ore-producing areas within the district by about 16 miles. The Yreka mineral belt in the Pine Creek area also appears to have been offset about 2 miles by movement along the Placer Creek fault. The Dobson Pass fault, along which the movement appears to have been contemporaneous with that along the Osburn fault, clearly truncates the southern Gem stock; this indirectly indicates that the major movement along the strike-slip faults occurred after the intrusion of the monzonitic stocks. Diabase dikes along the Osburn and Spring faults have been sheared and disrupted by movement along these faults subsequent to their emplacement.

An unfaulted capping of basalt lies astride the Osburn fault near Coeur d'Alene Lake and appears to be clear evidence that the Osburn fault has not been active since the basalt solidified. From the relation and appearance of this remnant of basalt to others nearby, it seems evident that these remnants are part of the Columbia River Basalt, and thus are middle Miocene in age. The most conclusive evidence, therefore, indicates that the major portion of the strike-slip faulting occurred some time after the intrusion of the monzonitic stocks, which are Cretaceous in age, and prior to the outpouring of the Columbia River Basalt, which occurred in Miocene time.

LATE NORMAL FAULTS

Faults, usually of relatively small displacement and along which the movement has been mostly normal, have been observed which offset ore deposits. Because of this relation, the faults must have formed at a relatively late stage in the structural evolution. They have been found underground at the Lucky Friday and Golconda mines, where the movement along any individual fault can usually be measured in tens of feet. The Zanetti, Upper and Lower Murray, and Haff faults, which offset the veins in the Dayrock mine, are apparently also late normal faults, but movement along these faults seems to have been somewhat greater. They appear to represent adjustments within blocks of ground that are bounded by larger faults, and a large number of additional faults probably belong in this category.

Along the Dobson Pass fault the movement has been normal, and the major displacement occurred late in the tectonic history of the district; the fault belongs in a different category, however, as it has resulted from a somewhat different set of mechanics and is greater in magnitude.

RELATION OF MONZONITIC STOCKS

Some folds to the northwest and southeast of the Gem stocks (pl. 9) trend diagonally to the trend of the stocks, and the pattern suggests that the major folds have been cut discordantly by the stocks. In a gross pattern, however, the alinement of the stocks is subparallel to a broad, elongate upwarp—the Burke-Trout Creek anticline—as indicated by similar small intrusives that crop out to the northeast near the axis of this fold. The local discordant relation, though, is good evidence that the formation of folds was principally prior to the intrusion of the stocks in Cretaceous time, and thus is in accord with other evidence indicating that these folds formed relatively early in the structural evolution of the region.

The Gem stocks and other small monzonitic intrusives in the district are cut by several faults. Just north of the Mullan map area a small monzonitic stock in Granite Gulch is in fault contact along its eastern border with rocks of the Prichard Formation across the north-trending French Gulch fault (Hosterman, 1956, p. 731). Movement along the Puritan fault, another north-trending fault, has been sufficient to bring unmetamorphosed rocks of the Prichard Formation in contact with the southwest edge of the north Gem stock. It has been postulated that these were among the early formed faults. In working out a plausible interpretation of the tectonic history, this postulate seems to be true, but the evidence clearly shows that there has also been considerable movement along them that occurred after intrusion took place.

The Dobson Pass fault forms the southwest contact of the southern Gem stock. Displacement along this fault has been large. Most, if not all of this displacement probably took place after the emplacement of the stocks, as none of the rocks in the immediate hanging wall show any effects of contact metamorphism. This is particularly true if one accepts the theory, already described, that the small monzonitic bodies to the west are cupolas of the Gem stocks which have been sheared off and displaced westward about 3½ miles by the Dobson Pass fault. Perhaps a westward-sloping upper surface on the stocks provided a weakness which originally localized the Dobson Pass fault. The distribution of magnetic highs over the Gem stocks as shown on the aeromagnetic map (pl. 8) suggests that the monzonite terminates at about the Osburn fault, and as the Dobson Pass and Osburn faults probably are genetically related, it is likely that much displacement along both faults occurred after monzonite emplacement. No magnetic high that might suggest a buried segment of the stock has as yet been discovered south of the Osburn fault, although the aeromagnetic map includes hardly any of the area south of the fault in which an offset segment of the Gem stocks would be expected.

Emplacement of the monzonite may very possibly have been controlled by such reverse faults as the Blackcloud, Carpenter Gulch, and Twomile faults, although there is clear evidence of some movement along the Blackcloud fault after emplacement of the monzonite. Both on the surface and underground in the Silverore-Inspiration workings, the thermal metamorphic aureole bordering a small monzonitic intrusive has been sharply truncated by the fault. The manner in which a small plug of monzonite is situated at the junction of, and in the footwalls of, the Twomile and Carpenter Gulch faults, fanning out in plan view along each fault, seems too fortuitous to be explained other than as control of the intrusive by the fault. The two small monzonitic plugs along the footwall of the Blackcloud fault are elongate parallel to this fault, but this pattern could be explained as well by displacement after monzonite emplacement as by fault-controlled intrusion of the monzonite.

RELATION OF DIABASE AND LAMPROPHYRE DIKES

The general distribution of the diabase and lamprophyre dikes as shown on plate 7 suggests a predisposition for certain areas and patterns that must in some way fit into the structural history of the area. Both types have been found in crosscutting relation to the monzonitic intrusives, and the lamprophyre dikes have been found at several places in crosscutting relation to main period veins. Indirect evidence suggests that the diabase dikes are also younger than the main period of mineralization, although arsenopyrite-gold-quartz veins of a later period of mineralization transect a diabase dike in the General mine. Thus, both types of dikes were emplaced relatively late in the tectonic history, and are most likely early Tertiary in age.

Diabase dikes are commonly along major faults that have a west-northwest trend. These dikes appear to be scattered at random throughout the district, in contrast to the lamprophyre dikes, which seem to be concentrated within restricted areas. Diabase dikes intrude many types of faults such as reverse faults (Blackcloud), steep-dipping faults (Ruth, San Jose-Mexican, and Reindeer), and strike-slip faults (Osburn, Placer Creek, and Spring). Shearing of the diabase, which in some places has been intense, shows that additional adjustment has taken place along most of these faults after intrusion of the dikes. Exceptions to these generalizations are two rather extensive diabase dikes, one of which occurs in the Silver Belt, where the dike appears to cross faults of large displacement, such as the Polaris, without being appreciably offset, and the other in the southeastern part of the Smelterville map area, where the dike extends, undisplaced, across the Divide fault.

The lamprophyre dikes tended to intrude along relatively minor structural features that are usually recognizable only because of the dikes that occupy them. These dikes trend northwest to northeast, the larger number being in the north-northwest octant. Shearing of the dikes indicates adjustment following intrusion. A lamprophyre dike exposed in the Star mine workings strikes across the vein and the Star fault and has been offset by that fault. Most of the lamprophyre dikes lie north of the Osburn fault, as indicated by exposures, which are much the same in all parts of the mining area. Whether the dikes intruded before or after major strike slip along the Osburn fault is unknown. At least no comparable concentration of lamprophyre dikes occurs south of the Osburn fault, where they might be expected to have been offset by right-lateral strike slip. The possibility that erosion has not been sufficient south of the Osburn fault to expose a comparable group seems counter to the fact that no good evidence has been found to indicate any appreciable uplift in the movement along the Osburn fault. Many similar dikes are exposed south of the Osburn fault in roadcuts along U.S. Highway 10 for several miles east of Coeur d'Alene Lake (Anderson, 1940, p. 24). Their concentration in restricted areas might best be explained by a similar localization of accessible openings at the time of intrusion.

RELATION OF FOLIATION AND CLEAVAGE

In the subsection entitled "Foliation and cleavage," the relation of faulting to foliation is discussed, and evidence is presented to indicate that some foliation and cleavage probably formed concurrently with most types of faults, that displacement along some faults has crumpled, folded, and distorted foliation, and that some foliation and cleavage is clearly older than strike slip along the Osburn fault.

RELATION OF BLEACHING

The pattern of bleached rocks clearly shows that the hydrothermal solutions responsible for the bleaching traveled along many of the faults now apparent in the district and seeped from the faults into the adjacent disrupted, broken rock. Thus the bleaching pattern is indicative of the original fault pattern prior to the main period of mineralization. Some faults, however, sharply separate bleached rocks from unbleached rocks; some faults may have dammed the hydrothermal solutions and limited the bleaching action to only one side, whereas others may have had movement along them subsequent to bleaching and have shifted bleached rock against unbleached rock. Along some of the faults, particularly in the Pine Creek area, the rocks have not been bleached. In many places, intensely foliated and phyllitic bodies of rocks have been bleached subsequent to foliation; in other places, however, foliated rocks appear bleached because they are intensely sheared and pulverized, yet they actually are relatively unaffected by hydrothermal solutions.

Faults that are known to limit or bound bleached zones for at least part of their length in the eastern part of the Coeur d'Alene district include the Frisco, O'Neill Gulch, Dobson Pass, Commander, Fanny Gremm, Paymaster, Tornado, Defiance, Blue Jay, D–6, and Reindeer faults, and the Deadman shear zone. In the western part of the Coeur d'Alene district the Page, Polaris, Big Creek, Alhambra, and Kruger faults form boundaries of bleached zones, and in that part of the district bleached rocks are principally concentrated south of the Osburn fault. The Placer Creek fault limits bleaching in the vicinity of the Castle Rock property.

The Frisco fault probably acted as a dam for bleaching solutions, but the Dobson Pass fault has probably offset bleached zones. There is little evidence to suggest which of the other faults dammed bleaching solutions and which have offset bleached zones. It is perhaps significant that faults believed to have large components of strike slip or that are possibly related to the strike-slip system of faults are prominent in the list of faults that bound bleached zones. This list includes the Osburn, Deadman, Commander, Polaris, and Fanny Gremm faults, and possibly the Paymaster, Big Creek, and Alhambra faults. The Dobson Pass fault, having dip-slip movement, is also placed in this group because it is directly related to the strike-slip movement along the Osburn. This relation would suggest that strike slip occurred later than bleaching.

RELATION OF VEINS

The ore deposits of the Coeur d'Alene district are described by Fryklund (1964) in a companion volume to this report. Therefore, only some of the general relations between veins and structural features that permit an integration of the mineralization with the structural evolution of the district will be discussed here. At least six types and generations of metallic mineralization have been found; arranged from oldest to youngest they are as follows: (a) Disseminated zones of arsenopyrite-pyrite that have only been found in the Silver Belt and eastward and restricted to areas south of the Osburn fault, (b) uranium-bearing veins, (c) main period of base-metal veins, (d) yellow sphalerite-galena-silver-free tetrahedrite veins, (e) stibnite-scheelite, gold-scheelite, and gold-quartz veins, and (f) arsenopyrite-gold-quartz veins that formed after diabase emplacement. Several other possible substages may also be present, but such evidence is incomplete.

The age of the uraninite has been established as ±1,250 million years, which places the first episode of mineral introduction well within Precambrian time. Some, and possibly all, of the bleaching may also have preceded the formation of the uranium veins. If, as will be shown, the main period was in Late Cretaceous or early Tertiary, then the episodes of mineral introduction in the Coeur d'Alene district have been concentrated into two relatively short periods, which were separated by a long interval that extended from Precambrian to Cretaceous.

In the following discussion, only the veins of the major stage of base-metal deposition are referred to unless specific exception is noted.

Characteristically, veins have formed along fractures and by replacing wallrocks adjacent to the fractures, but in places they have also formed in voids in the fractured zone. With few exceptions, the fractures along which the veins have formed have had relatively minor displacement. Almost invariably there has also been some displacement that occurred after ore emplacement along the vein-filled fractures with the result that shear zones in some places border and elsewhere form an anastomosing network through the veins. Galena is commonly foliated as a result of shearing after its deposition. Veins are also cut by transcurrent faults that offset them. Fault movement thus clearly both preceded and succeeded the formation of veins.

Some veins end abruptly at faults, and the fault appears to have acted as a dam to mineralizing solutions, but other faults appear to have offset the veins. The Golconda vein is cut by numerous normal faults that displace the vein by at most a few tens of feet, and the Lucky Friday vein is similarly cut into many segments by faults of relatively small displacement. The Dobson Pass fault, a low-angle normal fault, offsets the veins of the Dayrock mine, probably a large distance. The Hercules-Mercury fault system offsets the Hercules vein at least several hundred feet. The Polaris fault may offset veins in the Coeur d'Alene mines, but the evidence is not clear. The Frisco fault and related Gem fault truncate veins, but the Gem fault also has ore minerals along it; so, they presumably are faults that formed prior to mineralization. The Tiger-Poorman vein ends against the O'Neill Gulch fault, and although ore is slickensided along the fault, Ransome (in Ransome and Calkins, 1908, p. 173) suggested that the fault might have been in existence when the ore was deposited. McKinstry and Svendsen (1942, p. 228) suggested the following very plausible interpretation of the faults in the Burke area:

> ". . . that the faults are contemporaneous with the vein fractures, the faults and veins together forming a complementary system of shears. After the establishment of this fracture pattern stresses were so oriented as to keep the faults closed but to open the east-west fractures especially in the vicinity of the faults and these openings were the preferred places for ore-deposition. According to this view, postmineral movement on the faults was of only small magnitude, though sufficient to develop dragged ore and postmineral gouge.

Despite the data available, it is nevertheless extremely difficult to obtain a clear concept of whether a particular vein was offset by, or was dammed by a truncating fault. Old mine maps and even modern maps seldom show the relations clearly enough to permit a positive interpretation, and indeed it is difficult to establish criteria by which a distinction can be made, and which can guide the gathering of evidence. Where displacement occurred both before and after vein formation many criteria fail, and only a full examination and understanding of the relations can provide a satisfactory answer.

A fault occurring after vein formation is most clearly demonstrable where two segments of a vein, each of similar mineralogy, width, and attitude, are disalined on opposite sides of a fault, and where no subsidiary fractures parallel to the fault contain unsheared vein minerals. In many places in the Coeur d'Alene district, apparent offset segments of veins are on opposite sides of faults, but the segments have dissimilar mineralogy or are narrower or of different density of mineralization across a zone; such segments very likely represent independent loci of mineralization on opposite sides of a fault that formed before vein emplacement. At such places slickensiding or shearing of vein minerals near the fault may represent slight adjustment after vein emplacement but are not evidence that most of the displacement succeeded the emplacement of the vein. In many places where a vein has ended at a fault that might have appreciable displacement after vein formation, the pattern of exploration has not been conclusive in demonstrating that there is or is not a continuation of the vein beyond the fault.

The age of a fault against which a vein ends can be demonstrated in some places by the distribution of vein minerals along the fault or along fractures paralled to or branching from the fault. Careful distinction must be made between horses of vein and actual mineralization of the fracture. A pattern of mineralization suggestive of ponding of solutions near the fault, where veins expand in size, or "blossom" at a truncating fault, provides evidence that the fault formed before the veins had been emplaced.

In the Coeur d'Alene district most of the veins that end against faults show evidence of at least some displacement that occurred after vein emplacement and in many places are actually segmented even though there may have been a small amount of ore deposition in some of the truncating faults. Where faults truncate veins, the offset is generally small. Probably, only the major strike-slip faults and possibly the Dobson Pass fault show evidence of a large amount of movement that occurred after ore emplacement.

As discussed in the subsection on the "Osburn fault," the authors believe that the two major metal-producing areas were once adjacent but have since been moved apart about 16 miles by strike slip along the Osburn fault and that the Placer Creek fault has similarly offset the Yreka belt of mineralization. Movement along the Dobson Pass fault may have moved the veins of the Dayrock mine as much as 3½ miles westward.

Numerous examples of veins cutting monzonitic rock have been observed in the Coeur d'Alene district. From structural relations alone, there would appear to be little question that veins of the main period succeeded the emplacement of the monzonitic intrusives. Lead isotope studies have suggested a Precambrian age for the galena in the veins, but this anomalous condition must have some explanation other than that the galena was formed in the veins in Precambrian time.

At most of the places where the crosscutting relations between veins and monzonitic rock have been seen, sulfide veins usually transect apophyses or dikes of monzonitic rock or extend as stringers for short distances into these rocks, but Umpleby and Jones (1923, p. 25) noted that sulfide veinlets also extended for short distances into the main monzonite mass at the Success mine. Mine workings where these crosscutting relations have been found include those at the Gem, Tamarack-Custer, and Hercules mines on the east side of the Gem stocks and the Success, American (prospect), Rex, and Interstate-Callahan mines on the west side.

It is of structural significance that most of the known mineral deposits lie within relatively narrow linear belts 1,000–3,000 feet wide and from a mile or so to 15 miles long and that they all trend about 65° NW. Seven such belts are outlined by mines and prospects, five north of the Osburn fault and two south of it. The belts extend across folds and the monzonitic intrusives with no apparent interruption of their linearity, and similarly they cross some of the north-trending faults north of the Osburn fault. Mines in which the larger deposits are in anomalous positions include: (a) the Dayrock mine, whose deposits have been offset by movement occurring after ore emplacement along the Dobson Pass fault, and (b) the Hilarity, Douglas, and Constitution mines, whose deposits appear to have been offset by strike slip along the Placer Creek fault from their continuation as a part of the Yreka mineral belt in the Pine Creek area. The last three mines, however, are alined along a more northerly trend, which would have to be explained by an additional rotational movement for which there is no evidence. At least the probable large strike-slip movement occurring after ore emplacement along the Osburn fault has not changed the similarity in trends of the belts north and south of the fault. The restriction of a great majority of the mineral deposits, and particularly the larger ones, to these belts implies that most of the ore-bearing solutions were channeled through a series of throughgoing deep-seated fracture systems that cut across many earlier structural features as well as the intrusives.

In summary, the veins of the major period of ore formation were probably localized along a system of throughgoing fractures that were opened after the intrusion of the monzonite stocks. Much of the structural complexity was present prior to the formation of the principal ore deposits; however, the major amount of strike-slip movement took place after ore emplacement. During the period of strike-slip displacement there were minor adjustments along most faults other than those of the strike-slip system and also along many veins. These adjustments may have continued beyond the period of strike-slip movement.

INTERRELATION OF STRUCTURAL FEATURES

Many problems arise in attempting to interpret the structural evolution of the district. The observable relations may not everywhere seem to fit a simple plausible mechanical interpretation. Although clearly there have been multiple and continuing periods of deformation, it is difficult to explain each anomaly by local stresses while ignoring a degree of structural unity of the region as a whole that must have existed at any one time. The following discussions suggest some interpretations that explain certain relations.

Figure 34, *A* and *B*, illustrates how the fold trends may have been dragged by rotational stresses acting in a tectonic block more or less delimited by the Hope and St. Joe faults. Figure 34*A* shows a hypothetical block before deformation and figure 34*B* shows the same block after deformation. Although the movement arrows suggest stresses at the edges of the blocks, it should be kept in mind that the stresses were probably distributed across the entire block from below the crustal plate. The stresses, furthermore, rather than being concentrated at the edges as might be expected if they were applied to the edges of the block, must have culminated near the bisectrix of the block where the Osburn fault formed. If the movement was as suggested in the diagram, there would be shortening of the block in a north-south direction, and this may be in part the reason why the folds were warped as they were rather than being dragged west on the north side of the Osburn fault and east on the south side of the Osburn fault.

The diagrams in figure 35 are sketched after a model made of modeling clay, or Plasticine. Al-

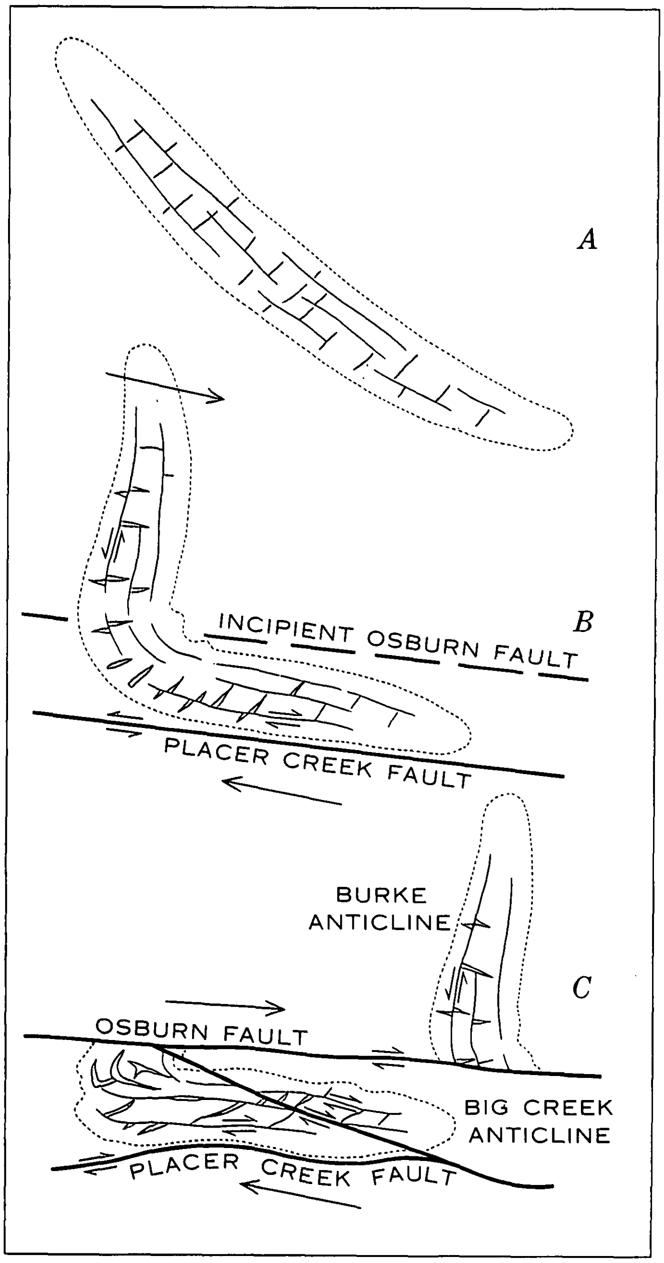


FIGURE 35.—How fractures originally related to folding or other causes may have behaved when folds were warped and then offset by strike-slip deformation. Diagram is based on Plasticine clay model. See text for discussion.

though this material does not permit an experiment in which the strength of material is proportionate to that of the rocks found in the field certain behaviors can be demonstrated. In figure 35*A* the zone of folding and fracturing is represented by an elongated roll of clay, and longitudinal and transverse faults related to folding are represented by cuts scribed with a razor. The cuts represent strength discontinuities in the mass of clay, and the effect upon them demonstrates what might happen to early-formed faults as the folded block is warped. It should be emphasized that although the movement arrows are shown as at the edge of a block, in all probability the stresses are distributed across the base of the block.

It can be seen on figure 35*B* that the transverse faults tend to open, while at the same time the longitudinal faults are tight shear planes. The longitudinal faults only open locally where inhomogeneities of deformation cause local tension along the faults. On figure 35*C*, the two halves of the fold, now recognizable as the Burke and Big Creek anticlines, are shown to have separated and the Big Creek anticline is shown to be distorted whereas the Burke anticline is not. Warping of the Big Creek anticline and adjacent areas includes dragging of the west end that opens several of the longitudinal faults, as well as transverse faults, and bows the entire set around so that some open cracks are oriented in a north-south direction. The transverse and longitudinal faults, once nearly at right angles, now join at low angles, and new strike-slip faults are initiated as earlier strike-slip faults such as the Placer Creek fault are warped and fail to accommodate the strain.

If the minerals are assumed to be emplaced only along open faults, their emplacement in the block would have occurred after most of the flexing had ceased but before the Big Creek anticline had been separated very far from the Burke anticline and before the open fractures of the Big Creek anticline had been closed and rotated to orientations representing complementary shears.

Some similarities between the model (fig. 35) and relations in the field are:

1. Both north-trending and west-trending veins along fractures in the Burke anticline block are mineralized, but west-trending veins are much more predominant, as indicated by the model and by field relations.
2. Left-lateral offset of veins is suggested both along the Gem and Fraction faults and along longitudinal faults in the model.
3. In the Big Creek anticline the veins and faults in the Bunker Hill area have orientations comparable to fractures of the model in the dragged, west end of the fold.
4. Both the model and the relations in the field indicate that the veins in the eastern part of the Big Creek anticline, as in the Coeur d'Alene mines area, have a more northerly trend and that the veins in the Polaris and Sunshine mine areas to the west have more easterly trends. The veins of the Coeur d'Alene mining area are also more nearly at right angles to major faults than are the Polaris, Sunshine, and related veins and may

be offset by right-lateral slip along the Polaris fault.

Some dissimilarities between the model and relations in the field are:

1. According to the model, if the fault pattern in the Burke anticline area were distorted during warping of the fold axis, the veins would be rotated, if at all, to a northeasterly trend. Instead, the veins in the field generally trend northwest.
2. According to the model, the mineral-filled fractures of the Big Creek anticline had more shearing along them after mineralization than those of the Burke anticline; however, the opposite generally appears to be true in the field.

Regardless of the differences of fault patterns in different parts of the Coeur d'Alene district, all the zones or belts containing the major ore bodies have almost exactly the same orientation, N. 65° W. This pattern implies that linear feeders oriented N. 65° W. were at some depth below the surface, and although the fractures observable at the surface controlled the positioning of individual ore bodies, they are principally superficial and did not control the overall pattern of distribution of veins.

The orientation of the zones of ore bodies is about 10° or 15° more northerly than the general trend of the Osburn fault; this suggests that although the deep feeders may have originated as strike-slip fractures, they are at enough of an angle to the Osburn fault for a tensional component normal to their surfaces to have formed by rotational stresses parallel to the Osburn fault. Such a tensional stress could have opened these fractures and produced excellent channels for mineralizing solutions.

The difference in trends of structural features in the basement rocks as compared to those at the surface would require a structural discontinuity between the surface rocks and the basement rocks. There is little on which to base an interpretation of the depth or nature of such a discontinuity.

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INDEX

[Italic page numbers indicate major references]

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