AN ABSTRACT OF THE THESIS OF

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The central part of the Bayhorse Mining District is located in the Salmon River Mountains in north-central Idaho between the towns of Challis and Clayton. The area is underlain by metasedimentary rocks of Early to Middle Paleozoic age that were profoundly affected by the emplacement of a plutonic complex in Middle Cretaceous time, both of which were later intruded and covered by volcanic rocks of Early Tertiary age. Both intrusive events were accompanied by significant mineralization. These basement rocks and the associated mineral deposits have been partly exposed by post-Miocene uplift and subsequent glacial and deep stream erosion.

The stratigraphic succession within the Bayhorse area consists of a series of alternating pelitic, carbonate and quartzite units that range from Latest Cambrian to Middle Ordovician in age.

Five sedimentary rock units have been described within the area of study and consist, from oldest to youngest, of the Garden Creek Phyllite, Bayhorse Dolomite, Ramshorn Slate, mixed lithology sequence and Clayton Mine Quartzite.

The lithologic and textural varieties of the Lower Paleozoic rocks, combined with regional considerations, collectively indicate that the Bayhorse area was transitional between marine shelf areas to the west, north and east and deeper miogeosynclinal areas to the south for most of Paleozoic time.

Central Idaho was affected by magmatic activity continually from Late Jurassic to Middle Cretaceous time. Synchronous with the onset of batholithic scale magmatism was folding and thrust faulting of the Paleozoic sedimentary rocks. The magmatic activity culminated in the formation of the Idaho Batholith and related outlying plutons, one of which is locally represented by the Juliette Creek intrusive complex.

Geologic evidence indicates that the Juliette Creek intrusive complex represents the upper parts of a much larger and somewhat deeper plutonic mass that was forcefully emplaced into the surrounding sedimentary rocks at depths ranging from 4 to 5 miles along anticlinal axes that paralleled the north-south structural grain of the region. In approximate order of emplacement the exposed part of the intrusive complex consists of quartz diorite, granodiorite grading to granite, and quartz-feldspar porphyry. The effects of thermal metamorphism were variably imposed upon the adjacent sedimentary rocks and the resulting changes in the lithologic characteristics of the country rocks aided in the modification of the pre-existing local structure by the forceful emplacement of the intrusive complex.

Hydrothermal alteration and sulfide metallization are predominantly structurally controlled and spatially, temporally and probably genetically related to the Juliette Creek intrusive complex. Fluorite mineralization is related to the later igneous activity of Early Tertiary age. The emplacement of the intrusive complex was of major importance in preparing the ground for the two later episodes of mineralization by significantly altering the pre-existing local structure and lithologic characteristics of the sedimentary rocks. The predominant structural feature of the district consists of two parallel elongate folds that formed in the Paleozoic sedimentary rocks by eastwardly directed compressional movement. Subsequent emplacement of the Juliette Creek intrusive complex has locally modified the pre-existing structure and caused the sedimentary rocks to break along predictable zones of weakness. The sulfide metallization is related to the upper parts of a large hydrothermal system that may be associated with stock-work molybdenum or porphyry-copper type mineralization at depth.

After this major period of magmatic, tectonic and hydrothermal activity the rocks of the district were again affected by a later, but similar sequence of events that culminated in the eruption of the rhyodacitic, andesitic and basaltic flows and pyroclastic deposits of the Challis Volcanics and the deposition of significant fluorspar in Early Tertiary time.

# Igneous Petrology, Structural Geology, and Mineralization of the Central Part of the Bayhorse Mining District Custer County, Idaho

by

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# IGNEOUS PETROLOGY, STRUCTURAL GEOLOGY AND MINERALIZATION OF THE CENTRAL PART OF THE BAYHORSE MINING DISTRICT, CUSTER COUNTY, IDAHO

## I. INTRODUCTION

This report is concerned with the central part of the Bayhorse Mining District which is located in the Salmon River Mountains in east-central Idaho between the towns of Challis and Clayton. Early Paleozoic sedimentary rocks of the region have been profoundly affected by two intrusive events, one in Mesozoic time and another in Early Tertiary time each of which was accompanied by mineralization. From 1877 to about 1925 the major mining activity in the area was confined to high-grade lead-silver lodes located in Paleozoic argillaceous and carbonate host rocks. Since that time there has been only periodic exploration and development within the area by several companies concerned primarily with locating additional lead-silver deposits. However, in 1947 the economic potential of the district was increased with the recognition of significant fluorspar mineralization confined largely to carbonate host rocks. Most recently, the possibility of stockwork molybdenum and porphyry copper metallization have been considered.

### Previous Geologic Investigation

Among the earliest contributors to the geologic information of the district was R. N. Bell, Chief Mine Inspector of the State of Idaho. During the period from 1900 to 1920 he published numerous short reports of mineral, mine and smelter production for the Bayhorse

Mining District in annual volumes of Mineral Resources of the United States. Additional articles by Bell (1900, 1901) provide descriptions of early mines in the Bayhorse district.

Umpleby (1913) published the earliest reconnaissance report dealing with the Bayhorse Mining District. He recorded considerable data for the base metal deposits of the region and the historical information provided for the individual mines is especially valuable. The district was again described in a more comprehensive reconnaissance report by Ross (1937) and assistants. This report included updated information concerning local stratigraphy and structure with additional data on the mineralization of the district. The largest mine in the district, the Ramshorn Mine, was the subject of a brief report by Michell (1939). It contains much detailed structural information on many presently inaccessible underground workings of the Ramshorn Mine. Anderson (1954) conducted a preliminary investigation of the fluorspar mineralization in areas north of the study area.

Three theses previously conducted in the district contain information pertinent to this study. Wahl (1925) presented a brief report on the Ramshorn Mine and Lokken (1925) conducted a metallurgical investigation of the ore from this property. Most recently, Chambers (1966) examined the geology and mineral deposits of the Bayhorse Mining District with particular attention given to the fluorspar deposits of Keystone Mountain, which are located approximately one mile north of Ramshorn Mountain.

To the writer's knowledge the most recent work in the district is presently being conducted by S. W. Hobbs and assistants of the U. S. Geological Survey. They are engaged in reinterpreting the geology of the 15 minute Clayton Quadrangle which includes most of the Bayhorse Mining District. The preliminary geologic map of the quadrangle is presently available as open file report 75-76 of the U. S. Geological Survey.

## Purpose and Methods of Investigation

Although the Bayhorse Mining District has been examined by several investigators, as previously noted, most of these studies were of a general character and conducted from 60 to 70 years ago. The primary objective of this study was to relate the various mineral deposits and alteration zones to one or more geologic features of the district and then to relate such geologic features to the search for additional mineralization. This was accomplished, in part, through detailed field studies of the intrusive, sedimentary and volcanic lithologies, and the products of contact metamorphism, wall rock alteration and vein fillings, and of features related to the complex structural development of the area.

Several methods were used in achieving these goals. Fifteen weeks were spent in field studies during the summer of 1975. Most of the area was mapped at a scale of 1:6000, but an area of approximately 2 square miles, centered around Nevada Mountain, was mapped at a scale of 1:2400. These data were subsequently combined to yield a two part geologic map (Pl. 1 and 2, back pocket) of the central part of the Bayhorse Mining District at a scale of 1:6000. The map shows the distribution of the major sedimentary rock types and structural features of the area, together with the compositional and structural characteristics of the Juliette Creek intrusive complex. In addition, the effects of contact metamorphism imposed upon the adjacent country rocks and the types and distribution of hydrothermal alteration are also shown. Information concerning the location of minor access routes and old mine workings is also supplied.

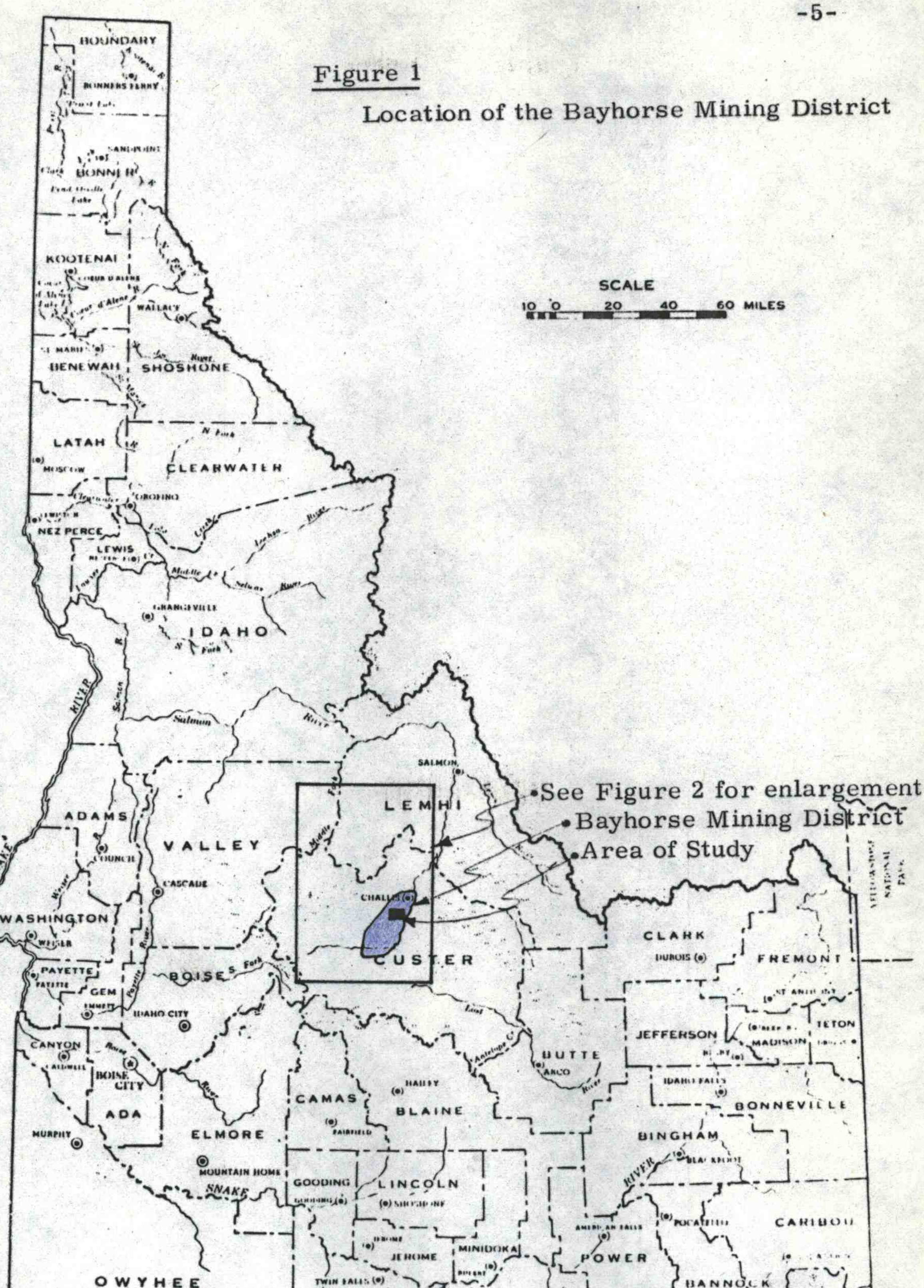
The standard procedures of geologic field mapping were supplemented by examination of numerous drill core and newly developed mines and reopened workings to obtain samples and to provide additional control for the construction of geologic cross-sections. Supporting data were obtained by studies of 130 thin sections, 22 major oxide chemical analyses and the X-ray identification of several minerals.

## Location and Accessibility

The Bayhorse Mining District is located near the center of the Salmon River drainage basin in east-central Idaho. The location of the study area within this mining district in shown in Figures 1 and 2. The area of study is 3.5 miles wide, 6.75 miles long and totals nearly 24 square miles in areal extent. It is located in central Custer County approximately 10 miles south-southeast of the town of Challis, which

Figure 1

Location of the Bayhorse Mining District



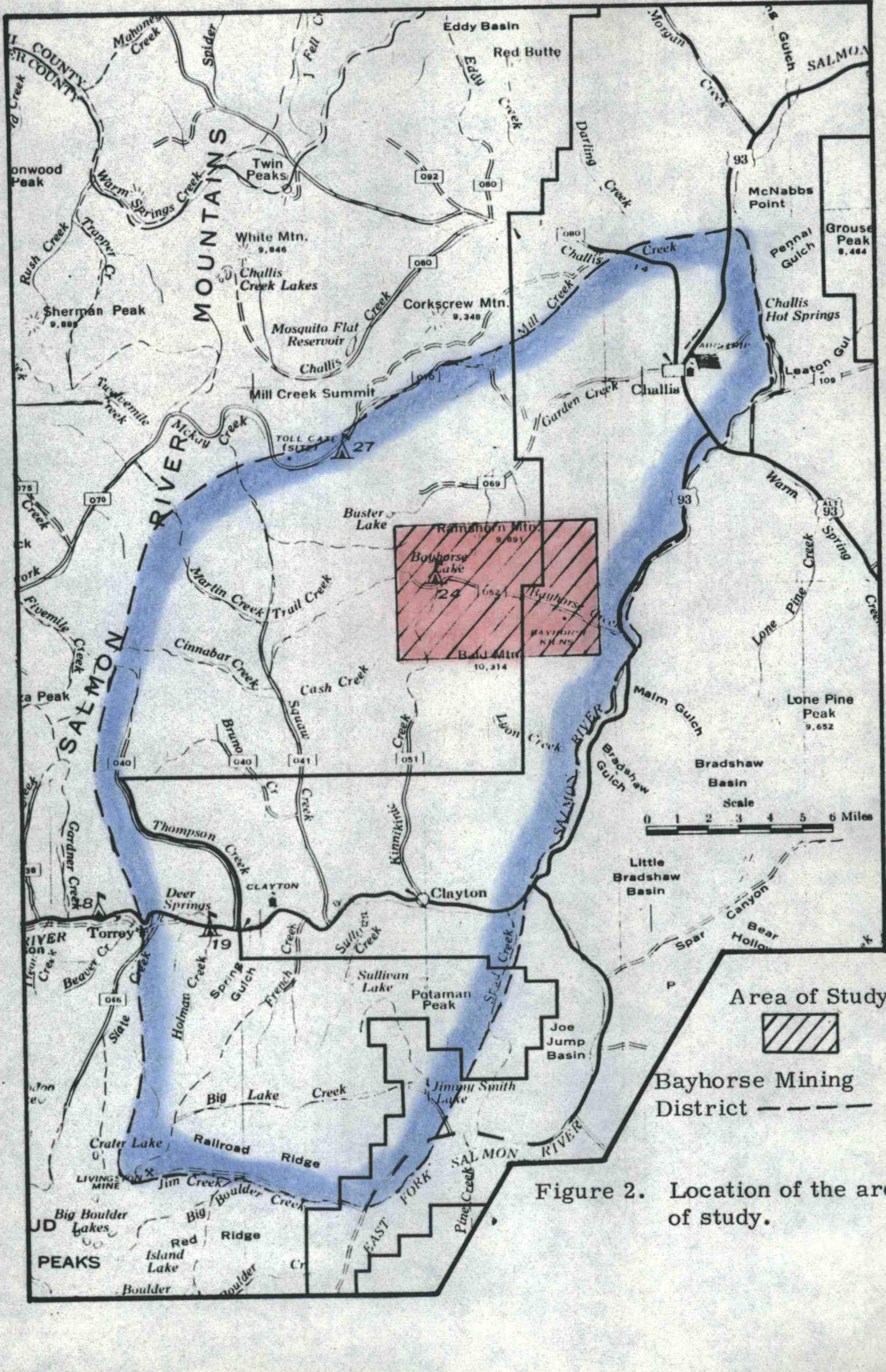



Figure 2. Location of the area of study.

is the county seat. The area is centrally located on the U. S. Geological Survey 15 minute Clayton Quadrangle (1963). The area of detailed mapping includes parts of T. 12 N., R. 18 and 19 E. and T. 13 N., R. 18 and 19 E., Boise Meridian of the 7.5 minute Bayhorse and Bayhorse Lake Quadrangles (1963). The western half of the study area is within the Challis National Forest.

Access to the central part of the Bayhorse Mining District is best gained by proceeding south from Challis on Alternate U. S. Highway 93 for 1 mile, turning right onto U. S. Highway 93 for 10 miles, and turning right again onto the gravelled Bayhorse Lake Road for 3 miles. The county maintains the road 5 miles farther through the center of the study area to Bayhorse Lake. From this improved gravelled road, a few dirt roads and jeep trails provide access to more remote parts of the area. Remnants of old wagon roads and mule trails from the early mining days of the district can still be found and greatly facilitate access to the more heavily forested parts of the study area. The area is also accessible from the north by jeep trails from the Challis Creek drainage basin. The nearest railhead is at Mackay, 55 miles southeast of Challis.

## Topography and Drainage

The Bayhorse Mining District is located along the eastern front of the Salmon River Mountain Range. The eastern part of the study area lies within the foothills of this range and the surface dips gently away from the mountain front towards the Salmon River.

The Salmon River Mountains are the result of deep stream erosion of a Middle Tertiary peneplain (Ross, 1937, p. 89). The pre-Tertiary erosion surface was nearly as precipitous as the present-day topography because in numerous places the base of the Tertiary volcanic sequence is located on steep slopes and in valley bottoms. An approach to a late-stage mature topography after eruption of the Tertiary volcanic sequence was interrupted by epeirogenic uplift. The result of subsequent rejuvenation was to superimpose the stream channels already occupying valleys in the incompletely leveled Middle Tertiary surface onto the underlying Paleozoic Rocks. Detailed geologic mapping indicates that zones of weakness in the underlying Paleozoic rocks influenced the stream pattern to only a minor degree.

This complex of deeply dissected uplands consists of flat-lying summit areas which are found at elevations ranging from 8500 feet to 9500 feet. Buffalo Ridge, within the far western part of the study area, is thought to be a remnant of this erosion surface. These summit areas are surmounted only by a few peaks rising several hundred feet higher. Such peaks as Ramshorn, Keystone and Bald Mountain presumably were monadnocks on this old erosion surface. The highest altitude within the study area is Ramshorn Mountain (9895 feet) and is nearly 3000 feet above the adjacent valley floors.

The effects of Wisconsin Glaciation (Ross, 1937, p. 96) are evident in stream valleys that head above 7600 feet. Well-developed cirques occupy the heads of Kelly Gulch, Bull of the Woods Gulch, Bayhorse Creek, Cold Spring Gulch and the east fork of Juliette Creek. A well-developed glacier step is a prominent geomorphic feature of the southernmost cirque at the head of Kelly Gulch. At these higher elevations streams flow through glaciated, U-shaped valleys. In contrast, the stream courses at lower elevations cut through steep V-shaped canyons. Morainal material and other glacial debris is not abundantly evident as these unconsolidated deposits have been greatly modified by subsequent stream action to closely resemble valley alluvium. The steep canyon walls also exhibit the more recent effects of extensive frost action, landslides, rockslides and snowslides.

From Buffalo Ridge the drainage pattern is primarily eastward toward the Salmon River. Bayhorse Creek, a tributary of the Salmon River, cuts transversely to the dominant north-south structural grain of the area. Short subsequent streams join the creek from both the north and the south to form a modified trellis drainage pattern. Extensive mass movement associated with the underlying volcanic rocks in the vicinity of Juliette Basin and the Bayhorse Lakes has produced a poorly drained and hummocky surface. For a more exhaustive discussion of the topography and geomorphology of the Bayhorse region the reader is directed to Ross (1937, p. 87-89).

## Climate and Vegetation

The general increase in elevation of nearly 3000 feet from east to west across the study area greatly influences the local snow cover and the amount and type of vegetation. The normal daily temperature seldom reaches above 32°C during the summer months or lower than -18°C during the winter months. Total precipitation varies only slightly from 2 inches per month throughout the year. The higher elevations often receive snow in excess of 150 inches per year. This cover is usually not completely melted until the end of June. Outdoor work during the 1975 field season was hampered by wetter-than-normal conditions caused by lingering snow cover and frequent mid-afternoon thunderstorms. The flow of water out of the Bayhorse Creek Drainage basin is largely dependent upon the melting snow cover, so toward the end of the summer the flow of water from this basin is often markedly diminished.

Bedrock in the central one-third of the study area is reasonably well exposed with only north facing slopes being heavily forested. However, in the eastern one-third of the area, where altitudes are generally less than 6800 feet, the bedrock is largely obscured by a cover of sage brush, various grasses and occasional cacti. Vegetation of the western one-third, from 7600 feet to 9200 feet in elevation is characteristic of the alpine areas of the region. The rocks of this area are largely obscured by scattered alpine meadows and heavily timbered stands of fir, spruce and pine. Those areas above 9200 feet in elevation are generally lacking in all but the hardiest types of vegetation.

# II. REGIONAL GEOLOGIC SETTING

The Bayhorse Mining District is located within the Northern Rocky Mountain physiographic province of east-central Idaho. Geologically, this region is underlain by metasedimentary basement rocks of Precambrian to Late Paleozoic age, granitic intrusions of Mesozoic to Tertiary age, and is covered in part be a veneer of Early Tertiary volcanics. Major inferred and observed structural trends cross the area and can be related to the depositional and intrusive events.

## Regional Lithologic Variations

For convenient reference, a generalized geologic map for central Idaho is included as Figure 3.

The Precambrian basement ($pC_1$ and $pC_3$) in this region is covered by a thick, varied and well-described sequence of Paleozoic sedimentary rocks (D-C and P-M). These rocks were profoundly affected by the emplacement of the Idaho Batholith and associated plutons (Mzi) during Mesozoic time. In Early Tertiary time the rocks of the region were again affected by the eruption of the flow and pyroclastic deposits of the Challis Volcanics ($Tv_1$). The Mesozoic and Paleozoic rocks have been exposed in several areas by subsequent erosion of the volcanic cover - the central part of the Bayhorse Mining District is one of these areas.

Within the area of study large parts of the stratigraphic record are missing. Paleozoic sedimentary rocks younger than Latest

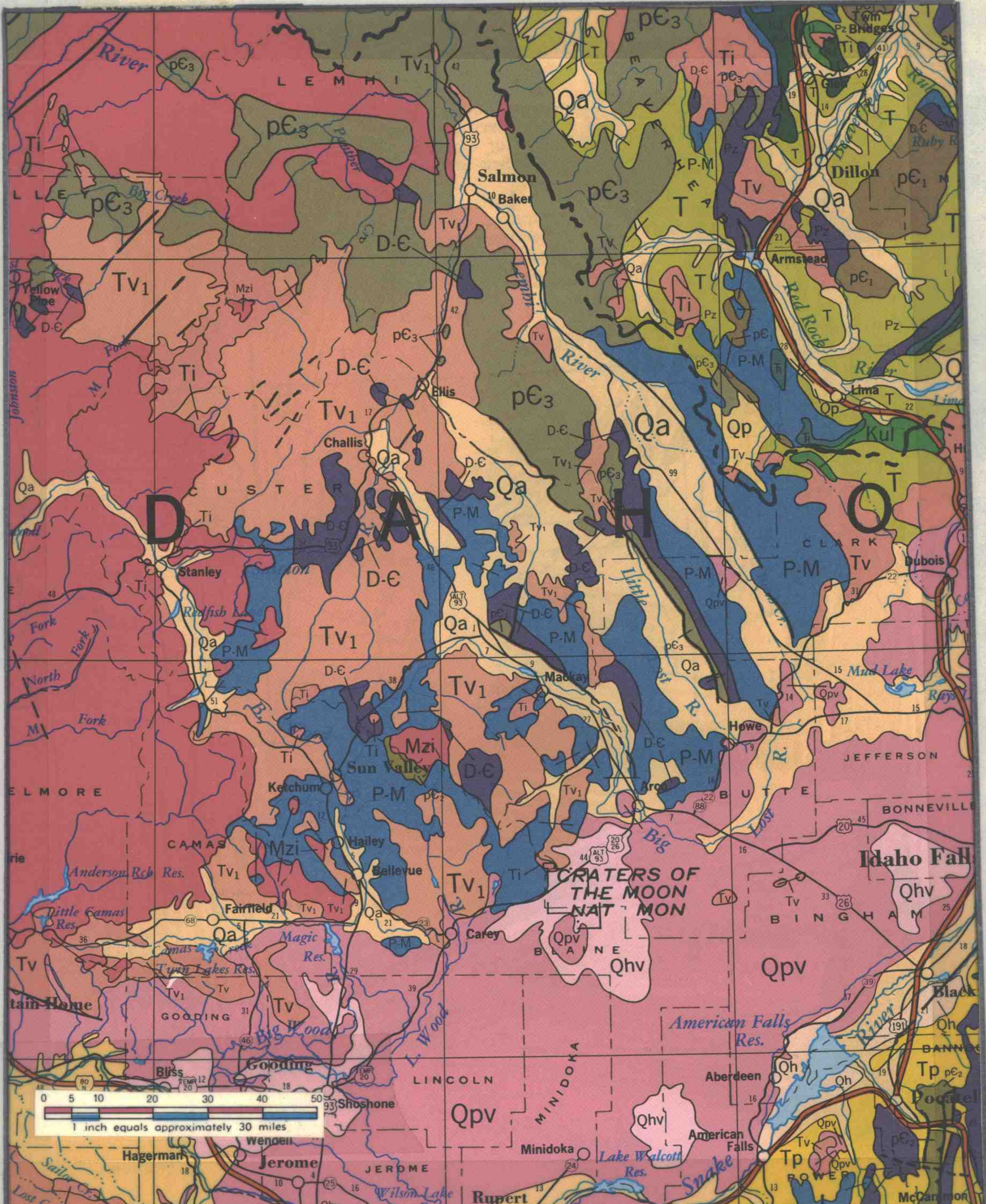



Figure 3. Generalized geologic map of east-central Idaho, Bayhorse District S.W. of Challis (from; Geological Highway Map of the Northern Rocky Mountain Region, Am. Assoc. Petroleum Geologists, 1972, Mp No. 5).

Cambrian in age and older than Middle Ordovician in age are absent. The entire Mesozoic sedimentary section is also missing. However, plutonic units of Middle Cretaceous age are present and have variably metamorphosed and deformed the Lower Paleozoic sedimentary rocks. Rocks of Tertiary age are represented by extrusive and intrusive volcanic lithologies of middle Eocene age. Surficial deposits of Quaternary age are of minor importance and consist of scattered patches of alluvium, landslide debris and glacial material.

The Beltian Series of Precambrian age is exposed along the northeastern part of the region and consists principally of quartzites, argillites and calcareous rocks. The Precambrian strata are unconformably overlain by Paleozoic rocks that are composed predominantly of carbonates, shales and quartzites. Several paleogeographic maps indicate that the Paleozoic rocks of central Idaho were formed as part of a major geosyncline (Sloss, 1950; 1955; Kay, 1951; Eardley, 1951; Churkin, 1962). However, Ross (1967) presents good evidence that the Cordilleran geosyncline was never widespread in the area of the Idaho Batholith and that the Paleozoic rocks were formed in a large marine embayment in which subsidence was insufficient to permit the accumulation of thick sedimentary deposits that are normally considered to be of geosynclinal character (Fig. 4, p. 16).

The Idaho Batholith, more aptly considered a massif of complex origin, is the dominant plutonic feature of central Idaho. Much generalized, the batholith can be characterized as a composite intrusion of Mesozoic age consisting of large and fairly uniform masses of granite and granodiorite that are surrounded by a somewhat older dioritic border zone (Ross, 1963a; 1963b). The chronology of emplacement of the Idaho Batholith is not well established because of its long and complex history and because of the effects of a widespread igneous-hydrothermal-tectonic event in Early Tertiary time (Armstrong, 1976; McDowell and Kulp, 1969). However, rocks of the border zone may be as old as Late Jurassic (156 m.y.) in age and the main mass of the plutonic complex is thought to have been emplaced by Middle Cretaceous time (125 m.y.) (McDowell and Kulp, 1969).

The eastern border of the Idaho Batholith is approximately 30 miles west of the Bayhorse townsite. Two plutons, thought to be related to the Idaho Batholith, are exposed within the Bayhorse Mining District. The Pat Hughes Creek intrusion is a small, isolated quartz monzonite stock that is located outside of the area of study near the northern end of Thompson Creek (Fig. 2, p. 6). The pluton has localized an important stockwork of quartz-molybdenite-pyrite veins. Biotite from the stock has yielded a K-Ar age date of 88.4 ± 3 m.y. (Marvin and others, 1973) The Juliette Creek stock, located within the area of study, is a composite intrusion and varies in composition from granite to quartz diorite. It is believed to be related to lead-silver metallization in the surrounding country rocks. A K-Ar age determination on biotite from this stock gave a date of 95.9 ± 3.3 m.y. (Hobbs, 1976 written comm.).

Rocks of the Challis Volcanics sequence intrude and cover many of the pre-Tertiary basement rocks. The greater part of the formation consists of latite and andesite flows with intercalated volcaniclastic beds and subordinate flows of rhyolite and basalt erupted from numerous small vents and fissures. Leonard (1976, verbal comm.) has tentatively recognized several large volcano-tectonic depressions that may have contributed substantially to the modification of the pre-Tertiary rocks. Flows from the lower part of the Challis Volcanics within the central part of the Bayhorse Mining district have given K-Ar dates of slightly less than 50 m.y. (middle-Eocene).

Regional Tectonic Setting

The differences in thickness and character between Paleozoic strata in the region indicate that a major marine embayment existed in east-central Idaho (Fig. 4) throughout the Paleozoic era (Ross, 1967). A hinge-line near the boundary between Idaho and Montana, with a shelf to the east and a trough to the west, controlled the deposition of the Paleozoic sediments. This trough wedged out to the north a little beyond Lat. 45° and seas rarely, if ever, spread across the site of the Idaho Batholith. Shores lay close to the present borders of the Idaho Batholith and extended eastward into Montana and Wyoming for most of Paleozoic time.

Structural complexities of central Idaho are much like those of the Basin and Range Province to the south. The Paleozoic strata

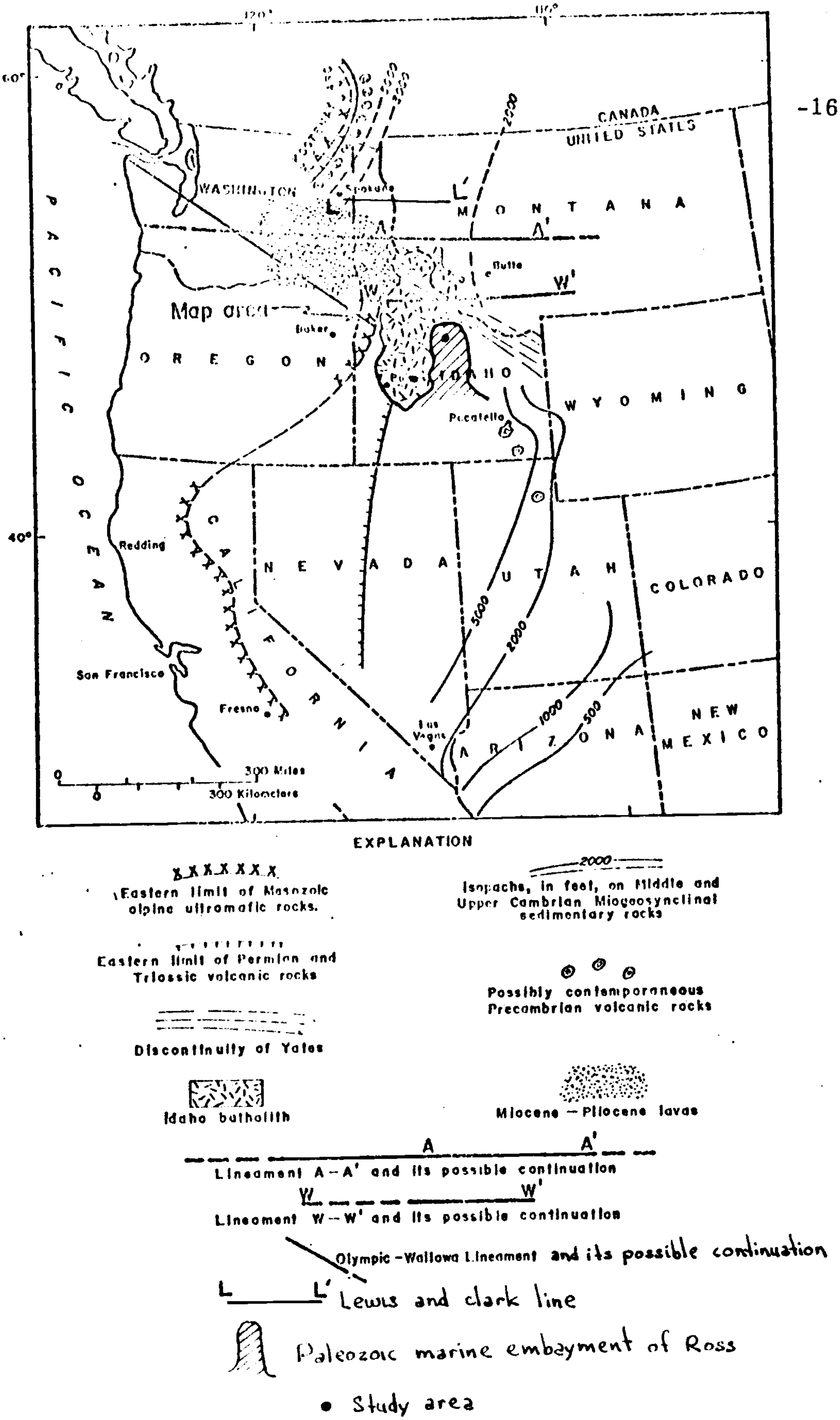



Figure 4. Regional tectonic setting (modified after Zietz, et al, 1971, fig. 5)

are highly folded and cut by numerous high-angle faults. Axes of folds developed in the Paleozoic rocks generally parallel the eastern border of the Idaho Batholith and are overturned toward the east. Gently folded Tertiary volcanics unconformably overlie these highly deformed Paleozoic strata and date the major structural deformation as post-Pennsylvanian and pre-middle Eocene. The entire region was broken by Late Tertiary and Pleistocene high-angle faults that produced the basin and range structure of the Lost River, Lemhi and Beaverhead Ranges.

Several prominent lineaments, possibly representing major basement structural trends, have been described in the Northern Rocky Mountain region(Fig. 4) and are indicative of the complex structural character of central Idaho. The Lewis and Clark Line, first described by Billingsley and Locke (1933) is a major zone of right-lateral strike-slip faults. The Olympic-Wallowa lineament was defined by Raisz (1945) and is based largely on geomorphic evidence. McKee (1967) suggests that it represents a zone of strikeslip faults that has undergone right-lateral displacement in post-Miocene time. Yates (1968) introduced the concept of a trans-Idaho discontinuity based upon left-lateral displacements of petrologic and stratigraphic elements of a continental scale. Zietz and others (1971) present magnetic data for the Pacific Northwest and Northern Rocky Mountain region that are consistent with the proposed presence of these lineaments and suggest two additional trends - A-A' and W-W'. Most of the ore deposits in central Idaho and western Montana lie along northwest and northeast-trending zones (Billingsley and Locke, 1941; Jerome and Cook, 1967). The data of Zietz and others indicates that several magnetic lineaments coincide with these zones. The Bayhorse Mining District lies along one of these lineaments.

The structural grain within the area of study reflects the influence of at least two intrusive events which were of great importance in preparing the ground for later mineralizing solutions. The emplacement of the Idaho Batholith accentuated an elongate series of pre-existing folds in the sedimentary rock complex that strike north-south and parallel the eastern margin of the batholith. Shortly thereafter, this regional structure was locally modified by the emplacement of the Juliette Creek intrusive complex. The rocks were subsequently cut by several longitudinal normal and reverse faults.

## III. PALEOZOIC SEDIMENTARY ROCKS

The stratigraphic succession within the Bayhorse district consists of a series of alternating pelitic, carbonate and quartzite units. The oldest sedimentary rocks exposed within the area of study are phyllites and dolomites that range from Latest Cambrian to Earliest Ordovician in age. These units are unconformably overlain by a sequence of Lower Ordovician to Middle Ordovician shale and quartzite beds.

The Paleozoic sedimentary rocks of the district have been briefly described by several previous investigators. For the purposes of this study the sedimentary rocks have been mapped as five units. Four of the units have been further subdivided to aid in discerning the detailed structural characteristics of the district. A diagrammatic columnar section depicting typical lithologies, thicknesses and contact relationships of stratigraphic and intrusive units is presented in Figure 5. The remainder of this chapter is a discussion of the Paleozoic sedimentary rock units from oldest to youngest.

Rock identification was accomplished by literature reference and field examination, and supplemented by microscopic, chemical and X-ray studies of select samples. Colors are described in terms of the U. S. Geological Survey Standard Rock Color Chart. Particle sizes are related to the Wentworth (1922) grade scale. Bedding thicknesses correspond to the scale of stratification thickness proposed

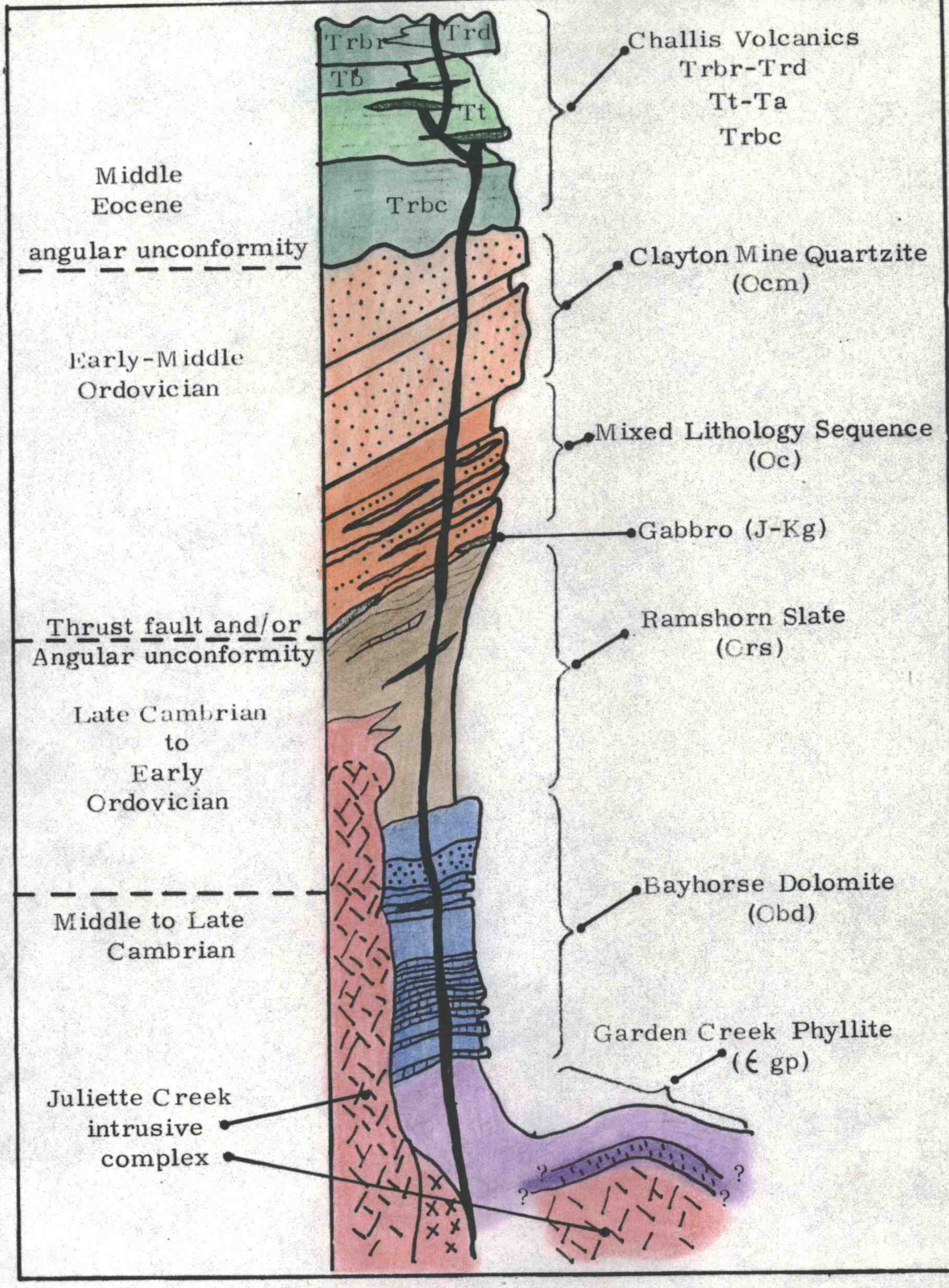



Figure 5. Diagrammatic geologic column of the Bayhorse area

by Ingram (1954) which, for convenience, has been included in the appendix (p. 304).

## Garden Creek Phyllite

The Garden Creek Phyllite is the oldest formation exposed in the area and forms the core of the Bayhorse Anticline, the major north-trending structure in the district. The formation has been exposed in two separate areas by streams cutting transversely to this major structure. It was originally described and named by Ross (1934, p. 941) from its exposure outside of the study area along the upper valley of Garden Creek, two miles north of Ramshorn Mountain. The phyllite also crops out, within the study area, on either side of Bayhorse Creek just west of the Bayhorse townsite, but it has not been identified in any other part of the region.

Field Description. The formation has been informally subdivided into two units; an upper phyllite and a lower dolomite unit. The lower dolomite unit was not described by Ross and is known only from exposures in the bottom of Bayhorse Creek and from several drill cores.

Downward erosion of Bayhorse Creek has exposed the upper 40 feet of the lower dolomite unit. The dolomite crops out as a narrow strip for a distance of 2000 feet along the stream channel and forms resistant steep-faced cliffs and ledges. The unit is a medium-gray (N 5) to grayish-pink (5 R 8/2) dolomite that is uniformly finely-crystalline. Weathering accentuates small fractures and joints and produces a rough pitted surface and a mottled coloration from grayish-orange (10 YR 7/4) to a dark yellowish-brown (10 YR 4/2). From the few places where the upper contact is exposed it appears sharp and conformable with the overlying phyllite unit. Bedding is commonly indistinct and very thick in the observable outcrops. However, the bedding becomes more distinct in the lowest, surface exposures and in drill core it tends to be more thinly bedded. At least 60 additional feet of dolomite exist below the creek as determined from drill core (Chambers, 1966, Pl. 9 and 10). The minimum total thickness of the dolomite unit would then be about 100 feet. As determined from drill core, the base of the unit is in contact with a quartz-feldspar porphyry intrusive phase that is thought to be related to the Juliette Creek intrusive complex. This lower contact is generally quite sharp, often silicified and in places slightly brecciated. Effects of contact metamorphism are strangely absent (p. 154 ). Although subsequent faulting of this contact has accentuated the original irregular character of the igneous-sedimentary rock contact, the contact generally parallels the upper surface of the dolomite unit. From an examination of the available drill core it is inferred that the outcrop area of the lower dolomite unit marks the structural high of the underlying intrusive phase (Figs. 6 and 7).

The lower dolomite of Bayhorse Creek is conformably overlain by the medium-dark-gray (N 4) to medium-gray (N 5) phyllite unit. Very-thinly-bedded, dark-gray (N 3) calcareous beds increase in abundance in the upper 50 to 75 feet of the phyllite unit until the

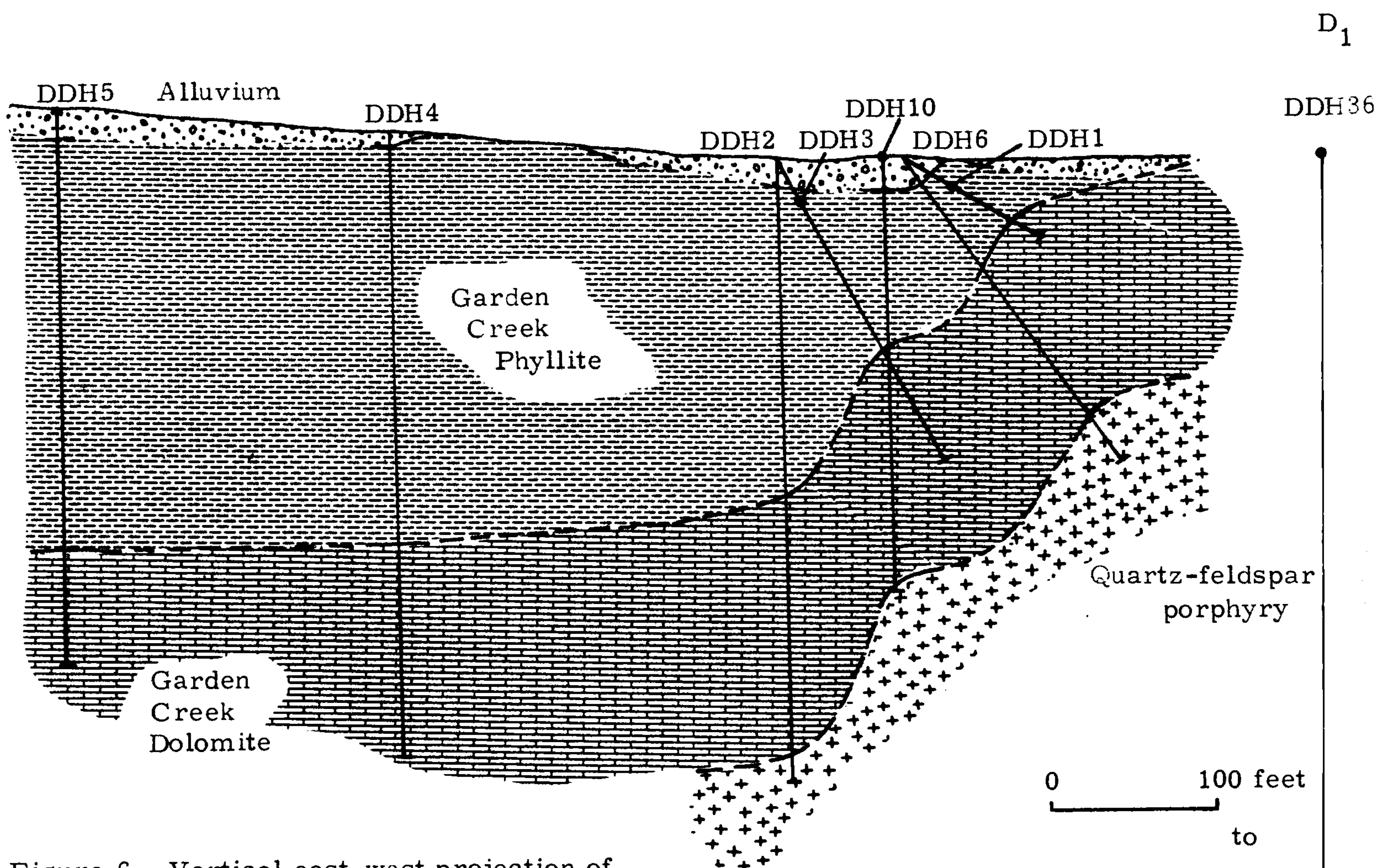



Figure 6. Vertical east-west projection of drill holes north of Bayhorse Creek near the western end of the exposure of Garden Creek Dolomite

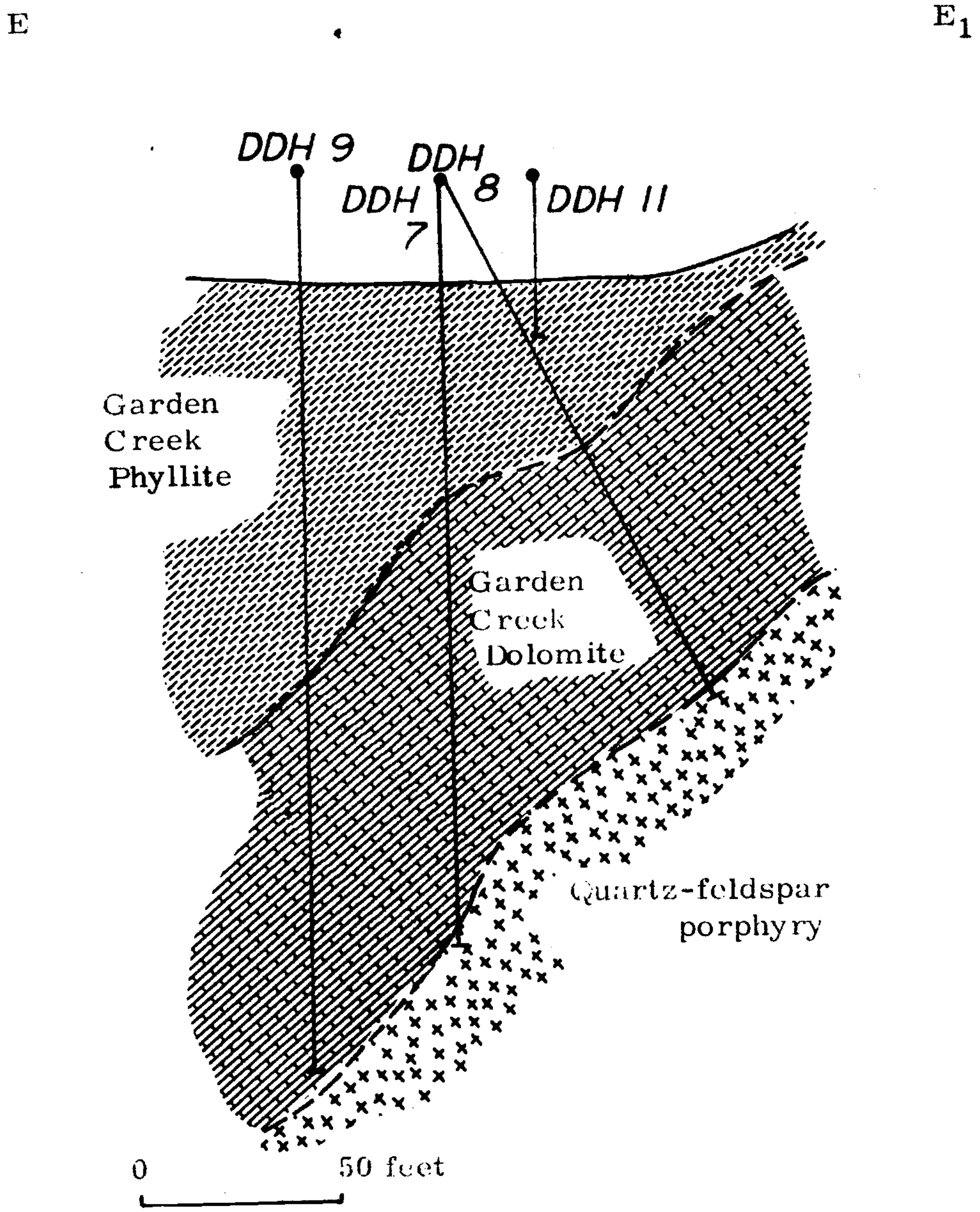



Figure 7. Vertical east-west projection of diamond drill holes on the south side of Bayhorse Creek near the western end of the exposure of Garden Creek Dolomite.

formation grades conformably into the overlying Bayhorse Dolomite. Concurrently, the argillaceous beds of the unit change gradually upward from a phyllite to a slate. Weathering causes the accentuation of abundant silvery muscovite on cleavage surfaces and a lightening of color to a medium-light-gray (N 6). The destruction of iron-bearing minerals causes the appearance of brownish-gray (5 YR 4/1) streaks and bands. The thin-bedded argillaceous beds are cut by close-spaced cleavage planes and are highly susceptible to water and frost action. Outcrops are generally poor as the phyllite weathers readily to small flakes and slivers that form smooth gentle slopes. The distribution of the phyllite is greatly accentuated in aerial photographs on south facing slopes by the preferential growth of grass and sage brush in contrast to the more characteristic forest cover of the adjacent carbonate rocks.

Bedding is commonly indistinct and care must be taken to distinguish it from slaty cleavage in those areas that have undergone more extreme deformation. Most of the argillaceous beds are less than 12 mm thick and are usually discernible on the basis of alternating medium-gray (N 5) and brownish-gray (5 YR 4/1) color bands. Bedding plane structures were not observed as parting in the phyllite is generally parallel to the prominent cleavage and not to bedding planes.

The phyllite exposed in the road cut just south of the Bayhorse townsite is highly folded and crenulated (Pl. 7 ). Veins and pods of bull-quartz up to 6 inches wide occupy the axial plane areas of

Plate 7

Garden Creek Phyllite exposed in the road
cut just south of the Bayhorse townsite

the larger folds. This deformation is apparently largely fault related as it decreases in intensity westward, away from the major north-trending Mill Fault. The intensely crumpled and distorted bedding within the mines also appears to be related to fault zones. Elsewhere, the bedding is commonly deformed near the contact with the overlying more competent Bayhorse Dolomite and small drag folds are present. Scattered outcrops in the center of the slope just north of Bayhorse Creek, however, have not undergone the deformation characteristic of the contact and fault related zones. Locally, the phyllite may display the effects of incipient thermal metamorphism.

Crumpling of indistinct bedding planes, poor exposures and the effects of numerous faults make contact relationships and thicknesses difficult to determine, but nearly 1000 feet of phyllite are necessary to meet the geometrical restrictions of the outcrop area. Added to the minimum thickness of the lower dolomite unit, the Garden Creek Phyllite has a thickness of at least 1100 feet. Significant fluorite and lead-silver mineralization are localized in the phyllite and dolomite units where major shear zones have increased the permeability of the rock.

Lithologic and Petrographic Description. Thin section examination reveals the lower dolomite of Bayhorse Creek to be very finely crystalline (less than $30\mu$) and to consist of interlocking anhedral crystals of dolomite and calcite. It is composed of approximately 55 percent micrite, 25 percent microspar, 15 percent pseudospar and 5 percent detrital quartz grains. The angular quartz grains correspond to very fine sand in size and are often partially replaced by dolomite. Bedding is marked by slight variations in the proportions and grain sizes of these constituents. Sparry calcite is present in scattered clots and fills hairline veinlets, and is believed to be a product of contact metamorphic recrystallization. Styolites are common and have consistently formed perpendicular to bedding. Although traces of brownish organic matter were observed, mainly associated with styolitic boundaries, no other organic remains were found.

The phyllite member contains subequal proportions of detrital quartz and white mica grains together with graphitic and iron-oxide compounds. Relict bedding, approximately one centimeter thick, is defined by alternating stringers and bands of grayish (N 4 to N 5) graphite-rich and brownish-gray (5 YR 4/1) iron-rich layers. The iron-rich layers are commonly slightly coarser grained. Quartz grains are silt sized, lensoidal in shape and oriented parallel to the foliation exhibited by the finely crystalline flakes of mica and graphite. This foliation forms a well-developed slaty cleavage that generally parallels the axial plane of the major folds. Porphyroblastic clots from 0.5 to 2 mm in diameter occur toward the base of the phyllite member where slaty cleavage intersects iron-rich laminations and a 'spotted' phyllite is formed. The porphyroblasts may be a product of either thermal metamorphic recrystallization related to the emplacement of the Juliette Creek intrusive complex or they may have formed in response to later hydrothermal activity (p. 152).

Regional Correlation and Age. The lower dolomite and the upper argillaceous units of the Garden Creek Phyllite are non-fossiliferous formations of marine origin that are known only from local exposures. The unit clearly forms the base of the local stratigraphic section and it is apparently more argillaceous than most of the rocks assigned to the Belt Series in adjacent areas (Ross, 1937, p. 12). It is overlain by the Bayhorse Dolomite which in turn is separated by an unconformity from what is thought to be overlying Early Ordovician strata. On the basis of these stratigraphic relations Ross (1937, pp. 12-24) tentatively assigned a Middle to Late Cambrian age to the Garden Creek Phyllite.

Bayhorse Dolomite

The Bayhorse Dolomite was originally described and named by Ross (1934, p. 941) from exposures in the cliffs just north of the Bayhorse townsite. The dolomite is exposed at intervals along the crest of the Bayhorse Anticline. The best exposures are located outside of the study area along Daugherty and Garden Creeks, 4 and 6 miles north of the Bayhorse townsite, and along Bayhorse Creek within the study area. It crops out in smaller areas 3 to 6 miles south of the Bayhorse townsite and has not been recognized outside of this region, as was the case for the Garden Creek Phyllite just described.

Field Description. Erosion of the easily weathered Garden Creek Phyllite undercuts the more resistant Bayhorse Dolomite to form prominent cliffs along the north side of Bayhorse Creek (Pls. 8 and 9). As the slope on the south side of the creek has been somewhat stabilized by the forest cover, the dolomite is much less exposed and weathers to isolated ledges and knobs. The greater part of the formation consists of thickly-bedded, grayish-black (N 2) to light-gray (N 7) dolomite that is locally intercalated with thin beds of moderate-brown (5 YR 4/4) shale. The dolomite beds grade downward into more thinly-bedded, grayish-black (N 2) calcareous layers. Oncolitic and indistinct stromatolitic algal remains and scattered chert lenses are common toward the middle of the section.

The Bayhorse Dolomite conformably overlies the Garden Creek Phyllite. This lower contact is gradational over 50 to 75 feet. The upper surface of the Bayhorse Dolomite was extensively eroded prior to deposition of the overlying argillaceous beds. Consequently, the dolomite has been entirely removed on the western limb of the Bayhorse Anticline one-half mile north of Garden Creek. On the same limb of the anticline, near the junction of Juliette and Bayhorse Creeks within the area of study, the upper units of the dolomite may also have been removed by erosion. Hence, the upper surface of the dolomite is quite irregular, with more erosion on the western limb of the anticline than elsewhere. On a smaller scale, the surface is everywhere very rough and vuggy and could possibly

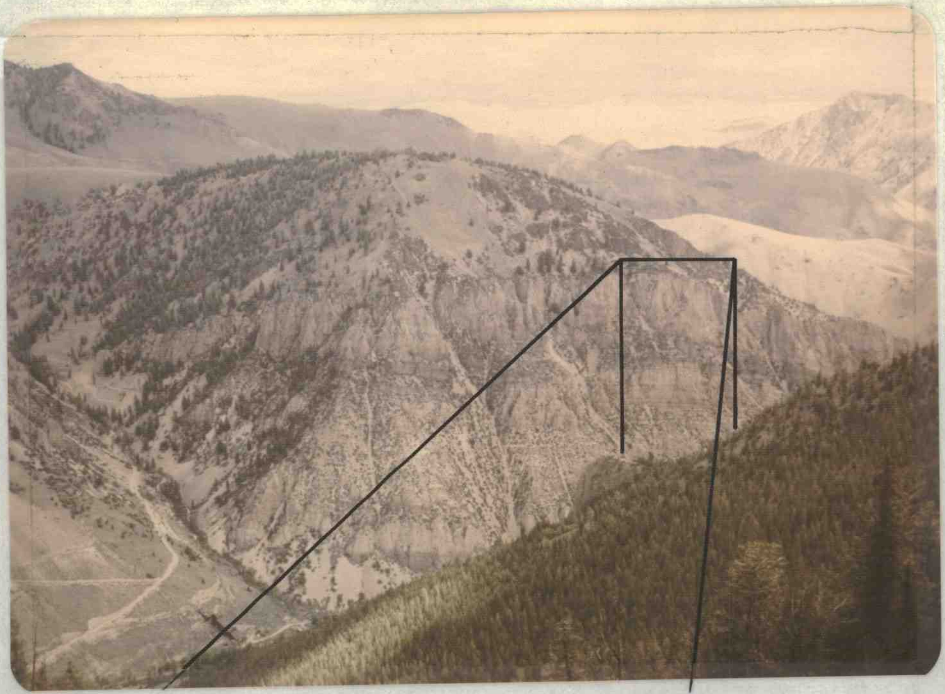


Plate 8. Cliff-face of Bayhorse Dolomite northeast of the Bayhorse townsite. Heavily forested north-facing slope in foreground.

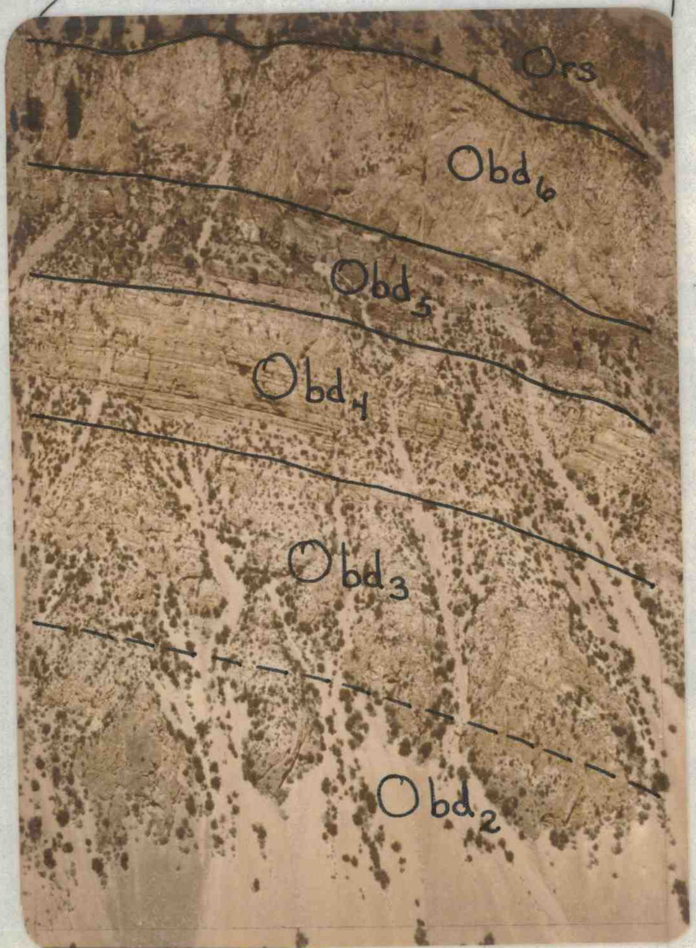



Plate 9. Close up view of the same cliff face.

represent a paleokarst topography (p. 284 ). The Ramshorn Slate overlying the dolomite is commonly silicified and highly bleached for distances of up to 20 feet from the contact as a result of later hydrothermal alteration.

The thickness of the Bayhorse Dolomite within the area of study ranges from 700 feet to 1000 feet depending upon the amount of erosion. From an examination of cross-section B-$B_1$ (Pl. 4, back pocket), the apparent thickness of the Bayhorse Dolomite on the south side of Bayhorse Creek is nearly twice that exposed on the north side. This difference in stratigraphic thickness is attributed to repetition of the section by faulting, coupled with minor deformational thinning of the Bayhorse Dolomite north of the creek (p. 202 ).

The Bayhorse Dolomite exhibits numerous features of structural significance. In addition, where open spaces have been created by deformation and solution, the Bayhorse Dolomite serves to localize significant fluorite and lead-silver mineralization.

Lithologic and Petrographic Description. The Bayhorse Dolomite consists of interlocking anhedral crystals of dolomite and calcite in varying proportions and crystal sizes. The carbonate may contain up to 10 percent detrital, silt-sized grains of quartz and scattered flakes of muscovite.

Umpleby (1913, p. 69) presented the following partial chemical analyses of two samples of dolomite from the wall rock of the Pacific Mine, which is located near the top of the dolomite.

| | Sample 1 | Sample 2 |
|---|---|---|
| $SiO_2$ | 7.00 % | 5.10 % |
| CaO | 35.00 | 30.60 |
| MgO | 14.63 | 20.18 |
| Ca/Mg | 2.4 | 1.5 |

On the basis of effervescence, however, the Ca/Mg ratio of the carbonate beds vary considerably, both horizontally and vertically over short distances, and indicates that dolomitization was probably a post-depositional process. In general, the Ca/Mg ratio of the carbonates increases with stratigraphic depth. In addition, the size of the dolomite crystals varies from place to place. Single light-colored dolomite crystals up to 2 mm in diameter are not uncommon and may be surrounded by more finely-crystalline calcite and dolomite. These large dolomite crystals weather to produce a rough, finely-studded surface. Milky-white quartz veinlets are common in the upper part of the Bayhorse Dolomite and, on the basis of hardness, the upper part of the formation has undergone silicification but this effect generally decreases stratigraphically down-section. Very coarsely crystalline calcite veins and veinlets are abundant throughout the dolomite section east of the Mill Fault, and several were mined in the past for smelter flux.

Faults cannot be easily traced through the overlying incompetent Ramshorn Slate or the even less competent underlying Garden Creek Phyllite. Although Chambers (1966,pp. 23 and 26, and Pl. 2) presents a measured section of the Bayhorse Dolomite exposed to the north of the study area, very few of the individual beds described can be used as persistently continuous and traceable marker beds. In an effort to define more precisely the structural elements of the district, the Bayhorse Dolomite was informally subdivided into 6 mappable units on the basis of certain broad lithologic characteristics (Pls. 8 and 9, p. 31). A descriptive geologic section of this formation and its six constituent units is presented in Figure 8. The following discussion is a description, from oldest to youngest of these six units.

The Garden Creek Phyllite is conformably overlain by the first unit of the Bayhorse Dolomite. The lower contact is ideally placed at the first appearance of carbonate layers. The first unit is approximately 250 feet in thickness and consists of thickly-laminated to very-thinly-bedded limy shale, shale, and shaley limestone. The layers vary in color from dark-gray (N 3) to black (N 1) and they are often separated by a thin styolitic layer of pinkish-gray (5 YR 8/1) calcite. The unit is a moderately resistant cliff former and the lower contact commonly marks the break in slope between the Garden Creek Phyllite and the overlying Bayhorse Dolomite.

The basal contact of the second unit is marked by the disappearance of shaley layers and a change in lithology to medium-bedded dolomitic limestones. The unit is approximately 170 feet thick and is resistant to weathering, thus it characteristically forms prominent cliffs. The second unit varies in color from light-gray (N 7) to

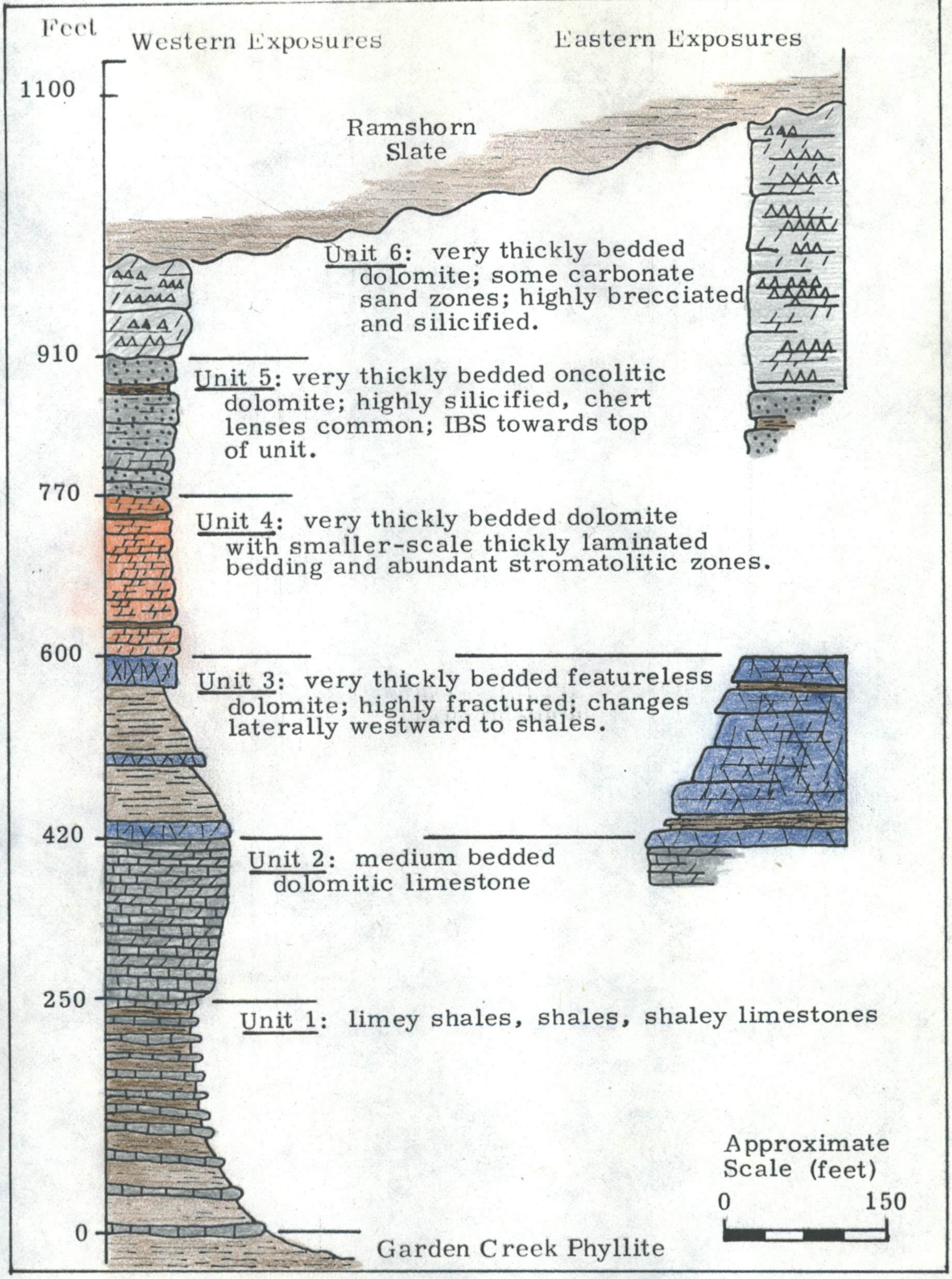



Figure 8 - Diagrammatic geologic section of the six members of the Bayhorse Dolomite.

medium-gray (N 5) and weathers to a light brown (5 YR 6/4). Although the unit is medium bedded on a large scale, the beds are often thickly-laminated on a smaller scale and several layers display vague stromatolitic structures.

The lower contact of the third unit is gradational over 10 to 20 feet and is often marked by a change in slope. The unit consists of roughly 180 feet of very-thickly-bedded featureless dolomite and calcareous dolomite. The small-scale laminations and prominent stromatolitic zones of the second unit are generally lacking in the third member. Layers of shale are intercalated towards the top and bottom of the unit in the eastern exposures and coalesce laterally to form a 150 foot thick shale sequence in western exposures. The carbonate of this unit is predominantly medium-light-gray (N 6) in color and changes little upon weathering. The unit is characteristically highly jointed in eastern exposures and weathers easily to form prominent slopes. Gentle slopes are also characteristic of this unit in western exposures as the dominant shale lithology is similarly susceptible to erosion. Calcite veins up to several feet across are very common in the eastern exposures of this unit, but it contains only minor occurrences of lead-silver mineralization.

The basal contact of the fourth unit is marked by the gradual disappearance of the predominant shale layers characteristic of the third unit and a change to the thickly-laminated bedding and abundant stromatolitic zones similar to those of the second unit.

The unit is 170 feet thick and is a moderate cliff former. It is dominantly light-gray (N 7) in color with scattered dark-gray (N 3) layers and weathers to a distinctive dark-yellowish-orange (10 YR 6/6). Shale layers are more abundant towards the top and bottom of the unit than in the middle part of the section. Minor lead-silver mineralization is localized in the fourth unit.

The lower contact of the fifth unit is gradational over 10 to 20 feet. The unit is approximately 140 feet thick and consists of medium-dark-gray (N 4) to black (N 1) dolomite interbedded with occasional very-pale-orange (10 YR 8/2) to dark-yellowish-brown (10 YR 4/2) shale layers. A prominent 6 foot thick shale bed near the top of the unit has been designated the interbedded shale (or IBS), which serves as a convenient stratigraphic marker when logging drill core. The fifth member is very-thickly-bedded. Characteristically, it contains numerous masses of oval silica that are interpreted to be recrystallized algal material. The nearly spherical masses range in size from 2 mm to 2 cm in diameter (average 4 mm). Because the oval masses correspond to the pisolite size range the fifth unit is locally referred to as the pisolite. As their original shape was nearly spherical they record the final stages of internal structural deformation of the unit over a wide area. The unit is locally silicified and chert lenses are common. Significant lead-silver mineralization is localized where the unit was brecciated.

The lower contact of the sixth unit is marked by the disappearance of pisolite-rich beds, which may lie upon or up to 6 feet above the interbedded shale. The sixth unit consists of very-thickly-bedded medium-light-gray (N 6) to medium-dark-gray (N 4) dolomite. The dolomite of this unit is the most coarsely crystalline and Mg-rich of the formation. The more coarsely crystalline aggregates have been purged of impurities and commonly alternate with more finely crystalline aggregates rich in impurities. Macroscopically, the texture is evidenced by alternating light and dark bands, which is locally known as "zebra" rock. Lenses and layers of dolomitized carbonate sand occur towards the top of the unit. Locally, the unit is highly brecciated and silicified. Suboriented dark dolomite clasts typify the lower part of the unit and they may be either bedding plane breccia clasts or possibly unreplaced remnants. The unit is unconformably overlain by the Ramshorn Slate, and therefore, varies in thickness from 0 to 275 feet from west to east across the map area. As the sixth unit is commonly sandy, highly brecciated, and located directly beneath the impermeable Ramshorn Slate, it is the host for most of the economically significant mineralization within the Bayhorse Dolomite.

Regional Correlation and Age. The Bayhorse Dolomite is a marine sequence of interbedded carbonate and shale units known only from local exposures. The silicified oval masses from the fifth member have been examined by Rezak (personal comm. cited in Ross, 1967, p. 773) and Johnson (personal comm. cited in Chambers, 1966, p. 27). Both men suggest that these masses resemble the calcareous algae Girvanella of supposed Middle Cambrian age, but dolomitization and silicification have obliterated any diagnostic internal structures in the material collected. However, even should these identifications be correct, Rezak (1957) would question the presence of Girvanella as proof of a Cambrian age. Hobbs (oral comm., 1975) suggests that the formation is of Earliest Ordovician age on the basis of fragmentary micro fossils from the dissolution of several hundred pounds of dolomite. As the Bayhorse Dolomite is unconformably overlain by strata believed to be of Early Ordovician age, and is totally unlike any known member of the Belt Series (Ross, 1937, p. 14), the formation is probably Earliest Ordovician and/or Latest Cambrian in age.

## Ramshorn Slate

The Ramshorn Slate was first described and named by Ross (1934, p. 945) from exposures along the upper valley of Bayhorse Creek near the Ramshorn Mine, for which the formation was named (Pl. 11). The Ramshorn Slate forms the large Ramshorn Anticlinorium and part of the Bayhorse Anticline to the west. The Ramshorn Slate is the thickest formation exposed within the study area, and its outcrop distribution completely encircles the dolomitic and phyllitic core of the Bayhorse Anticline. Regionally, it is exposed as a narrow north-south strip, 2 to 5 miles wide and 20 miles long, centered just west of the Bayhorse townsite.


Plate 10. View looking north of the Ramshorn Mine located on the southern flank of Ramshorn Mountain.

Plate 11. Ramshorn Slate showing characteristic step folding and prominent axial plane slaty cleavage.

<u>Field Description.</u> Except for the basal conglomerate, exposed north of the study area, the Ramshorn Slate is composed exclusively of a thickly-laminated argillaceous rock with a few intercalated sandy and calcareous beds. It lies unconformably upon the eroded surface of the Bayhorse Dolomite with only slight angular discordance. The slate is dominantly light-olive-gray (5 Y 5/2) and grayish-red (5 R 4/6) in color. Locally the color is lightened by calcareous material and white mica flakes, or darkened by carbonaceous matter. Additionally, hydrothermal oxidation of iron-bearing compounds (associated with fracture zones) has locally imparted a distinct moderate-red (5 R 4/6) coloration to the slate. Throughout the formation bedding is commonly indistinct and greatly distorted and folded. It is usually discernible only as faint bands of slightly differing color or texture. Well-developed slaty cleavage is the most prominent feature of the rock and, in contrast to the bedding, bears a rather consitent relationship to the large-scale folding of this formation that in turn provides much information on the structural development of the area. The slate weathers readily to plates and slabs that form steep slopes of highly mobile talus, with isolated ledges and knobs standing in relief (Pl. 11).

Finely-crystalline, medium-dark-gray (N 4) limestone crops out as poorly-exposed, isolated ledged 10 to 15 feet thick along the ridge southeast of Nevada Mountain. Bedding within the limestone and slate in this area is indistinct and the contact relations with the enclosing Ramshorn Slate are obscured by talus. The limestone is highly sheared and fractured and in places is associated with shale and limestone breccia which has localized minor lead-silver metallization. The outcrop area is on strike with a steeply-dipping fault zone mapped just north of the exposure.

The exposure of limestone is probably related to a fault because (1) it is quite unlike any of the carbonate beds from the underlying Bayhorse Dolomite and (2) the vertical displacement along the proposed fault zone would have to be considerable to bring any part of the dolomite to this structural position. Ross (1937, p. 15) has reported that limestone lenses are conspicuous near the top of the Ramshorn Formation, along Kinnikinic Creek 12 miles southwest of the Bayhorse townsite. These relationships indicate that the limestone is probably similar in character to the isolated pods described by Ross farther south.

Sandy beds are common throughout the section but predominate toward the bottom and top of the formation. Bedding plane structures and fossils are rare as the rock parts parallel to the prominent slaty cleavage rather than parallel to bedding. However, ripple marks, load casts and flutes were noted from one locality on the cliffs northeast of the Bayhorse townsite where sandy layers separated easily from finer-grained layers. Michell (1937, p. 3) and Chambers (1966, pp. 35-36) describe a gradual change in lithology of the slate from a fine-grained, thin-bedded argillaceous facies to a coarser, sandier and thicker-bedded one in the vicinity of the Ramshorn Mine. However, this writer believes that the lithologic change is partly, if not totally, caused by a difference in metamorphic grade related to the thermal aureole surrounding the Nevada Mountain and Skylark stocks (p. 141 ).

The absence of easily recognizable horizon markers within the formation makes it difficult to eliminate the effects of faulting and intense folding to estimate the true stratigraphic thickness of the Ramshorn Slate.

Umpleby (1913) estimated that the slate along Bayhorse Creek has a thickness in excess of 4000 feet. Ross (1937, p. 16) believed that this was too great and that the slate probably was closer to 2000 feet in thickness. Since that time, several holes have been drilled in an attempt to reach the Bayhorse Dolomite - Ramshorn Slate contact in the vicinity of the Ramshorn Mine. Only two diamond drill holes succeeded in reaching this contact. They were collared at approximately 7500 feet elevation and intersected the contact at approximately 1800 feet below the surface. These results nearly double the known thickness of Ramshorn Slate in this area but do not take into account any repetition of the section caused by faulting or folding. However, an examination of the drill core shows that after the orientation of the hole is taken into account, bedding varies only slightly from a 55° dip which suggests that any variation caused by folding is probably slight. In addition, taking into account the small displacements evidenced by faults within the slate in this area the effects of faulting are also probably quite small. The computed stratigraphic thickness of the section below the surface as determined from drill core and an examination of geologic section $C_4$-$C_5$ (Pl. 5, back pocket), then, is near 1000 feet. Thus, by adding the drill hole data to the exposed thickness of 200 feet, the total thickness of this formation approximates 3000 feet. However, as the upper contact may be a thrust fault the estimate of 3000 feet is probably a minimum thickness for the formation.

Along the ridge just east of Beardsley Gulch, only one-half as much Ramshorn Slate is exposed between the Bayhorse Dolomite and the isolated quartzite remnants capping the ridge. This difference in thickness indicates that a major discontinuity exists between the Ramshorn Slate and the overlying quartzite units (p. 193 ).

Lithologic and Petrographic Description. The Ramshorn Slate consists of subequal proportions of detrital quartz grains, rarely larger than fine sand in size, enclosed by finer aggregates of light and dark micaceous minerals, clays and organic matter. The micaceous minerals have developed a strong preferred orientation parallel to the plane of slaty cleavage. In the sandy beds where quartz grains predominate over the platey minerals, the slaty cleavage is less well developed. The quartz grains are angular and often display strain lamallae. Low-grade thermal metamorphism adjacent to the Juliette Creek stock has significantly altered the character of the slate.

Regional Correlation and Age. The overlying Paleozoic rocks and Tertiary volcanic rocks obscure the exact relationship of the slate to other Paleozoic formations of adjacent regions. Fossils have not been discovered in the greater part of the Ramshorn Slate as bedding planes are not easily inspected. Kirk (personal comm. cited in Ross, 1937, p. 17) has recovered several species of graptolites, from an area 17 miles south of the Bayhorse townsite. These graptolites were found in rock thought to be correlative with the Ramshorn Slate and have been referred to the lower Deepkill horizon of the Lower Ordovician. However, this correlation is now in doubt (Hobbs and others, 1967, p. J17) The Ramshorn Slate is separated from the fossiliferous Saturday Mountain Formation of undoubted late Middle Ordovician age by a thick sequence of quartzite, dolomite and shale. Although a possible disconformity in the stratigraphic sequence (representing a hiatus of indefinite duration) makes it difficult to assign a definite age, the Ramshorn Slate is presently regarded as of Early Ordovician or possibly Latest Cambrian in age largely on the basis of stratigraphic position.

Clayton Mine Quartzite and Interbedded Siltstone and Quartzite

More than 3500 feet of alternating quartzite, dolomite and shale were mapped in central Idaho by Ross (1937) as a single unit and named the Kinnikinic Quartzite. The formation has since been redefined and subdivided by Hobbs, Hays and Ross (1967) into six formations of widely differing lithologies and ages. The Clayton Mine Quartzite was one of the lower formations defined from the re-examination of the Kinnikinic Quartzite on the basis of exposures in the cliffs and on the ridge west of the Clayton Mine on Kinnikinic Creek 12 miles southwest of the study area. As presently defined, the interbedded siltstone and quartzite, or mixed lithology sequence, lies between the overlying Clayton Mine Quartzite and the underlying Ramshorn Slate. The mixed lithology sequence has yet to be formally described and named. The precise stratigraphic relations of the two sequences to each other and adjacent Paleozoic rocks of the region are complicated by a cover of Tertiary volcanic rocks and by a possible local thinning and removal by thrust faults.

Within the Bayhorse Mining District, the two sequences crop out on the flanks and at intervals along the crests of the Bayhorse and Ramshorn Anticlines. Within the study area, the two formations are best exposed just north and east of the Bayhorse Lakes. Additionally, quartzite float, scattered over many of the ridges and several isolated outcrops in the eastern part of the study area are thought to correlate with these sequences. Althought the Clayton Mine Quartzite is a distinct formation separate from the underlying mixed lithology sequence, they will be described together for purposes of comparison as only the proportions of similar lithologic and structural characteristics vary.

Field Description. Within the study area the two sequences consist of interbedded siltstone, shale and feldspathic quartzite in varying proportions. A diagrammatic columnar section of these formations is presented in Figure 9. To aid in the structural interpretation of the area, two prominent shale layers were mapped as persistent, continuously traceable marker beds.

Both sequences are locally cross-jointed and weather to form large piles of coarse, blocky talus. The quartzite units are comparatively resistant to erosion and form some of the highest and steepest cliff faces in the region. The lower and thicker of two prominent shale layers is mapped as the upper part of the mixed lithology sequence and weathers easily to flakes and plates that form gentle slopes and valleys in marked contrast to the adjacent quartzite units. The quartzite sequences are well delineated on aerial photographs by the marked absence of vegetation.

Within the area of study the mixed lithology sequence has a larger proportion of siltstone and shale layers interbedded with the quartzite units than does the overlying Clayton Mine Quartzite. The lower and the thicker of the two prominent shale layers is mapped as the upper one-third of the mixed lithology sequence. The lower two-thirds of the sequence consists of thin individual beds or groups of beds of quartzite separated by thin to very thick siltstone and shale layers. The quartzite units are very-light-gray (N 8) to light-gray (N 7) in color and consist mostly of sand-sized grains of quartz with

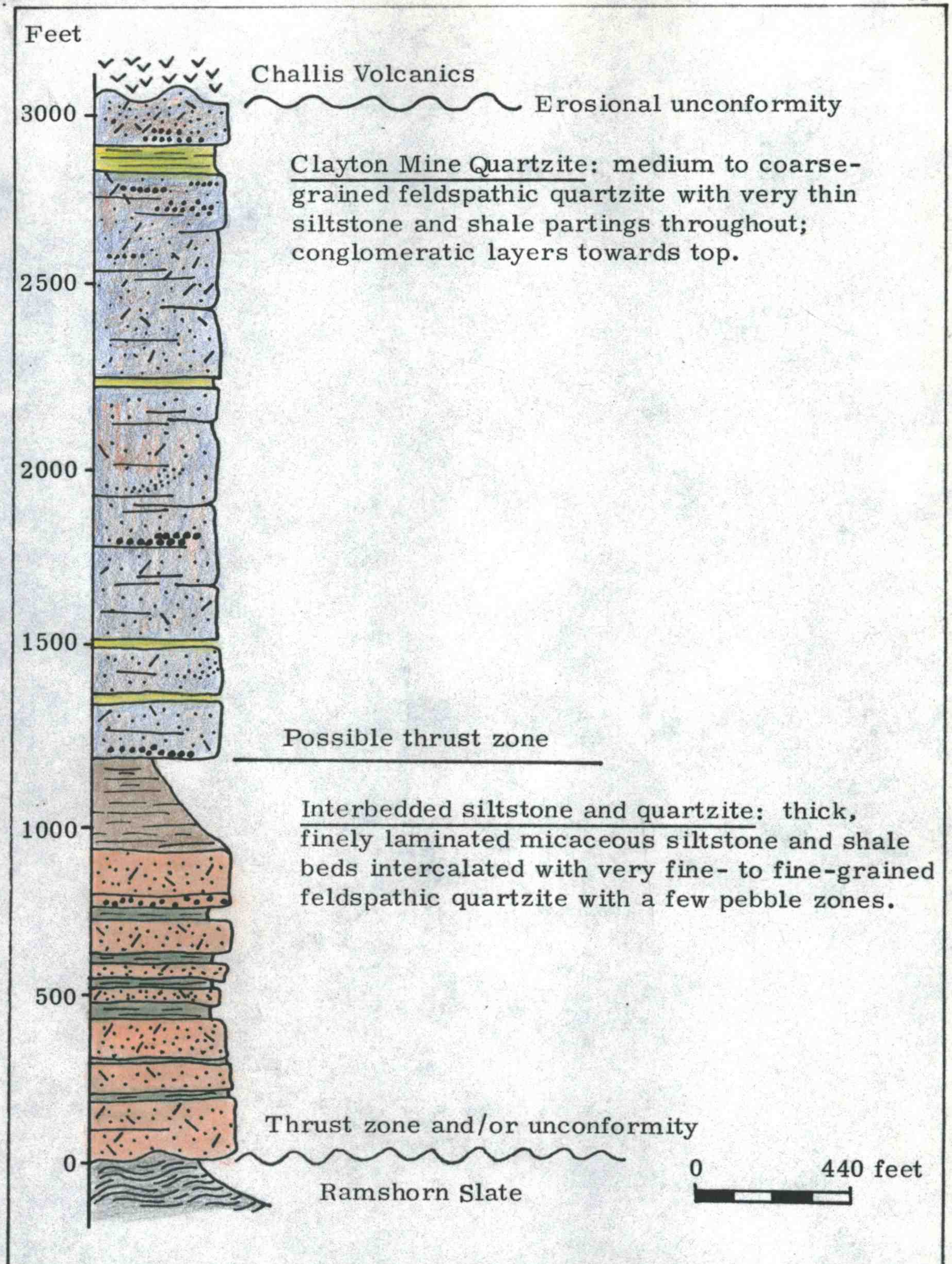



Figure 9 - Diagrammatic columnar section of the quartzite sequences.

minor admixtures of feldspar. The quartzites are generally medium-bedded and display minor cross-stratification that is marked by layering of limonite specks. The oxidation of iron-bearing compounds stains the quartzite dark-yellowish-orange (10 YR 6/6), dark-reddish-brown (10 R 3/4) and very dusky-red (10 R 2/2). The argillaceous units are yellowish-gray (5 Y 8/1) and light-olive-gray (5 Y 6/1) partly sandy, siltstone and shale. The layers are well-bedded, generally fissile and variably micaceous. The dolomite layers described by Hobbs (1975, p. 17) were not observed within the exposed section.

The quartzites of the Clayton Mine Formation are more heterogenous in composition, degree of sorting and bedding characteristics. The quartzite units of this sequence consist predominantly of rounded, sand and gravel-sized quartz grains that are characteristically poorly sorted. Interstitial angular feldspar grains occur throughout the section. Bedding of the quartzite varies widely from very-thickly-bedded to very-thinly-bedded. Individual beds or groups of beds are separated by thin micaceous siltstone and shale partings. Cross-stratification is common and occurs at intervals in thin layers throughout the exposed section. The color of the quartzite units range from medium-light-gray (N 6) to very-light-gray (N 8) and commonly has a yellow to orange cast. Quartz grains, with purple and pink tinges give a mottled appearance to some of the quartzite units. The argillaceous units are similar to those occurring in the underlying mixed lithology sequence. The conglomerate layers, pebbly quartzite and scattered pebbles common in the upper two-thirds of the Clayton Mine Quartzite described by Hobbs (1967) are largely lacking from the quartzite exposed within the study area. Hobbs also describes two layers of dolomite toward the bottom of the type section near Clayton. Carbonate beds, correlative with the dolomitic beds were not found in the exposed section within the study area.

From an examination of geologic section C-$C_4$ (Pl. 5, back pocket) it is apparent that the mixed lithology sequence totals approximately 1250 feet in thickness. The upper shale layer is on the order of 250 feet thick and the lower quartzitic unit is about 1000 feet thick.

The upper contact of the Clayton Mine Quartzite is covered by Tertiary volcanics. The exposed part of the Clayton Mine Quartzite totals nearly 3000 feet in thickness and the prominent shale bed is about 100 feet thick.

The contact with the underlying Ramshorn Slate is thought to be a bedding plane thrust (p. 192). Therefore, it is not unreasonable to believe that similar bedding plane thrust zones may have been localized by the thicker intraformational argillaceous layers within the quartzite sequences. The isolated quartzite and slate outcrops capping ridges in the eastern part of the study area are all highly brecciated and silicified and similar in character to the mixed lithology sequence. However, the limited extent of the exposures makes this correlation questionable and the rocks may be correlative with the Clayton Mine Quartzite. These erosional remnants are interpreted to be representative of a thrust plate that moved over the top of the Ramshorn and Bayhorse Anticlines. Siderite and minor sulfide mineralization are localized along small faults and joints in western exposures of the mixed lithology sequence.

Lithologic and Petrographic Description. The quartzite beds of the mixed lithology sequence are nearly monomineralic and well-sorted. They are composed of 80 percent of sand-sized quartz and chert grains with as much as 20 percent of interstitial feldspar, white mica and opaque iron-oxide grains all cemented by quartz overgrowths. The quartzite members of the Clayton Mine Formation are coarser grained, less sorted and contain more feldspar than the quartzite units of the underlying mixed lithology sequence. Quartz and chert grains are well-rounded and correspond in size to sand and gravel. Quartz grains predominate over those of chert in both sequences. The quartz is usually clear and vitreous, and commonly displays strain lamallae in thin section. Feldspar grains are similar in size to the quartz grains, but are more angular and are commonly replaced by aggregates of quartz and sericite.

The siltstone and shale units consist of subequal proportions of angular quartz grains, rarely larger than fine sand in size, enclosed by finer-grained aggregates of white mica and clays. The platy minerals are variably oriented parallel to bedding and produce a crude bedding plane foliation.

Regional Correlation and Age. Quartzite is widely distributed in the Bayhorse region. The complex structural history of central Idaho, and the cover of Tertiary volcanic rocks, obscure the exact relationship of the Clayton Mine Quartzite and the mixed lithology sequence to Paleozoic rocks of adjacent regions. However, the two formations are thought to intertongue southward with the lower part of the argillaceous Phi Kappa Formation (Churkin, 1962).

The ages of the quartzite sequences are not known with certainty as fossils have not been found in any part of the formations. In addition, their stratigraphic relations are imperfectly known as thrust faulting may have significantly modified their original distribution. The Clayton Mine Quartzite lies below the basal fossil-bearing zone of the Ella Dolomite of undoubted Early Middle Ordovician age, but the contact may be an unconformity representing a hiatus of indefinite duration (Hobbs and others, 1967, p. J1). As the age assignment of the underlying Ramshorn Slate has been questioned it is no longer useful in limiting the age of the overlying quartzite sequences. The quartzite formations are probably of Early Ordovician age although they may be somewhat older.

### Origin and Depositional Environment of the Paleozoic Rocks

Shorelines of the Paleozoic seas were highly irregular and fluctuated widely throughout central Idaho and eastern Montana in response to epeirogenic and eustatic changes in sea level. Variations in stratigraphic thickness and lithology are frequent. In addition, structural and metamorphic complexities related to Mesozoic intrusive activity and the extensive cover of Tertiary volcanic rocks further complicate correlations and obstruct an accurate reconstruction of the paleogeography of the region. Most of the map units are known only from local exposures within the core of the eroded Bayhorse Anticline and they are largely lacking in features diagnostic of a particular environment of deposition.

The positive area over the site of the Idaho Batholith created a north-south seaway centered over the Bayhorse district. The Bayhorse region was probably transitional between shallower shelf areas to the west, north and east and deeper miogeosynclinal areas to the south for most of Paleozoic time (Ross, 1967). Ross (1937, pp. 39-43) investigated the distribution of heavy-minerals in the principal Paleozoic rocks exposed within central Idaho and concluded that the feldspar, zircon, rutile, augite and dark tourmaline in the pre-Mississippian rocks were characteristic of granitic terranes and suggestive of a cratonic source for the sediments.

The sea floor was probably gently undulating and characterized by a series of large swells and swales. Within the depressions, depth below wave base would provide the necessary lack of mechanical energy for the accumulation of silt and clay. Additionally, in response to epeirogenic and/or eustatic changes, periodically restricted circulation and lack of overturn would lead to deoxygenation and a reducing environment. The Garden Creek Phyllite may have been deposited in such a depression. The uniformly fine-grained and thinly-laminated character of the rock is consistent with such an interpretation. The absence of fossilized organic material is not unusual as silt and clay containing sulfur is initially an inhospitable environment for most organisms. Also, any borings, trails or tests that may have existed from the few organisms known from this period might have been subsequently destroyed by low-grade metamorphism. In addition, the prominent slaty cleavage exhibited by the Garden Creek Phyllite does not permit easy inspection of bedding planes for fossils.

The gradual transition from an argillaceous lithology to a carbonate lithology on a local scale without a break in sedimentation is also consistent with an undulating topography on the floor of a shallow, restricted seaway. Epeirogenic and/or eustatic changes resulting in higher energy environments with improved circulation would favor the development of carbonate mud mounds over the deposition of pelitic sediments in a euxinic environment. The stromatolitic and oncolitic zones within the Bayhorse Dolomite are indicative of profuse growth and deposition of calcareous algae in agitated shallow water near the low tide mark. A progressive lowering of relative sea level resulted in the initiation of an erosion cycle upon the carbonate complex of the Bayhorse Dolomite. Considerable relief was developed upon the carbonate unit before rapid resubmergence of the area again placed the district in a position to receive argillaceous sediments corresponding to the Ramshorn Slate.

The Ramshorn Slate is uniformly thickly-laminated and composed dominantly of silt and clay, although thin layers and lenses of sand-sized detrital grains are dispersed throughout the formation. Diagenetic sulfur-bearing minerals are lacking, the oxidation of iron-bearing compounds imparts a distinctive reddish tinge to the slate, and carbonaceous material is much less abundant in comparison to the Garden Creek Phyllite. These features suggest a slightly higher energy, less restricted environment of deposition for the Ramshorn Slate than for the contrasting Garden Creek Phyllite. Fossils would be expected to be more abundant in an environment of this character, but again well-developed slaty cleavage severely restricts examination of bedding planes.

Within the Bayhorse District the base of the overlying quartzite sequences may mark an unconformity and/or a zone of thrust faulting. A contact of similar character has been traced over most of southeastern Idaho and southwestern Montana and marks a pronounced break in sedimentation corresponding to the pre-Middle Ordovician major global unconformity recognized by Sloss and others (1963) and Gussow (1976). The nearly pure quartzite sequences represent relatively rapid, coarse clastic deposition, essentially in pace with subsidence rates, under moderately strong energy conditions from which extensive winnowing removed detrital fines to the south into the more rapidly subsiding axial parts of the trough.

Middle and Upper Paleozoic sedimentary rocks are absent from the study area. However, those ranging in age from Middle

Ordovician through Mississippian are exposed within 20 miles to the east, south and west and have undoubtedly been removed from the area by subsequent erosion of the structural highs within the district. The spatial distribution and similar lithologic character of the Upper Paleozoic rocks of adjacent regions are consistent with the continuation of an environment of deposition similar to that just proposed for the Lower Paleozoic rocks of the Bayhorse area.

## IV. MESOZOIC INTRUSIVE ROCKS

The Paleozoic sedimentary rocks of the area have been affected by two separate intrusive events of quite different character during the Mesozoic Era. The first intrusive episode was of a large scale and initiated the intense structural deformation of the region. This episode is thought to be directly related to the emplacement of the main mass of the Idaho Batholith. Although the effects of this event are demonstrably present within the area of study, the only igneous rocks that could be related to this episode of intrusion are small gabbroic sill and dike-like masses that were injected along a zone of structural weakness. Hobbs (1975) believes the gabbroic intrusions are Early Cretaceous or Lake Jurassic in age, but suggests that they could be slightly older. The second intrusive episode is thought to be closely related to the later stages of emplacement of the Idaho Batholith. Although, regionally of a much smaller scale, it profoundly affected the structural development of the immediate area and was very important in preparing the ground for later mineralizing solutions. This episode resulted in the emplacement of an intrusive complex of silicic composition, here named the Juliette Creek intrusive complex, from 90 to 96 m.y. (Middle Cretaceous).

A description of the gabbroic intrusive rocks will be followed by a description of the Juliette Creek intrusive complex. The nomenclature used for the plutonic rocks largely follows the classification of

Johannsen (1939). Chemical classifications are in accord with the classification of Nockolds (1954) and colors are described in terms of the U. S. Geological Survey Standard Rock Color Chart.

## Gabbro

Ross (1937) mapped several isolated exposures of gabbroic sills and dikes in a narrow north-trending band from Clayton, 10 miles south of the Bayhorse townsite, to Garden Creek, 3 miles north of the townsite. Within the area of study the gabbro crops out intermittently along the ridge crest on the west side of the cirque at the head of Bull of the Woods Gulch and along the divide north of the Skylark Mine.

Field Description. The gabbroic rocks are exposed as a thin, discontinuous layer of erosional remnants approximately concordant with the contact between the Ramshorn Slate and the overlying mixed lithology sequence. Contact relationships are obscured by talus and hydrothermal alteration has largely destroyed the internal structure of the gabbro. However, the sill apparently dips 35° to 45° W and where present ranges up to 100 feet in thickness. The gabbro is greenish-black (5 G 2/1) on fresh surfaces and moderate-yellowish-brown (10 YR 5/4) when weathered. Block pieces of gabbro float are found in relative abundance in the valley of Bayhorse Creek as far east as the Bayhorse townsite. Undoubtedly, the gabbroic float was derived from similar isolated pods no longer exposed to direct observation.

Lithologic and Petrographic Description. Extensive alteration of the rock makes it difficult to precisely determine the primary mineralogy. However, the rock was apparently medium to coarsely crystalline and contained interlocking anhedral crystals of calcic plagioclase, clinpyroxene, hornblende and ilmenite. Approximately 60 percent of the original rock consisted of labradorite (about $An_{60}$) laths which were partically enclosed by clinopyroxene (28 percent), probably augite. Interstitial ilmenite crystals composed the remaining 2 percent of the rock. The original mineral assemblage and subophitic texture have been subsequently overprinted by an alteration assemblage consisting of pseudomorphic aggregates of quartz, albite, epidote, carbonate and small quantities of zeolites after calcic plagioclase. Late magmatic brown hornblende replaces pyroxene and has altered to chlorite, pale-green acicular amphibole and small amounts of biotite. Sphene and leucoxene indicate the former presence of ilmenite. Relics of primary calcic plagioclase and clinopyroxene indicate that the rock was originally of a gabbroic composition.

Regional Correlation and Age. The distribution of the tabular gabbroic masses over the region, always in or near the upper part of the Ramshorn Slate or the overlying quartzite sequence, suggests that they were emplaced along a continuous zone of weakness at this stratigraphic position. An erosional unconformity and/or an early zone of low-angle overthrusting may mark the contact within the study area. The gabbroic rock is lithologically and spatially unlike any other rock type exposed within the region and, because of

No Page 60

its restricted exposure and intense hydrothermal alteration, the age of the gabbro is not precisely known. The major structural deformation and intrusive activity within the region occurred near the Cretaceous-Jurassic time boundary and it is not unreasonable to presume that the gabbroic masses were injected about this time; perhaps related to the early phases of the Idaho Batholith.

## The Juliette Creek Intrusive Complex

The uppermost part of two cupolas associated with a large underlying intrusive complex have been exposed by Early Tertiary block faulting and subsequent erosion of the overlying strata. Data from a regional airborn magnetic survey (Fig. 10) and from examination of drill core indicate that the largest part of the complex probably underlies most of the Bayhorse district beneath a relatively thin cover of Paleozoic sedimentary rocks. The age of the complex, based on several K-Ar age determinations ranges from 90 to 96 m.y. (Middle Cretaceous). At least three separate but probably cogenetic plutonic phases of silicic composition have been recognized. As contacts are poorly exposed the relative ages of the three different phases can only be surmised from indirect evidence. Apparently, the quartz diorite phase was the first to be emplaced. It was followed by a larger granodiorite phase. The granodiorite grades through quartz monzonite to granite from its core to its margin. In addition, dikes of aplite and pegmatite that are compositionally similar to the

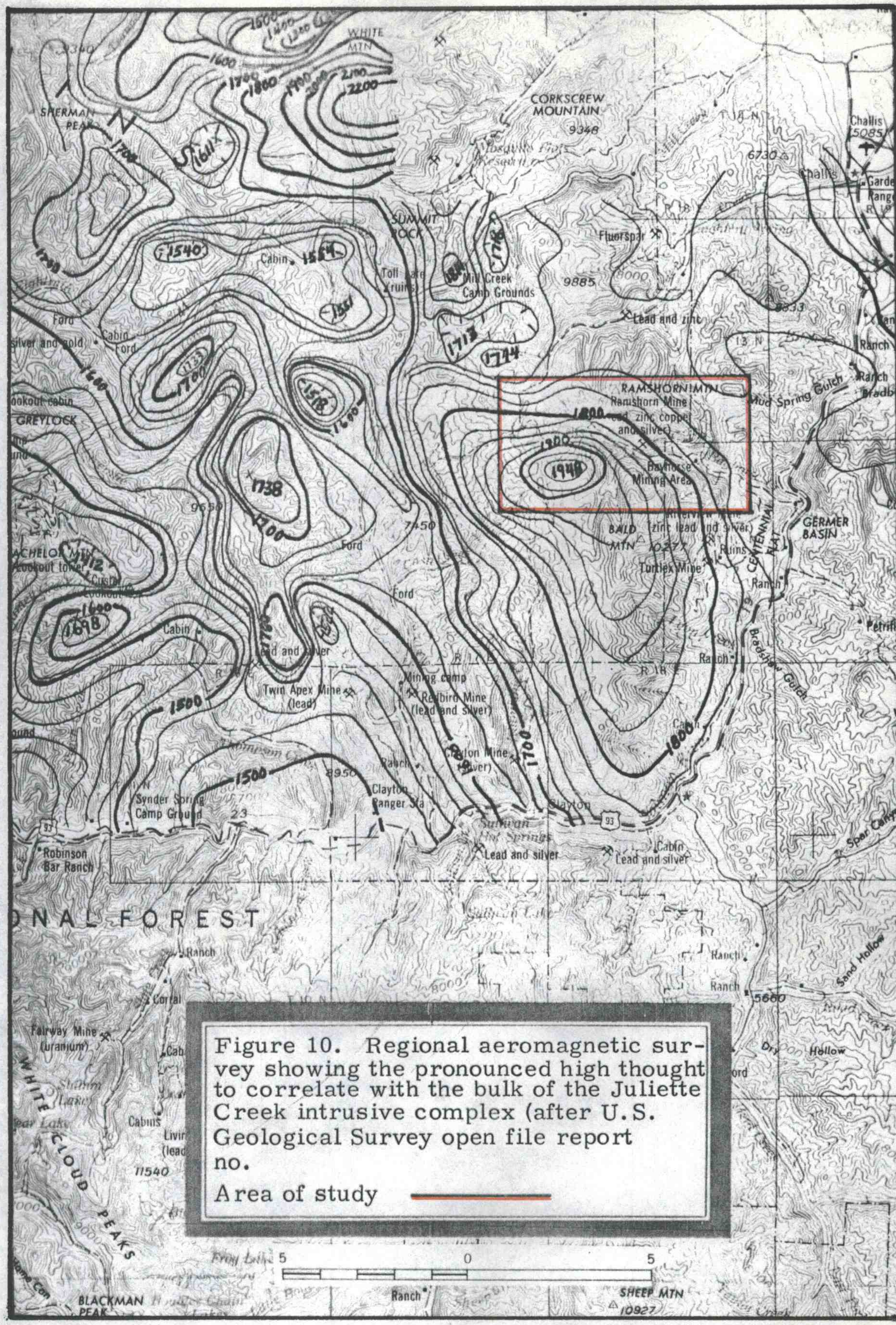



Figure 10. Regional aeromagnetic survey showing the pronounced high thought to correlate with the bulk of the Juliette Creek intrusive complex (after U.S. Geological Survey open file report no.

Area of study

the granodiorite phase intrude the country rocks and in part probably form an outer border zone to the granodiorite. The third phase is a quartz-feldspar porphyry. It is known only from drill core and although highly altered, the original character was significantly different from the other intrusive phases of the complex. The major modal constituents of all the phases of the intrusive complex are plotted in Figure 11.

The largest exposure of quartz diorite and granodiorite represents approximately one-third of a square mile in areal extent. It is centered over Nevada Mountain just west of Juliette Creek and is here referred to as the Nevada Mountain stock. Another stock-shaped part of the complex is exposed in scattered outcrops 1 mile north of Nevada Mountain, just west of the Skylark Mine, and will be referred to as the Skylark stock. The intrusive phases are not evident on aerial photographs as they differ little in topographic expression or vegetational cover from the surrounding country rocks. The intrusive complex can be subdivided into four distinctive lithologies, which in order of apparent emplacement consistof (1) quartz diorite, (2) granodiorite, (3) aplite and pegmatite dikes and (4) quartz-feldspar porphyry.

## Quartz Diorite

The quartz diorite phase was emplaced in Ramshorn Slate and is known only from small surface exposures on the southern slope

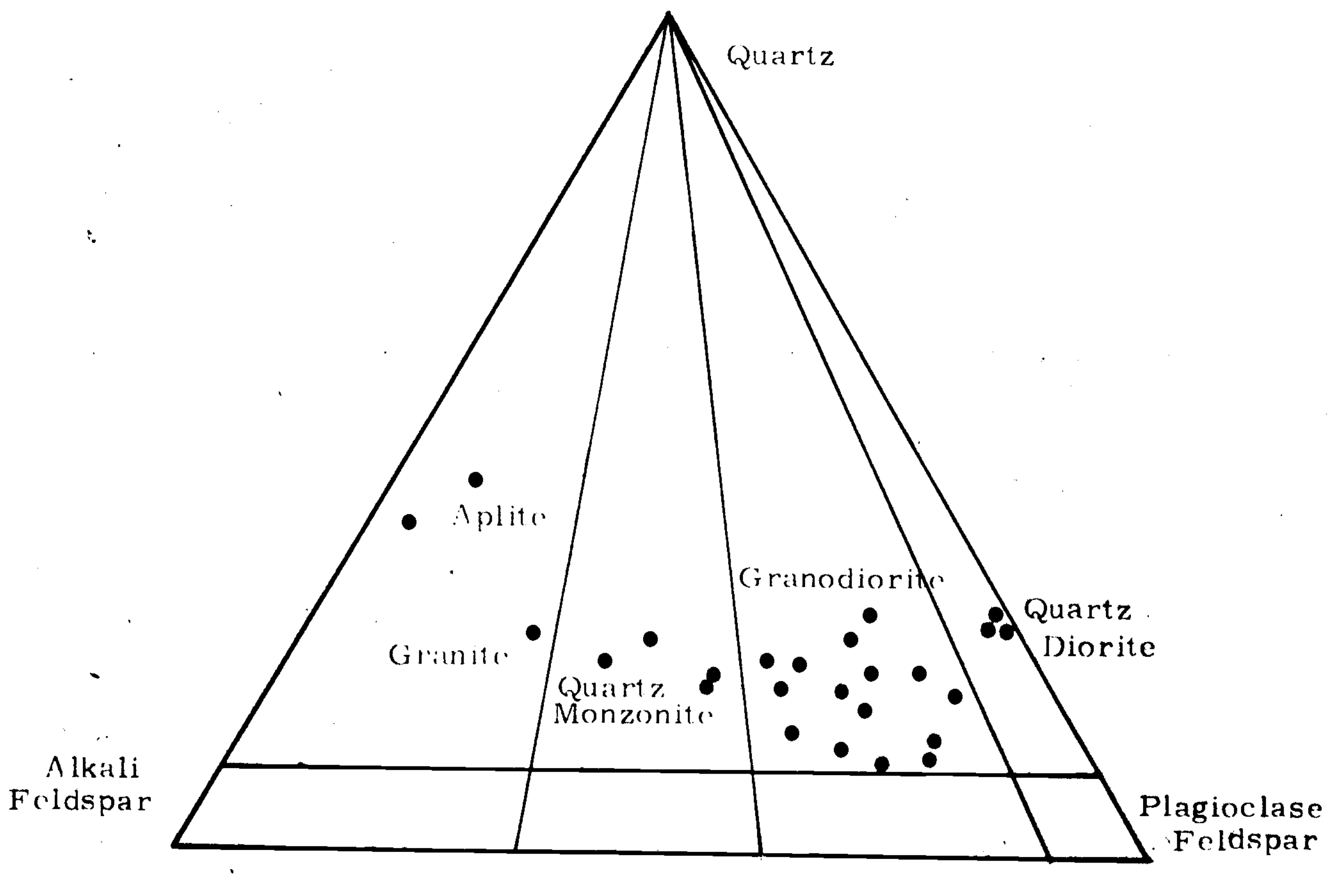



Figure 11. Plot of all samples showing major constituents of the various phases of the Juliette Creek intrusive complex (modal estimates from point counts and stained slabs, classification after Nockolds, 1954).

of Nevada Mountain near Juliette Creek.

Field Description. On fresh surfaces this unit is a dark-gray (N 3) in color and weathers to a mottled dark-greenish gray (5 G 4/1) and moderate brown (5 YR 4/4). Weathering of the quartz diorite has formed smooth rounded knobs cropping out through a steep talus slope covered with angular blocks of quartz diorite and hornfels. Jointing of the quartz diorite is neither well-developed nor are attitudes consistent. Neither foliation nor lineation were observed in this plutonic unit.

The contacts of the quartz diorite with the granodiorite are obscured by talus and a thin veneer of hornfels. The geometry of the granodiorite, hornfels veneer and the quartz diorite suggests the presence of a discontinuity between the two phases, which tends to indicate that the two phases are not lithologic gradations of the same intrusive mass, but rather two discrete phases (Fig. 12). Xenoliths, similar in lithologic and magnetic properties to the quartz diorite phase, occur within blocks of granodiorite float along Juliette Creek. They provide the most direct evidence that emplacement of the quartz diorite phase probably pre-dated that of the granodiorite phase.

Lithologic and Petrographic Description. Hand specimens of quartz diorite are medium crystalline (1 mm) and equigranular. The quartz diorite is characterized by abundant mafic minerals (25 to 30 percent) that contrast sharply in color with the enclosing siliceous groundmass to produce a distinctive "salt and pepper" appearance

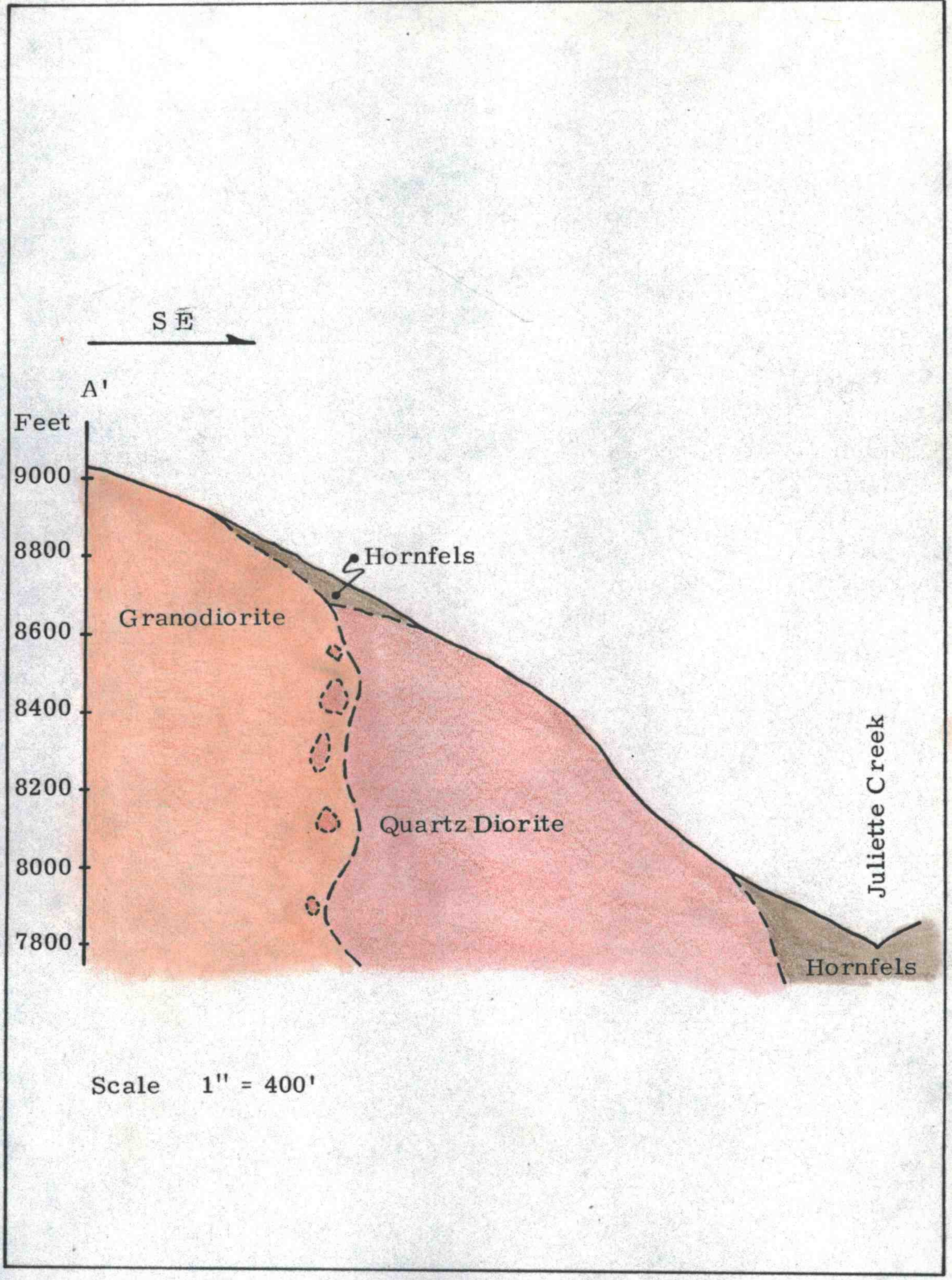



Figure 12 - Cross-section from point A', Plate 1 southeast across the quartz diorite phase showing the geometry of the granodiorite, hornfels veneer, and quartz diorite that is suggestive of two discrete intrusive phases.

(Pl. 13). Slight alteration of the mafic minerals imparts a greenish tinge to the rock, but it is otherwise largely unaltered. Disseminated blebs of pyrite (up to 1 percent) are commonly visible. Based upon a free swinging magnet, the quartz diorite phase is non-magnetic.

Modal analyses of three samples of quartz diorite are presented in Table 1. Thin section examination of the quartz diorite reveals a relatively simple texture and mineralogy (Pl. 14). The rock exhibits a xenomorphic granular texture with crystals ranging from 0.5 mm up to 1.5 mm in diameter. The primary magmatic constituents of this rock type include plagioclase feldspar (50 to 63 percent), quartz (7 to 12 percent), hornblende (7 to 17 percent), biotite (5 to 14 percent), and traces of apatite, orthoclase feldspar, sphene, magnetite, and zircon. Minor alteration products include chlorite, biotite, opaque oxides, calcite, clays, sericite, sphene and zeolites.

The plagioclase feldspar is calcic andesine ($An_{46-50}$) and occurs largely as irregular stubby crystals up to 2 mm long. Polysynthetic albite twinning and normal zoning are well developed in all crystals. The feldspar is commonly microfractured and sericite, calcite and clay occur as ubiquitous but very minor alteration products.

Quartz occurs as highly irregular interstitial crystals. The quartz is relatively clear, but encloses a myriad of minute crystal inclusions. Liquid inclusions are rare and very small. Crystals are highly strained and polygonalized and are interpreted to be indicative


Plate 13. Handspecimen of quartz diorite with stained section; orthoclase (yellow) and plagioclase feldspar (pink).

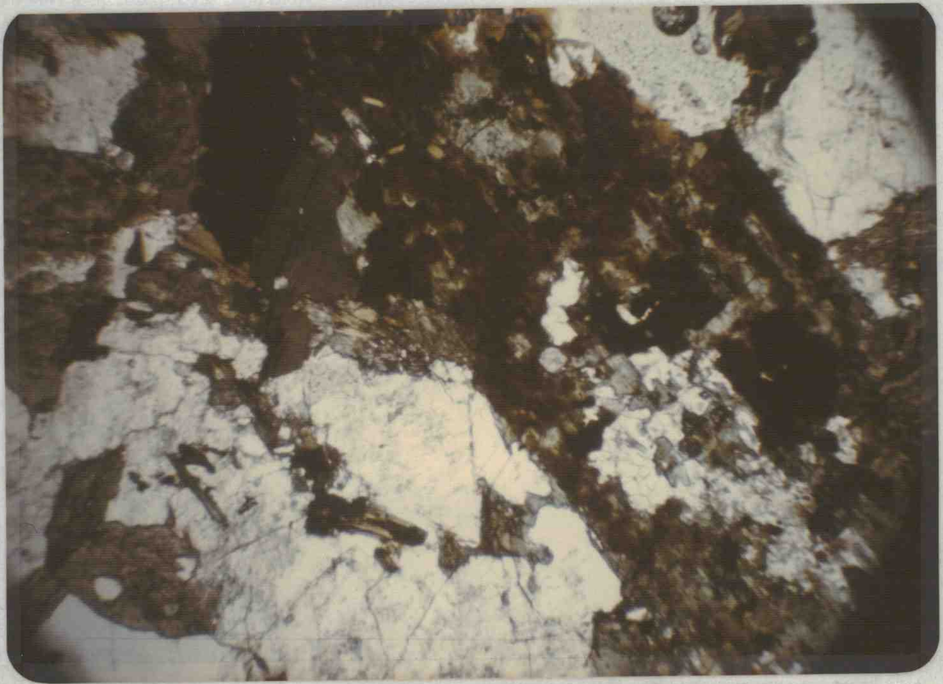


Plate 14. Photomicrograph of quartz diorite ( 35 x)

Table 1. Modal and chemical analyses of quartz diorite compared to the average diorite and quartz diorite of Nockolds.

| Chemical Analyses (percent) | | | | Modal Analyses (percent) | | | |
|---|---|---|---|---|---|---|---|
| | Average** Diorite | 7-29-75-8CS | Average** Quartz Diorite | | 7-29-75-8CS | 7-29-75-9CS | 7-29-75-7CS |
| $SiO_2$ | 51.86 | 60.3 | 66.15 | Quartz | 7 | 12 | 11 |
| $Al_2O_3$ | 16.40 | 15.6 | 15.56 | Andesine | 50 | 63 | 62 |
| FeO* | 9.70 | 10.7 | 4.78 | Orthoclase | 2 | 1 | 2 |
| MgO | 6.12 | 3.6 | 1.94 | Hornblende | 17 | 15 | 7 |
| CaO | 8.40 | 5.1 | 4.65 | Biotite | 7 | 5 | 14 |
| $K_2O$ | 1.33 | 2.25 | 1.42 | Apatite | 2 | 2 | 2 |
| $Na_2O$ | 3.36 | 3.5 | 3.40 | Opaques | 2 | 1 | 1 |
| $TiO_2$ | 1.50 | 1.60 | 0.42 | Sphene | 1 | 1 | 1 |
| MnO | 0.18 | --- | --- | Zircon | Tr | Tr | Tr |
| $P_2O_5$ | 0.35 | --- | --- | Sericite | 12 | Tr | Tr |
| | 99.14 | 100.65 | 98.32 | | 100 | 100 | 100 |

*Total iron reported as FeO
**Average of Nockolds (1954)

of intense post-emplacement deformation. The modal content of quartz in the intrusive phase essentially straddles the diorite-quartz diorite composition field. This is also indicated by the chemical composition of the rock.

Rare orthoclase anhedra are present as small interstitial crystals. Staining techniques best reveal its presence.

Subhedral to anhedral hornblende laths are the dominant mafic constituent of this plutonic rock. The randomly oriented laths may be as long as 5 mm and commonly enclose many euhedral crystals of apatite. In contrast to the other mineral phases, the hornblende is highly altered and now consists largely of pseudomorphic aggregates of light brown chlorite, pale brown biotite, calcite and clots of magnetite and sphene. As the other mineral constituents are largely unaltered, these replacement products are most likely the results of deuteric alteration.

Primary biotite forms tabular crystals of random orientation. It is highly pleochroic from very-light-brown to dark-reddish-brown and is associated with trace amounts of euhedral zircon and apatite. Twins, kink bands and strain lamallae are quite common and are interpreted to be indicative of post-emplacement deformation. The primary biotite is very fresh and the only alteration products are small amounts of chlorite and magnetite.

There is an observable increase in alteration intensity of the quartz diorite proceeding from north to south over the outcrop area. This gradual change is marked by an increase in the alteration products of the feldspar and mafic minerals, and by an increase in the abundance of disseminated pyrite. This change in alteration intensity undoubtedly represents the effects of a superimposed hydrothermal event.

Chemistry. A representative sample of quartz diorite was analyzed for major oxide constituents and compared to the average diorite and quartz diorite of Nockolds (1954) as summarized in Table 1. The chemical composition of the rock has features characteristic of both the average diorite and quartz diorite and it plots near the transition zone between the two. Concentrations of $SiO_2$, $Al_2O_3$, MgO, CaO and $Na_2O$ show a slight tendency to be closer to the average quartz diorite composition than the average diorite. The total iron content of the sample, however, is much higher than that of the average quartz diorite. This is to be expected as the modal content of mafic minerals and pyrite in the sample is probably greater than that of the average quartz diorite. The high $K_2O$ content is accounted for by the abundance of hydrothermal sericite.

## Granodiorite

The granodiorite phase forms most of the exposed part of the Juliette Creek intrusive complex and crops out over a total area of slightly less than one-third square mile.

<u>Field Description.</u> This plutonic unit occurs as two bullet-shaped masses emplaced within the Ramshorn Slate. Indirect evidence, previously discussed, suggests that the granodiorite phase has also intruded the quartz diorite phase. The largest of the two steep-sided plugs crops out over the central part of Nevada Mountain. The smaller plug, the Skylark stock, is exposed on the south-facing slope one mile north of Nevada Mountain. Several isolated exposures are also present between the two plugs in the valley of Bayhorse Creek. The geometry of the restricted outcrop pattern, the isolated pendants of country rock and the lithologic variation within the intrusive phase suggest that the uppermost parts of the igneous complex have only recently been exposed by erosion(Pls. 1 and 3, back pocket).

Hydration and expansion of biotite and hornblende have produced an extensive gruss on the Skylark stock to form smooth forested slopes with scattered, rounded outcrops. The breakdown of iron-bearing minerals imparts a light-brown (5 YR 5/6) coloration to the otherwise moderate-light-gray (N 6) rock.

The ridge crest of Nevada Mountain is underlain by a similarly weathered granodiorite. Formation of the gruss on the intrusion in this area has produced a saddle-shaped ridge between more resistant hornfels caps. The erosional expression of the granodiorite changes eastward and is readily evident from an examination of the topography in this area. The saddle-shaped ridge forms a broad crescent in map view around a slightly dome-shaped core. Lithologically, this core area differs to a small degree from the ridge area. The granodiorite core gradually changes to a quartz monzonite near the border of the stock. The central part of the intrusion is a moderate-light-gray (N 6) in color and the more abundant mafic constituents have not undergone the breakdown to form the intense gruss and iron staining characteristic of the ridge area.

The difference in topographic expression in this area may be a function of the difference in duration of chemical weathering between the two areas. The ridge was probably part of the pre-Tertiary erosion surface while the veneer of hornfels has only recently been removed from the core area. In addition, the effects of fault-related hydrothermal alteration have undoubtedly aided the development of gruss on both the Skylark stock and the ridge area of the Nevada Mountain stock. The destruction of magnetite by weathering and hydrothermal alteration has left the granodiorite of the Skylark stock and the ridge area of the Nevada Mountain stock non-magnetic as opposed to the highly magnetic samples from the core area.

Joints in the granodiorite are not well developed and their attitudes do not show any consistent relationship except where flow-banding is developed. Although nowhere prominent, flow-banding is developed in scattered outcrops in the central part of the Nevada

Mountain stock. The banding is marked by lense-like stringers of dark mafic minerals alternating with lighter colored silicic minerals. The attitude of the flow bands vary within rather narrow limits from N. 20° W. to N. 40° W. in strike and from 30° N.W. to 35° N.W. in dip and apparently developed as a primary flow feature of the magma near the upper part of the eastern wall of the original magma chamber. Well-developed joints parallel the flow-banding.

Contact relations, discussed under the previous section concerning the quartz diorite and in a later section concerning the aplite-pegmatite, indicate that emplacement of the granodiorite probably post-dates the quartz diorite and is nearly contemporaneous with injection of the aplite and pegmatite phases.

Lithologic and Petrographic Description. The granodiorite is predominantly coarsely crystalline (1 to 3 mm) and equigranular. However, it is variably porphyritic and contains scattered anhedral phenocrysts of quartz (about 5 mm in diameter) and euhedral orthoclase laths (about 10 mm in length). Rare euhedral orthoclase crystals (about 4 cm in length) set in a coarsely crystalline equigranular groundmass can be found in exposures of the Skylark stock. Orthoclase commonly has a pink color that contrasts with the lighter plagioclase feldspar and darker mafic minerals. The quantity of primary quartz gradually increases through the border zone of granodiorite as the constituent mafic minerals decrease in abundance. In addition, the proportion of orthoclase to plagioclase increases from margin to interior zones of the Nevada Mountain and Skylark stocks and the granodiorite grades into a quartz monzonite and locally approaches a granite in composition (Pls. 15 and 16).

Modal analyses of 5 samples of granodiorite are presented in Table 2. Listed in Table 3 are modal analyses of 2 samples of quartz monzonite and 1 sample of granite from the margin of the granodiorite phase. The primary mineral assemblage of the granodiorite phase includes plagioclase feldspar (55 to 66 percent), quartz (10 to 18 percent), orthoclase feldspar (9 to 15 percent), biotite (2 to 7 percent) and hornblende (1 to 6 percent). Accessory minerals include apatite, sphene, zircon and magnetite. The intensity and type of alteration varies considerably over the exposed area of the granodiorite phase, and the products of later hydrothermal alteration are discussed in more detail on pages 277 to 279. Alteration products attributable to deuteric processes include sericite, quartz, chlorite, biotite, calcite, epidote, clays, zeolites, opaque oxides and sphene.

The plagioclase feldspar is andesine ($An_{33-36}$). It occurs as anhedral crystals 1 to 2 mm in length that are twinned according to the albite, carlsbad and pericline laws. The precise composition of the feldspar is difficult to determine because of the strong normal and oscillatory zoning commonly present. The crystals are usually polygonalized and well-developed strain lamallae are ubiquitous. Narrow exsolution lamallae of orthoclase can also be observed and


Plate 15. Handspecimens of granodiorite and aplite with stained sections showing gradation from granodiorite through quartz monzonite and granite to aplite (orthoclase, yellow; plagioclase feldspar, pink).

Plate 16. Photomicrograph of granodiorite (x-nicols, 35x).

Table 2. Chemical and modal analyses of unaltered granodiorite samples compared to the average granodiorite of Nockolds.

| | 7-22-75-7C | 7-22-75-8C | 7-22-75-4C | 7-22-75-2C | 7-22-75-84 | Average of samples | Average** granodiorite |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 69.7 | 66.0 | 68.8 | 66.8 | --- | 67.8 | 66.88 |
| $Al_2O_3$ | 15.1 | 15.8 | 15.1 | 14.9 | --- | 15.2 | 15.66 |
| FeO* | 3.7 | 4.4 | 3.6 | 5.0 | --- | 4.1 | 3.92 |
| MgO | 1.0 | 1.2 | 0.8 | 1.4 | --- | 1.1 | 1.57 |
| CaO | 2.0 | 3.2 | 2.5 | 3.0 | --- | 2.7 | 3.56 |
| $Na_2O$ | 4.5 | 4.6 | 4.3 | 4.3 | --- | 4.4 | 3.84 |
| $K_2O$ | 3.15 | 2.80 | 3.30 | 2.95 | --- | 3.10 | 3.07 |
| $TiO_2$ | 0.45 | 0.50 | 0.40 | 0.60 | --- | 0.49 | 0.57 |
| MnO | --- | --- | --- | --- | --- | --- | 0.07 |
| $P_2O_5$ | --- | --- | --- | --- | --- | --- | 0.21 |
| | 99.60 | 98.50 | 98.80 | 98.95 | | 98.89 | 97.78 |
| Quartz | 12 | 16 | 10 | 18 | 17 | 14.6 | |
| Andesine | 66 | 55 | 62 | 55 | 65 | 60.6 | |
| Orthoclase | 13 | 15 | 14 | 10 | 9 | 12.2 | |
| Biotite | 5 | 6 | 5 | 7 | 2 | 5.0 | |
| Hornblende | 1 | 5 | 3 | 6 | 3 | 3.6 | |
| Accessories | 3 | 4 | 3 | 3 | 3 | 3.2 | |
| Opaques | Tr | 1 | 1 | 1 | 1 | 0.9 | |
| | 100 | 100 | 100 | 100 | 100 | 100.1 | |

*Total iron reported as FeO

**Average of Nockolds (1954)

Table 3. Chemical and modal analyses of unaltered quartz monzonite samples compared to the average quartz monzonite and calc-alkali granite of Nockolds.

**Chemical analyses (percent)**

| | Average** calc-alkali granite | Quartz monzonite 7-22-75-24 | Average** quartz monzonite |
|---|---|---|---|
| $SiO_2$ | 72.08 | 70.0 | 69.15 |
| $Al_2O_3$ | 13.86 | 16.6 | 14.63 |
| FeO* | 2.53 | 4.2 | 3.49 |
| MgO | 0.52 | 0.5 | 0.99 |
| CaO | 1.33 | 1.5 | 2.45 |
| $K_2O$ | 5.46 | 4.10 | 4.58 |
| $Na_2O$ | 3.08 | 3.30 | 3.35 |
| MnO | 0.06 | --- | 0.06 |
| $P_2O_5$ | 0.18 | --- | 0.20 |
| | 99.47 | 100.50 | 99.46 |

**Modal analyses (percent)**

| | Quartz monzonite 7-22-75-24 | Quartz monzonite 7-23-75-12H | Granite 7-24-75-19H |
|---|---|---|---|
| Quartz | 20 | 21 | 24 |
| Andesine | 42 | 42 | 25 |
| Orthoclase | 33 | 33 | 40 |
| Biotite | 1 | 2 | 3 |
| Hornblende | 2 | Tr | 5 |
| Accessories | 2 | 2 | 3 |
| Opaques | Tr | Tr | Tr |
| | 100 | 100 | 100 |

*Total iron reported as FeO
**Average of Nockolds (1954)

appear to be strain induced in many cases (Pl. 16a). The feldspar has been variably altered to sericite, clays, calcite and minor epidote. The plagioclase feldspar content of the intrusive phase decreases with increasing proximity to the borders of the stocks where it may constitute as little as 25 percent of the rock.

Quartz occurs as clear anhedral phenocrysts (5 mm) and as smaller crystals (1 to 2 mm) in the groundmass. Crystals are ubiquitously highly strained and polygonalized and are indicative of significant post-consolidation strain. The quartz content of the granodiorite gradually increases to 20 percent and more towards the margins of the intrusions.

Orthoclase occurs as interstitial anhedra 1 to 2 mm long and as two distinct generations of euhedral phenocrysts. One population of phenocrysts ranges from 5 to 10 mm in length whereas the other is much larger and ranges from 3 to 4 cm in length. The larger phenocrysts are relatively rare and are widely scattered through the granodiorite. Patchy perthite and strain induced perthite are abundant. Strain lamallae are also quite common. The orthoclase is usually clouded and altered to clays. The orthoclase content of the plutonic phase is generally low, but increases towards the margins of the intrusion to as much as 40 percent so that the granodiorite grades into quartz monzonite and, in at least one place in the Skylark stock, it approaches a granite in composition.

Primary biotite flakes, 1 to 2 mm across, are pleochroic from light to dark brown. Twins, kink bands and strain lamallae are ubiquitous. The biotite is usually associated with abundant euhedral apatite, sphene, minor zircon and primary magnetite. Chlorite and opaque oxides are the dominant alteration products of the biotite. As expected, biotite decreases in abundance as the silicic border phases of the complex are approached.

Hornblende occurs as ragged interstitial laths up to 2 mm long. The mineral is totally altered to pseudomorphic aggregates of chlorite, biotite, magnetite, sphene and rare calcite and epidote. The mineral aggregates are interpreted to be the products of late magmatic reaction as hornblende is commonly the only mineral so highly altered. Hornblende also decreases in abundance near the margins of the intrusive phase, but not to the extent that biotite decreases.

Intensely altered rocks found near Bayhorse Creek northwest of the Nevada Mountain stock were mapped as granodiorite. Samples from these exposures exhibit textural and compositional features similar to the granodiorite just described, and they are interpreted to be highly altered equivalents.

Chemistry. Four samples of granodiorite were analyzed for major oxide constituents and the results are summarized in Table 2 (p. 77) and compared to the average granodiorite of Nockolds (1954). The composition of the granodiorite phase of the complex does not differ significantly from the average granodiorite. The slight differences that do exist are to be expected from normal variations in modal compositions.

A chemical analysis of a representative of quartz monzonite is included in Table 3 (p. 78) and compared to the average calc-alkali granite and average quartz monzonite described by Nockolds (1954). The major oxide constituents of the quartz monzonite sample are similar to those of the average quartz monzonite.

## Aplite and Pegmatite

Injections of aplite and associated pegmatite are spatially and probably genetically related to the granodiorite phase of the Juliette Creek intrusive complex.

Field Description. The aplite intrusions are white to pink in color and most exhibit a sugary texture (Pl. 15, p. 77). The injections range in width from a few millimeters to tens of meters. The smaller injections are found intruding the hornfelsed country rock along relic bedding and foliation planes near the margins of the granodiorite phase. The larger intrusions generally cut the hornfels at steep angles and their emplacement is evidently closely related to fractures. Although relatively rare, pegmatitic segregations of quartz, muscovite, orthoclase and in one locality tourmaline occur toward the centers of many of the smaller injections. They are commonly highly altered and crossed by veinlets containing minor siderite and sulfides.

Lithologic and Petrographic Description. From thin section examination, the aplite has a finely crystalline (1 to 2 mm) equigranular texture (Pl. 17). Two modal analyses of representative samples of the aplite phase are presented in Table 4. It is composed of interlocking anhedral crystals of quartz (28 to 32 percent), potassium feldspar (30 to 40 percent) with traces of muscovite, biotite and rare magnetite and apatite. Tourmaline is very scarce and is only associated with the pegmatitic phases of the injections on the northern slope of Nevada Mountain.

The potassium feldspar is orthoclase and is present both as individual anhedra and as patchy perthitic intergrowths with plagioclase feldspar. The orthoclase is invariably replaced by cloudy kaolin group minerals and minor sericite as indicated by the chalky character of hand specimens.

Quartz occurs as graphic and myrmekitic intergrowths produced as a result of late-stage magmatic reactions. It is also present as individual anhedral crystals which have commonly been highly strained and polygonalized in response to post-consolidation strain.

The plagioclase feldspar is rarely unaltered and is largely replaced by kaolin group minerals and minor sericite. Because of intense alteration, the composition of the plagioclase feldspar is not known with certainty, but is undoubtedly highly sodic.

Plate 17. Photomicrograph of aplite (x-nicols, 35x)

Table 4. Chemical and modal analyses of altered aplite samples compared to the average calc-alkali granite of Nockolds.

| | Chemical Analyses (percent) | | |
| --- | --- | --- | --- |
| | 7-22-75-5H | 7-23-75-6SD | Average** calc-alkali granite |
| $SiO_2$ | 80.0 | 76.5 | 72.08 |
| $Al_2O_3$ | 13.1 | 13.7 | 13.86 |
| FeO* | 2.3 | 3.0 | 2.53 |
| MgO | 0.1 | 0.1 | 0.52 |
| CaO | 0.1 | 0.1 | 1.33 |
| $K_2O$ | 3.60 | 5.10 | 5.46 |
| $Na_2O$ | 0.40 | 0.40 | 3.08 |
| $TiO_2$ | 0.05 | 0.05 | 0.37 |
| MnO | --- | --- | 0.06 |
| $P_2O_5$ | --- | --- | 0.18 |
| | 99.65 | 98.95 | 99.47 |

| | Modal Analyses (percent) | |
| --- | --- | --- |
| | 7-22-75-SH | 7-23-75-6SD |
| Quartz | 32 | 28 |
| Orthoclase | 30 | 40 |
| Plagioclase | 5 | 3 |
| Muscovite | 4 | 1 |
| Biotite | 2 | 3 |
| Kaolinite | 22 | 16 |
| Sericite | 5 | 9 |
| | 100 | 100 |

*Total iron reported as FeO
**Average of Nockolds (1954)

Muscovite, biotite, magnetite and apatite occur as randomly oriented interstitial crystals. The platy minerals, where present in pegmatitic phases, are commonly very coarsely crystalline and oriented perpendicular to the plane of injection.

Chemistry. Two whole-rock chemical analyses of characteristically altered aplite are listed in Table 4. The aplite samples are much higher in $SiO_2$, and much lower in MgO, CaO, $Na_2O$ and $TiO_2$ than the average calc-alkali granite of Nockolds (1954). This is in accordance with a derivation from late-magmatic fluids. These chemical differences have undoubtedly been magnified by variances in modal composition between the samples and the average modal composition of Nockolds (1954) as a consequence of the effects of later hydrothermal alteration.

## Quartz-Feldspar Porphyry

The quartz-feldspar porphyry is known only from drill core taken from the area one mile west of the Bayhorse townsite. This intrusive phase is highly altered and is herein named for its only two megascopic components.

Field Description. The porphyry is in intrusive contact with the lower dolomite unit of the Garden Creek Phyllite, as indicated by small inclusions of argillaceous limestone and dolomite in the quartz-feldspar porphyry. Several drill holes penetrate this contact and indicate that the intrusive phase has a very irregular top (Figs. 6 and 7, pp. 23-24). The upper contact varies as much as 150 feet in vertical distance for 150 feet of horizontal distance. The extreme irregularity of the upper contact is undoubtedly the result of primary intrusive activity, accentuated by steeply-dipping fault zones. The deepest hole to penetrate the porphyry failed to locate the bottom of the intrusive phase and indicates that it is at least 860 feet thick at its structural high point. The quartz-feldspar porphyry varies little in character over its entire known areal extent and thickness. Although the size and shape of the porphyry is not known with certainty, its forceful emplacement has clearly affected the adjacent country rocks as indicated by the parallelism exhibited by the upper contact of the lower dolomite member of the Garden Creek Phyllite and the intrusive contact.

Although the quartz-feldspar porphyry has been intensely altered, it is evident that the porphyry is lithologically different from the igneous rocks exposed to the west and is clearly representative of a distinct intrusive phase. Radiometric age determinations suggest that at least the alteration if not the emplacement of the porphyry is closely related in age to the emplacement of the intrusive rocks exposed to the west. However, the chronologic emplacement of the quartz-feldspar porphyry relative to the other phases of the Juliette Creek intrusive complex is not clearly discernible.

Lithologic and Petrographic Description. Modal analyses of six samples of the porphyry are presented in Table 5 and are indicative of the highly altered character of the rocks. Hand specimens of quartz-feldspar porphyry are predominantly medium-light-gray (N 6) in color and are characterized by abundant quartz (20 percent) and highly altered feldspar phenocrysts (30 percent) set in a finely crystalline siliceous groundmass (Pl. 18). The quartz crystals range from 1 to 3 mm in diameter and are generally clear, rounded and cut by micro-fractures. Anhedral relic feldspar crystals range from 3 to 7 mm in length and commonly have soft, white rims with dark green cores that are indicative of intense alteration to kaolinite and sericite. Finely crystalline aggregates of sericite impart a greenish tinge to the otherwise gray groundmass. Widely spaced hairline veinlets transverse the porphyry at odd angles and are commonly filled with silica, fluorite and sulfides.

Thin section examination of the porphyry reveals a very simple mineralogy (Pl. 19) . Subequal proportions of finely crystalline quartz, kaolin and sericite compose about 80 percent of the typical sample. However, carbonate may be present in amounts up to 30 percent and is usually associated with trace amounts of epidote. The alteration products form an interlocking finely crystalline aggregate. Mineral proportions and crystal habits vary as a function of the original composition and texture of the replaced minerals.

Table 5. Modal and chemical analyses of quartz feldspar porphyry from diamond drill hole #36.

| Chemical Analyses (percent) | | | Modal Analyses (percent) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | DPW150** | DPW1012 | | DPW150 | DPW158 | DPW266 | DPW373 | DPW530 | DPW1012 |
| $SiO_2$ | 69.1 | 72.7 | Quartz | 25 | 25 | 57 | 50 | 50 | 37 |
| $Al_2O_3$ | 13.8 | 12.8 | Sericite | 45 | 55 | 22 | 15 | 10 | 20 |
| FeO* | 5.6 | 5.2 | Kaolinite | -- | Tr | 13 | 25 | 40 | 36 |
| MgO | 1.0 | 0.3 | Carbonate | 30 | 20 | 8 | Tr | Tr | 7 |
| CaO | 1.7 | 0.3 | Epidote | Tr | Tr | Tr | Tr | -- | Tr |
| $K_2O$ | 4.25 | 5.65 | Pyrite | Tr | Tr | Tr | -- | -- | Tr |
| $Na_2O$ | 0.3 | 1.2 | Fluorite | -- | -- | -- | 10 | Tr | -- |
| $TiO_2$ | 0.25 | 0.2 | Ilmenite | Tr | Tr | Tr | Tr | Tr | Tr |
| | 96.00 | 98.35 | | | | | | | |

*Total iron reported as FeO

**Numbers refer to vertical distance from hole collar

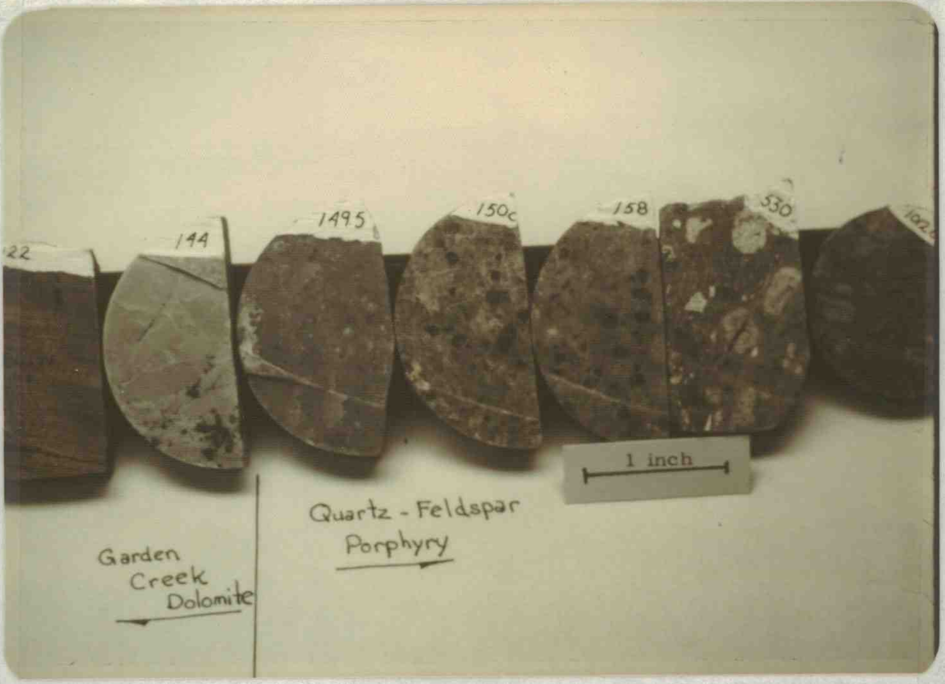



Plate 18. Representative sections of quartz-feldspar porphyry from diamond drill hole #36; numbers indicate depth below surface.

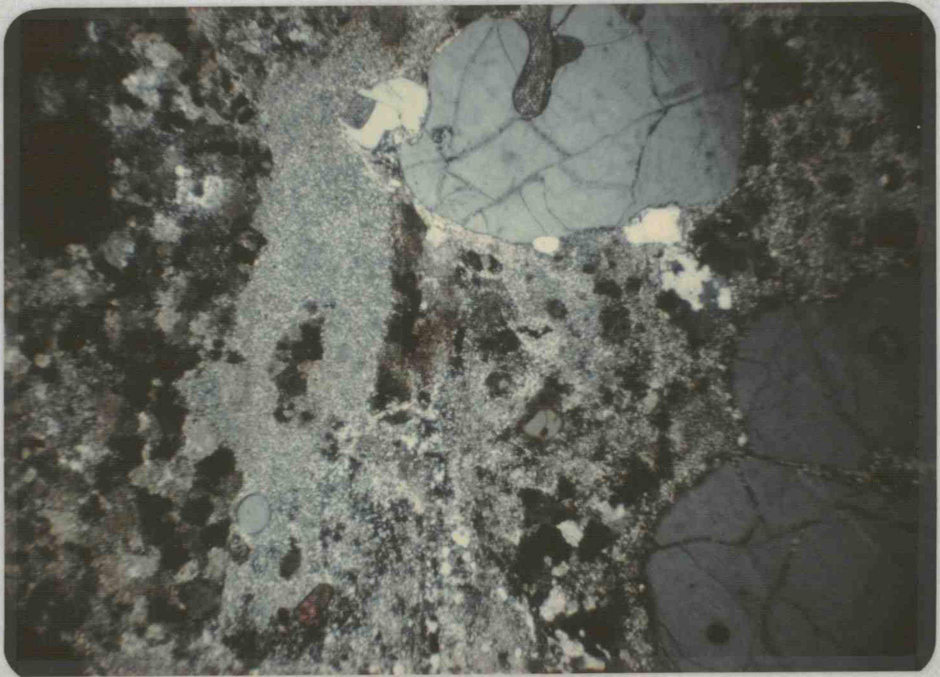


Plate 19. Photomicrograph of altered quartz-feldspar porphyry (x-nicols, 35x)

Quartz is present as microcrystalline aggregates in the groundmass and as graphic and myrmekitic intergrowths in addition to rounded and highly embayed phenocrysts. Strain lamallae, producing a gridiron pattern, and microfractures are ubiquitous in the larger quartz crystals and are indicative of significant post-consolidation strain. Finely crystalline sericite is commonly developed along the fractures in the phenocrysts and also occurs as a reaction rim surrounding the larger quartz crystals. Large fluid inclusions are common in the embayed phenocrysts and three phases can often be discerned. Graphic and myrmekitic intergrowths are noticeably more abundant than in any previously described phase of the complex. Finely crystalline quartz also occurs with sericite and kaolinite as pseudomorphic aggregates after feldspar.

The feldspar phenocrysts are completely replaced by finely crystalline sericite, kaolinite and quartz. The original composition of the feldspar cannot be determined with certainty. Probably they were orthoclase judging from the shape of sericite and kaolinite pseudomorphs and the pervasive alteration products indicative of the original potassic composition of the feldspar. The groundmass of the porphyry is thought to have been composed dominantly of plagioclase feldspar as pseudomorphic aggregates are commonly lath-shaped. One small plagioclase feldspar relic with well-developed polysynthetic albite twinning was observed toward the bottom of drill hole number DPW 36.

Calcite and epidote are present as separate euhedral crystals, but more commonly as scattered irregular clots in the groundmass and feldspar pseudomorphs.

Other mineral phases found in trace amounts include ilmenite, pyrite and fluorite. The former presence of ilmenite is indicated by leucoxene and reddish iron oxide alteration products. Except for traces of alteration products of ilmenite, the mafic minerals and their alteration products appear to be completely absent. Pyrite occurs as isolated euhedral crystals localized by widely-spaced quartz-filled microfractures and veinlets. The pyrite-quartz veinlets are commonly cut by small fluorite-filled fractures. The characteristic pervasive alteration of this late intrusive phase is undoubtedly a result of intense hydrothermal action which will be discussed in more detail on page 280.

Chemistry. Unaltered or even slightly altered samples of quartz-feldspar porphyry were not found. Whole rock analyses for two characteristically altered specimens are presented in Table 5 . Sample DPW 150 comes from the top of the quartz-feldspar porphyry intersected by DDH 36 at a depth of 150 feet and sample DPW 1012 comes from 862 feet deeper. Based both on the chemical analyses and inspection of the drill core, it is apparent that the chemical composition of the altered porphyry changes only slightly over 862 feet of vertical extent and is indicative of the pervasively altered character of the intrusive phase.

The rock is relatively high in $SiO_2$, $K_2O$ and $Al_2O_3$ and low in all other constituents except FeO. The relatively high FeO content is probably largely due to the presence of introduced pyrite. Contents of $SiO_2$, $K_2O$ and $Na_2O$ increase slightly with depth while $Al_2O_3$, FeO, MgO, and CaO decrease slightly. Taken in conjunction with modal analyses of samples at intervals between DPW 150 and DPW 1012 a subtle zonation of the alteration assemblage of the quartz-feldspar porphyry is discernible.

# VI. PETROGENESIS AND EMPLACEMENT OF THE JULIETTE CREEK INTRUSIVE COMPLEX

The Juliette Creek intrusive complex consists of at least three separate but genetically related intrusive phases of normal calc-alkaline affinity that were emplaced during Middle Cretaceous time. The complex was forcefully emplaced into the surrounding Paleozoic rocks along zones of weakness parallel with the north-south structural grain of the region. The emplacement of the intrusive complex was of major importance in preparing the ground for the later mineralizing solutions that followed and significantly altered the pre-existing local structure and lithologic characteristics of the Paleozoic rock units. The complex is thought to have cooled from temperatures ranging from 725°C to 800°C at depths ranging from 4 to 5 miles. The small plug-shaped masses that are known within the area are thought to represent the uppermost parts of a much larger and deeper plutonic mass.

## Age Relationships

Evidence for the time of emplacement of the intrusive complex comes from a variety of field relationships and several radiometric age determinations.

Country Rock-Intrusive Complex Age Relations. Small erosional remnants of the Challis Volcanics are found in depositional contact with rocks of the intrusive complex. The volcanic country rocks show no evidence of alteration or metamorphism by the plutonic rocks. The exposed part of the complex is bordered on the north, east and south by the Ramshorn Slate which has been metamorphosed to a hornfels by contact with the intrusive. Although very rare, xenoliths of quartzite are present near the roof zone of the complex. On the basis of these field relationships, the complex is post-Middle Ordovician and pre-middle Eocene in age

Broader considerations, however, permit the age of the complex to be more definitely fixed. As the major intrusive activity in central Idaho occurred during the Cretaceous Period it is concluded that the Juliette Creek intrusive complex is also of this age; a conclusion which is in close agreement with radiometric age determinations. As previous mentioned, geologic evidence indicates that the quartz diorite phase of the Juliette Creek intrusive complex is believed to have been emplaced first and was followed by the granodiorite phase with its quartz monzonite and aplite-pegmatite border zone. The exact position of the quartz-feldspar porphyry in this emplacement sequence can not be determined from field inspection, but radiometric age determinations indicate that at least the alteration of the porphyry is closely related in time to the emplacement of the other intrusive phases.

Radiometric Age Determinations. Radiometric K-Ar and Pb-$\alpha$ age determinations for the Juliette Creek intrusive complex and intrusive rocks of adjacent areas are listed in Table 6. Because micas will lose radiogenic $Ar^{40}$ at temperatures as low

Table 6. Radiometric age determinations for the Juliette Creek intrusive complex and plutons in adjacent areas.

| Location | Sample No. | Mineral | Rock Type | Age (m.y.) | Analyst |
|---|---|---|---|---|---|
| *1. Skylark Mine | D2340M | sericite (K-Ar) | vein selvage | 92.9 ± 3 | U.S.G.S. |
| *2. Nevada Mountain stock | ------- | biotite (K-Ar) | granodiorite | 95.9 ± 3 | -------- |
| **3. Diamond drill hole #36 | ------- | sericite (K-Ar) | quartz-feldspar porphyry | 90 to 94 | Shell research |
| +4. Pat Hughes Creek stock | D2215 | biotite (K-Ar) | vein selvage | 86.9 ± 3 | U.S.G.S. |
| +5. Pat Hughes Creek stock | D2215 | muscovite (K-Ar) | vein selvage | 85.9 ± 3 | U.S.G.S. |
| +6. Pat Hughes Creek stock | ------- | --------(K-Ar) | quartz monzonite | 88.4 ± 3 | -------- |
| #7. Idaho batholith near Pat Hughes Creek stock | ---- | biotite (K-Ar) | granite? | 94.5 ± 1.9 | Armstrong |
| #8. Meyers Cove | CPR 121 | zircon (Pb-$\alpha$) | granite | 60 ± 10 | Jaffe and others |
| #9. Meyers Cove | CPR 121 | zircon (Pb-$\alpha$) | granite | 62 ± 10 | Jaffe and others |
| #10. Middle Fork Salmon River | FWC 6-67 | biotite | granite | 42.7 ± 1.4 | Armstrong |
| #11. Middle Fork Salmon River | FWC 6-67 | whole rock (Sr) | granite | 47.0 ± 9 | Armstrong |
| #12. Middle Fork Salmon River | ------- | zircon ? | granite | 59 ± 10 | Ross |
| #13. Mackay | ------- | zircon (Pb-$\alpha$) | granite | 40 ± 10 | Nelson and Ross |
| #14. Pioneer Mountains | 862 | biotite (K-Ar) | quartz monzonite | 44.7 ± 1.3 | Armstrong |

*From Hobbs, written communication, 1975.
**N. L. Industries report; analysis done by Shell Research in 1950's

+From Marvin and others, 1973
#From Armstrong, 1976, Table 1B, pp. 12, 13.

as 200°C (Armstrong, 1966) the effects of a widespread igneous-hydrothermal-tectonic event in Early Tertiary time (McDowell and Kulp, 1969; Armstrong, 1976) may have caused partial loss of argon. Therefore, from dating magmatic biotite from the central part of the Nevada Mountain stock, a minimum age of 95.9 ± 3.3 m.y. is indicated as the time of cooling for the granodiorite phase of the Juliette Creek intrusive complex. Radiometric age determinations on hydrothermal sericite from vein selvage material near the Skylark Mine indicate that at least one mineralizing event affected the area at a slightly later date of 92.9 ± 3.3 m.y. Less reliable determinations on sericite from the altered quartz-feldspar porphyry phase indicate a similar age for the alteration of the porphyry phase of from 90 to 94 m.y. This magmatic-hydrothermal event at approximately 95 m.y. is significantly younger than the Early Cretaceous (125 m.y.) age of major igneous activity related to the Idaho Batholith, and it is older than the magmatic-hydrothermal-tectonic event of late Eocene (42 m.y.) age (McDowell and Kulp, 1969). Biotite from rocks of the Idaho Batholith southwest of the Juliette Creek intrusive complex have given a date of 94.5 ± 1.9 m.y. Thus, the Juliette Creek intrusive complex can reasonably be considered an outlier of the Idaho Batholith related to the last stages of igneous activity.

## Form of the Intrusive Complex

The outcrop pattern, drill hole intersections, and intense local deformation of the Paleozoic sedimentary rocks adjacent to the intrusive phases of the complex reflect two distinct shapes for the two major phases of the complex. The form of the Nevada Mountain and the Skylark stock is quite different from the form of the quartz feldspar porphyry phase and is indicative of other differences in the physical and chemical character of the two plutonic rock units.

The geometric relationships of the outcrop patterns of both the Nevada Mountain stock and the Skylark stock to the topography greatly restrict the shape of this part of the complex (Pls. 1 and 3, back pocket). The two stocks are quite probably interconnected just below Bayhorse Creek and are noticeably bullet-shaped with steep sides that flare outward with depth and upward arching tops. There is some evidence to suggest that at least the Skylark stock may dip more gently to the west beneath the overthrust quartzite sequences than portrayed on the geologic sections. Unpublished (N L Industries, company files) geophysical studies suggest that the exposed part of the stock may bottom at depth. The structural development of the Ramshorn Anticlinorium (Fig. 24 d, p. 175) would be more easily explained if the Skylark stock was emplaced more nearly parallel with the overlying quartzite-Ramshorn Slate contact. Also, the overlying competent quartzite unit could have reasonably exerted a certain degree of control over the emplacement of the Skylark stock by guiding the igneous mass along a zone of structural weakness.

Although high-angle faulting has subsequently accentuated the bullet-like shapes of the two partially exposed western parts of the intrusive complex, it is evident that this part of the complex is stratigraphically and topographically higher in elevation than the corresponding quartz-feldspar porphyry phase of the eastern part of the complex. The exact character of the physical connection between the quartz-feldspar porphyry phase and the granodiorite and quartz diorite phases to the west is not known with certainty. As previously discussed, the quartz-feldspar porphyry is lithologically quite distinct from the western phase, so it is not unreasonable to suppose that the two phases are discontinuous units separated by country rock.

Drill hole intersections and the shape of the Bayhorse Anticline indicate that the quartz-feldspar porphyry phase has a much broader and flatter top and is shaped more like a piston than a bullet. Regional aeromagnetic data (Fig. 10, p.62 ) suggest that the entire Bayhorse Mining District is underlain by a large, continuous igneous mass. The Juliette Creek intrusive complex most likely represents small cupola-like projections on the upper surface of this much larger plutonic mass.

Mode and Depth of Emplacement

Field relations of the Juliette Creek intrusive complex to the adjacent country rocks clearly indicate that the complex was forcefully emplaced into the transitional zone between the epizone and mesozone levels of intrusion as defined by Buddington (1959). Since the intrusive complex has features characteristic of both zones, the depth of emplacement of this igneous mass can be rather narrowly limited to the range from 4 to 5 miles. Independent calculations based upon stratigraphic considerations are entirely consistent with such a range for the depth of emplacement of the complex. In addition, the effects of thermal metamorphism on the adjacent country rocks support this depth range and are discussed on pages 141 to 151.

The Juliette Creek intrusive complex has the following features normally considered to be indicative of plutons of the epizone. The intrusive plugs are relatively small and in sharp contact with the country rock. The complex consists predominantly of variably porphyritic granodiorite with relatively little lithologic diversity. Late-stage aplitic dikes, associated with small concentrations of pegmatite and granophyre, are volumetrically of minor importance and wholly restricted to the border and roof zones of the complex. Foliation and lineation within the complex are indistinct and restricted to the border zones of the intrusive mass. Regional metamorphism of the country rocks is well below the green-schist grade of metamorphism and parallelism of schistosity in the adjacent argillaceous wall rocks of the igneous complex is absent.

The plutonic complex also has certain features usually inferred to be characteristic of plutons of the mesozone. The contact relationships of the intrusive complex with the country rocks are complex and are of both a discordant and concordant character. Chilled border zones, contact breccias, explosion breccias, xenoliths and roof pendants are almost totally absent as are any possible co-magmatic volcanic rocks. Miarolitic structures are wholly absent from the aplite and pegmatite dikes. Characteristically, the argillaceous country rocks of the area are slate and phyllite which have been intensely deformed and variably metamorphosed near the border of the intrusive complex.

Buddington (1959) also suggests that epizonal plutons are generally younger than Early Cretaceous in age, while plutons of mesozonal character are usually somewhat older. The Middle Cretaceous age of the Juliette Creek intrusive complex is broadly consistent with the suggested period of time necessary to permit erosion to expose plutons of the transitional zone.

Broader geologic considerations are also in close agreement with the depth of emplacement estimated from the zonal characteristics described by Buddington (1959). It is certain that a large amount of erosion has taken place since the time of emplacement of the intrusive complex. The magmatic-hydrothermal-tectonic event affecting central Idaho during the middle Eocene (McDowell and Kulp, 1969; Armstrong, 1976) was preceded by profound elevation of the surface which initiated the erosion cycles of the early Eocene (Umpleby, 1913, p. 36 and Ross, 1937, p. 88). The comparatively great accumulations of fluviatile deposits in adjacent areas during the early Eocene are indicative of the high elevations rapidly attained in parts of central Idaho. The total amount of erosion following emplacement of the intrusive complex during the Middle Cretaceous, but preceding the deposition of the middle Eocene volcanics is not known. However, the Nevada Mountain stock is cut by the Eocene erosion surface upon which at least 4000 feet of relief was developed (Ross, 1937, p. 88). From an examination of the thickness of the regional stratigraphic units as revealed in the anticlinal structures of the district (Ross, 1937, Pl. 1), it is apparent that a much greater thickness of Paleozoic sedimentary rocks was removed after emplacement of the complex. As uplift and erosion are not believed to have been operative on a large scale in this region during most of Triassic and Jurassic time, it is not unreasonable to assume that the complex was emplaced beneath most of the 20,000 to 25,000 feet of Early Ordovician to Pennsylvanian sedimentary rock.

Mineral vein material holds a remarkable degree of continuity over a large vertical and horizontal extent. The repetitive introduction of solutions of diverse composition during repeated pressure release through opening and reopening of fissures connected to a surface environment would produce quite different effects from those observed. Thus, they suggest that the igneous system was operative at a considerable depth below the surface.

The specific gravities of 5 samples of unaltered granodiorite and 5 samples of Ramshorn Slate were determined and are presented below.

| | | | | | |
|---|---|---|---|---|---|
| Granodiorite | 2.86 | 2.83 | 2.79 | 2.75 | 2.82 |
| Slate | 2.65 | 2.61 | 2.59 | 2.57 | 2.68 |

The specific gravity of the slate is less than that of the granodiorite. In addition, roof pendants and country rock xenoliths are notably absent. These observations suggest that a passive mode of emplacement characterized by piece-meal magmatic stoping was not an effective process in this system and supports the contention that a forceful mode of emplacement was the dominant process of magma intrusion.

## Physical Conditions at Time of Emplacement

The three main phases of the Juliette Creek intrusive complex were emplaced into a similar environment, but in slightly differing physical states. The quartz diorite phase was first to be emplaced and was essentially liquid as indicated by the absence of phenocrysts and the uniformly equigranular character of the rock. Although the deuteric alteration of hornblende to biotite indicates the presence of late-magmatic water, there is little else to suggest that water was an important constituent of the intrusive phase. The quartz diorite must have been nearly solid upon emplacement of the granodiorite phase as indicated by xenoliths of quartz diorite in the granodiorite and the relatively sharp character of the contact between the two phases.

The granodiorite is variably porphyritic and has phenocrysts of both plagioclase feldspar as well as orthoclase of two distinct generations that suggest a two-stage process of crystal growth. However, the granodiorite was essentially liquid upon emplacement and did not carry enough crystals to produce any significant flow structure. Apparently, the molten rock solidified after movement of the magma had ceased as brecciation of the intrusion and country rock is absent. The absence of chill margins and the coarse, equigranular texture of the groundmass suggest relatively slow cooling. In addition, the large thermal aureole surrounding the granodiorite phase suggests comparatively high temperatures. The granodiorite did have sufficient water, at least towards the end stages of magmatic differentiation, to produce some minor aplite and pegmatite dikes. However, the absence of the effects of pervasive alteration, quartz phenocrysts, hydrous mineral phases, and fluid inclusions suggest that the granodiorite neither was saturated with water nor could it have served as a source for mineralizing solutions.

Emplacement of the quartz-feldspar porphyry phase was physically different from that of the quartz diorite and granodiorite phases. The porphyry contains nearly 50 percent phenocrysts of feldspar and quartz which indicate that crystallization had proceeded far toward completion prior to emplacement. Thus, the magma was in a partially solid state when it was forced into the country rocks. The restricted development of the thermal aureole in the adjacent carbonate and argillaceous country rocks as compared to the aureole surrounding the western intrusive phases indicates that the quartz-feldspar porphyry was comparatively cooler upon emplacement. The porphyry also differed significantly in its water content. The pervasive alteration associated with the intrusive phase and the abundance of fluid inclusions are indicative of higher water pressures and comparatively large amounts of excess water. The presence of quartz phenocrysts may also be indicative of a high water content of the parent magma.

The development of a quartz-feldspar porphyry can be explained in at least two ways. The ternary diagram for the system quartz-albite-orthoclase (Q-Ab-Or) is presented in Figure 13 (Tuttle and Bowen, 1958).

Point A represents a magma with an $SiO_2$ content

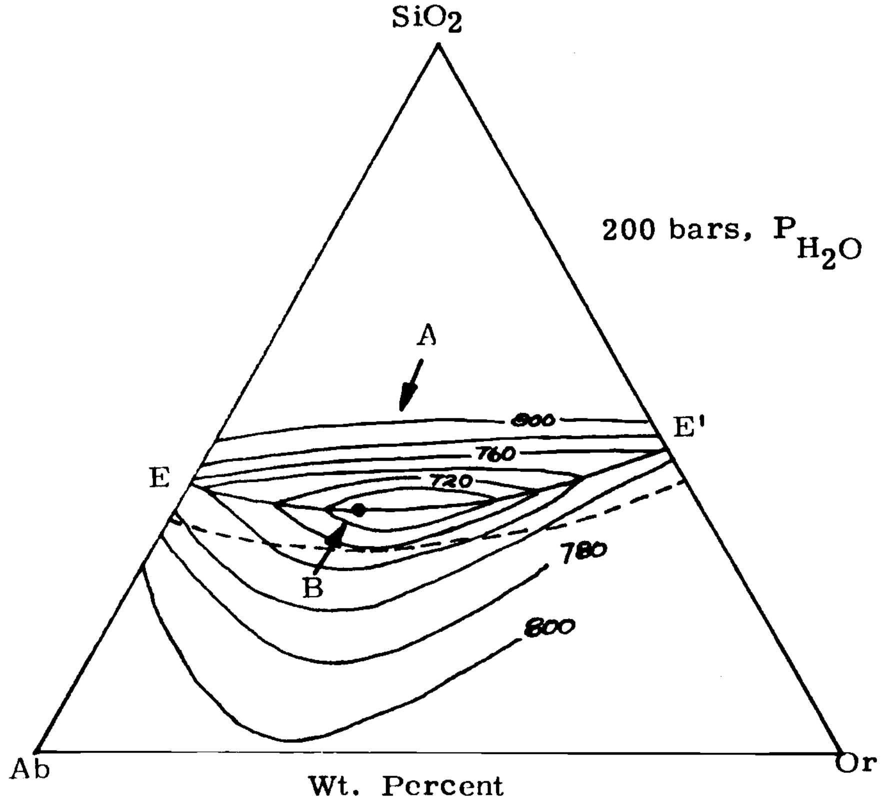



Figure 13 - Ternary eutectic diagram (modified after Tuttle and Bowen, 1958).

greater than 75 percent. Quartz will crystallize first as the magma cools and the composition of the magma will move toward the eutectic along E-E'. When the eutectic composition is reached, feldspars and quartz will crystallize. Rapid cooling at this stage would produce a quartz-feldspar porphyry. However, few magmas including the quartz-feldspar porphyry are sufficiently rich in silica to precipitate quartz in the above manner.

The second process involves an increase in the amount of water or $P_{H_2O}$ of a magma whose composition plots below the eutectic trough (point B in Fig. 13). Such an increase may come about by the concentration of water in the upper part of the magma chamber as crystallization proceeds by the incorporation of water from country rocks or by crystallization of anhydrous phases. The effect of the addition of water to the system is to lower the eutectic trough towards Ab-Or.

As the magma whose composition plots at point B cools, feldspar begins to crystallize and the composition of the magma is driven upward toward the trough. Addition of water causes the eutectic trough to simultaneously migrate downward toward point B. If sufficient water were added to the system the trough could be depressed below the composition of the remaining magma. This would then result in the precipitation of quartz with concomitant resorbtion of feldspar. Rapid cooling at this point would result in the formation of a quartz-feldspar porphyry if the original feldspar crystals were incompletely resorbed. If water was lost from the system because of a sudden release of pressure during the final stages of emplacement, perhaps through gas streaming along fracture zones, the liquidus would move back towards its original position and result in the resorbtion of the earlier formed quartz crystals. Such a process would account for the embayed appearance of the "quartz eyes" in the quartz-feldspar porphyry. It would also provide a mechanism for the sudden transfer of heat away from the intrusive and thus explain the absence of contact metamorphic effects on the adjacent country rocks. Geologic evidence, therefore, indicates that the quartz-feldspar porphyry was water rich. The above discussion presents a generalized explanation for the formation of the highly embayed quartz phenocrysts in this rock.

It is important to note that all three phases were subjected to considerable post-consolidation stresss as all discernible crystal phases are intensely strained. This may have been caused by either one of two separate events, or more likely by a combination. Stress related to the volcano-tectonic event that resulted in the eruption of the Challis Volcanics in middle Eocene time could explain the observed effects. However, the emplacement of yet another phase or phases of the intrusive complex not presently exposed might also account for the observed strain and mineralization of the district. The existence of additional igneous phases at depth is not inconsistent with the available aeromagnetic data, but it is admittedly highly speculative to suggest any relationship with mineralization events.

## Chemical and Mineralogical Variation

The small exposures of the Juliette Creek intrusive complex severly limit detailed observations regarding any chemical and mineralogical variations that may exist. The quartz diorite phase is essentially homogeneous in chemical and mineralogical composition over the small area where it is exposed. Any discernible variation in the primary chemical and mineralogical composition of the quartz feldspar porphyry phase that may have existed has been subsequently masked by intense hydrothermal alteration. The granodiorite phase is somewhat better exposed and has undergone less alteration so that variations in the primary chemical and mineralogical composition of the rock are discernible from field observations and the available chemical data and they warrant a brief comment.

Major oxide constituents vary in a systematic manner with distance from the intrusive contact. Evidently, late-stage magmatic liquid became progressively enriched in $SiO_2$ and $K_2O$ and correspondingly depleted in CaO, $Na_2O$, FeO and MgO. This trend is perhaps best reflected by the variation in mineralogy. A gradational change in lithology from granodiorite through quartz monzonite to granite and finally aplite and pegmatite with increasing proximity to the intrusive contact is apparent. The character and geometry of these variations are quite normal and indicate that the processes of magmatic fractionation were operative on a small scale along the upper margins of the granodiorite intrusive phase. The geometry of the variation pattern also indicates that the complex has not undergone a great deal of erosion as the more silicic border phases can still be found scattered over the top of the complex.

# VI. TERTIARY VOLCANIC ROCKS

Following the major period of deformation during Mesozoic time, the region was rapidly uplifted and deeply eroded. The approach towards a gently rolling peneplain was halted by rejuvenation of the mature topography in early Eocene time. Steep and locally precipitous slopes were carved in the nearly flat surface, so that the total relief was probably as great as that of the present day topography. It was upon this surface that the Tertiary volcanic deposits were formed.

## Challis Volcanics

The volcanic rocks of this part of central Idaho belong to the sequence termed the Challis Volcanics by Ross (1934). The formation is widely scattered over the region (Fig. 3, p. 12) and is centered near the town of Challis, for which the sequence was originally named. The original description of the Challis Volcanics (Ross, 1934, pp. 46-48) was of a general character, but more detailed information has become available and they have since been redefined and restricted (Ross, 1961). The Challis Volcanics represent the lower part of the Early Tertiary stratigraphy within the Bayhorse Mining District and they locally cover the Paleozoic and Mesozoic rocks of the area. Within the district, the formation is a thick, coherent unit consisting mainly of flows and flow breccias of a wide compositional range and in which sedimentary and pyroclastic deposits and locally interbedded.

Regional deformation and erosion have separated the exposures of the formation into large areas. The distribution of the erosional remnants indicate that with the possible exception of some of the highest peaks, the formation originally covered most of the Bayhorse district. The Challis Volcanics vary greatly in thickness over their regional extent, but are generally near 2500 feet thick, although locally they may exceed 5000 feet. The stratigraphic relations of similar units within the sequence of volcanic rocks vary greatly because they are all affected by the order and extent of eruptive events, the local paleotopography and intermittent erosion.

Although the formation varies in character from place to place, (Ross, 1961) believed that certain general characteristics were sufficiently consistent to permit subdivision into three major members. The greater part of the formation consists of flows ranging from latite to andesite in composition with intercalated beds of tuff, rhyolite and basalt. This aggregate was termed the latite-andesite member.

Scattered through the latite-andesite member are thick assemblages of dominantly pyroclastic rocks and sedimentary rocks mostly as fillings of large separated depressions. Thin flows of basalt and calcic and calc-alkaline andesite are commonly interbedded with the clastic rocks. This assemblage was named the Germer tuffaceous member and was described from exposures in the Germer Basin three miles southeast of the Bayhorse townsite. A distinctive series of silicic rocks, commonly associated with the Germer tuffaceous member, was designated the Yankee Fork Rhyolite Member. The volcanic rocks that are exposed within the map area were originally mapped by Ross (1937) as part of the latite-andesite member of the Challis volcanics. The Germer tuffaceous member is not well-developed and the Yankee Fork Rhyolite Member is not present.

An attempt was made to further subdivide the volcanic rocks that are exposed within the area of study. A diagrammatic columnar section is presented in Figure 14 to show the generalized characteristics of the sequence. Lack of continuity between units and generally poor exposures complicate correlations, so contacts may not be exactly as represented in some areas. Removal of the volcanic rocks from the top of the anticlinal structures in the district has effectively separated the volcanic rocks into two separate sequences. Hence, the correlation between the volcanic rocks of the western margin of the study area with those of the eastern margin is not known with certainty. The Challis Volcanics were divided into six separate units and will be discussed in approximate order from oldest to youngest: (1) rhyodacite lava of the Bayhorse Lakes, (2) bedded silicic tuff, (3) andesitic lava flows, (4) rhyodacite lava northeast of Beardsley Gulch, (5) rhyodacite lava of Buffalo

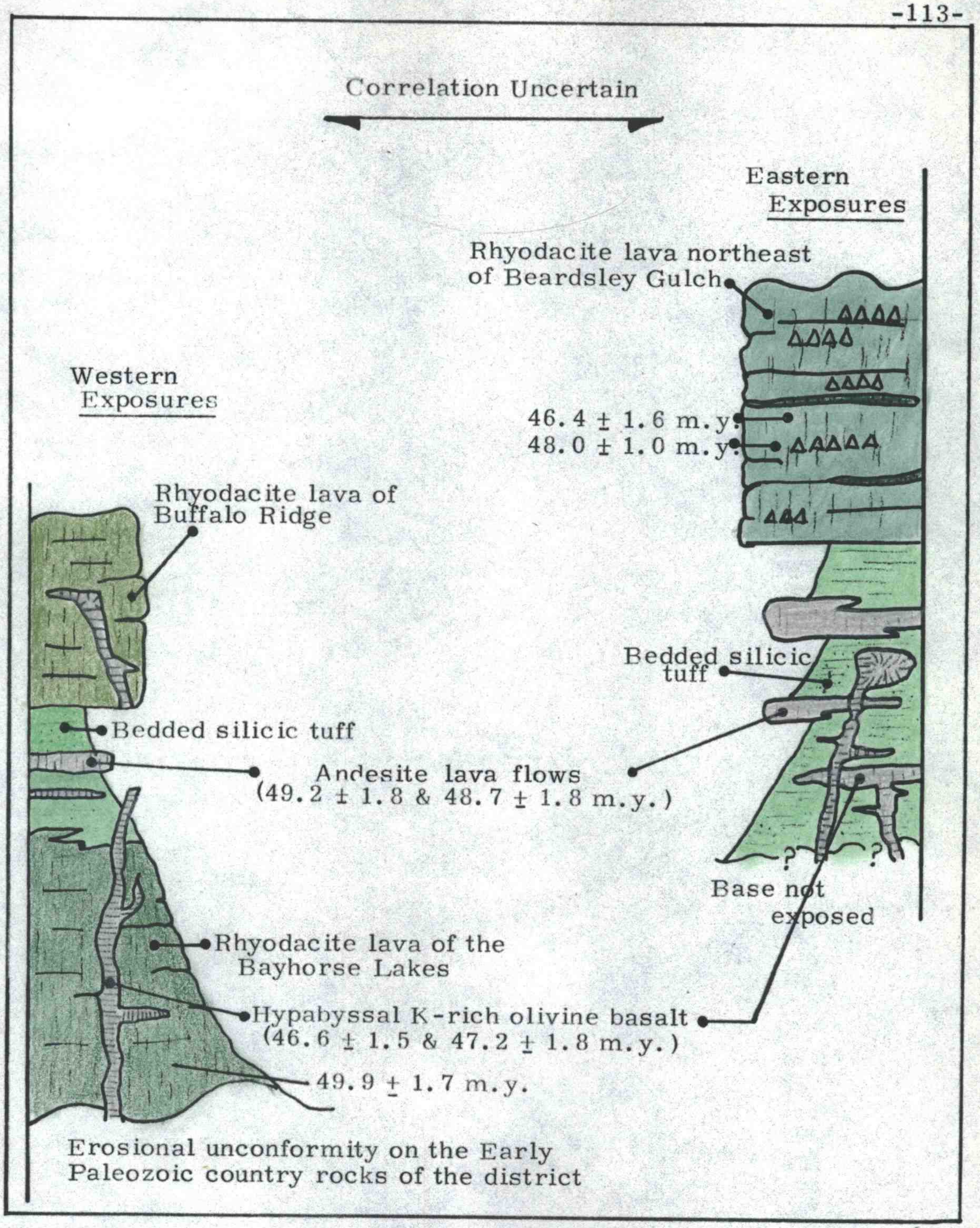



Figure 14.
Columnar section of the Challis Volcanics exposed within the area of study. Thicknesses are highly variable so the section is diagrammatic and not to scale.

Ridge, and (6) hypabyssal K-rich olivine basalt.

Rhyodacite Lava of the Bayhorse Lakes. Juliette Basin and adjoining areas to the north are underlain by rhyodacitic lavas that filled depressions in the ancient topography and contributed to the formation of a near level surface, locally surmounted by isolated ridges and knobs of quartzite and slate. Weathering of the lavas has produced a smooth gently rolling surface with only scattered rounded knobs cropping out through the cover of vegetation. Flows of the sequence are predominantly light-bluish-gray (5 B 7/1) on fresh surfaces and weather readily to a light-olive-gray (5 Y 5/2). Columnar jointing is not well-developed in the lavas, but flow banding is generally present. Attitudes of subtle flow banding are variable, but tend toward the horizontal, indicating that the lavas originally flowed out on a gently rolling surface. Thus, they have been only slightly modified by subsequent folding and faulting. Joint sets, measured on the few available exposures have a near vertical plunge and strike to the northeast. Contact relationships are poorly exposed in the deeply weathered outcrops. However, the outcrop pattern indicates that the lavas lie with marked unconformity upon the Paleozoic rocks of the area. Hence, the thickness of the unit is highly variable, but probably does not greatly exceed several hundred feet.

The rhyodacitic lavas are predominantly vitrophyric and contain subequal proportions of from 20 to 50 percent phenocrysts, as large as 2 mm across (Pl. 20), and glass. Crystals of plagioclase feldspar, quartz, biotite and amphibole in varying proportions are visible in hand specimen and are commonly set in a crumbly devitrified goundmass. Xenoliths of slate and quartzite are locally present.

Thin section examination shows that the rock generally consists of fragment trains of broken, embayed phenocrysts in a partially devitrified glassy groundmass in which crystallites are commonly present (Pl. 20) . The groundmass commonly has an index of refraction less than 1.5 and generally composes greater than 50 percent of the rock so the flows can be expected to contain more than 10 percent normative quartz. Devitrification enhances otherwise faint flow banding within the glass. Some flows having a more felsitic groundmass are composed of intimate intergrowths of small needles of feldspar and quartz.

The plagioclase feldspar was originally rounded, commonly poikolitic and is now ubiquitously broken into angular fragment trains. The plagioclase feldspar displays a high degree of oscillatory zoning that hinders precise determination of composition. Polysynthetic albite twinning in crystals that are less zoned are of a composition near calcic andesine-sodic labradorite ($An_{50}$).

Quartz phenocrysts occur as highly broken fragments of originally rounded and embayed crystals. Small crystals of

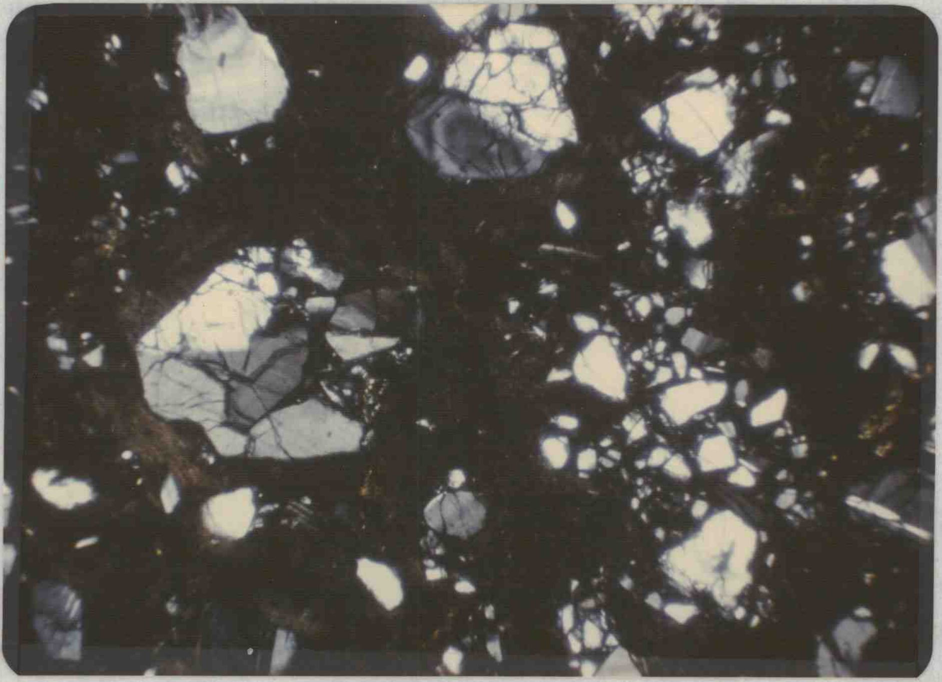


Plate 20. Photomicrograph of rhyodacite lava of the Bayhorse Lakes (x-nicols, 35x)

orthoclase displaying well-developed rhombic cross-sections are also present in small quantities. In addition to broken crystals, the effects of strain during extrusion of the lavas are similarly displayed by crystals of kinked and broken biotite and amphibole. They also poikolitically enclose euhedral apatite needles and trace amounts of zircon.

Pyroxene is restricted in occurrence to local, more-andesitic flows where both orthopyroxene and clinopyroxene are present. The pyroxene is commonly embayed and poikolitically encloses glass, feldspar and quartz. Feldspar phenocrysts are less common in these flow rocks.

Alteration products include chlorite and magnetite after biotite, amphibole and pyroxene together with clay minerals, sericite, carbonate and zeolites after feldspar. McIntyre (Hobbs and others, 1975, p. 5) reports that flows of both normal and reverse magnetic polarity are present within the sequence. Biotite has yielded a K-Ar age determination of 49.9 $\pm$ 1.7 m.y. (R. F. Marvin, written comm., 1973, cited in Hobbs and others, 1975, p. 5).

Two samples were selected as representative of the larger part of the sequence and analyzed for major oxide constituents. The results of the analyses are presented in Table 7 and compared to Nockolds average quartz latite and rhyodacite. The

Table 7. Chemical and modal analyses of rhyodacite lava of the Bayhorse Lakes compared to the average quartz latite and rhyodacite of Nockolds.

Chemical Analyses (percent)

| | Average** quartz latite | WAH-56 | WAH-57 | Average** rhyodacite |
|---|---|---|---|---|
| $SiO_2$ | 70.15 | 70.5 | 66.30 | 66.27 |
| $Al_2O_3$ | 14.41 | 15.1 | 15.47 | 15.39 |
| FeO* | 3.23 | 3.4 | 4.52 | 4.37 |
| MgO | 0.63 | 0.6 | 1.64 | 1.57 |
| CaO | 2.15 | 3.0 | 3.92 | 3.68 |
| $K_2O$ | 4.50 | 2.65 | 2.98 | 3.01 |
| $Na_2O$ | 3.65 | 3.1 | 3.76 | 4.13 |
| $TiO_2$ | 0.42 | 0.45 | 0.59 | 0.66 |
| MnO | 0.06 | --- | --- | 0.07 |
| $P_2O_5$ | 0.12 | ---- | --- | 0.17 |
| | 99.32 | 99.80 | 99.18 | 99.32 |

Modal Analyses (percent)

| WAH-56 | | WAH-57 | |
|---|---|---|---|
| Phenocrysts | | Phenocrysts | |
| Plagioclase | 30 | Plagioclase | 20 |
| Quartz | 10 | Quartz | 18 |
| Biotite | 10 | Biotite | 8 |
| | | Hornblende | 11 |
| Groundmass | | Groundmass | |
| Devitrified glass | 50 | Devitrified glass | 53 |
| | 100 | | 100 |

*Total iron reported as FeO
**Average of Nockolds (1954)

differences in the various oxide constituents are accounted for by variations in the modal content of biotite and hornblende in these samples. The two samples are in close agreement with the average biotite granodiorite and hornblende-biotite granodiorite sub-groups of Nockolds, and they correspond closely in composition with the rhyodacite group of rocks.

Bedded Silicic Tuff. Pyroclastic rocks, mapped as bedded silicic tuff crop out along the western and eastern margins of the study area. The tuffaceous rocks exposed over the western area lie upon the rhyodacite sequence previously described and are interbedded with thin layers of andesite which are described in the next section. Silicic tuff is the lowest visible unit of the volcanic rock sequence in eastern exposures and is similarly interbedded with thin layers of andesite flow rock. The silicic tuff of the eastern area borders the type area of the Germer tuffaceous member, three miles southeast of the Bayhorse townsite and probably is correlative with it. The tuffaceous rocks of both areas vary greatly in detail over their areal extent, so much so, that nearly each new exposure presents slightly different characteristics from the last. However, the tuffaceous rocks of both areas share certain general lithologic and stratigraphic characteristics and although the rocks of the two sequences may not be precise stratigraphic equivalents, they were mapped as one unit.

The silicic bedded tuff readily weathers to rounded, float covered hills and is best exposed near the more resistant outcrops of dike and flow rocks. The sequence consists predominantly of the medium to very finely crystalline products of explosive volcanism and the units range from ash fall tuff to crystal-rich lapilli tuff.

Tuff, indicative of an ignimbritic origin, has been reported from the Germer Basin area, but none was noted within the area of study. Rocks of the sequence are generally light-gray (N 7) to very-light-gray (N 8) in color. Small lenses of mudstone, sandstone and conglomeratic material are locally indicative of minor water-sorting. Fossilized wood and leaf fragments are also locally present. The thickness of the tuffaceous sequence is variable, but as indicated by the outcrop pattern, probably does not greatly exceed 400 feet anywhere within the study area.

The most common variety of tuff consists mainly of crystal fragments of igneous minerals, commonly less than a millimeter across, enclosed in a very fine grained groundmass of similarly broken crystals with admixtures of glass shards and dust. Pumice fragments and xenoliths of slate, quartzite and porphyritic lava are locally present. The crystalline components consist of fragments of embayed quartz crystals, orthoclase, zoned plagioclase feldspar (andesine to oligocene), biotite, hornblende and pyroxene in varied proportions. Accessory minerals that are commonly present in trace amounts include apatite, sphene and zircon both as separate crystals and as inclusions in biotite and hornblende. Silica is the dominant alteration product and it is commonly accompanied by chlorite group minerals and magnetite granules that replace the mafic constituents. Sericite, clay minerals and carbonate commonly replace the feldspars.

Although no chemical analyses were made of the crystal and vitric tuffaceous rocks, the uniformly low index of refraction of the associated glass fragments and the predominance of quartz, orthocloase feldspar and sodic plagioclase feldspar are indicative of the overall silicic composition of the sequence.

<u>Andesitic Lava Flows</u>. Andesitic flow rocks occur as isolated local accumulations that are interstratified with the bedded silicic tuff along the western and eastern margins of the study area. The largest exposure is located along the east-central border of the map area. It is slightly less than 500 feet thick at its greatest development and this unit thins rapidly to the east of the district. The andesite is remarkably fresh in surface exposures and is rather resistant to weathering. Thus, it stands in relief as small ledges and is commonly found capping ridges. Only one outcrop, located midway up Beer Keg Gulch, displayed well-developed columnar jointing. McIntyre (oral comm., 1975) suggests that the geometry of the andesitic flows to the east of the study area

and the association with numerous small intrusive dikes and plugs are indicative of a small shield-shaped volcanic edifice.

The andesitic rocks are dark-gray (N 3) and dark-greenish-gray (5 G 2/3) and weather to a light-brown (5 YR 6/4) and moderate-brown (5 YR 4/4). The flows are variably microporphyritic with as much as 25 percent of subhedral olivine and pyroxene up to 2 mm across as phenocrysts in a much more finely crystalline groundmass. Nearly spherical vesicles up to several centimeters in diameter are locally abundant and are commonly filled with cryptocrystalline silica.

Microscopic examination shows that the andesitic rocks generally have a variably microporphyritic hyalophitic to hyalopilitic texture where turgid iron-rich glass envelops microlites of plagioclase feldspar and microphenocrysts of olivine, plagioclase feldspar, augite and hypersthene (Pl. 21 and Table 8). Plagioclase feldspar occurs as microlites in the groundmass and as larger microphenocrysts. Both generations are within the Labradorite composition field. The larger crystals commonly display oscillatory zoning and many are embayed and poikolitic. Albite and pericline twinning are ubiquitous within the larger crystals. Subhedral crystals of olivine, augite and hypersthene occur in subequal proportions as microphenocrysts. Apatite needles are also present in trace amounts as are quartz xenocrysts. Although the andesitic flow rocks are generally quite fresh, clay minerals,

Plate 21. Photomicrograph of andesite
(x-nicols, 35x)

Table 8. Chemical and modal analyses of two andesite flows compared to the average calc-alkali andesite.

| Chemical Analyses (percent) | | | |
|---|---|---|---|
| | Average calc-alkali andesite | WAH21-75 | WAH21 |
| $SiO_2$ | 59.0 | 58.8 | 57.6 |
| $Al_2O_3$ | 18.0 | 15.4 | 16.5 |
| FeO* | 6.4 | 7.8 | 7.2 |
| MgO | 3.3 | 5.2 | 3.3 |
| CaO | 6.3 | 5.8 | 5.7 |
| $K_2O$ | 2.0 | 2.60 | 2.80 |
| $Na_2O$ | 3.9 | 3.1 | 3.1 |
| $TiO_2$ | 0.8 | 1.15 | 0.90 |
| MnO | -- | -- | -- |
| $P_2O_5$ | -- | -- | -- |
| | 99.7 | 99.85 | 99.10 |

| Modal Analyses (percent) | | | |
|---|---|---|---|
| Eastern area WAH 21-75 | | Western area WAH21 | |
| Phenocrysts | | Phenocrysts | |
| Hypersthene | 6 | Plagioclase | 30 |
| Augite | 4 | Augite | 7 |
| Olivine | 5 | Hypersthene | 10 |
| | | Olivine | 3 |
| Groundmass | | Groundmass | |
| Plagioclase microlites | 30 | Glass | 50 |
| Glass | 30 | | |
| Hypersthene | 13 | | 100 |
| Augite | 10 | | |
| Olivine | 2 | | |
| | 100 | | |

*Total iron reported as FeO

sericite and carbonate are ubiquitous minor alteration products of feldspar. Olivine invariably shows some alteration to iddingsite. The pyroxene is usually unaltered.

K-Ar age determinations on lithologically similar flows near the base of the local volcanic stratigraphic section northeast of the area of study near Daugherty Spring gave ages of 49.2 $\pm$ 1.8 m.y. and 48.7 $\pm$ 1.8 m.y. (R. L. Armstrong, 1974, cited in Hobbs and others, 1975).

Two whole rock chemical analyses are presented in Table 8 for selected samples of andesite and they are compared to the average calc-alkaline andesite. The chemical composition of the flow rocks does not vary significantly from the average calc-alkaline andesite.

Although the modal compositions of the andesites from the two spatially separated areas are different, the two rocks are chemically quite similar and would appear to be genetically related.

McIntyre (Hobbs and others, 1975) maps several flows of K-rich olivine basalt in place of the andesitic flow rocks described here. However, the chemical analyses of the selected samples presented in Table 8 are definitely of andesitic composition. Also, the modal analyses of five additional samples did not differ significantly from those presented in Table 8. Hence, the writer believes that these flow rocks are predominantly of andesitic composition and may be intercalated with minor amounts of K-rich olivine basalt.

Rhyodacite Flows Northeast of Beardsley Gulch. Lavas and flow breccias cap the hills in the northeast corner of the area of study and overlie the bedded silicic tuff and intercalated basalt flows previously described. Fresh samples are light-olive-gray (5 Y 5/2) and weather readily to a moderate-yellowish-brown (10 YR 5/4). The silicic volcanic rocks are dense, brittle and highly fractured and form prominent cliff faces with basal blocky to crumbly talus piles. Based upon subtle flow banding and columnar jointing the flows lie upon a gently undulating surface. The thickness of the unit within the map area is variable, but probably does not greatly exceed 600 feet. The regional geometry of the sequence suggests that the thick flow and dome-like masses of the sequence were extruded chiefly from vents located beneath and near Blue Mountain, which is located 2 miles northeast of the northeast corner of the study area (Hobbs and others, 1975). The sequence contains flows of both normal and reverse polarity (Hobbs and others, 1975). The flow sequence is cut by numerous steeply dipping, north trending faults and joints that evidently have localized latter hydrothermal solutions as the volcanic rocks are generally highly silicified and zeolitized along these zones.

In hand specimens subhedral phenocrysts of white plagioclase feldspar (3 to 4 mm) and black pyroxene (4 to 6 mm) are readily visible in subequal proportions and total from 20 to 40 percent of the rock. The groundmass is very finely crystalline.

In thin section, the rhyodacitic flows display a porphyritic hyalopilitic texture in which phenocrysts of plagioclase feldspar, clinophroxene, orthopyroxene, biotite and trace amounts of apatite are randomly oriented in a groundmass of turbid iron-rich glass that is commonly devitrified (Pl. 22). The plagioclase feldspar varies from andesine to labradorite in composition and occurs as large subhedral crystals that are usually embayed and poikolitic. The crystals commonly display polysynthetic twinning and oscillatory zoning. Many of the crystals are transversed by closely spaced anastamosing fractures indicative of strain during flow. The feldspar is relatively unaltered although sericite, clay minerals and carbonate are localized by cross cutting microfractures. Pale-green augite and pleochroic hypersthene occur as embayed poikolitic subhedra. Biotite is pleochroic from yellow to dark brown and commonly contains inclusions of zircon and apatite. The mafic constituents are usually altered to magnetite granules and clay minerals along crystal margins and microfractures. Pseudomorphs of iddingsite are indicative of the former presence of olivine as small (0.05 mm) subhedral crystals. The

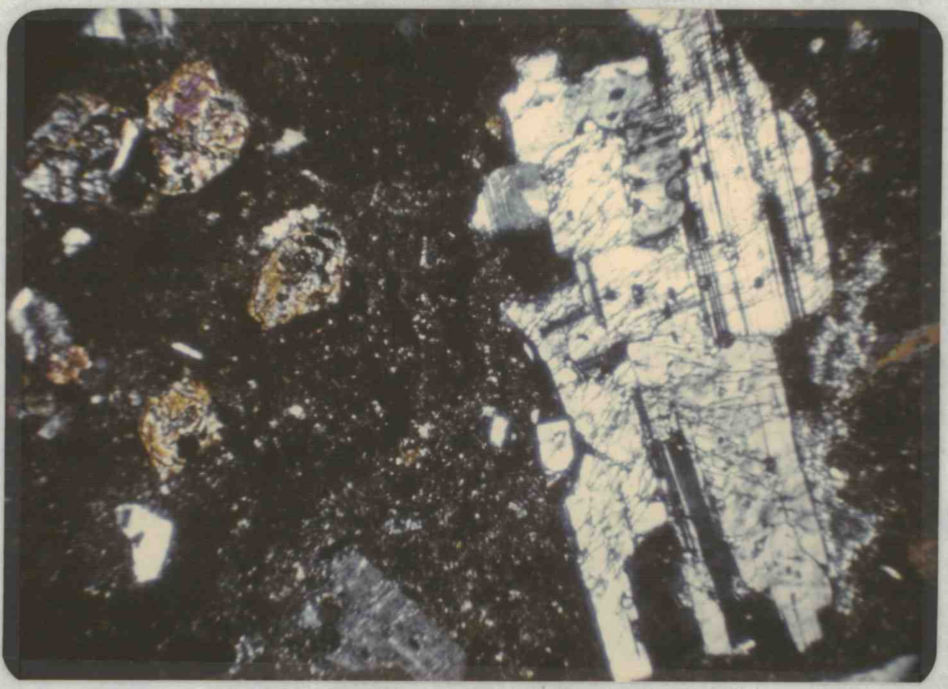


Plate 22. Photomicrograph of rhyodacite lava northeast of Beardsley Gulch (x-nicols, 35x)

Table 9. Chemical and modal analyses of rhyodacite lava northeast of Beardsley Gulch compared to the average rhyodacite and hypersthene-bearing granodiorite of Nockolds.

**Chemical Analyses (percent)**

| | Average** rhyodacite | WAH-63 | Average** hypersthene-bearing granodiorite |
|---|---|---|---|
| $SiO_2$ | 66.27 | 63.3 | 62.64 |
| $Al_2O_3$ | 15.39 | 15.3 | 15.82 |
| FeO* | 4.37 | 5.6 | 5.90 |
| MgO | 1.57 | 3.3 | 2.83 |
| CaO | 3.68 | 4.6 | 4.72 |
| $K_2O$ | 3.01 | 2.90 | 2.62 |
| $Na_2O$ | 4.13 | 3.1 | 3.37 |
| $TiO_2$ | 0.66 | 0.70 | 1.32 |
| MnO | 0.07 | ---- | 0.09 |
| $P_2O_5$ | 0.17 | ---- | 0.27 |
| | 99.32 | 98.80 | 99.58 |

**Modal Analyses (percent)**

| | WAH-63 |
|---|---|
| Phenocrysts | |
| Plagioclase | 29 |
| Hypersthene | 7 |
| Augite | 3 |
| Biotite | 2 |
| Groundmass | |
| Devitrified iron-rich glass | 59 |
| | 100 |

*Total iron reported as FeO
**Average of Nockolds (1954)

glass groundmass is commonly devitrified and zeolitized.

K-Ar age determinations from samples near Blue Mountain (R. L. Armstrong, 1974, cited in Hobbs and others, 1975) give ages of 46.4 ± 1.6 m.y., 48.0 ± 1.0 m.y. and an anomalously young age of 44.7 ± 1.0 m.y. which is probably caused by a relatively high degree of alteration in the sample.

A whole rock chemical analysis of a representative sample of rhyodacite is presented in Table 9 and compared to the average rhyodacite and hypersthene-bearing granodiorite of Nockolds (1954). The slight variance in oxide constituents of the selected sample from the average rhyodacite are accounted for primarily by variations in the modal abundance of hypersthene.

Rhyodacite Lava of Buffalo Ridge. Rhyodacitic flow rocks overlie the bedded silicic tuff of the western part of the district and cap Buffalo Ridge. The rocks of this sequence are dense, brittle and highly fractured and they weather readily to form blocky talus piles characteristic of the ridge top. Attitudes of faint flow banding and columnar jointing from exposures along Buffalo Ridge northwest of the study area indicate a gently rolling surface that is perhaps inclined slightly to the west. Within the study area the unit is somewhat less than 500 feet thick.

The rhyodacitic lavas are a light-olive-gray (5 Y 6/1) on fresh surfaces and weather to a grayish-brown (5 YR 3/2).

Hand specimens are distinctly porphyritic and contain approximately 45 percent of phenocrysts of plagioclase feldspar, pyroxene and rare biotite as large as 3 mm in size. The groundmass consists of more finely crystalline aggregates of a similar mineralogy.

Thin section examination shows that the rocks are nearly holocrystalline with a porphyritic intersertal texture in which only small amounts of turbid iron-rich glass fill the interstices between randomly oriented microlites of plagioclase feldspar, quartz and apatite in addition to the phenocrysts of plagioclase feldspar, clinopyroxene, orthopyroxene and rare biotite (Pl. 23). The plagioclase feldspar is Andesine ($An_{43-47}$) and occurs as minute microlites in the groundmass and as embayed and poikolitic phenocrysts. Polysynthetic albite twinning is abundant as is oscillatory and normal zoning. Clear diopsidic augite and pleochroic hypersthene are present as subhedral phenocrysts and as smaller crystals in the groundmass. Biotite occurs as rare flakes in the groundmass. The biotite is generally highly altered to opaque iron oxides, but only minor alteration of the other constituents is normally evident.

A representative sample of rhyodacite was analyzed for its major oxide constituents and the analysis is presented in Table 10 together with the average rhyodacite and hypersthene-bearing granodiorite of Nockolds (1954). The differences in the major

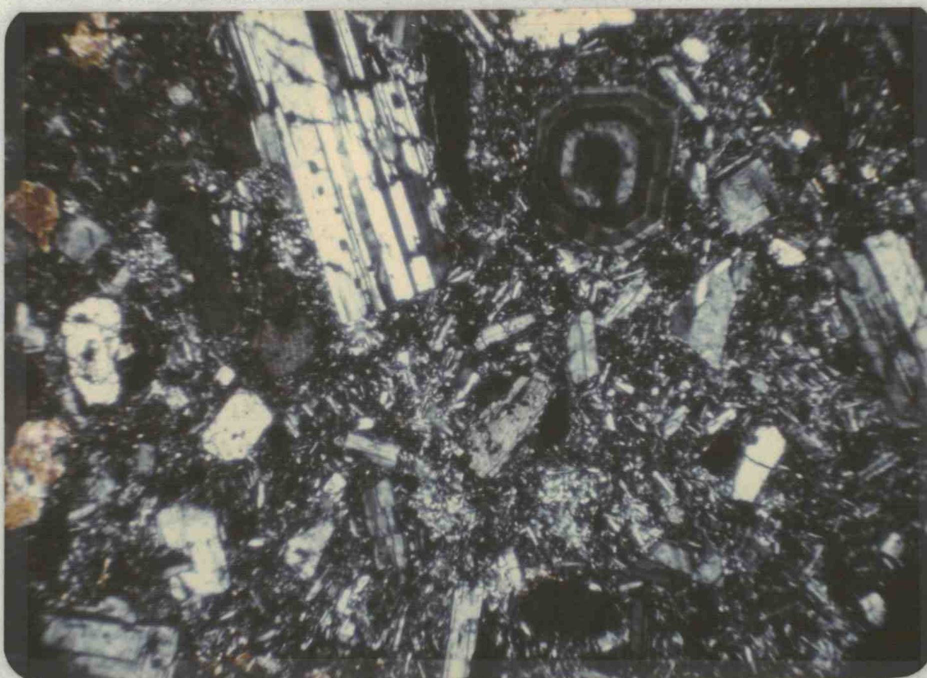


Plate 23. Photomicrograph of rhyodacite lava of Buffalo Ridge (x-nicols, 35x)

Table 10. Chemical and modal analyses of rhyodacite lava of Buffalo Ridge compared to the average rhyodacite and hypersthene-bearing granodiorite of Nockolds.

| | Chemical Analyses (percent) | | | Modal Analyses (percent) | |
|---|---|---|---|---|---|
| | Average** rhyodacite | WAH-18 | Average** hypersthene-bearing granodiorite | WAH-18 | |
| $SiO_2$ | 66.27 | 60.0 | 62.64 | Phenocrysts | |
| | | | | Plagioclase | 20 |
| | | | | Hypersthene | 10 |
| $Al_2O_3$ | 15.39 | 16.7 | 15.82 | Augite | 6 |
| FeO* | 4.37 | 6.6 | 5.90 | Biotite | 4 |
| MgO | 1.57 | 3.9 | 2.83 | | |
| CaO | 3.68 | 5.9 | 4.72 | Groundmass | |
| | | | | Plagioclase microlites | 35 |
| $K_2O$ | 3.01 | 2.55 | 2.62 | Iron-rich glass | 14 |
| $Na_2O$ | 4.13 | 3.1 | 3.37 | Quartz | 8 |
| $TiO_2$ | 0.66 | 0.80 | 1.32 | Apatite | 1 |
| MnO | 0.07 | ---- | 0.09 | | |
| $P_2O_5$ | 0.17 | ---- | 0.27 | | 100 |
| | 99.32 | 99.55 | 99.58 | | |

*Total iron reported as FeO
**Average of Nockolds (1954)

oxide constituents are accounted for by the abundance of hypersthene and calcic andesine in the sample of rhyodacite lava.

Hypabyssal K-Rich Olivine Basalt. Intrusive masses of basaltic rock occur as small dikes and irregular plug-shaped bodies throughout the area of study. All of the dikes have a near vertical dip and parallel the dominant north-south structural trend within the district by following major fault zones within the country rocks.

A crescent-shaped plug was mapped towards the southern end of Buffalo Ridge. Two additional plug-shaped masses occur near the eastern margin of the district on either side of Bayhorse Creek and apparently mark the center of a small eruptive edifice as previously mentioned.

The smallest dike observed is exposed on a cliff face of Bayhorse dolomite on the western limb of the Bayhorse anticline just north of Bayhorse Creek. It is about one foot in width and crosses the dolomite in an irregular, near vertical path. This was the only intrusive mass well enough exposed to allow close examination of contact relationships. Chill margins or thermal metamorphic effects were absent from the small dike as would be expected. The largest dike mapped was traced for nearly a mile across the southern end of Buffalo Ridge. The dike varied from 20 to 50 feet in width and cropped out as piles of blocky talus and isolated ledges of basalt that locally display well-developed horizontal columnar joints.

One dike, east of Little Bayhorse Lake is noticeably different from the other hypabyssal basaltic rocks in the area. The dike was emplaced near the intersection of the Nevada Mountain fault zone and a major bedding plane thrust fault. The basaltic dike has xenolith inclusions of quartzite, shale, granodiorite, silicic tuff and silicic volcanic rocks in a matrix of iron-rich glass and broken crystals of plagioclase feldspar, olivine and pyroxene. The quartzite and shale fragments display the effects of thermal metamorphism as the margins of the xenoliths have recrystallized to become more coarsely crystalline than their interiors. Evidently this dike never vented to flush the included country rock fragments from its channelway.

The basaltic intrusions are uniformly dark-gray (N 3) and very finely crystalline with widely scattered phenocrysts of pyroxene and olivine up to 2 mm across. From thin section examination the rocks were found to have an intersertal texture with olivine (8 to 14 percent), pyroxene (2 to 4 percent), opaque iron oxides (7 percent) and turbid glass (22 to 38 percent) occupying the angular interstices of plagioclase feldspar microlites (25 to 27 percent) and phenocrysts of olivine (20 to 25 percent) (Pl. 24). Plagioclase feldspar is calcic labradorite ($An_{63-66}$) that occurs as microlites in the groundmass. Clear

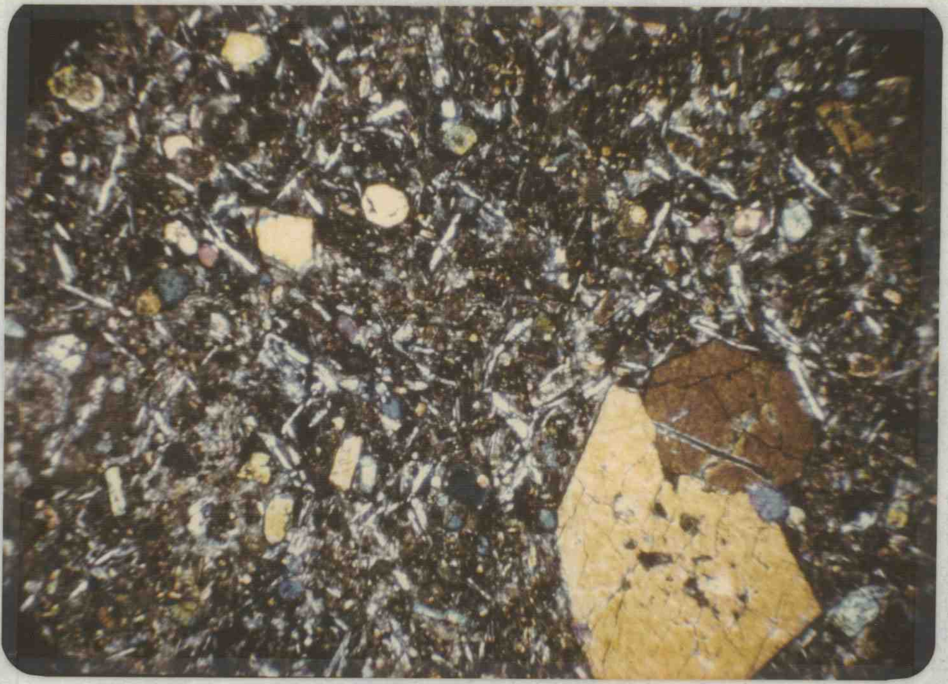


Plate 24. Photomicrograph of hypabyssal K-rich olivine basalt (x-nicols, 35x)

augite is present as small subhedral crystals in the groundmass together with granules of opaque iron oxides. Olivine is found as small euhedral to subhedral crystals in the groundmass and as large subhedral phenocrysts that are commonly twinned. Although generally fresh and clear, the olivine is commonly altered to iddingsite, serpentine group minerals and carbonate along through-going microfractures. Pseudomorphic aggregates of carbonate, quartz and opaque iron oxides can be found replacing augite. Labradorite is generally only slightly altered to carbonate, clay minerals and quartz.

K-Ar age determinations from samples of similar intrusive basaltic rocks two miles southeast of the southeast corner of the study area yielded ages of 46.6 $\pm$ 1.8 m.y. (R. L. Armstrong, 1974, cited in Hobbs and others, 1975).

The uniform lithology and chemical composition of the hypabyssal basaltic rocks is demonstrated by the chemical and modal analyses of two widely separated samples presented in Table 11. Nockolds (1954) uses the term "central" basalts for those found in association with the typical calc-alkaline andesites, dacites and rhyodacites characterizing continental volcanic centers. The basaltic rocks within the area of study are compositionally similar to the average central basalt of Nockolds, but differ in two respects. The modal content of olivine and the chemical con-

Table 11. Chemical and modal analyses of hypabyssal K-rich olivine basalt compared to the averages "central" basalt of Nockolds.

| Chemical Analyses (percent) | | | | Modal Analyses (percent) | |
|---|---|---|---|---|---|
| | "Central"** basalt | WAH 20a-75 | WAH 59 | Western Area WAH 20a-75 | Eastern Area WAH 59 |
| $SiO_2$ | 51.33 | 49.4 | 48.9 | Phenocrysts | Phenocrysts |
| | | | | Olivine 8 | Olivine 6 |
| $Al_2O_3$ | 18.04 | 11.9 | 11.2 | | |
| $FeO$* | 9.10 | 9.9 | 8.6 | Groundmass | Groundmass |
| $MgO$ | 6.01 | 10.2 | 7.9 | Plagioclase microlites 47 | Plagioclase microlites 52 |
| | | | | Opaques 7 | Opaques 5 |
| $CaO$ | 10.07 | 9.6 | 12.4 | Glass 31 | Glass 33 |
| | | | | Pyroxene 4 | Olivine 2 |
| $K_2O$ | 0.82 | 1.40 | 1.80 | Olivine 3 | Pyroxene 2 |
| $Na_2O$ | 2.76 | 1.8 | 3.3 | 100 | 100 |
| $TiO_2$ | 1.10 | 1.05 | 0.75 | | |
| $MnO$ | 0.16 | ---- | ---- | | |
| $P_2O_5$ | 0.16 | ---- | ---- | | |
| | 99.55 | 95.85 | 94.85 | | |

*Total iron reported as FeO
**Average of Nockolds (1954)

tent of $K_2O$ is notably higher than that of the central basalt, and have been used to modify the name of the rocks. The basalts are apparently more highly altered than evident from an examination of the thin sections. Approximately 5 percent of the rock did not show up in the chemical analyses and this is thought to be caused by the volatilization of carbonate alteration products during the analytical procedure. Intrusive basaltic rocks have been encountered in drill holes and underground workings within the area and such hidden intrusive masses have been given credit for complicating the interpretation of a variety of geophysical techniques.

# VII. METAMORPHISM

The effects of regional metamorphism are largely absent within the Bayhorse district. However, those of contact metamorphism are well-developed in the Ramshorn Slate adjacent to the Nevada Mountain and the Skylark stocks. In contrast, the carbonate and the phyllitic rocks adjacent to the quartz-feldspar porphyry phase of the intrusive complex have been nearly unaffected by contact metamorphism.

## Regional Metamorphism

The thickness of the Late Paleozoic section in the Bayhorse region overlying the Early Paleozoic rocks of the district did not greatly exceed 25,000 feet (determined from Ross, 1967, Pl. 1). An extrapolation of the average geothermal gradient of 35 m/°C (Judson, 1968) to this depth indicates a temperature of about 200 °C. These conditions were evidently adequate to form quartzite, phyllite and slate from their non-metamorphosed equivalents. However, the absence of laumontite, prehnite, albite, muscovite, chlorite, epidote, zoisite and other products of low-grade burial metamorphism in the argillaceous sedimentary rocks together with the persistence of the original clastic texture indicates that temperatures have not greatly exceeded this value even during the period of increased heat flow when the Idaho Batholith was emplaced.

## Contact Metamorphism

The effects of thermal metamorphism on the argillaceous and carbonate country rocks adjacent to the intrusive complex vary markedly from one intrusive phase to the other. The variation in the products of thermal metamorphism is largely a function of the original composition of the adjacent sedimentary rock units and the pressure-temperature conditions imposed with magma emplacement. The thermal aureoles adjacent to the Nevada Mountain and Skylark stocks are so well developed as to enable fault structures to be traced through the otherwise homogeneous Ramshorn Slate. In marked contrast, the effects of thermal metamorphism associated with the quartz-feldspar porphyry intrusive phase of the complex are minimal. The differences between the two aureoles reflect primary differences in the physical and chemical character of the two igneous masses as previously discussed. The thermal effects imposed upon the argillaceous rock units and the physical and chemical conditions of their development will be discussed first followed by a similar discussion of the carbonate rocks.

Argillaceous Rocks. Thermal metamorphism of the Ramshorn Slate has produced a contact aureole of hornfels that extends from 1500 to 3500 feet from the exposed contacts of the Nevada Mountain and Skylark stocks. This apparent variance in the development of the metamorphic aureole is caused by the oom-bined effects of the geometry of the hornfels-intrusive outcrop pattern and post-emplacement faulting of the aureole. The change from non-metamorphosed Ramshorn Slate to the low-temperature subfacies of the pyroxene hornfels grade of thermal metamorphism near the intrusive contact is gradual and shows both vertical and horizontal variation depending upon the local composition of the slate and the distance from the pluton.

With development of porphyroblasts the slate rapidly loses its prominent slaty cleavage, but retains its relic bedding as subparalled porphyroblasts to within a few feet of the intrusive contact. The slate gradually becomes a very hard, coarse-grained hornfels that is dark-gray (N 3) in color and weathers to a grayish-orange (10 YR 7/4). The hornfels characteristically breaks into angular blocks along joints and fractures rather than into the small flakes characteristic of the unmetamorphosed slate.

In hand specimen, the higher-grade hornfels exhibits a coarse sugary texture and lower-grade samples resemble the sandy layers of the Ramshorn Slate (Pl. 25). Cordierite is generally the most evident constituent as it forms grayish-black (N 2) nodular porphyroblasts that range in size from small incipient crystals up to crystals 5 mm in diameter. Smaller andalusite and biotite por-phyroblasts commonly occur with the cordierite crystals. The

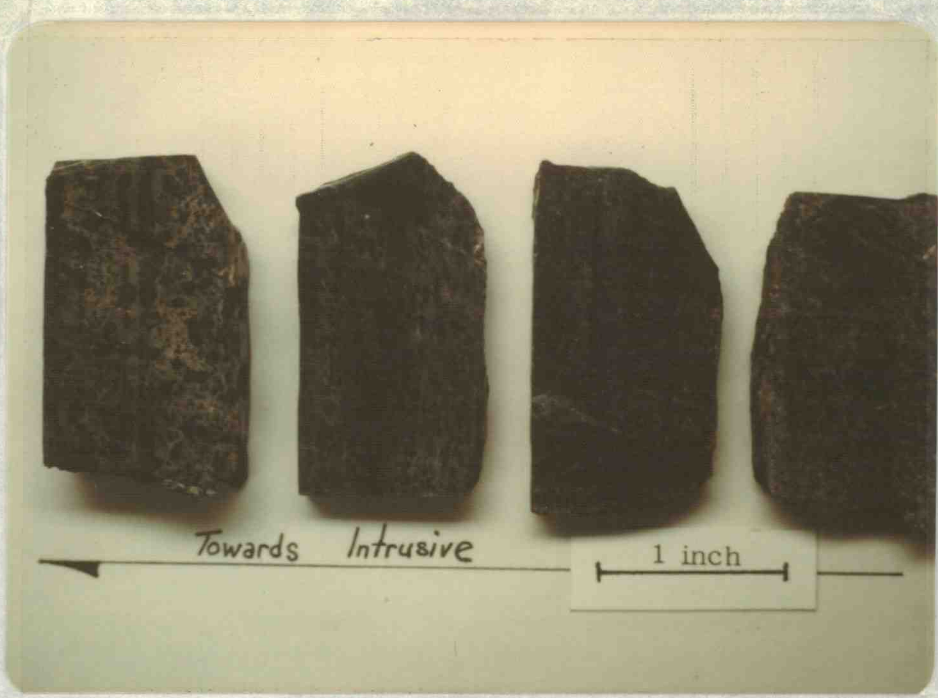



Plate 25. Hand specimens of hornfels showing the change in metamorphic grade with distance from the intrusive contact.

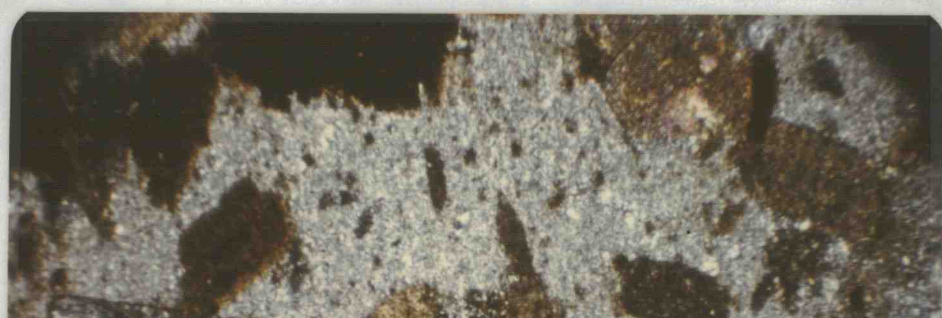



Plate 26. Photomicrograph of hornblende-hornfels (x-nicols, 35x). Cordierite (Co) showing sector twinning and andalusite (An) with biotite (Bi) in a matrix of quartz and sericite.

groundmass of the hornfels generally consists of finely crystalline sericite, quartz and feldspar. The original bedding planes of the slate are preserved as alternating layers of biotite and cordierite concentrations which probably formed in response to local compositional differences in the original rock.

Thin section examination shows that the hornfels aureole consists of a relatively simple mineralogy and texture corresponding to the albite-epidote hornfels facies, the hornblende hornfels facies and the lower temperature subfacies of the K-feldspar-cordierite hornfels facies as the intrusive contact is approached. Ternary diagrams depicting stable mineral assemblages for various bulk compositions of the three hornfels facies are presented in Figures 15, 16 and 17. The texture varies from blastopelitic in the lower metamorphic grades to granoblastic polygonal in the higher grade hornfels.

The beginning of the albite-epidote hornfels facies is characterized by the reaction between kaolinite and quartz to form pyrophyllite and the preferred growth of the stable sedimentary minerals such as muscovite and biotite, which have resulted in the enhancement of the pre-existing slaty cleavage of the Ramshorn Slate. Chlorite is also present and epidote is found in trace amounts. Pyrophyllite breaks down to form andalusite and quartz towards the highest temperature end of this facies. Andalusite

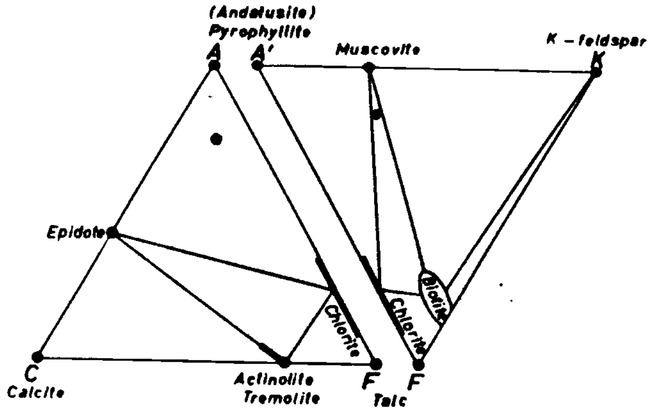



Figure 15. Albite-epidote-hornfels facies. Andalusite may occur in the highest temperature part of this facies (after Winkler, 1967, Fig. 13, p. 65). Point represents the composition of the Ramshorn Slate.

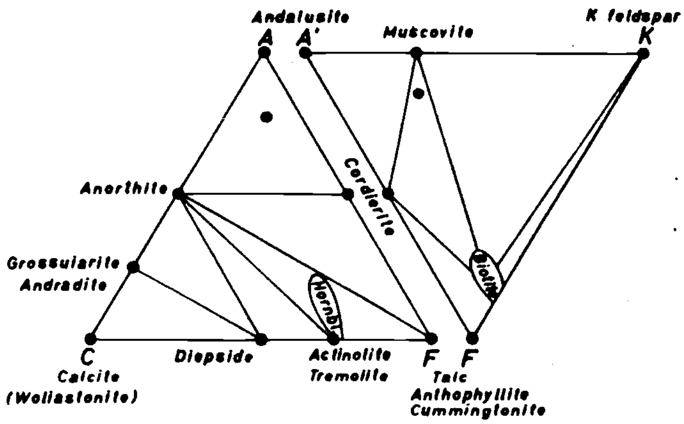



Figure 16. Hornblende hornfels facies. The coexistence of andalusite and biotite is possible, but cannot be shown in this diagram (after Winkler, 1967, Fig. 14, p. 66). Point represents the bulk composition of the Ramshorn Slate.

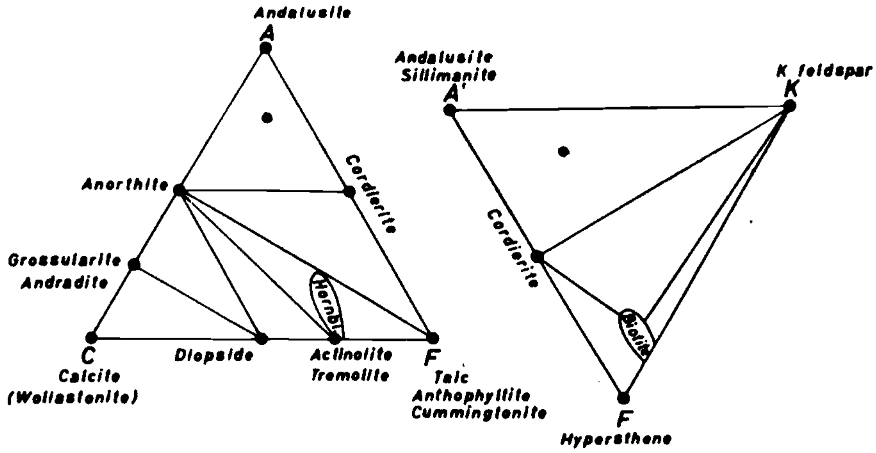



Figure 17. Orthoamphibole subfacies of the K-feldspar-cordierite-hornfels facies. Biotite may coexist with andalusite. Sillimanite, instead of andalusite, occurs in the highest temperature part of this subfacies (after Winkler, 1967, Figs. 14 and 15, pp. 66 and 67). Point represents the bulk composition of the Ramshorn Slate.

occurs as clear, highly irregular poikolitic crystals. Pyrophyllite is also probably present, but it is not petrographically discernible from muscovite.

Minerals characteristic of the hornblende-hornfels facies begin to develop (Pl. 26) with increasing grade of metamorphism. Chlorite, muscovite and quartz react to form cordierite, biotite and more andalusite. Plagioclase feldspar takes the place of epidote. Cordierite occurs exclusively as pseudohexagonal, irregularly bounded porphyroblasts crowded with inclusions of the more finely crystalline mineral constituents. Cordierite is easily distinguished by its ubiquitous penetration twins and characteristic sector extinction. Cordierite also has a tendency to be replaced both along crystal margins and along fractures by a yellowish member of the chlorite family. Pleochroic halos around enclosed zircon and sphene crystals are also diagnostic of cordierite. Biotite becomes much more prominent and forms highly pleochroic crystals that vary from deep red to clear in color. The crystals rapidly lose their initial orientation with increasing grade of metamorphism and tend to occur as more randomly oriented poikioblastic flakes up to 2 mm in diameter. Pleochroic halos around enclosed sphene and zircon crystals are also abundant in the biotite flakes. Andalusite is common and retains its irregular, poikolitic crystal habit. Plagioclase feldspar is a minor constituent and occurs as interstitial anhedral crystals in the groundmass. Clinozoisite and quartz are also present as small euhedral to subhedral crystals scattered throughout the groundmass.

The highest grade of metamorphism is reached in the ortho-amphibole subfacies of the potassium feldspar-cordierite hornfels facies. This facies is locally developed within a few tens of feet from the intrusive contact on the north-facing slope of Nevada Mountain. It forms by the reaction of muscovite and quartz to form potassium feldspar and $Al_2SiO_5$. Muscovite is markedly absent from rocks of this facies and potassium feldspar is abundant as anhedral crystals in the groundmass. The potassium feldspar is orthoclase and it commonly displays microperthitic stringers and threads. The plagioclase feldspar is albite that is present in small quantities as anhedral crystals that commonly display polysynthetic albite twins. Black tourmaline needles up to 4 mm long are also a constituent of the hornfels near this contact. Tourmaline is also uniquely associated with the pegmatitic injections in this area. The restricted occurrence of tourmaline is probably due to the local hydrothermal introduction of boron.

Metamorphosed and non-metamorphosed samples of Ramshorn Slate were analyzed for their major oxide constituents and are presented in Table 12. From an examination of the chemical analyses it may be inferred that metasomatism of the

Table 12. Chemical analyses of Ramshorn Slate, hornfels and fault gouge.

| | Ramshorn Slate | Hornfels | Fault gouge |
|---|---|---|---|
| $SiO_2$ | 58.0 | 59.4 | 53.3 |
| $Al_2O_3$ | 22.6 | 23.3 | 26.8 |
| FeO* | 8.1 | 8.7 | 5.2 |
| MgO | 2.4 | 2.6 | 0.6 |
| CaO | 0.4 | 0.1 | 0.6 |
| $K_2O$ | 4.35 | 3.60 | 6.50 |
| $Na_2O$ | 1.8 | 1.0 | 0.6 |
| $TiO_2$ | 0.85 | 0.80 | 0.70 |
| | 98.50 | 99.50 | 94.30 |

*Total iron reported as FeO
**From Skylark Mine

Ramshorn Slate during thermal metamorphism was essentially nil. The relatively low CaO and $Na_2O$ content and the high $Al_2O_3$, $K_2O$, MgO and FeO contents of the slate account for the scarcity of epidote and plagioclase and the abundance of andalusite, cordierite and biotite in the hornfelsed equivalent. Local variations of bulk composition within the slate readily account for the variations in mineral proportions and texture. Increasing proximity to the intrusive contact appears to correlate well with the overall increase in metamorphic grade towards the Nevada Mountain and Skylark stocks.

The instability of muscovite in the presence of orthoclase feldspar and the absence of sillimanite (a pressure-temperature field indicator) limits the depth of formation of the highest grade hornfels to less than about 30,000 feet (2500 bars) and the temperature of the country rock near the intrusive contact to between 575 °C and 700 °C (Fig. 18). The depth of formation of the metamorphic aureole surrounding the Nevada Mountain and Skylark stocks as determined from the depth of emplacement of the intrusive complex previously derived from field considerations, more closely limits the physical conditions of formation of the thermal aureole.

The temperatures near the intrusive contact probably ranged from about 625 °C to 650 °C as the depth of emplacement of

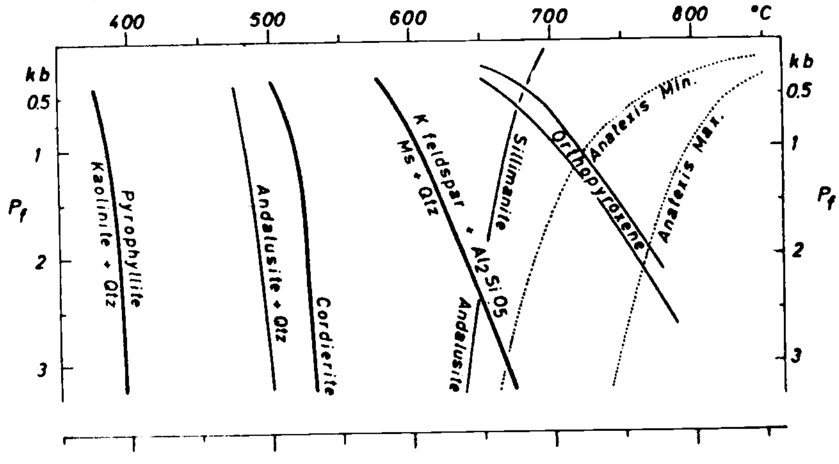



Figure 18. Important reactions and pressure-temperature fields of the hornfels facies (modified after Winkler, 1967, Fig. 16, p. 73). The shaded area represents possible conditions of formation of the thermal aureole surrounding the Nevada Mountain and Skylark stocks.

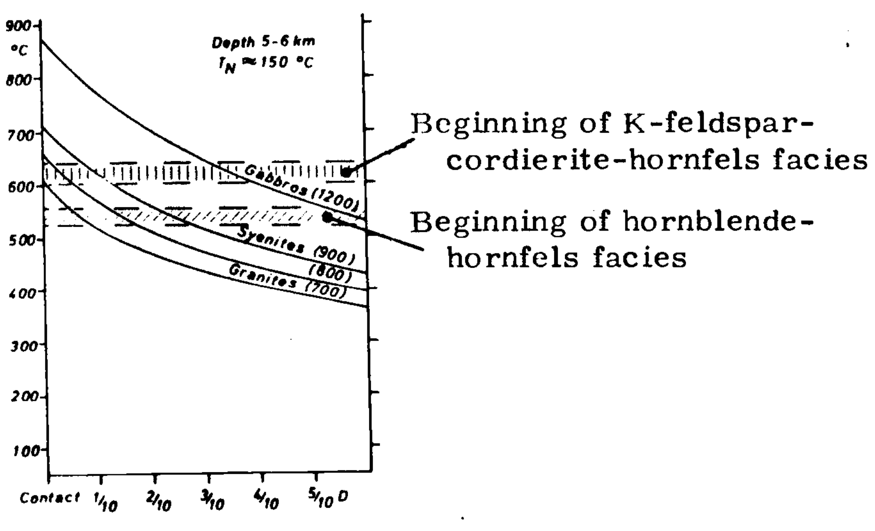



Figure 19. Heating of the country rock adjacent to various intrusions (after Winkler, 1967, Fig. 19, p. 83). Distance from the contact is given in fractions of D. D thickness of plate-like intrusion.

the complex is thought to range from four to five miles (1500 to 2000 bars, Fig. ). The temperature of the intrusive phase at the time of emplacement can be roughly estimated from a consideration of the above metamorphic reaction and the temperatures of the country rock near the intrusive contact. Magmatic temperatures may have approached 800 °C, but were probably closer to 725 °C as the diagnostic hornfels facies is restricted to one small locality and the main phase of the complex is granodioritic rather than granitic in composition (Fig. 19). Small amounts of magnetite, hematite and chlorite that replace biotite and cordierite are probably the result of late-stage hydrothermal alteration related to the intrusive complex.

A distinctive spotted phyllite is developed in the lower part of the argillaceous unit of the Garden Creek Phyllite. The spotted phyllite is erratically distributed in exposures along Bayhorse Creek just west of the Bayhorse townsite. The geometric distribution of the spotted phyllite is coincident with the structural high of the underlying quartz-feldspar porphyry and may have developed in response to the effects of thermal metamorphism related to the emplacement of the underlying intrusive phase.

The spotted phyllite differs from the non-spotted phyllite only in the presence of highly altered grayish-red (5 R 4/2) porphyroblasts of an unknown mineral that range from 1 to 3 mm in diameter. Megascopically, the porphyroblasts are comparatively hard, spherical in shape and display three prominent directions of cleavage. Thin section examination and x-ray diffraction analysis shows that they are hexagonally-shaped aggregates consisting largely of opaque iron oxides enclosing oriented inclusions of detrital quartz and muscovite grains. The oriented inclusion trains within the porphyroblasts have been variably rotated after their formation relative to the prominent foliation. In addition, pressure shadows containing quartz and muscovite are well-developed around the porphyroblastic aggregates. These relationships indicate that the porphyroblasts were developed before the major deformation of the area. Similar porphyroblasts have been described by Bosman (1964) and have been regarded as incipient cordierite crystals.

However, the porphyroblastic aggregates might also be interpreted as completely oxidized pyrite crystals. The pyrite crystals may have been either diagenetic or hydrothermal in origin. The spotted phyllite is closely associated with mineralized fracture zones and invariably shows the effects of hydrothermal bleaching. In a strongly neutralizing gangue the oxidation of pyrite may result in hard pseudomorphs termed limonite "dice" (Blanchard, 1968, p. 68). In either case, the present exposure does not provide any evidence as to whether the porphyroblasts are incipient metamorphic crystals resulting from the effects of thermal metamorphism or whether they are hydrothermally altered pre-existing crystals. However, the erratic distribution of the spotted phyllite in surface exposures near mineralized fracture zones suggest that the restricted development of the porphyroblasts is related to near vertical channelways along which heat may have been transferred from the underlying intrusion to the overlying argillaceous country rocks by hydrothermal fluids.

Carbonate Rocks. The effects of contact metamorphism upon the carbonate units within the Paleozoic sedimentary sequence are known only from drill core and are mineralogically, chemically and texturally different from those just described for the argillaceous units. The lower carbonate unit of the Garden Creek Phyllite is in direct contact with the quartz-feldspar porphyry phase of the intrusive complex and is the only carbonate unit known to be closely associated with the contacts of the complex. The contact has been penetrated by several drill holes. In many holes, the contact is knife-sharp and in other holes it is marked by a silicified and sericitized zone up to 12 inches thick. In general, the carbonate unit was mineralogically and texturally unaffected by the intrusive phase. The unit is stained a grayish-orange (10 YR 7/4) in places, but generally retains its medium-gray (N 5) to grayish-pink (5 R 8/2) color up to the intrusive contact. In places, this unit may have been slightly recrystallized, but elsewhere the carbonate unit has remained a very thinly laminated micritic dolomite as previously described (Pl. 27).

The development of lime-magnesia silicates by reaction between carbonate and silica is pressure sensitive, in that a volatile gas phase, usually $CO_2$, must be able to escape for the reaction to go to completion. If the evolved carbon dioxide cannot escape, calcite and dolomite will continue to recrystallize along with associated impurities without reaction to Ca-Mg silicates. However, the development of the porphyroblasts in the overlying phyllite, as previously discussed, suggests that fractures were indeed present and thereby allowed the volatiles to escape.

Thin section examination and staining indicate that the rock is essentially monomineralic and consists of dolomite with a minor admixture of calcite. Detrital quartz grains are present but rarely exceed five percent of the rock (Pl. 28). In such a silica-poor carbonate rock thermal metamorphism would be expected to take place as a simple recrystallization with a gradual coarsening of the textures, and a concomitant loss of sedimentary features, to yield a dolomitic marble with a granoblastic polygonal texture. At extreme temperatures, silica-poor dolomite breaks down to form calcite plus periclase, or in the presence of water

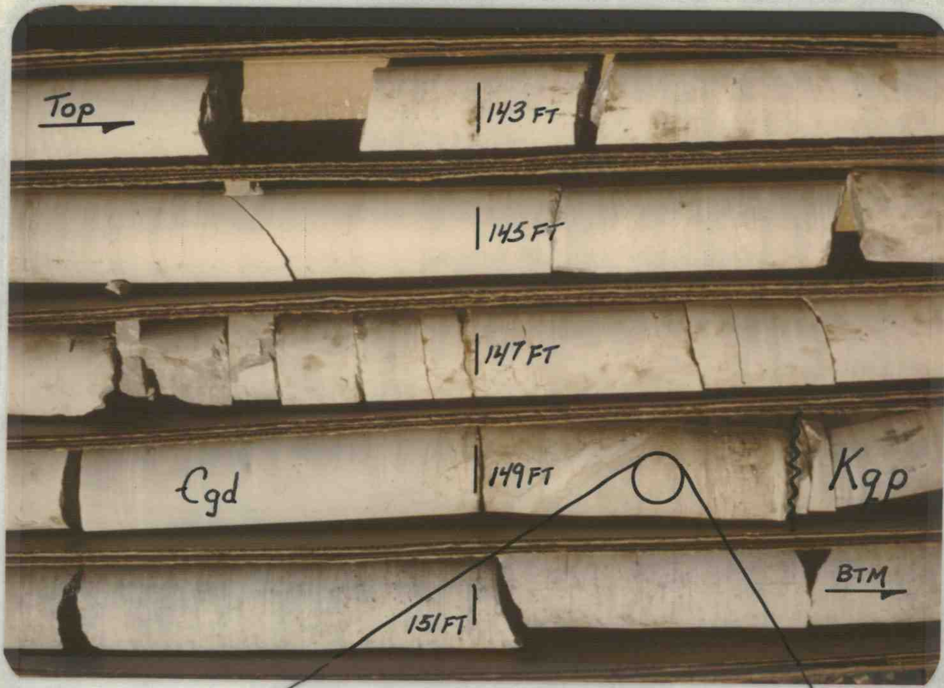



Plate 27. Contact zone of quartz-feldspar porphyry and the lower dolomite unit of the Garden Creek Phyllite. Numbers represent depth below surface in feet.

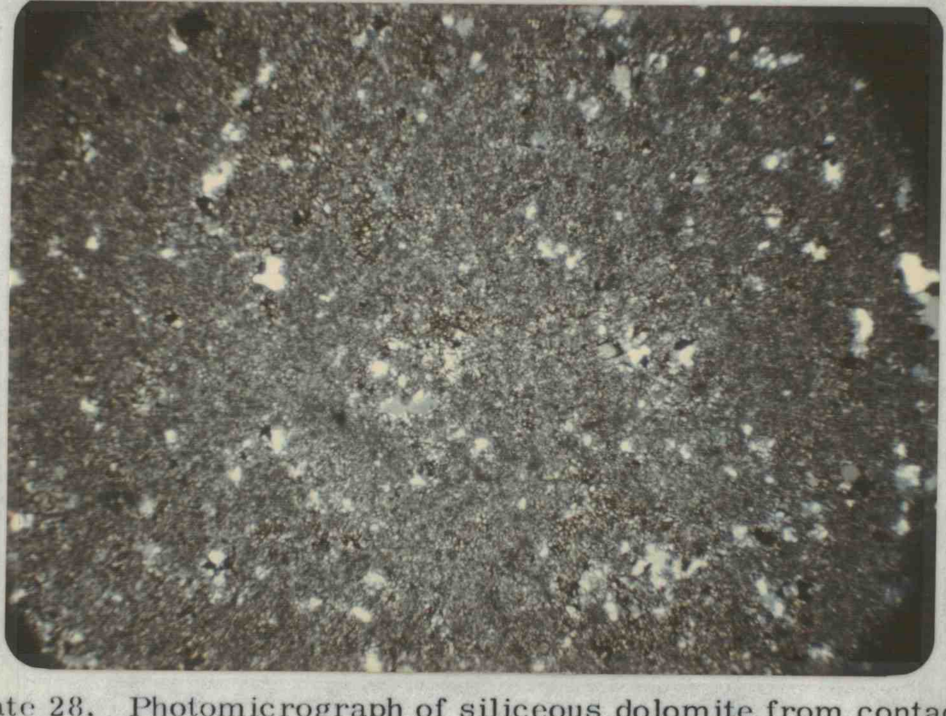


Plate 28. Photomicrograph of siliceous dolomite from contact zone (x-nicols, 35x).

vapor, calcite plus brucite with evolution of carbon dioxide gas (Winkler, 1967, Fig. 5, p. 34). Periclase was not found within the contact zone thereby indicating that temperatures within the carbonate country rocks adjacent to the intrusive phase were less than 650 °C to 825 °C; probably much less as recrystallization is evident only on a small scale and the thinly laminated character of the dolomite is largely preserved. This is in accordance with field evidence that suggests that the quartz-feldspar porphyry was relatively cool and water-rich at the time of emplacement.

Approximately 300 feet of what is thought to be the upper part of the Bayhorse Dolomite was penetrated by a deep drill hole in the vicinity of the Ramshorn Mine. Precisely which unit of the formation is represented is not certain, but the absence of oncolitic zones (indicative of the fifth unit) and the presence of interbedded shale units suggest that the fourth unit or possibly a lower unit is unconformably overlain by the hornfelsed Ramshorn Slate. The effects of thermal metamorphism are more evident in this drill core intersection. Here, iron has been locally introduced along bedding planes resulting in sporadic recrystallization of the dolomite to ankerite and with an accompanying change in color from gray to brown. In addition, talc is present filling small fractures in the more argillaceous of the carbonate beds. The presence of talc, a pressure-temperature field indicator, limits the temperature of the country rock to at least 400 to 500 °C (Winkler, 1967, Fig. 5, p. 34). The more pronounced development of thermal metamorphism in the carbonate units in close proximity to the Nevada Mountain stock, as compared to the lesser effects imposed upon a similar carbonate lithology directly adjacent to the quartz-feldspar porphyry, supports the contention that much higher magmatic temperatures were associated with the granodiorite intrusive phase than with the quartz-feldspar porphyry phase.

# VIII. STRUCTURAL GEOLOGY

The Paleozoic sedimentary rocks of the Bayhorse region have been deformed into eastwardly overturned folds that closely parallel the eastern boundary of the Idaho Batholith. These folds have been subsequently modified by several kinds of faults. The major folding and thrust faulting of the Paleozoic rocks are closely related to the intrusion of the Idaho Batholith. Emplacement of the Juliette Creek intrusive complex has locally modified the pre-existing structure of the district and is largely responsible for producing a variety of physical and chemical changes in the country rocks which made them more receptive to the mineralizing solutions that followed. High angle normal and reverse faults within the map area generally do not involve great displacement and they tend to parallel the north-south structural grain of the region. Several have had a long history of periodic movement initiated by the emplacement of the Juliette Creek intrusive complex. The major folding and faulting of the Paleozoic rocks preceded extrusion of the Tertiary volcanics. Subsequent deformation has involved only minor tilting and broad warping of the volcanic strata.

Although the structural deformation of the area is multi-stage and complex in character, many of the variables commonly encountered in field problems of this kind can be fixed. A good deal of information on the structural development of the area can be deciphered from a few features ubiquitously present and readily observable in the rock units. As the major ore controls within the district are apparently structural in character, the following interpretation of the structural history of the area is of considerable exploration significance.

## Folds

The predominant structural feature of the region consists of a series of parallel elongate folds that have been formed in the Paleozoic rocks by west to east compressional movement related to the emplacement of the Idaho Batholith. The most prominent fold in the region is the sinuous Bayhorse Anticline. The anticline is traceable for 50 miles from a point west of Challis in a southerly direction to a point east of Sun Valley (Ross, 1934, Fig. 3, p. 74). The anticline is covered at intervals by Tertiary volcanic rocks and is periodically interrupted by west to east thrust faulting. The anticline is particularly well-developed within the area of study and has apparently been lifted higher here by orogenic forces than elsewhere because the oldest rocks in the region are exposed in its core.

A second anticlinal structure, of more local significance, parallels the Bayhorse Anticline and lies just to the west of it. This second anticline is here termed the Ramshorn Anticlinorium. The anticlinorium is not traceable as far to the north and south as is the Bayhorse Anticline due to the cover of Tertiary volcanic rocks and the poor outcrop expression of the Ramshorn Slate in which the anticlinorium is developed. However, the Ramshorn Anticlinorium is very well exposed within the area of study adjacent to the Nevada Mountain and Skylark stocks.

A variety of structural indicators are present within the rocks of the Bayhorse district. Shear cleavage, slip cleavage and fracture cleavage are of minor importance as they are restricted in occurrence. Joints are a ubiquitous feature of the Bayhorse Dolomite and occur in such diverse orientations as to provide support for nearly any theory of structural development that one would care to propose (Fig. 20). However, joint planes are noticeably more abundant in the dolomite of the eastern part of the central bulge area of the Bayhorse Anticline (Pl. 29, p.180 ). In addition to bedding plane attitudes, slaty cleavage is of particular importance in determining both the orientation of folds and faults in the argillaceous and carbonate units of the area and the orientation of the stresses responsible for the deformation. Slaty cleavage is particularly well-developed within the Ramshorn Slate and Garden Creek Phyllite as both argillaceous units acted incompetently to regional compressive stress. Although slaty cleavage is the most prominent feature of the argillaceous rocks, bedding is also usually discernible as faint bands of slightly differing

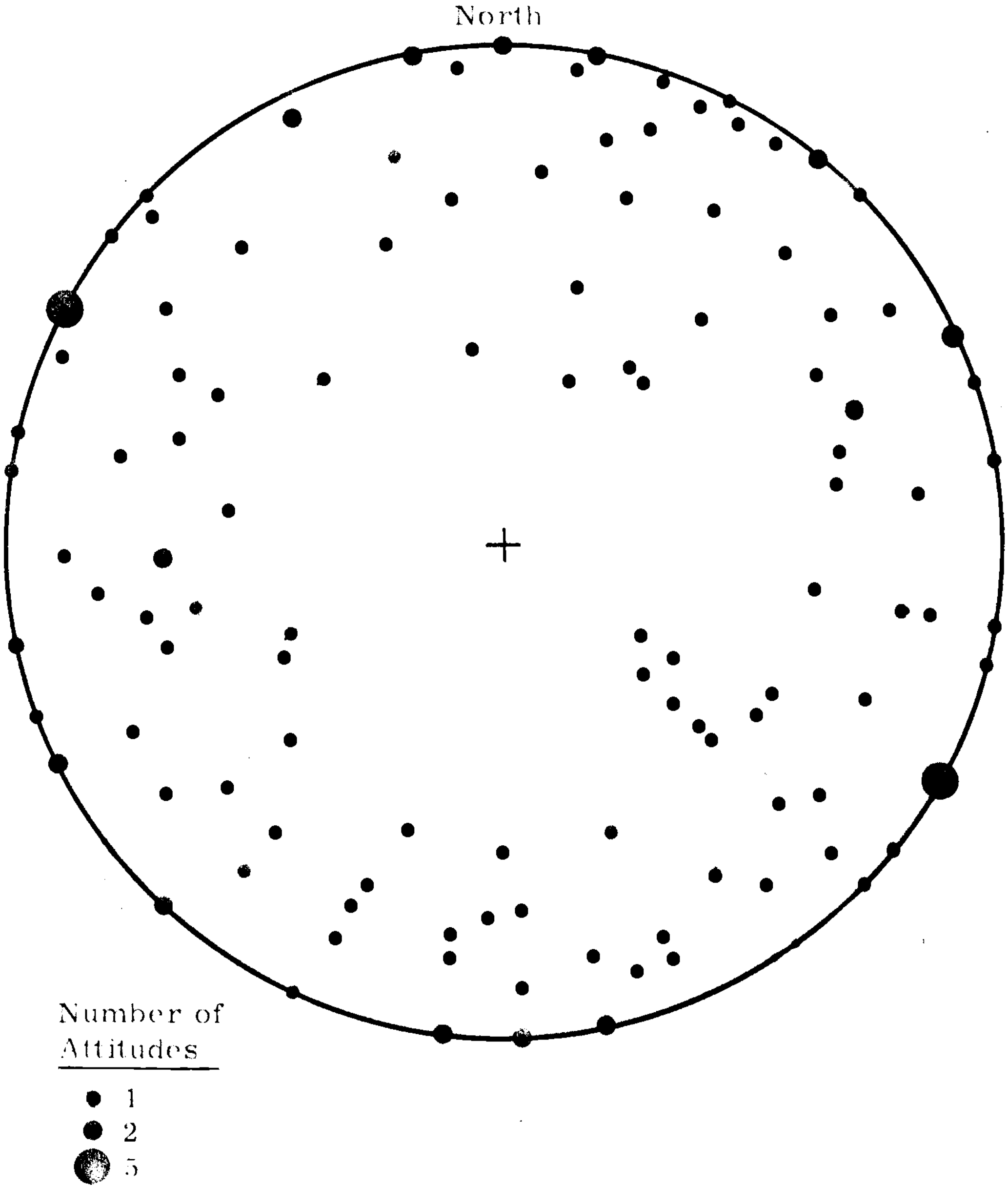



Figure 20. 116 poles to joint planes taken mostly from the Bayhorse Dolomite east of the Mill Fault plotted on the lower hemisphere of the Schmidt stereonet. Each attitude represents an outcrop area of approximately 200 square feet.

texture and/or color. Where subsequent movement along planes of slaty cleavage has produced shear cleavage, bedding is obliterated. Chambers (1966, p. 64) and Hobbs (oral comm., 1975) both indicate that the pronounced development of slaty cleavage is largely confined to the area of study even though the argillaceous units are similarly folded elsewhere. Slaty cleavage is best developed in proximity to the Juliette Creek intrusive complex. Elsewhere, the slaty cleavage, although present, is not nearly as prominent a feature. The folds in these outlying areas are characteristically broad and open as compared to the more tightly folded slate near Nevada Mountain. Differences in the degree of folding and corresponding development of slaty cleavage indicate that the compressive strain responsible for the deformation were higher where the slaty cleavage is best developed. In addition, the thermal metamorphism of the argillaceous country rocks adjacent to the intrusive complex may have contributed to the enhancement of a poorly developed but pre-existing slaty cleavage through preferential crystal growth of micaceous minerals in the lower grade parts of the aureole. However, as cordierite and andalusite formed close to the igneous contact, the preferred orientation of platy minerals is rapidly lost and slaty cleavage is obliterated in the higher grade hornfels.

Areas, several tens of feet square, are generally required to expose complete bedding plane folds and to demonstrate that slaty cleavage commonly parallels the axial planes of these large folds. Folding is rarely on a scale small enough to be seen in hand specimen, but where present the slaty cleavage shows no particular tendency to parallel the axial planes of these smaller folds. The use of slaty cleavage as a consistent indicator of the attitude of the axial planes of large-scale folds is complicated by the bending of cleavage planes in response to differing texture, composition and/or strain fields. Faults are also partly responsible for the variance in the attitudes of slaty cleavage throughout the study area. Fortunately, these complicating factors can be removed by direct field observation in most cases and slaty cleavage attitudes can be used with reasonable assurance as general indicators of the attitude of the axial plane of the major folds within the district. When used in conjunction with bedding plane attitudes, the history of structural deformation can be well defined. The lithologies involved in the Ramshorn Anticlinorium and the Bayhorse Anticline are significantly different and, in part, account for the differences in form between the two structures. The character and mode of formation of the Ramshorn Anticlinorium is discussed first and is then followed by a similar discussion of the Bayhorse Anticline.

Ramshorn Anticlinorium

The Ramshorn Slate reacted quite incompetently to regional compressive stress and at first inspection appears to have been deformed in a highly complex, non-coherent manner. Although a continuous stratigraphic marker horizon is not evident, the character of the anticlinal structure can be rather precisely delineated by careful field observations of slaty cleavage and bedding plane attitudes on fairly abundant outcrop where transversely cutting streams provide a cross-sectional view of the anticlinorial structure. Michell (1939) mapped parts of the underground workings of the Ramshorn Mine that are now mostly inaccessible. His report adds another dimension to the structure by providing detailed data on the attitudes of slaty cleavage and bedding within the internal, axial parts of the anticline.

Description. In the western part of the study area, the Ramshorn Slate has been folded and crumpled along north-trending axes into a broad anticline upon which many smaller folds have been superimposed. The anticlinorium is overturned to the east in the vicinity of Ramshorn Mountain, and becomes gradually more symmetrical with depth both to the north and south.

The trace of the axial plane of this structure is roughly coincident with a line joining Ramshorn Mountain on the north and the upper part of Juliette Creek on the south. The anticlinorium can be followed from the contact with the overlying quartzite sequences on the west for approximately two miles to the east where the structure is in fault contact with the western limb of the Bayhorse Anticline. The crest of the anticlinorium is nearly horizontal with neither the large anticline nor the superimposed smaller folds showing any distinct plunge. The strike of the axial plane, as determined from the attitudes of slaty cleavage, varies from due north to N. 15° E. (Fig. 21). In surface exposures, the western limb of the anticlinorium is more gently dipping than the eastern limb. The eastern limb is near vertical and is overturned toward the top. Michell (1939, p. 2) noted that the west limb of the anticline seems to steepen with depth and that the eastern limb flattens so that the anticlinorium tends to become more symmetrical with depth. This is also indicated by a gradual change in attitude of the axial plane dips gently westward at the highest elevations and dips steeply eastward at the lowest elevations (Fig. 22).

The southern extension of the anticlinorium is not well defined as it has been extensively modified by emplacement of the Nevada Mountain stock, development of the accompanying thermal aureole and subsequent high angle faults and erosion. However, the anticlinorial structure can be discerned from an examination of outcrops on the east and west flanks of Juliette Creek in the extreme southern part of the study area. As last observed, the

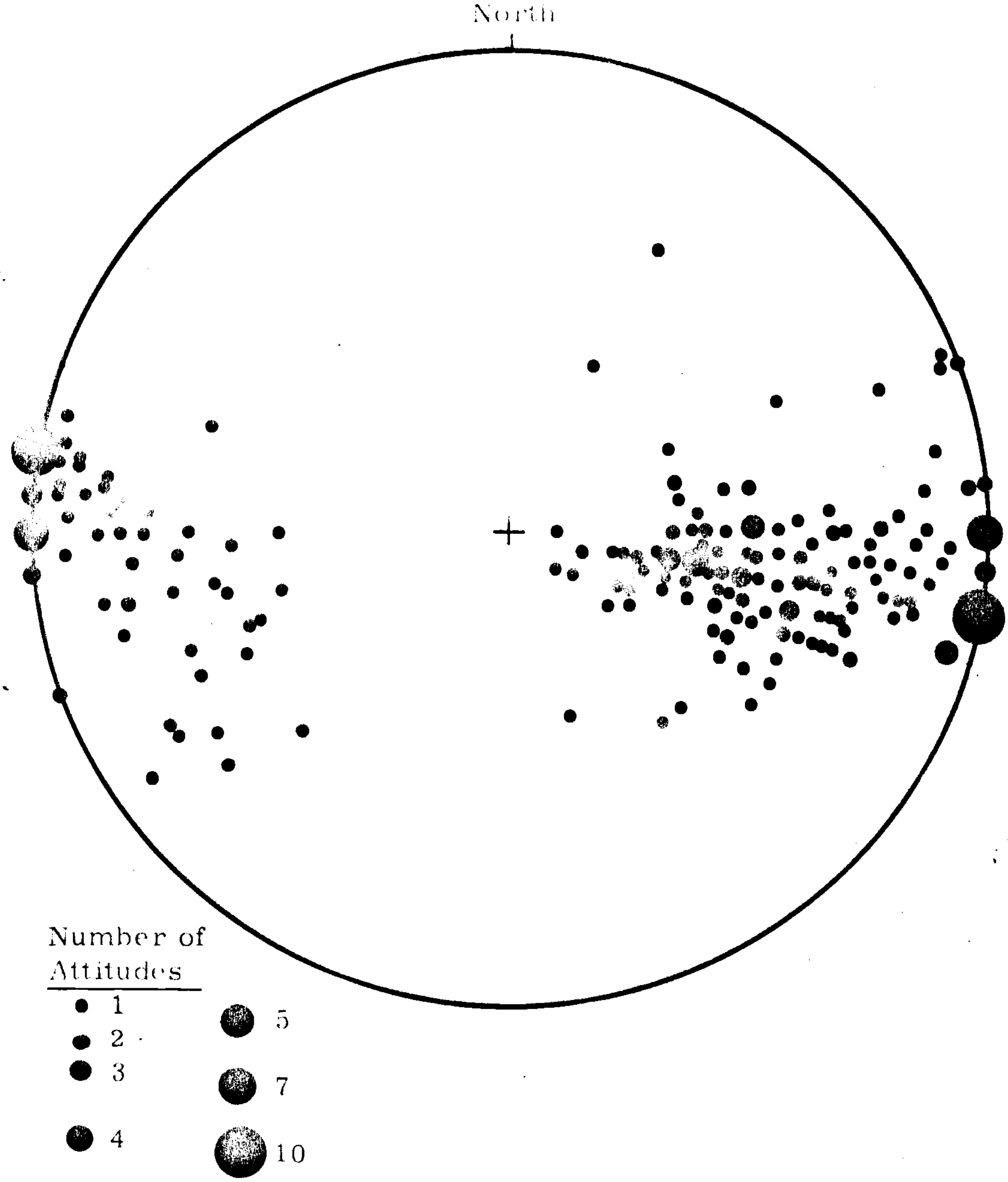



Figure 21. 163 poles to slaty cleavage from the Ramshorn Slate near the Ramshorn Mine area plotted on the lower hemisphere of the Schmidt stereonet. Each attitude represents an outcrop area of approximately 200 square feet. This data is contoured on Figure 21a.

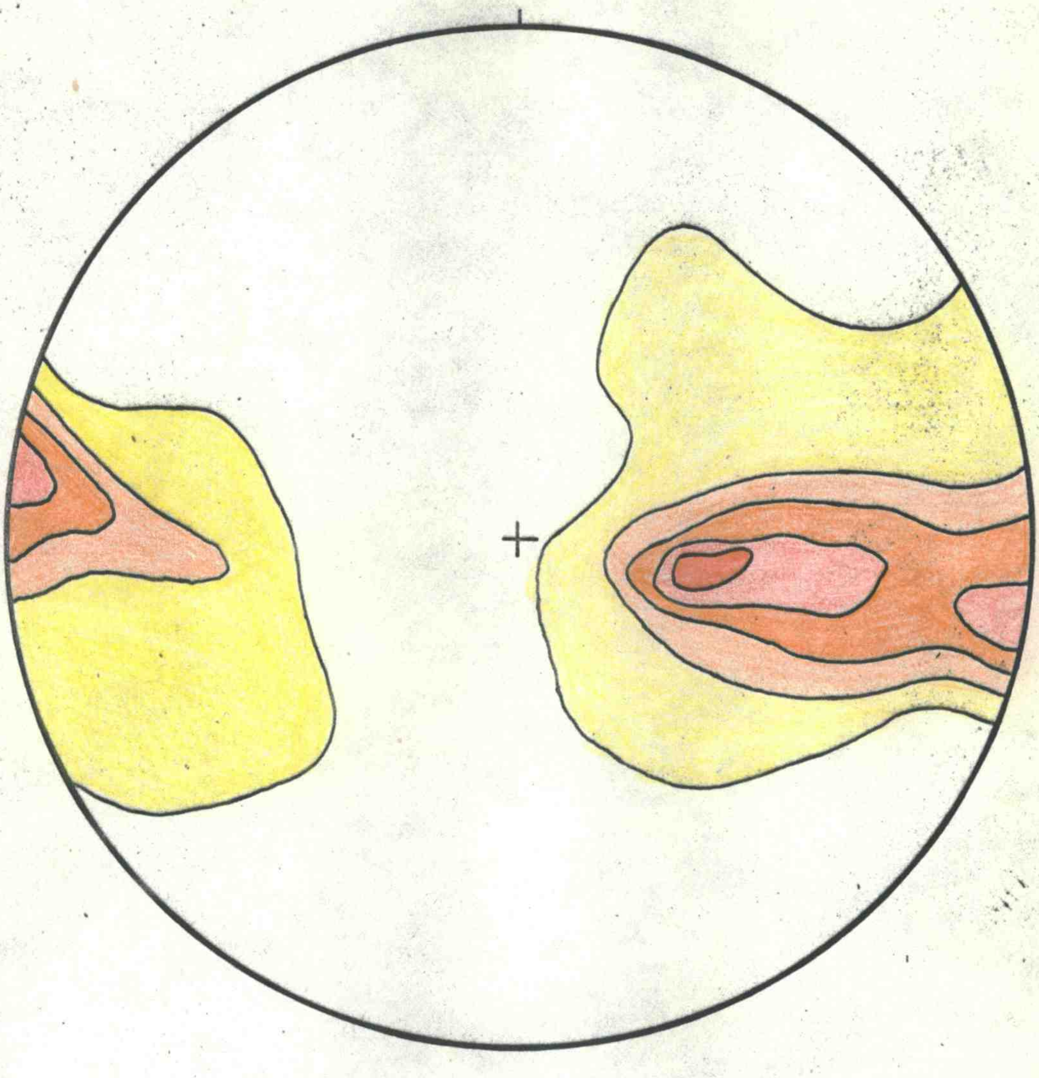


Figure 21a. Contour diagram of point diagram shown in Figure 21. Contours are 2, 4, 6, 8 and 10 percent. The two maximums are caused by variations in sample density as related to the available outcrop.

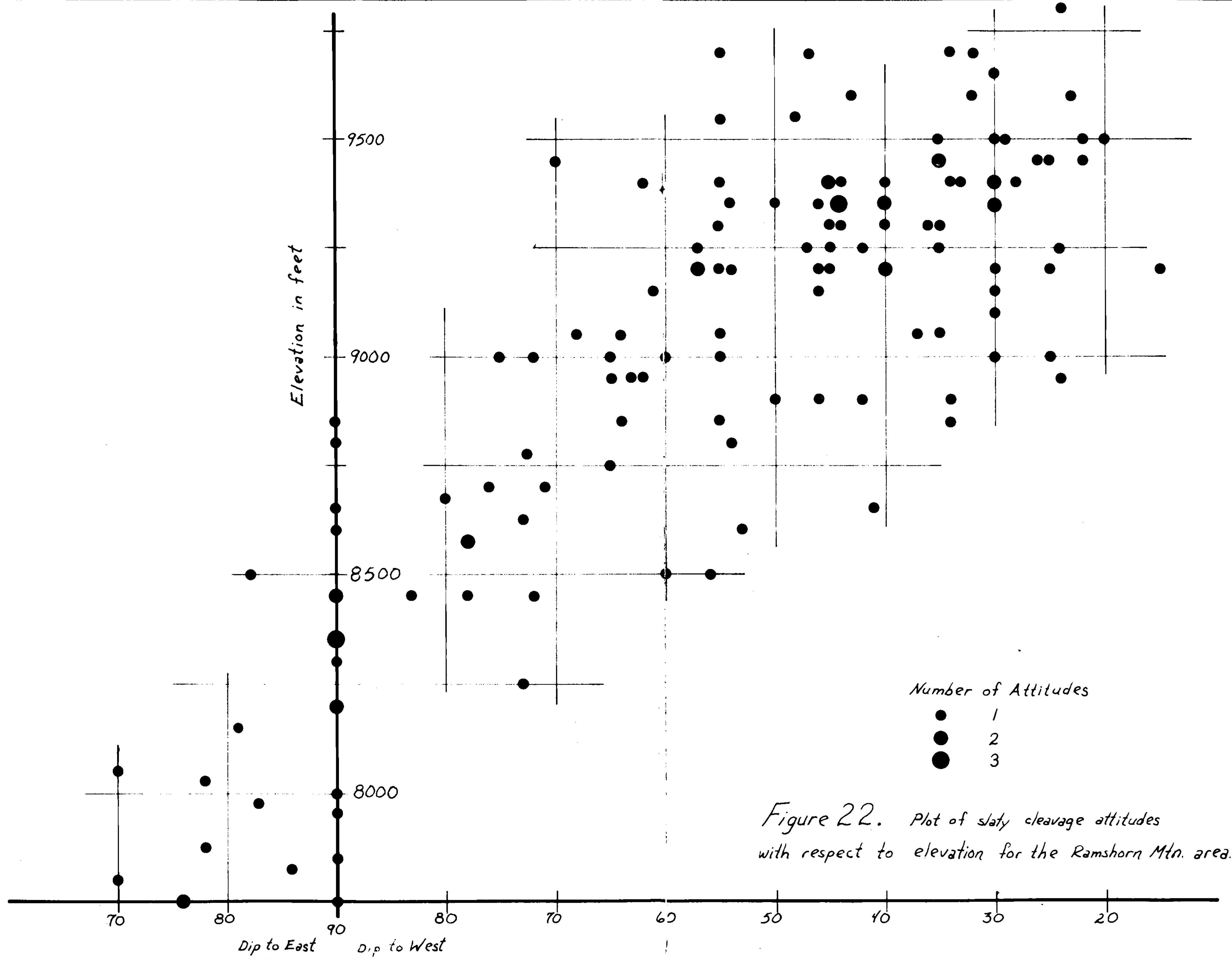



Figure 22. Plot of slaty cleavage attitudes with respect to elevation for the Ramshorn Mtn. area.

anticlinorium has apparently become more symmetrical before it passes out of the area to the south. The northern extension of the anticlinal structure is much better defined and becomes more symmetrical as it passes undisturbed out of the area to the north.

Individual fold sets can commonly be traced over large distances and, when combined with other sets, they characterize the form of deformation as parallel folding in which the anticlinal folds become sharper with depth, broader, and more open upward. Axial plane faults and bedding plane slippage features are common as the shape of the folds change. The western limb of the anticlinorium is characterized by small scale chevron folds that alternate with open and gently undulating folds. In contrast, the eastern limb of the anticlinorium has been more intensely deformed and consists of a series of steeply dipping to overturned beds that have been repeatedly bent into near horizontal attitudes to form a series of step folds (Fig. 23).

Structural Development. The formation of the anticlinal structure can best be explained as the product of two closely related episodes of deformation in which maximum compressive strain was similarly oriented from the west and east.

Slaty cleavage forms perpendicular to the axis of the greatest principal strain. The relatively consistent north-south strike of slaty cleavage and bedding planes are indicative of the

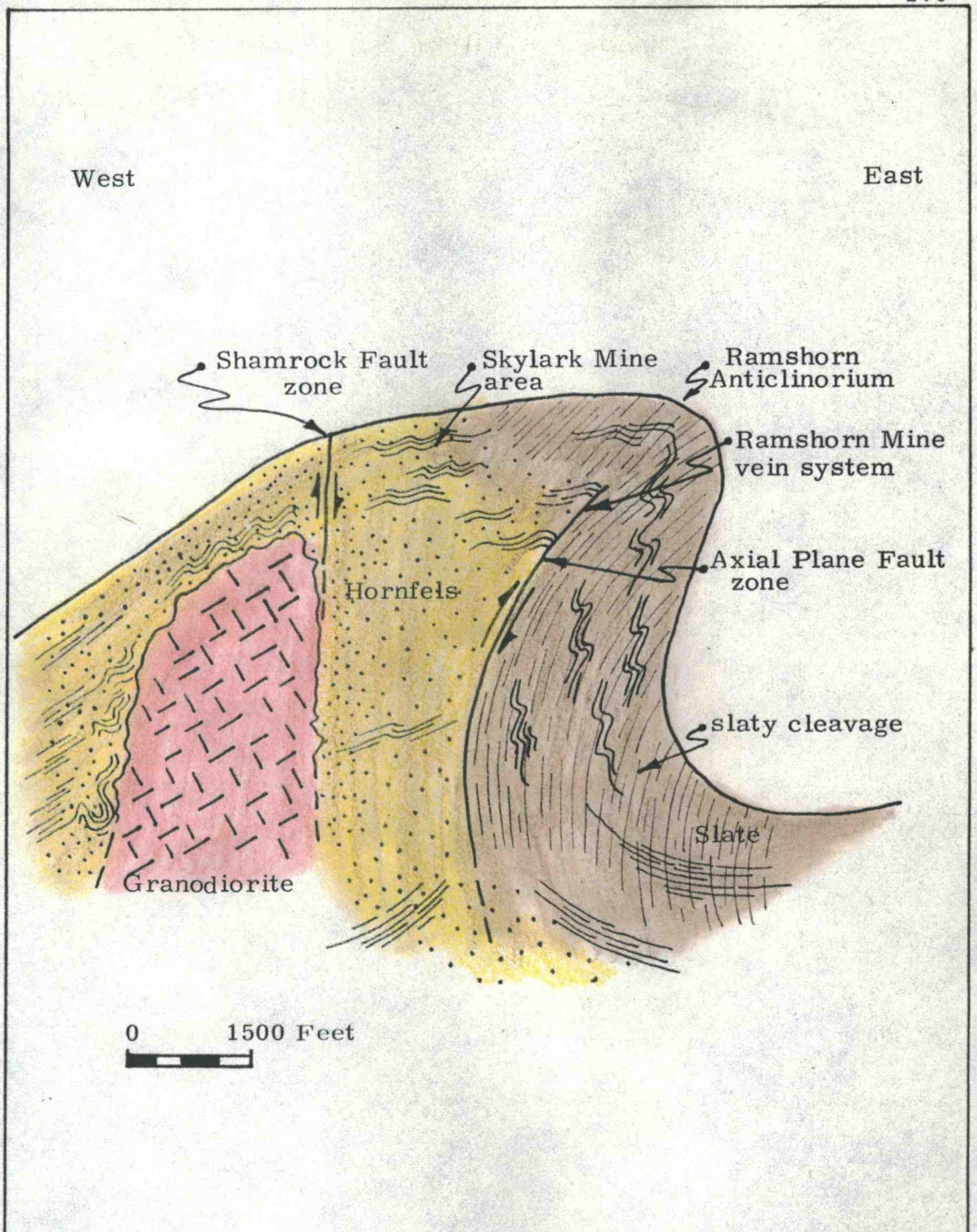



Figure 23 - Diagrammatic cross-section of the Ramshorn Anticlinorium. Approximate scale only; supplements cross-section $C_3$-$C_6$, Plate 5 (back pocket).

general east-west orientation of compressive strain that produced buckle folding of the Ramshorn Slate. The stress field within the slate was controlled by the neighboring competent units and varied in a systematic manner becoming greater from the west to the east with increasing elevation. This differential character of the deforming stress is indicated by the increasingly eastward asymmetry of the anticlinorium in the upper levels of the fold and the concomitant change in the attitude of the slaty cleavage from gentle westward dips to steep eastward dips with decreasing elevation.

A regional strain field of this character might reasonably be explained by compressive strain directed from the west to the east in association with lateral stresses preceding and accompanying the emplacement of the various phases of the Idaho Batholith. Within the regional strain field the extreme differences in the competency of the neighboring rock units produced the asymmetric character of the anticlinorium and initiated thrust faulting that was contemporaneous with or closely followed the formation of the fold structure.

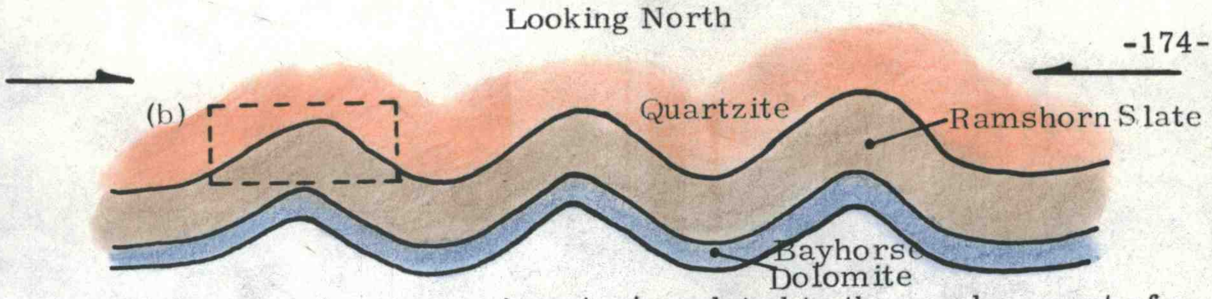
The quartzite sequences overlying the Ramshorn Slate represent a highly competent rock unit that is thought to have slid over the less competent Ramshorn Slate. A local thrust zone, of small displacement, is mapped toward the upper elevations of

Ramshorn Mountain (Pl. 11, p. 40). It is believed to be a product of this deformational process. A major zone of high angle faulting is associated with the axial plane of the major anticlinorial fold. It is probably an extension of the process described above, whereby the progressive geometric development of parallel folding eventually created a major zone of weakness that corresponds to the axial plane of the overall structure. The non-throughgoing character of the axial plane fault zone also suggests development in this manner.

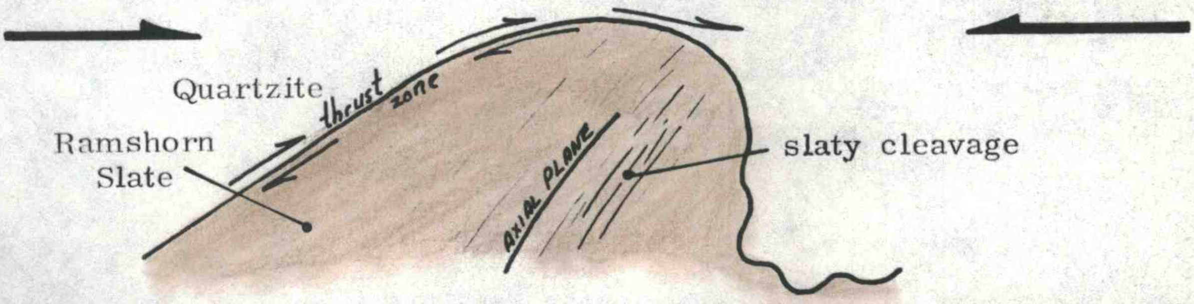
The restricted development of the extreme asymmetry of the Ramshorn Anticlinorium and the associated well-developed slaty cleavage, mineralized axial plane fault zones and several other features of the associated Bayhorse Anticline (pp. 178 to 185) suggest that at least part of the early structural development of the area was caused or at least enhanced by factors of a more local significance. The only apparent difference between the structural development of the study area and adjacent regions in the emplacement of the Juliette Creek intrusive complex which could reasonably supply the necessary stress to explain the anomalous structural features of the Bayhorse district.

Superimposed upon the effects of the previously described regional strain field would be those imposed upon the argillaceous country rocks by the forceful emplacement of the

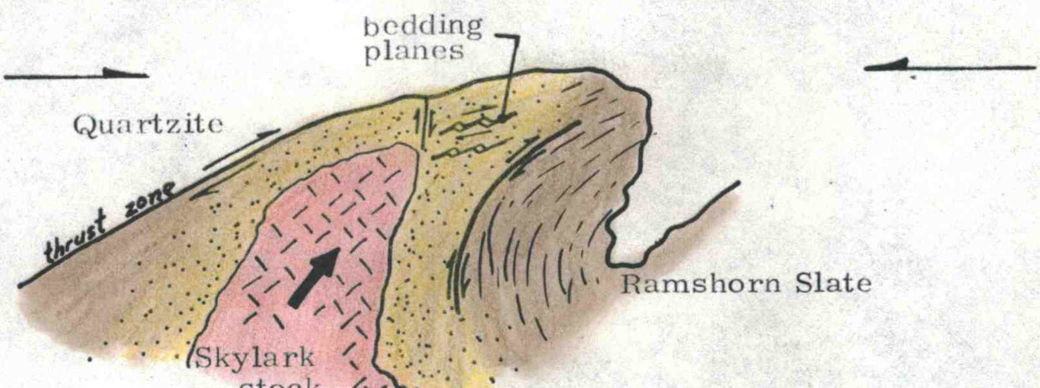
Juliette Creek intrusive complex (Fig. 24). During initial strain, the argillaceous rock failed incompetently by ductile folding with the development of slaty cleavage. Under increasing strain the rock deformed in a more competent manner by brittle fracture along pre-existing zones of weakenss. This tendency toward brittle failure of the Ramshorn Slate would be enhanced by the process of thermal metamorphism and the development of the metamorphic aureole in the country rocks adjacent to the Juliette Creek intrusive complex. The low grade edge of the aureole, marked by the development of andalusite and cordierite porphyroblasts, and the destruction of slaty cleavage, roughly coincides with the axial plane zone of the Ramshorn Anticlinorium. Differences in hardness between hornfels and slate probably aided in localizing the shear stress that resulted in brittle failure along the axial plane zone. Contemporaneous development of the Bayhorse Anticline from a more competent lithology probably produced a buttress that acted to "pin" the eastern front edge of the developing Ramshorn Anticlinorium and enhanced the asymmetrical character of the anticlinorium. With emplacement of the Nevada Mountain and Skylark stocks, the initially upward directed stresses were also properly oriented to enhance the development of axial-plane faulting of the anticlinorium. The emplacement of the Skylark stock also provided a mechanism by which open fractures might




a) Initial regional compressive strain related to the emplacement of the Idaho Batholith enhanced a series of elongate, symmetric folds in the Paleozoic rocks.



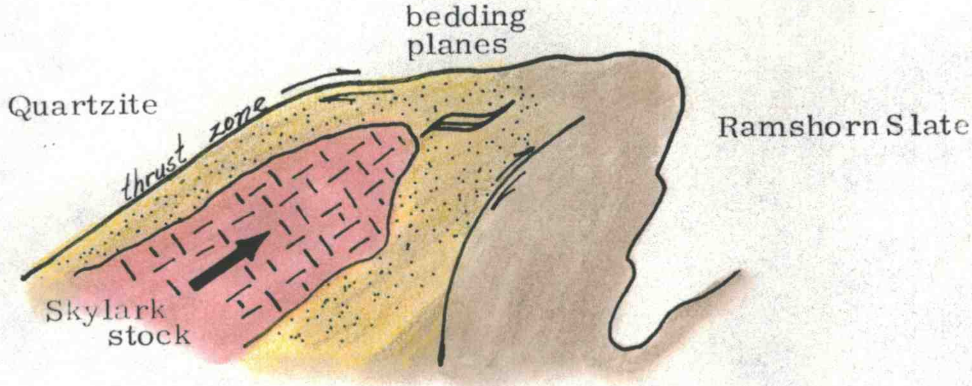

b) Continued regional strain produced asymmetric to overturned folds with development of axial plane slaty cleavage. The more competent quartzite unit overlying the Ramshorn Slate was soon unable to take up the strain by ductile deformation and slid over the incompetent slate.




c) Upon emplacement of the Skylark stock the slate was metamorphosed to a hornfels. Slaty cleavage was obliterated and bedding planes were enhanced. Under the action of the more vertically oriented stress related to the forceful emplacement of the Skylark stock the asymmetry of the anticlinorium was enhanced, the axial plane zone of the structure was broken by shearing, the marginal zones of the intrusive were fractured, and the bedding planes on the western limb of the anticlinorium were opened.

Figure 24; a, b, c. Development of the Ramshorn Anticlinorium.

Looking North



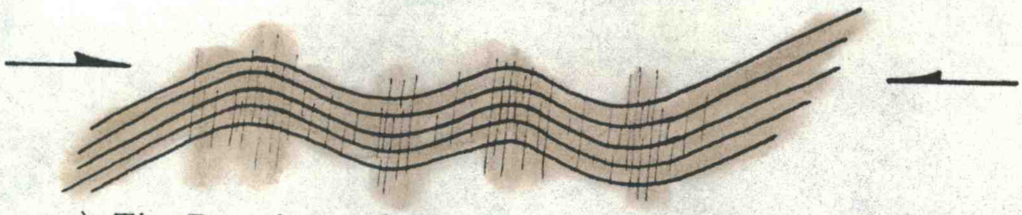

d) An alternate configuration of the emplacement of the Skylark stock (p. 97).

Figure 24 d. Development of the Ramshorn Anticlinorium.

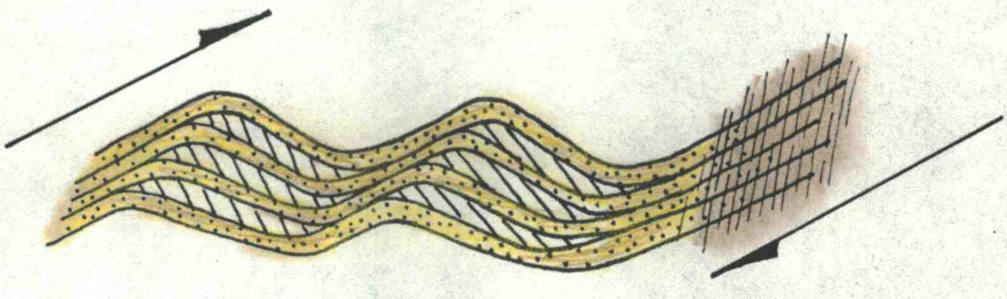
be created between bedding planes on the western limb of the anticlinorium. Most of the western limb is located within the thermal aureole surrounding the Skylark stock, well within the limit of hornfels development. The obliteration of near vertical slaty cleavage and concomitant enhancement of nearly horizontal bedding planes within the hornfels zone may have provided planes of weakness which opened in response to the stress couple (Fig. 25). In addition, shear strain was probably localized along the margin of the stock to produce the near vertical fault zones bounding the intrusive mass similar to those of the Shamrock fault zone.

This interpretation may explain the manner in which the ground was prepared shortly before the entrance of the mineralizing solutions. The previously impermeable argillaceous rocks were fractured along (1)a steeply dipping eastern zone coinciding with the axial plane of the anticlinorium, (2) a near-vertical zone associated with the margins of the igneous intrusions, and (3) along the bedding planes of the western limb of the anticlinorium (Fig. 24). The persistence of these features with depth, and their possible continuation to the north and south, are important to the search for additional fissure-type mineralization and will be discussed in Chapter 9.

Western Limb of Ramshorn
Anticlinorium



a) The Ramshorn Slate reacted incompetently to initial regional strain by folding with concomitant development of slaty cleavage.



b) Upon emplacement of the Skylark stock the slate was metamorphosed to a hornfels. Slaty cleavage was obliterated and bedding planes were enhanced. Under the action of more vertically oriented stress related to the forceful emplacement of the Skylark stock the brittle hornfels broke along bedding planes and slid one over the other creating nearly concordant lense-shaped fracture zones.

Figure 25 - Mechanism by which fracture zones could be created between the near horizontal bedding planes of the western limb of the Ramshorn Anticlinorium.

Bayhorse Anticline

The Bayhorse Dolomite is a persistent, easily recognizable stratigraphic marker that enables the shape of the elongate Bayhorse Anticline to be rather precisely determined because transversely cutting streams have exposed cross-sectional profiles of the anticlinal structure.

Description. The shape of the anticline can be traced by reference to the dolomite formation over an area nearly 15 miles long and 2 ½ miles wide (Hobbs and others, 1975). In plan view, the axis of the Bayhorse Anticline is gently convex to the east bending from a due north strike south of the study area to a strike N. 25° W. to the north of the study area. If the complicating offsets of major longitudinal faults are removed, the intersection of the Bayhorse Anticline with a horizontal plane roughly corresponding to the 6000 foot contour, yields a plan view that is diagnostic of the formation of the fold structure (Fig. 26 and Pl. 29).

The western edge of the anticline is uninterrupted and closely parallels the arcuate shape of the anticlinal axis. In contrast, the eastern margin is much more irregular and marked by a pronounced bulge in the central part of the anticline which is centered in the area of study. This bulge also marks the area of highest uplift from which the structure plunges gently to both the north and south. The eastern limb of the anticline is generally

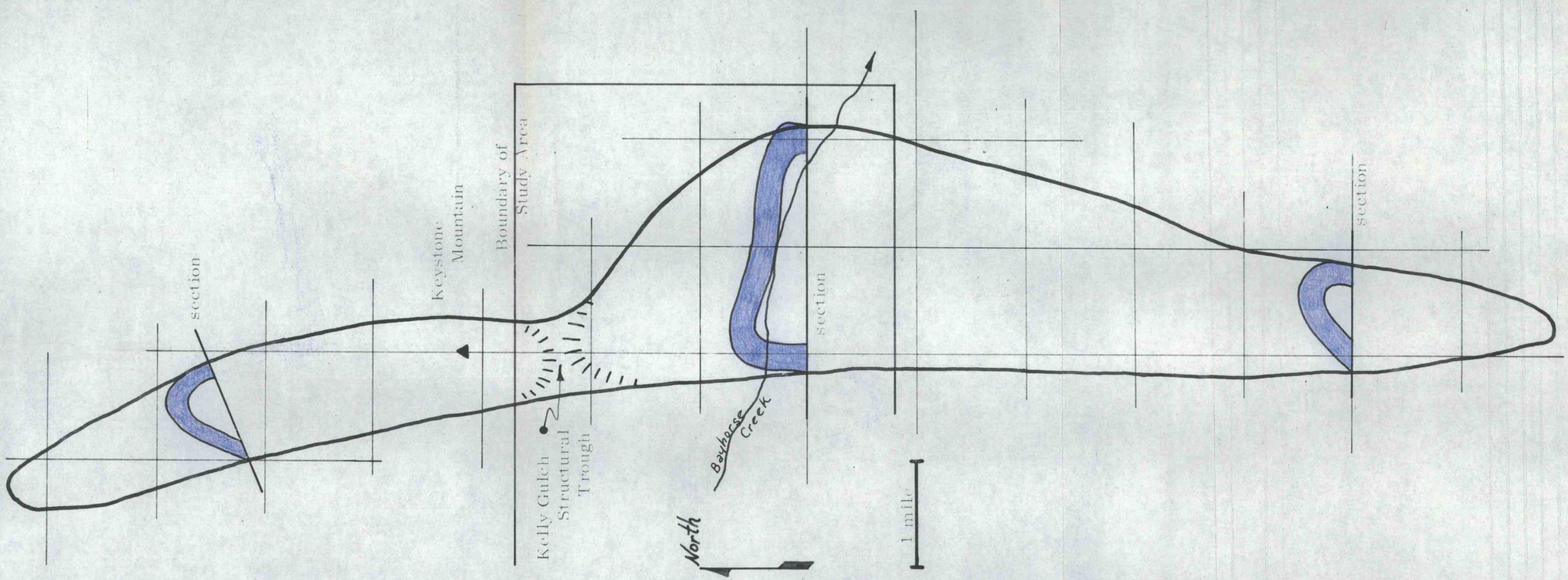



Figure 26. Plan view of the Bayhorse Anticline taken along the 6000 foot contour level.

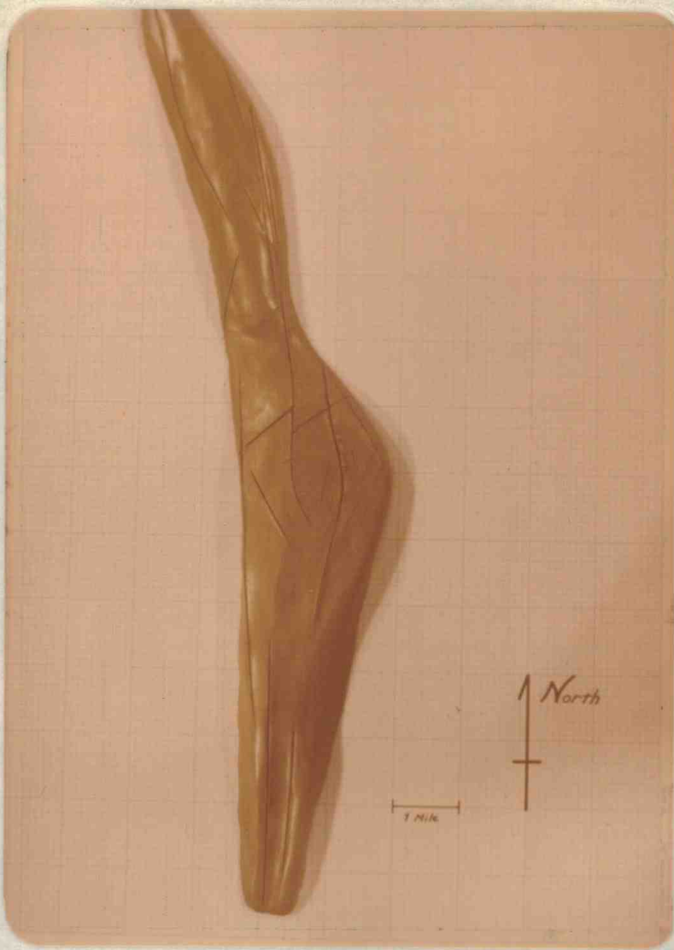



Plate 29. Clay model giving a three dimensional view of the Bayhorse Anticline.

more steeply dipping than the western limb, making the overall structure asymmetric to the east.

The intersection of the topography with the Bayhorse Anticline indicates that a local structural trough crosses the anticlinal axis transversely in the vicinity of Kelly Gulch. This structural depression separates a high point on the crest of the anticline near Keystone Mountain from a structurally higher point over Bayhorse Creek.

The northern extension of the anticline has a distinctly narrower plan view and averages one mile in width for most of its length in contrast to the two and one-half mile width of the central bulge area. Chambers (1966, p. 60) indicates that the anticline has an asymmetric, cone-shaped profile as it plunges northward from Keystone Mountain. The western limb of the anticline dips nearly 45° W. The dolomite beds bend abruptly near the crest of the anticline and then dip from vertical to overturned on the eastern limb of the anticline.

The southern extension of the anticline plunges gently southward from Bayhorse Creek and tapers in plan view from the central bulge area to form a narrow, cone-shaped anticline asymmetric to the east and similar in profile to the northern extension just described.

The central part of the anticline was mapped in detail and exhibits several features not common to the two extremities. The western flank of the anticline gradually rolls from dips near 45 degrees to the north and south of the study area to dips that range up to vertical within the area of the central bulge. The crest of the anticline in this area is much broader and bedding attitudes are near horizontal. The eastern flank of the bulge area is overturned to the east. In profile, the central part of the Bayhorse Anticline is box-shaped with vertical sides and a horizontal top (Pls.30, 31 and 32).

The Garden Creek Phyllite, in the core of the anticline, acted least competently of any of the rocks exposed within the area. Slaty cleavage is well-developed in the few available exposures and closely parallels the regional structural grain. However, its use as a structural indicator is limited because of poor exposures.

Small scale features indicative of intraformational strain are common within the Bayhorse Dolomite. They include drag folds, imbricate brecciation and tension cracks, but provide little information as to the mode of formation of the anticlinal structure. There is evidence of thinning of the dolomite beds on Pacific Mountain and in Beardsley Gulch. Flattened disks of silicified pisolites of the fifth member of the dolomite formation have been stretched from their normally ovoid shape found elsewhere. The change in shape of the pisolites indicates that


Plate 30. Western corner of the Bayhorse Anticline; looking north.


Plate 31. Crest of the Bayhorse Anticline; looking north.


Plate 32. Eastern corner of the Bayhorse Anticline; looking north.

stretching did not exceed 15 percent.

Structural Development. The development of the Bayhorse Anticline is based largely upon a consideration of the peculiar shape of the fold and the necessity of integrating this deformational process with those that formed the associated Ramshorn Anticlinorium to the west.

As indicated by the areal extent of the basal conglomerate of the Ramshorn Slate (Chambers, 1966, p. 54) the ancestral Bayhorse Anticline was a prominent topographic feature by early Ordovician time. This early structure would be easily accentuated by the the more intense deformation of the Mesozoic Era. The overall asymmetry of the fold is similar to that of the Ramshorn Anticlinorium, and it is reasonable to assume an initial regional strain field similar to that proposed for the early development of the Ramshorn Anticlinorium. Regional strain was directed from the west to the east and was differential in character decreasing in intensity with depth. As related to the emplacement of the Idaho Batholith, this strain field easily accounts for the initial tightening and asymmetry of the broad open folds formed during Paleozoic time and the concomitant overthrusting of the overlying quartzite sequences.

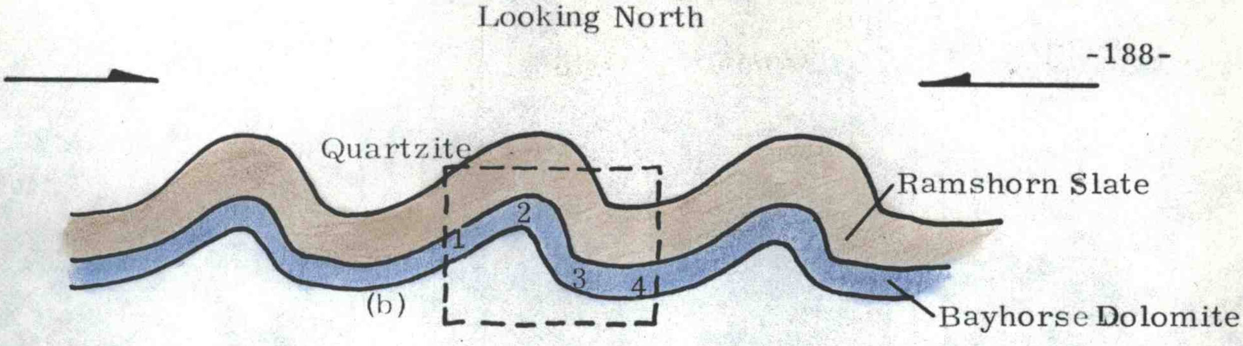
The regular and gently arcuate trace of the western limb of the Bayhorse Anticline in plan view is in marked contrast to the irregular trace of the eastern limb with its pronounced central bulge. If the regional eastwardly directed strain was acting in a differential manner horizontally as well as vertically, to produce the irregular eastern limb of the anticline, then a parallel effect would be expected on the western limb. As the western limb parallels the eastern limb only along the northern and southern extension of the anticline, some other factor of more local significance is thought to be responsible for the development of the oddly shaped central bulge of this anticline.

Uniformly applied regional stress might account for the regular western limb and at the same time cause the formation of the irregular eastern limb, provided the eastern margin was differentially fixed or responded differently to the applied stress. However, neither the lithologic or structural inhomogeneities necessary to cause a variation in the physical properties of the rock of the magnitude needed to account for the observed features, nor the fixed buttress-like mass (Ross, 1934, p. 8) needed to "pin" the front edge of the anticline are in evidence. The structurally higher, box-shape of the central part of the anticline is also at variance with the gently plunging northern and southern cone-shaped extensions, and is difficult to account for with uniformly applied regional strain.

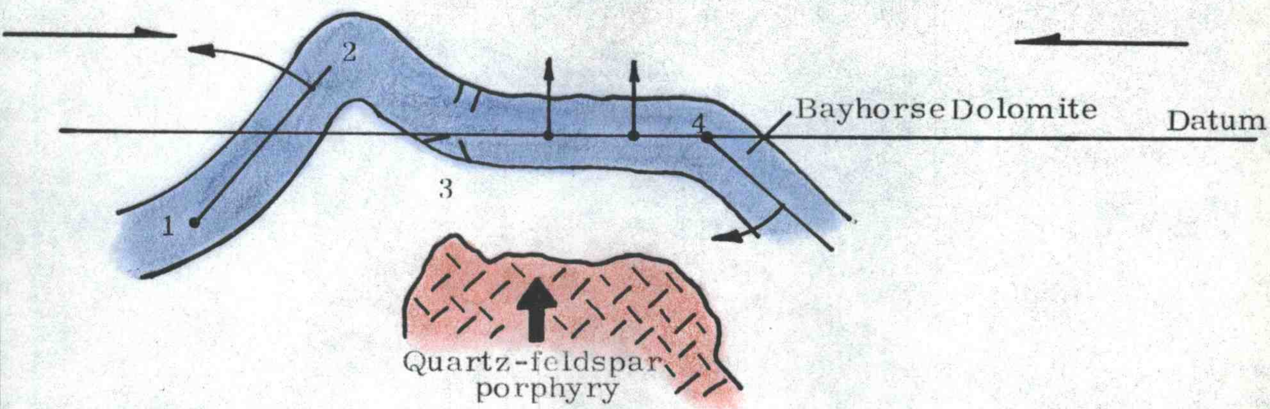
Because the shape of the Bayhorse Anticline is difficult to account for by one continuous deformational event, and because the anomalous features of the Bayhorse and Ramshorn Anticlines are apparently related to events of a more local extent, the emplacement of the Juliette Creek intrusive complex is believed to have significantly modified the pre-existing regional structure on a local scale.

The similarities between the shape and width of the northern and southern extensions of both the Ramshorn Anticlinorium and the Bayhorse Anticline support the contention that shortly before the intrusion of the igneous complex the Bayhorse and Ramshorn Anticlines were parallel structures that passed through the area as narrow, elongate anticlines with asymmetric, cone-shaped profiles. Upon intrusion of the quartz-feldspar porphyry phase, or perhaps underlying related phases of the intrusive complex, the central part of the Bayhorse Anticline was uplifted and refolded (Fig. 27).

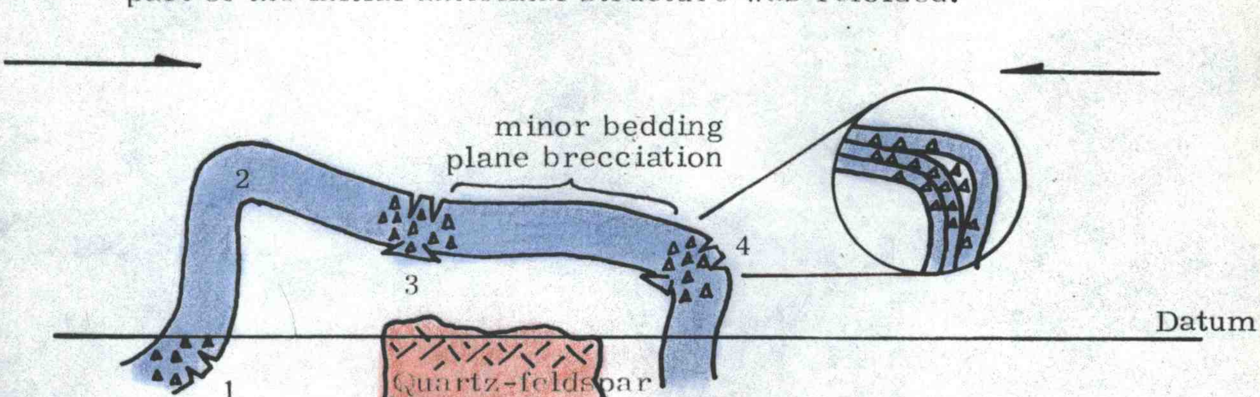
Evidence from drill core suggests that the intrusion closely parallels the structural high of the area. In addition, the regional magnetics previously discussed support the contention that the intrusive phase is piston-like in shape with vertical sides and a horizontal top, and that the porphyry phase probably merges to the south with a larger plutonic mass at depth. As the piston-shaped intrusion was wider than the original fold structure, part




a) Regional compressive strain related to the emplacement of the Idaho Batholith enhanced a series of elongate, asymmetric folds in the Paleozoic rocks.




b) Upon emplacement of the quartz-feldspar porphyry, the central part of the initial anticlinal structure was refolded.




c) Four zones of pronounced brecciation were created towards the final stages of emplacement of the complex. In addition to zones 1, 2 and 3, a fourth zone may have been formed along the structural discontinuity near Kelly Gulch.

Figure 27. Development of the Bayhorse Anticline

of the previously unfolded dolomite to the east was incorporated in the new fold to eventually form the local eastward bulge on the central part of the anticline. The western limb of the fold was steepened by pivoting to the west. The eastern limb was flattened and moved upward. The old hinge line between the eastern limb and the unfolded rock also moved upward. However, as the sense of bending was opposite to the original fold this area deformed in a more brittle manner than the other parts of the structure. Within the area controlled by this pre-existing hinge line the upper part of the dolomite was locally fractured and brecciated. The unfolded rock to the east was lifted in response to the force of the intruding magma and folded over the edge of the piston-shaped intrusion to form the steeply dipping eastern flank of the Bayhorse Anticline.

As previously mentioned, the area near Kelly and Beardsley Gulches corresponds to a prominent structural low in the crest of the Bayhorse Anticline. This feature appears to cut the anticline transversely from northwest to southeast. The position of the structural low corresponds closely with both the northern limit of the bulge area and the northern edge of the intrusive phase as indicated by the available aeromagnetic data. This zone is also on strike with a large vertical fault mapped by Hobbs and others (1975) northwest of the district. The depression may be caused by a major zone of transverse faulting related to the northern margin of the intrusive phase. Alternatively, the depression might be more aptly characterized as a transverse synclinal trough caused by ductile deformation and extension of the dolomite that was directly related to the emplacement of the porphyry phase. It is certain that a structural discontinuity does exist in this part of the anticline, but its exact character and any influence that it may have had upon the following periods of mineralization is presently unclear.

As the Bayhorse Anticline developed it acted as a buttress with respect to the contemporaneous formation of the Ramshorn Anticlinorium. In this way, the Bayhorse Anticline progressively fixed the lower parts of the Ramshorn Anticlinorium and forced its eastern limb to steepen. Contemporaneous with the emplacement of the intrusive complex, regional compressive stress culminated in producing overthrusting which contributed to such features as the formation of bedding plane slippage and the asymmetry of the two major folds.

Prior to the development of major faults and mineralization in the district, several zones of weakness had been formed within the Bayhorse Dolomite as a result of the emplacement of the Juliette Creek intrusive complex. The eastern hinge line of the early Bayhorse Anticline now roughly coincides with the trace of the Mill Fault. The upper part of the Bayhorse Dolomite along this old hinge line would have been highly brecciated by tensional strain accompanying the development of the anticline. In addition, major zones of brecciation might have been localized along the structural discontinuity near Kelly and Beardsley Gulches. A third zone may have been opened at depth along the western hinge line where the early anticlinal structure was rotated westward. A final zone of major extensional strain was located along the eastern corner of the present structure.

The processes responsible for the formation of these zones of weakness in both anticlinal structures which are of considerable importance to the search for additional mineral deposits acted over a restricted area in direct response to the stresses accompanying the emplacement of the Juliette Creek intrusive complex. Hence, these processes and the resulting zones of weakness can be expected to have diminished rapidly in intensity away from the central part of the anticline.

## Faults

Following the major episode of folding and thrust faulting, regional compressive stress relaxed and was superceded by at least two periods of major tensional stress that resulted in block faulting. The first period of extensional faulting closely followed the terminal stages of the emplacement of the Juliette

Creek intrusive complex, and resulted in the development of many dip-slip faults that were mostly of relatively small displacement. During the subsequent magmatic-hydrothermal-tectonic event that accompanied the extrusion of the Tertiary volcanics, many of the pre-existing faults were reactivated and some were substantially enlarged and a few new faults were formed. Faults within the district can be conveniently classed as bedding plane slippage faults, dip-slip faults of both large and small displacement, and faults of questionable location and character.

Bedding Plane Slip Faults

The first faults to form in the rocks exposed in the Bayhorse district developed in response to eastwardly directed compressive strain near the close of the major episode of folding. Major bedding slippage took the form of low-angle thrust faults that developed over the crests of the anticlinal structures. The competent quartzite units are thought to have moved over the incompetent slate of the Ramshorn Formation. Only scattered remnants of the thrust sheet remain as isolated knobs and ledges of quartzite breccia capping ridge crests throughout the area.

The contact of the quartzite sequence with the underlying Ramshorn Slate along the western border of the map area is largely obscured by talus. Although direct evidence for the existence of a thrust fault at this contact is lacking, several other lines of evidence suggest its presence. Wherever the quartzite remnants are found, they consist of angular blocks of quartzite and shale up to three feet in diameter cemented by a silicified groundmass of more finely broken equivalents. The limited exposures hamper a precise determination, but the lithologic similarities suggest a correlation with the mixed lithology sequence. The brecciated and silicified character of the remnants, the highly sheared appearance of the shale clasts and the geometry of the outcrop pattern suggest that the remnants are representative of a thrust plate that once extended over the area.

In western quartzite exposures, bedding plane shear and breccia zones of a discontinuous character are indicative of the localization of bedding plane thrusts in the intercalated shale units. The difference in stratigraphic thickness of the Ramshorn Slate of from 3000 feet adjacent to Ramshorn Mountain, to less than 1000 feet east of Beardsley Gulch, suggests either a profound angular unconformity and/or a major zone of thrust faulting. The quartzite sequences near the Bayhorse Lakes dip gently westward and overlie asymmetrically folded Ramshorn Slate.

Ross (1937) and Hobbs (1975) have mapped major thrust faults in a similar stratigraphic position in areas just south of the study area. Their interpretations are based upon more definitive stratigraphic and textural evidence than remains within the area of study. The consistent association of highly altered intrusive gabbro with the recognized zones of thrust faulting in areas to the south suggest that the intrusive gabbro located near the contact of the quartzite and Ramshorn Slate on the ridge west of Bull of the Woods Gulch may also be localized by a similar zone of weakness. Although none of these features are alone diagnostic of the presence of a major zone of thrust faulting, when all are considered together and with the additional difficulty of explaining the various features in other ways, the existence of an overriding thrust plate within the area of study is quite reasonable.

Major bedding plane slippage also occurred within the Ramshorn Slate on the western limb of the Ramshorn Anticlinorium. The open fractures created in response to the intrusion of the Skylark stock (Fig. 24 c and d, p. 174 ) later localized the base-metal mineralization of the Skylark Mine area.

Bedding plane slippage also accompanied the late stages of folding in the Bayhorse Dolomite and had its greatest development along the top of the anticline (Fig. 27c, p. 188 ). The eastern corner of the box fold developed bedding plane breccias and open fractures as the upper part of the dolomite moved over the lower part to produce the vertical difference in symmetry. These zones were localized stratigraphically in the upper parts of the Bayhorse Dolomite along the dividing line between the symmetrical core and the asymmetrical top of the anticline. From an exploration standpoint, it is important to note that these zones of brecciation decrease in intensity westward as the "plastering effect" of the eastwardly-directed strain increases. These features are all directly observable in cliffs of dolomite to the north of Bayhorse Creek, and in the many underground mine workings still accessible in the district.

Dip-Slip Faults of Small Displacement. There are several generations of dip-slip faults in the area and they vary greatly in orientation and displacement. After relaxation of regional compressive stress, tensional stress resulted in many variably oriented dip-slip faults of generally small displacement. They may be reasonably related to the roof zone of the Juliette Creek intrusive complex in a manner similar to that suggested by Bateman (1950, p. 313) for elongate cupolas. Dip-slip faults of small displacement are not easily traced through the poorly exposed argillaceous rock units. The character of these faults is most readily discernible from underground mine workings and from surface exposures where they cut the Bayhorse Dolomite in the cliffs north of Bayhorse Creek. The strike of these faults generally parallels the north-south structural grain of the district, but ranges to the extreme of nearly east-west trending fault zones. The faults dip nearly vertical and have undergone several periods of movement as indicated by variously oriented slickenslides and tension cracks. The net displacement, however, rarely exceeds a few tens of feet and they are usually traceable for only short distances.

The dip-slip faults having the larger displacements are the most easily recognized, but it is the faults having the smaller displacements that are economically most important. Although many of the smaller faults localize small amounts of mineralization, their major significance is that they formed channelways which guided the mineralizing solutions. Where dip-slip faults intersected zones of brecciation formed by bedding-plane slip faults and acted to guide the ore-bearing solutions to these zones, deposition of ore minerals filled the open space in abundance. Faults of this character occur throughout the area, but their location is difficult to predict. Therefore, discovery of significant quantities of additional ore is largely dependent upon the location of the more predictable zones of bedding plane brecciation.

The dip-slip faults of small displacement on Pacific Mountain are important from two respects. A southerly projection of their strike through the incompetent Garden Creek Phyllite intersects a similar extension of the McGregor fault zone over the structural high in the vicinity of the Garden Creek Dolomite. This intersection is thought to account for the deformation and brecciation of the lower dolomite unit that prepared the ground for the mineralizing solutions that later flooded the area. Additionally, the northern projection of these faults intersects the early hinge-line zone of the Bayhorse Anticline, and probably aided in further breaking the ground and in guiding the mineralizing solutions tothe intensely brecciated zone in this area.

Some of the dip-slip faults of small displacement are obviously post-ore in character as they cut mineralized faults and breccia zones. They probably represent the effects of late tensional stress related to the development of the major longitudinal faults that cross the area.

Dip-Slip Faults of Large Displacement. The most prominent faults in the region are steeply-dipping longitudinal faults that have large vertical and horizontal displacements. These faults generally post-date the emplacement of the Juliette Creek intrusive complex and the two periods of mineralization in the district. They pre-date the major extrusive activity that formed the overlying Tertiary volcanic sequence as many of the faults localize dikes and are apparently covered by parts of the volcanic sequence. These faults have certainly undergone multiple stages of movement, as indicated by the orientation of slickenslides and tension cracks. Parts of some of the fault zones localize small amounts of rebrecciated sulfide mineralization that is indicative of the presence of the fault zones early in the structural development of the district. The larger faults presumably developed as a normal consequence of the coalescence of smaller fault zones under regional stresses not directly related to the emplacement of the Juliette Creek intrusive complex, but to much later relaxational stress after the removal of the vertical pressure of the superincumbent sedimentary rocks. The pre-existing zones of weakness developed in the elongate folds probably controlled the development of the major longitudinal faults.

The Nevada Mountain fault zone is well delineated topographically by a prominent scarp on the west side of Nevada Mountain. The fault zone can be traced northward from beneath the cover of Tertiary volcanics by the juxtaposition of differing lithologies and grades of hornfels, shear and breccia zones, and basaltic dikes to the vicinity just east of Little Bayhorse Lake where it loses its identity in the poorly exposed volcanic rocks. The fault zone strikes N. 10° W. and dips approximately 60° W. Although the height of the fault scarp indicates that the hanging wall has been down dropped with respect to the footwall at least several hundred feet the exact character of the net displacement is difficult to determine. Breccia clasts of both mineralized vein material and volcanic tuff are indicative of a long history of periodic movement ending in post-Miocene time. Numerous slickenslided surfaces indicate that the last movement on the fault zone was of a dip-slip character. The Nevada Mountain fault zone forms the western boundary of the pronounced domal uplift in the central part of the district, and separates the area still covered by Tertiary volcanic rocks to the west from the structural high to the east. This fault zone is associated with a belt of intense hydrothermal alteration along most of its traceable extent.

The development of the axial plane faults of the Ramshorn Anticlinorium has been previously described. Although this fault zone has undergone multiple stages of movement (Ross, 1937, p. 121 and 122) as indicated by the sheared and brecciated character of the vein material, little post-mineralization offset has resulted. The net displacement along the fault zones cannot be determined with certainty, but the capped character (Fig. 23, p. 170) of the axial plane fault zone is also indicative of a small amount of displacement. Slickenslided surfaces and tension cracks indicate variable directions of last movement that are predominantly of a dip-slip character. In accordance with the structural model previously described for the development of the anticlinorium, the axial plane fractures can be expected to continue to the north beneath the ridge leading to the summit of Ramshorn Mountain and to gradually lose their identity as the intensity of folding decreases away from the area influenced by the emplacement of the Skylark stock. The southern extension of the axial plane zone is lost as it is enveloped by the Nevada Mountain stock and the adjacent thermal aureole. It may become traceable again as it passes south of the intrusive disturbance near the head waters of Juliette Creek, as indicated by bedding plane and slaty cleavage attitudes in the area. A similar structural setting should continue to the south of this area as predicted by the proposed structural development of the anticlinorium. Indeed, Hobbs (1975) has mapped a major fault zone on trend with the axial plane zone of the Ramshorn Anticlinorium just to the south of the study area.

The Ramshorn and Bald Mountain Faults mark the structural transition from the Ramshorn Anticlinorium on the west to the Bayhorse Anticline on the east. Outcrop in this area is generally poor and the precise character of the structural transition is unclear. The isolated segment of Bayhorse Dolomite south of Bayhorse Creek is difficult to explain by any other means other than complex close-spaced faulting. In addition, abrupt changes in attitudes of bedding planes and slaty cleavage are indicative of a structural discontinuity. The fault zones strike north-south and appear to be near vertical. Parts of the fault zones localize small quantities of sulfide mineralization which indicate the presence of fault zones early in the structural history of the area.

Structurally, the Pacific Mountain area is a horst bordered by down dropped blocks of the Bayhorse Anticline. The McGregor Fault bounds the block on the west and the Mill Fault bounds it on the east.

The McGregor Fault is well delineated by the juxtaposition of differing lithologies. Breccia zones and well developed slickenslides also mark the position of the fault. The fault has a rather peculiar shape as it strikes north-south and dips approximately 50 degrees to the west in the vicinity of Kelly Gulch. However, to the south it changes attitude to N. 25° W. and dips nearly vertical. The trace of the fault suggests that it may represent the intersection of two separate faults. The fault zone has a vertical displacement of approximately 500 feet as determined from the stratigraphic offset of the Bayhorse Dolomite.

The Mill fault forms the eastern boundary of the Pacific Mountain horst and has the largest displacement of any fault known in the area. The fault is clearly delineated by a prominent scarp just south of Bayhorse Creek. Here and elsewhere the juxtaposition of markedly different lithologies, numerous breccia zones and slickenslided surfaces, and abrupt changes in the orientations of bedding planes and slaty cleavage also mark the trace of the fault zone. As indicated by the offset of the Bayhorse Dolomite, the fault has a vertical displacement of approximately 1500 feet.

The trace of the Mill Fault coincides closely with the hypothesized early hinge line of the Bayhorse Anticline which quite probably aided in localizing the Mill Fault.

<u>Faults of Questionable Location and Character.</u> For lack of adequate exposure, faults are not easily traced through several parts of the district. Nevertheless, there are features that indicate the presence of major fault structures.

The area mapped as Bayhorse Dolomite south of the Bayhorse townsite is a heavily timbered area of scarce outcrop. Contacts are based on lengthy extrapolations from one outcrop to another and are most certainly not exactly as represented. An examination of geologic section B-$B_1$ (Pl. 4, back pocket) shows a difference in thickness from the southern exposures of dolomite to the northern exposures of nearly 1000 feet. Although there is evidence of thinning of the dolomite on the north-central cliffs, it is not so great as to totally account for the variation in thickness. In addition, the lower units are apparently thicker to the south than to the north, and such differential structural thinning is contrary to the stresses thought to be involved in the development of the Bayhorse Anticline. Although there is some lateral variation within the units of the dolomite, there is no evidence to indicate that the difference is caused by primary depositional facies changes. On the contrary, there is no variation between northern and southern exposures of dolomite to the east of the Mill Fault. Therefore, the section south of the Bayhorse townsite has most likely been repeated by faulting, which apparently has had a greater effect on the lower units of the Bayhorse Dolomite that on the upper units. The exact character of the proposed fault zones is uncertain, and a variety of fault orientations and displacements could account for the observed features. However, the faults in this area probably correspond in strike to the north-south structural grain of the area and dip nearly vertical. Conceivably, they could be southern extensions of the fault zones crossing Pacific Mountain.

Only clearly discernible zones of weakness have been delineated in the Ramshorn Slate as the poor outcrop expression of the formation hampers precise location of fault zones. Evidence for additional fault zones within the Ramshorn Slate is based largely upon marked lineaments discernible from aerial photographs of the area. The structural discontinuity crossing the Bayhorse Anticline in the vicinity of Kelly and Beardsley Gulches has already been mentioned. There is a pronounced lineament striking across this area at N. 45° E. in marked contrast to the predominant north-south structural grain of the district and perpendicular to the previously discussed structural discontinuity. The lineament is clearly delineated on aerial photographs (Pl. 33).


Plate 33. Aerial photograph of Pacific Mountain showing the trace of two lineaments, A-B and B-C. Bayhorse townsite = BT

It can be traced southwestward from a valley in the cover of Tertiary volcanic rocks across Beardsley and Kelly Gulches to the crest of Pacific Mountain where it is offset in enechelon fashion to the northeast. The lineament continues to the southwest along a prominent notch in the Ramshorn Slate across Bayhorse Creek and follows Juliette Creek to join the fault mapped in this area on the basis of offset in the thermal aureole surrounding the Nevada Mountain stock. The lineament aids in explaining the absence of the continuation of the fault sliver of Bayhorse Dolomite from the south side to the north side of Bayhorse Creek. The sense of displacement, however, would be opposite to that indicated along Juliette Creek and a scissor-type movement is suggested with the pivot point slightly southeast of the confluence of Juliette Creek with Bayhorse Creek. This type of movement is consistent with the gradual decrease in grade of the hornfels on the down-dropped side of the lineament as the displacement increases southward. The dip of the possible fault apparently rolls from near vertical to an easterly dip in going from northeast to southwest, as indicated by the intersection of the fault zone with the topography. The dip of the contact zone of the Nevada Mountain stock may have influenced such a change in dip.

The trace of the lineament crosses the northern slope of Pacific Mountain and intersects several features of possible economic importance. Several early mine workings are located at the intersection of the lineament with the McGregor Fault. The lineament also crosses the breccia pipe and approximates a western boundary of the Pacific Mountain ore zones. Whether this lineament represents the trace of a fault that possibly aided in localizing mineralization or latter cut it is not clear. Nonetheless, the correlation between these features seems more than fortuitous.

A second lineament approximates the eastern boundary of the study area (Pl. 33). This lineament is marked by several springs and is positioned over the trace of the eastern side of the Bayhorse Anticline. The development of a fault zone in this position is not unexpected as the vertical side of the anticline would easily localize shear stress related to the emplacement of the Juliette Creek intrusive complex.

## IX. MINERAL DEPOSITS

A detailed account of the early history of the Bayhorse Mining District can be gleaned from the old reports of Umpleby (1913), Ross (1937) and Chambers (1966). Hence, only a brief summary of the early mining activity in the area is presented here.

Settlement of the Bayhorse Mining District began in 1877 with the discovery of several fissure-filling deposits of lead and silver. The first and most productive period of mining in the district was from 1877 through 1898. Umpleby (1913, p. 56) estimated that a total of $10,000,000 ($50,000,000 in 1976 prices) in metals was extracted from the district during this period. Approximately 71 percent of the total metal value was derived from silver (7,500,000 oz.), 28 percent from lead (58,000,000 lbs.) and less than one percent from copper (3,000,000 lbs.) and trace amounts of gold (10,000 oz.). Although at no time since its discovery has the district been entirely inactive, an increase in metals prices initiated a brief revival of mining activity in 1915 and the renewed development resulted in considerable production from 1920 to 1925. Ross (1937, p. 6) has indicated that production from 1906 through 1927 totalled $2,500,000 ($12,500,000 in 1976 prices). Although there are about 50 known deposits within the Bayhorse Mining District, nearly 90 percent of the total production has come from three properties; the Ramshorn, Skylark and Red Bird Mines. The Ramshorn and Skylark Mines are located within the study area and together account for about 70 percent of the total production from the district. At least a dozen other mining properties are located within the study area and have recorded some production in the past. Since about 1925 there has been only periodic exploration and development of the district aimed primarily at locating additional lead-silver metallization. In 1947, a slightly different emphasis was placed upon the district with the recognition of significant fluorspar mineralization. Although considerable exploration and development work followed, it was concerned primarily with locating additional fluorspar and associated sulfide deposits within the district and production from the known deposits of fluorspar has been small. However, significant reserves of fluorspar have been blocked out and should support a sizeable mining operation in the future. Most recently, attention has been focused on evaluating the potential of the district for disseminated porphyry-type or stock-work molybdenum mineralization.

The writer did not attempt to map the extensive underground workings from the early mining days of the area as an economic study of the few remaining accessible parts of the mines would add little to the detailed reports of Bell (1900, 1901), Umpleby (1913), Lokken (1925), Ross (1937), Michell (1937), Chambers (1966) and the several mining companies that have recently worked in the area. However, an attempt has been made to correlate the location, structure and the mineral and alteration assemblages of the deposits with the regional geology and to extract features that might be of exploration significance in the search for additional mineralization.

The restricted development of a large percentage of the production of the district to an area of anomalously deformed and hydrothermally altered country rock in the vicinity of a partially exposed intrusive complex suggests that the magmatic, hydrothermal, and structural development of the area are intricately related to the mineralization of the Paleozoic rocks. The mineral deposits within the map area can be subdivided with respect to age, mineralogy and dominant structural control. At least two and possibly three periods of mineralization are responsible for the formation of three mineralogically distinct types of ore deposits. As related to the potential for undiscovered deposits, the characteristics of the fissure-filling metallic sulfide deposits will be presented first, followed by a discussion of the fluorite mineralization in the area. Lastly, evidence bearing on the potential of the area for localizing disseminated porphyry-type or stockwork molybdenum mineralization will be presented.

Pre-Tertiary Metallic Deposits

The metallic sulfide deposits have been among the most productive of central Idaho and are interrelated in origin and character. However, several characteristics permit subdivision of the deposits into two well-defined groups. Umpleby (1913, p. 59) classified the deposits on the basis of mineralogy as lead-silver and silver-copper deposits. The two types also differ in form and geologic occurrence which are a function of host rock and structural control. These differences led Ross (1937, p. 101) to classify the deposits as irregular replacement deposits in Paleozoic calcareous rocks and lodes that follow shear zones in Paleozoic rocks of several kinds. Chambers (1966, p. 69) did not believe that these features were as definitive as previously suggested, and chose to follow a simple two-fold division into fissure-filling veins and breccia deposits.

This writer has not followed any of these earlier subdivisions. Each previous classification does embody certain general characteristics of the metallic sulfide deposits that occur within the study area, but each omits important features of the deposits. From the investigation that the writer has made the mineralogy, structural control and form of the deposits are clearly a function of two quite distinct host rock environments. Consequently, a two-fold subdivision of the metallic sulfide deposits into those occurring in Paleozoic carbonate rocks and those occurring in Paleozoic argillaceous rocks is the classification followed here.

The most widely mineralized rock within the study area is the Bayhorse Dolomite, which is known to localize a dozen lead-silver deposits; some of which have had considerable production in the past. The deposits are characteristically quite irregular and follow zones of intense brecciation in the carbonate rocks. Although less widely distributed, deposits characterized by silver-copper minerals are by far the largest and most productive of the district. They are confined to shear zones in the argillaceous rocks of the area.

## Host Rock and Structural Characteristics

Those deposits that are enclosed by carbonate host rocks occur within the Bayhorse Dolomite and the lower dolomite unit of the Garden Creek Phyllite. The larger deposits of this type are located on the east side of the Bayhorse Anticline stratigraphically between the fifth unit of the Bayhorse Dolomite and the overlying Ramshorn Slate. The effects of mineralization are markedly absent from exposures of Bayhorse Dolomite elsewhere within the study area. In the vicinity of the eastern hinge line of the initial anticline and along the eastwardly bulging limb of the present structure, bedding plane slippage has been most effective in fracturing the brittle dolomite; thus opening the rock to later mineralizing solutions. The resulting breccias are stratiform in character and show an apparent independence of major vertical fractures. In addition, the limited extent of the breccia bodies and the highly angular, slightly rotated character of the clasts are indicative of only slight tectonic movement. The greater competency of the dolomite as compared to the overlying slate was probably instrumental in causing brecciation of the upper parts of the carbonate unit as a response to structural adjustment during folding. Throughgoing longitudinal fracture zones provided a vertical course that allowed mineralizing solutions to rise upward through the dolomite. Where the fracture zones crossed areas of bedding plane brecciation the solutions spread laterally beneath the entrapping cover of the comparatively impermeable Ramshorn Slate.

Although extremely irregular in detail, most of the deposits are generally flat-lying and blanket-shaped, and tend to be conformable to bedding although they are commonly modified by local joints and fracture zones. The carbonate host rocks provided both a structurally permeable and chemically favorable environment in which the forced lateral migration of mineral-bearing solutions through the carbonate rocks beneath an impermeable cover allowed ample contact for chemical reactions and the precipitation of ore minerals.

The reactiveness of the carbonate environment coupled with the extremely sensitive character of the chemical system produced irregularities in the detailed character of the deposits. Certain beds may be thoroughly mineralized, whereas nearby and apparently similar beds are scarcely affected. Individual ore bodies within such zones occur as stringers and masses of diverse sizes and shapes. Ore consists of veinlets, small pods and bunches of argentiferous galena with generally insignificant amounts of sphalerite, pyrite, tetrahedrite and chalcopyrite between silicified fragments of dolomite that have been cemented by quartz, calcite and fluorite. Ore shoots have maximum dimensions of tens rather than hundreds of feet and even these include much barren rock. Blocking out large reserves in small deposits of this kind are particularly difficult.

The lower dolomite unit of the Garden Creek Phyllite is not known to have localized any significant quantities of ore grade material. The unit does present an identical environment, both physically and chemically, which parallels the situation just described involving the Bayhorse Dolomite and overlying Ramshorn Slate. The few diamond drill holes that have penetrated the lower carbonate unit have indicated that the dolomite is mineralized in a manner similar to that of the Bayhorse Dolomite. It seems significant that the environment represented by the lower dolomite unit, almost identical to a stratigraphically higher unit that is known to localize significant quantities of mineralization, has been only locally examined for additional concentrations of ore minerals.

Although deposits localized by the argillaceous rocks of the district are thought to have originated from the same processes responsible for the formation of the deposits enclosed by carbonate rocks, the characteristic of the two types of deposits differ in several important ways as a function of the differing physical and chemical properties of their respective host rocks. The most significant quantities of mineralization within the district are localized by the Ramshorn Slate. The Garden Creek Phyllite is known to have localized small deposits of a similar character.

The adjoining Ramshorn and Skylark vein systems have been the two most product properties of the Bayhorse Mining District. They are located on the south and southwest flanks of Ramshorn Mountain respectively. Both systems follow planes of weakness in the slate which preceded the period of local deformation. The Skylark vein system approximately parallels the gently dipping bedding planes of the west flank of the Ramshorn Anticlinorium in contrast to the Ramshorn vein system which more nearly follows the well-defined slaty cleavage of the axial zone of the same structure. This is the major difference between the two vein systems and was caused solely by the differential thermal effects and the structural deformation imposed upon the Ramshorn Slate by the emplacement of the adjacent Juliette Creek intrusive complex. Both deposits are fissure-fillings and are correspondingly tabular in shape. In contrast to the highly irregular size and shape of the breccia deposits enclosed by carbonate host rocks, the vein systems are bordered by the well-defined walls of the shear zones that they occupy and are remarkably continuous in form and character throughout the 1650 feet of known vertical extent. Where offshoots from the main mineralized bodies do occur, they follow joints or other minor planes of parting as only thin stringers or mere films.

Within the Ramshorn vein system, each fissure is marked by a zone of sheared, sericitized wall rock up to 20 feet wide that is generally bleached. This zone is ubiquitously present along each fissure, even where sulfide mineralization is lacking. The fissure system forms a complex series of anastamosing veins which pinch and swell erratically (Fig. 28). The system generally strikes N. 15° W. and dips gently to the west at higher elevations, but more steeply at lower elevations. The close spatial distribution and overall geometry of the shear zones corresponds precisely with the axial plane of the Ramshorn Anticlinorium. The outer edge of the higher grade part of the thermal aureole surrounding

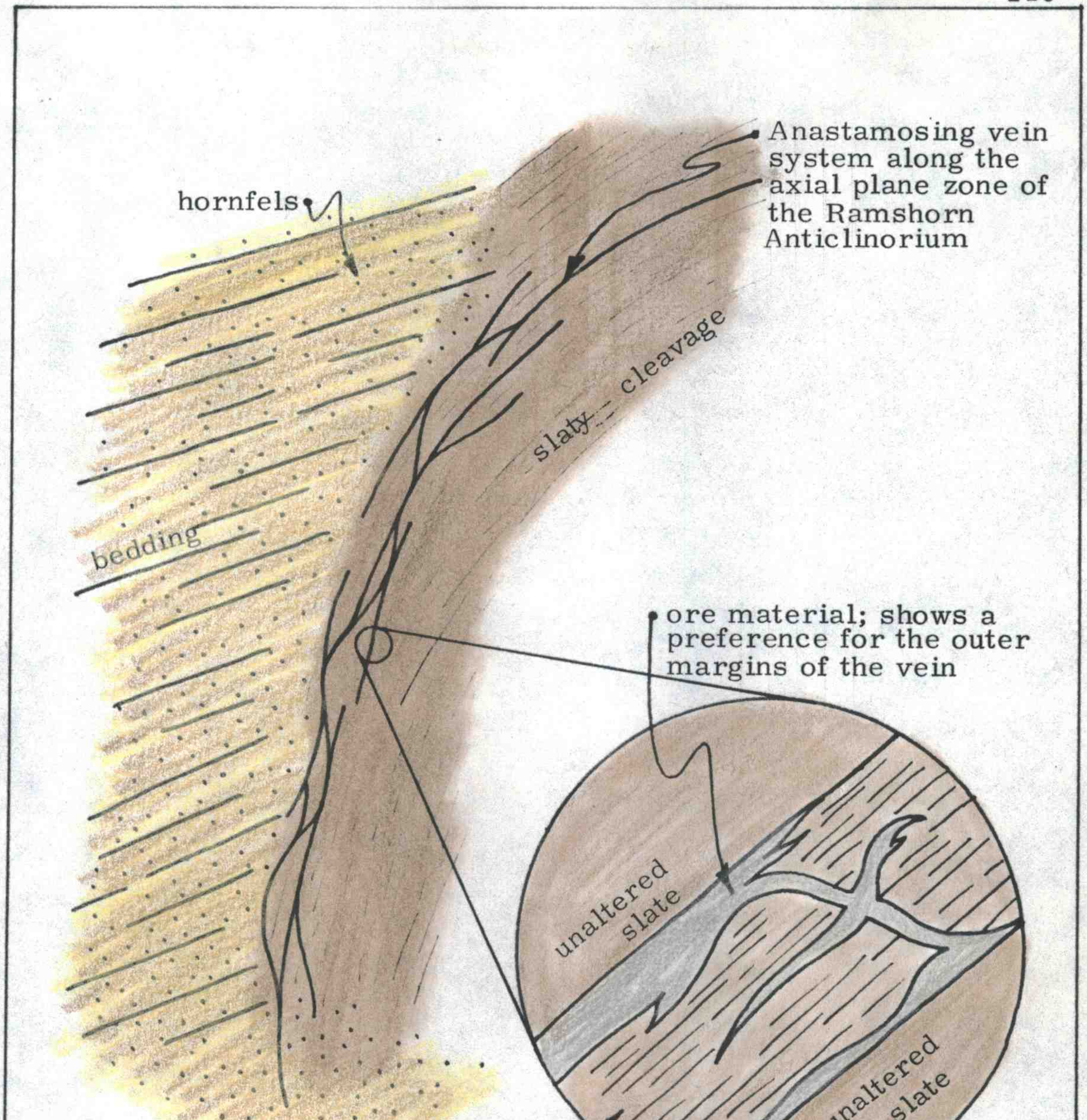



Figure 28 - Ramshorn vein system.

the Nevada Mountain and the Skylark stocks also corresponds closely with this zone and may have aided in localizing the necessary shear stress during the major deformation of the Ramshorn Slate. As a definite stratigraphic marker is lacking, the character of the pre-mineralization movement can only be deduced from a consideration of the hypothesized mode of formation of the entire structure as previously discussed. Post-mineral movement has resulted in a variety of displacements along the pre-existing shear zones. It was accompanied by local brecciation of vein matter and small offsetting faults. However, the post mineral disturbance was apparently slight as the movement does not materially alter the size or shape of the original deposits.

The zone of shearing within individual fissures is commonly much wider than the material carrying sulfide mineralization. The ore material within any one shear zone mimics the geometric character of the overall fissure system by forming a similar series of anastamosing veins (Fig. 28). Ore shoots are of a thin, branching lense-shape and are extremely erratic in size and distribution within individual shear zones. The ore bearing material varies in thickness from thin films to as much as 10 feet wide. However, the average is closer to 2 feet in width and the minerals consist of argentiferous tetrahedrite, with insignificant quantities of galena, pyrite, sphalerite, arsenopyrite and chalcopyrite intricately intergrown in a gangue of siderite. Umpleby (1913, p. 65) described one of the larger ore shoots as elongate down dip between 350 and 400 feet long, 140 feet wide and averaging two feet in thickness.

The Skylark vein system adjoins the Ramshorn vein system to the east. Although the Skylark system shares several features in common with the Ramshorn system, it differs in several important respects. The veins generally strike N. 10° W. and dip at approximately 20° W. The system tends to parallel the bedding planes in the enclosing slates. Slaty cleavage has been largely obliterated by the thermal metamorphism associated with the Juliette Creek intrusive complex, and relic bedding planes have been accentuated by development of metamorphic minerals. The Skylark vein system is not as geometrically complex as the Ramshorn system and can be characterized as a stack of parallel sheets with limited interconnections. There is generally an appreciable amount of sheared and altered material along the particular bedding plane followed by the shear zone. However, this zone is rarely more than three feet wide and bordered by firm unaltered wallrock. This contrasts to the more extensive development of sheared and altered rock characteristic of the individual veins of the Ramshorn system. Simple bedding plane shear together with tension perpendicular to bedding caused by the stresses accompanying the emplacement of the Skylark stock would reasonably account for the opening of the relic bedding planes with comparatively minor development of a shear zone gouge (Fig. 24, p. 174). Within this crushed zone, the ore-bearing material occurs in narrow, irregular, lense-shaped shoots similar to the Ramshorn ore shoots just described.

The Shamrock vein is a narrow, steeply dipping shear zone similar in character to the Ramshorn vein system that is marked by a series of caved adits and scanty surface outcrop. The Shamrock vein borders the Skylark vein system on the west (Fig. 25, p. 177). Whether the Shamrock vein represents a small cross structure of minor importance, or whether it once served as the trunk vein along which mineralizing solutions passed to reach the larger Skylark system, is not clear. It does correspond closely with the projected edge of the Skylark stock and could conceivably represent a major zone of shearing associated with the contact zone of the intrusion.

Wall Rock Alteration. The physical and chemical character of the host rocks significantly affect the character of the alteration products as indicated by the two distinctly different alteration assemblages. One is characteristic of carbonate host rocks, and the other of argillaceous host rocks.

After the initial brecciation of the Bayhorse Dolomite, the formation was evidently flooded with carbonate and silica bearing solutions. Silicification was particularly intense in the upper one-third of the formation as was recrystallization of the dolomite. Secondary dolomite and ankerite formed as irregular lenses and bands roughly parallel to bedding. In thin section, the dolomite is more coarsely crystalline (2 mm vs. 0.5 mm) and much clearer than the ankeritic crystals. Apparently, iron-rich impurities, purged from the centers of the dolomite rhombs have been incorporated in the ankeritic crystals and acted to inhibit the growth of these crystals. The contact with the overlying Ramshorn Slate near the larger deposits in the Bayhorse Dolomite is locally bleached and silicified. Thin section examination of this zone reveals finely disseminated blebs of opaque iron oxides set in a finely crystalline groundmass of silicified clays. The concentration of iron from the Ramshorn Slate to form the oxide blebs and its possible removal to aid in the formation of ankerite is probably largely responsible for the extreme lightening of color.

The Ramshorn Slate was also intensely bleached along the pre-mineral shear zones of the Ramshorn and Skylark vein systems. Contacts with unbroken country rock are sharp and alteration effects are confined to the shear zones. The effects of wall rock alteration however, differ slightly between the two vein systems as a function of the degree of thermal metamorphism imposed upon the wall rock.

The gouge zones of the Ramshorn vein system consist of finely powdered white clay in which quartz crystals and patches of silicification are only locally discernible. A whole rock chemical analysis of the altered slate from a shear zone within the Ramshorn vein system was made. It is compared to an analysis of unaltered slate in Table 12 (p. 149). The analyses were normalized with respect to $Al_2O_3$. The altered shear zone has been depleted in $SiO_2$, FeO, MgO and $Na_2O$ while the $K_2O$ content has increased. The process of silicification was apparently operative on only a small scale in these deposits. The removal of Fe and Mg probably contributed to the formation of the prevalent siderite gangue associated with the fissures. The close spatial association of the leached shear zone and the iron concentrate (siderite) suggests that iron was a relatively immobile component of the system. $SiO_2$ and $Na_2O$ were probably flushed out of the system whereas $K_2O$ was a relatively unsoluble component.

The host rock for the Skylark vein system is predominantly hornfels. The altered shear zones developed in this environment are characterized by an abundance of sericite with minor calcite scattered throughout a finely powdered white clay similar to that described for the Ramshorn shear zones. Silicification is of only local significance. Sericite is apparently present in two generations; the earlier resulted from thermal metamorphism and is more finely crystalline that the later sericite which represents metasomatic alteration by hydrothermal solutions. In proximity to the shear zones, andalusite and cordierite are completely replaced by coarsely crystalline chlorite, sericite and calcite.

Mineralogy

Because of the difficulty encountered in examining the many old mines in the district, and in procuring representative ore samples from the long abandoned mines, it was not possible to make a detailed study of the mineralogy of the metallic and non-metallic minerals. Therefore, the older literature (principally Umpleby, 1913; Lokken, 1925; and Michell, 1925) was relied upon for a description of the mineralogy of the original deposits. However, several specimens were collected, polished and briefly examined petrographically for their constituent minerals and paragenetic relationships. The results of this brief study combined with megascopically discernible field relations are in large part consistent with the observations contained in the older literature and are summarized below.

Although the deposits localized in both carbonate and argillaceous rocks can be classified by their leading metals as lead-silver and silver-copper deposits, respectively, they both have certain minerals in common. The metallic minerals present include tetrahedrite, galena and pyrite with small quantities of sphalerite, arsenopyrite and chalcopyrite. Tetrahedrite and galena are valued primarily for their silver content. The proportions of tetrahedrite and galena vary between the two types of deposits such that tetrahedrite predominates over galena in the deposits enclosed by argillaceous host rocks, but is much subordinate to galena in the deposits enclosed by calcareous host rocks.

The two types of deposits differ most in the composition of their accompanying non-metallic mineral assemblages. Siderite is associated only with the deposits enclosed by argillaceous rocks and is nearly absent from the deposits enclosed by carbonate. Conversely, fluorite, quartz, calcite and barite are the important non-metallic minerals of the deposits enclosed by carbonate host rocks.

Non-Metallic Minerals. Siderite and quartz are the most persistent non-metallic minerals introduced into the vein systems of the Ramshorn Slate and Garden Creek Phyllite, and are intricately intergrown with the metallic minerals. Siderite is the most conspicuous and abundant of the introduced minerals whereas quartz is only rarely discernible as isolated euhedra and as irregular intergrowths with the more abundant mineral constituents. Siderite is commonly very coarsely crystalline. Fresh samples are pale yellowish-orange (10 YR 8/6) and translucent, but weather readily to a dark brown color. Limonite, hematite and manganese oxides are the predominant alteration products of the siderite.

The association of siderite with the largest and most valuable deposits of the district and its scarcity in nearby, less important deposits was originally noted by Ross (1937, p. 106). It is apparent to the writer that this association is clearly a function of the physical and chemical character of the host rock, which is consistent with the many characteristics of the two types of deposits already mentioned. Siderite is found where iron, and lesser quantities of magnesium, magnanese and calcium were available to the rising hydrothermal solutions. The abundance of siderite in association with the argillaceous rocks is largely a function of the availability of iron relative to the carbonate rocks. That these elements were relatively immobile and derived from a nearby source during mineralization is indicated by the prevalence of siderite in and near leached zones of argillaceous rock compared to its rarity in adjacent carbonate rocks

Quartz, the dominant non-metallic mineral in deposits localized by carbonate rocks, has partly recemented the breccia fragments. Quartz also accompanied and succeeded sulfide and later fluorite mineralization as indicated by intricate intergrowths, cross-cutting relationships and thin coatings. Calcite was introduced and removed at various times and places during mineralization. Barite is only rarely present and accompanied the introduction of the metallic minerals. Fluorite is commonly present in abundance, but has been deposited on the sulfide minerals as the product of a later period of mineralization.

Metallic Minerals. Argentiferous tetrahedrite and galena are the principal silver-bearing minerals in the district. Insignificant quantities of pyrite, arsenopyrite, sphalerite and chalcopyrite occur with the principal ore minerals. Although tetrahedrite and galena commonly occur in the same deposit, their proportions vary greatly and they are usually separated into discrete bunches. The sulphantimonides are more abundant in the deposits associated with argillaceous host rocks and the sulfides are more characteristic of those deposits localized by carbonate rocks.

Tetrahedrite is present as irregular fist-sized clots and roughly tabular masses intergrown with siderite and as microscopically disseminated blebs throughout the siderite in the Ramshorn and Skylark vein systems. It is dark-gray with a metallic luster on fresh surfaces, but quickly loses its luster upon exposure to weathering. Tetrahedrite is of much less importance in those deposits formed in carbonate host rocks where it occurs as an accessory mineral scattered through the silicified carbonate breccia as irregular bunches and seams.

Galena occurs as veinlets, isolated crystals and scattered masses and pods in both types of deposits. However, it is the primary ore mineral of those deposits localized by carbonate host rocks whereas it is present as an accessory ore mineral in deposits of the Ramshorn and Skylark type. Galena and tetrahedrite are rarely intergrown and usually are segregated into dissociated batches that commonly fill totally separate vein systems.

Sphalerite occurs as amber colored to nearly black, finely crystalline masses that are generally disseminated in small amounts throughout the groundmass of gangue and as thin coatings on tetrahedrite and galena in both types of deposits. It has been largely oxidized to smithsonite. Calamine was found in quantities large enough to warrant a few shipments of ore in deposits of carbonate host rocks near Beardsley Gulch.

Pyrite occurs sparsely as disseminated euhedral crystals and finely crystalline masses. Arsenopyrite also occurs sparingly as rhombohedral crystals in siderite. Chalcopyrite is present as narrow veinlets and small inclusions in tetrahedrite and as narrow films along fractures in siderite.

Paragenesis. The sequence of deposition of the principal vein forming minerals is rather definite, but that among the accessory minerals is variable and recurrent. The paragenetic sequence is summarized in Figure 29 and is similar for both types of deposits.

Siderite is clearly the earliest mineral formed as all the other minerals occupy fractures or embayments in it. However, quartz occurs as large doubly terminated crystals and as intricate intergrowths with both siderite and tetrahedrite. Although tetrahedrite is generally found in cross cutting relationship to the siderite, it is in places so microscopically intergrown as to also suggest some contemporaneous deposition. Where arsenopyrite can be found, it is similarly related to the siderite, but its relationship to the tetrahedrite and quartz is uncertain. Chalcopyrite fills narrow fractures and lines cavities in the tetrahedrite and locally it appears to be intergrown with the mineral. Galena is found as isolated inclusions in the tetrahedrite, but, conversely, tetrahedrite is also found within galena. More commonly, however, galena is found as separated bunches filling cavities in siderite and tetrahedrite. Chambers (1966, p. 80) has cited differences in crystallinity and mineral associations as evidence for possibly two distinct stages of galena deposition. In those deposits characterized by carbonate host rocks, small amounts of barite are found intergrown with and coating galena. Pyrite fills cavities in tetrahedrite and siderite, but is coated by chalcopyrite. Sphalerite commonly forms coatings on the surface of all the other minerals.

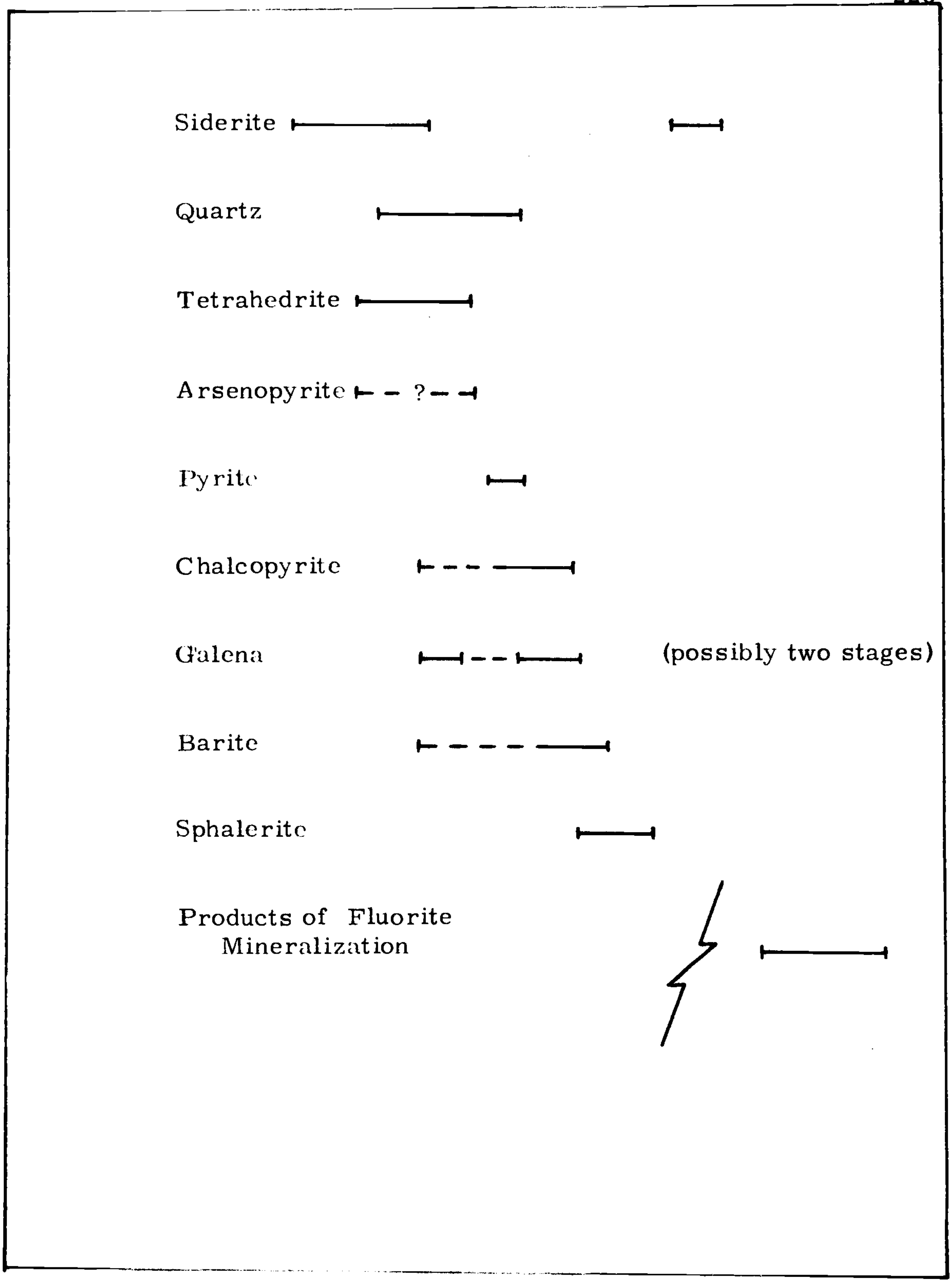



Figure 29 - Paragenetic sequence of the minerals characteristic of the metallic sulfide deposits.

Small crystals of siderite which protrude from the sides of small cavities are also among the last minerals to form. The products of later fluorite mineralization are superimposed upon the minerals deposited during this period and are discussed in a later section.

As indicated from the available mine records, the ores are remarkably consistent in mineralogy and texture over their known horizontal and vertical distribution. The lowest level of the Ramshorn Mine is 1800 feet below the exposed top of the vein system, and similar deposits are known in the Garden Creek Phyllite 1400 feet lower. Within each type of deposit, the minerals present and their relative proportions vary only slightly in an unpredictable manner. The host rocks adjacent to those deposits associated with argillaceous rocks commonly contain large percentages of disseminated pyrite as irregular blebs and euhedral crystals that seem to increase in abundance with depth.

## Tenor of the Ores

All of the ore mined from the district has been high in silver and has carried only trace amounts of gold. Base metals have always been of secondary importance and account for less than 20 percent of the total value of the production from the area. The most richly productive period in the history of mining in the district was that in which secondarily enriched ore was chiefly mined. Ross (1937, p. 118) reports that selected ore from this period contained as much as 700 to 1000 and even 3000 ounces of silver to the ton and averaged as much as 30 percent lead and 20 percent copper. The ease of mining in the soft, oxidized ground and the use of extensive hand sorting were probably at least as effective as the more natural processes of supergene enrichment in obtaining the high values reported. Unoxidized ore is commonly reported to have averaged about 100 ounces of silver to the ton, eight percent lead and three percent copper with a trace of gold. From 1877 to 1884, The Ramshorn Mine produced ore averaging 120 ounces of silver to the ton, and eight percent lead; the old records do not mention copper . These averages reflect the early mining of oxidized ore. From 1902 to 1926, mining of the unoxidizied ore from the Ramshorn and Skylark Mines produced ore averaging 45 ounces of silver to the ton, four percent lead, 0.74 percent copper and 0.26 ounces of gold to the ton.

Although of relatively high grade, the deposits were comparatively small. The total production from the Ramshorn Mine is near 50,000 tons and that of the Skylark Mine is near 30,000 tons.

Deposits formed in carbonate rocks account for little more than five percent of the total production from the district. Individual properties produced small tonnages (less than one ton to approximately 500 tons) of hand picked oxidized ore that ran between 50 and 80 ounces of silver to the ton, 30 and 60 percent lead, 2 and 3 percent zinc, and 0.7 and 0.9 percent copper. Ore shipped by lessee operations from the Pacific Mine in the late 1950's averaged 8.5 ounces of silver to the ton and six percent lead.

Oxidation and Secondary Enrichment

Supergene enrichment of sulfide mineralization is accomplished by replacement of sulfide minerals with those minerals having a higher metal value. Silver, lead and zinc are the metals most commonly enriched during supergene processes in this area. Although oxidized sulfide minerals comprised a large part of the early production of the area, oxidation was not complete even at the highest levels. The former extent of oxidation can be judged only from old reports and from the magnitude of the old mine workings.

The extent of oxidation is quite erratic and appears to be largely fracture-controlled. The effects of oxidation in the Ramshorn deposit are apparent for 800 feet below the uppermost level of the mine. However, the mine is located on a steep slope so that ore, even in the deeper mine levels, was generally within 200 feet of the surface. Although the Skylark vein system is similarly located near the surface, the extent of oxidation was much less. Presumably, the Skylark system lacked the near vertical slaty cleavage and shear zones characteristic of the

Ramshorn vein system that controlled oxidation. The Beardsley - Excelsior Mine, located in carbonate host rocks, is extensively fractured and meteoric ground waters were able to circulate freely through the deposit thoroughly oxidizing the sulfide minerals. However, primary minerals predominate in both the Pacific and Riverview properties even though they are both located in intricately jointed dolomite just below the surface. The relatively recent removal of the overlying impermeable Ramshorn Slate from these last mentioned areas may account for the variation in oxidation.

Host rocks throughout the area are generally steeply inclined and joint and slaty cleavage planes are everywhere prevalent. Therefore, the ground-water level for the region is probably nearly coincident with the bottoms of the numerous canyons. All of the deposits thus far developed are well above this level and it is reasonably concluded that the relatively dry climate, in conjunction with a rapidly lowered water table, has left unoxidized sulfide minerals well up in the zone of oxidation. In addition, the lack of pyrite together with the neutralizing influence of a carbonate environment in an actively circulating ground water system combined to slow the oxidation process. There is no evidence to indicate that any of the deposits within the district have been greatly eroded and it seems certain that the uppermost parts of this large and complex magmatic-hydrothermal system have only recently been exposed.

Age of the Deposits

The metallic sulfide deposits of the district have long been regarded as having originated from hydrothermal solutions related to the magmatic activity associated with the Idaho Batholith (Umpleby, 1913, p. 38; Ross, 1937, p. 101 and 102). This was based largely upon a comparison with similar deposits elsewhere in Idaho which were thought to have a rather precisely defined age. Anderson (1951) has since disputed the original age assignment of such temporally "similar" deposits and argues for at least five metallogenic epochs in Idaho; namely, (1) late Precambrian, (2) Early Tertiary, (3) Middle Tertiary, (4) Late Tertiary and (5) Quaternary. The inference is that by a similar comparison the metallic deposits of the Bayhorse district were formed during the Early Tertiary period of mineralization rather than during an older Middle to Late Cretaceous period. Chambers (1966, p. 96) also considers the metallic deposits to be of Early Tertiary age.

The Eocene surface of erosion truncates many of the deposits. In addition, the Challis Volcanics that cover the area do not contain metallic sulfide mineralization. Therefore, the deposits were certainly formed before the onset of the magmatic activity that fed the voluminous eruptions of the Challis Volcanics during the middle Eocene. The deposits were formed in Paleozoic host rocks and filled shear and breccia zones related to structural adjustment of the country rock during the forceful emplacement of the Juliette Creek intrusive complex. In addition, small veins, similar in character to the larger lodes, locally cross-cut the intrusive phases of the complex and the larger lodes are unaffected by the thermal aureole surrounding the intrusive phases. The deposits clearly post-date the major structural deformation and magmatic activity of the area. From radiometric age determinations, the Juliette Creek intrusive complex cooled at least 95.9 $\pm$ 3.3 m.y. ago. The Middle Cretaceous age assignment for the complex is consistent with the idea that it is related to the later stages of emplacement of the Idaho Batholith.

In an attempt to more precisely determine the age of mineralization, an additional radiometric age determination on sericite from vein selvage material from the Skylark Mine was made by the U. S. Geological Survey. A minimum age for the wall rock alteration, presumably related to the hydrothermal solutions, was determined to be 92.9 $\pm$ 3.3 m.y. In addition, the mineralogical homogeneity over the great vertical extent of the vein systems correspond to Lindgren's mesothermal range of moderate temperature and pressure deposition. These features are entirely consistent with the mineralizing environment believed to be active during Middle to Late Cretaceous time. The effects of rebrecciation are prevalent in all of the sulfide deposits. Deposition closely following the major magmatic-tectonic period of Middle Cretaceous age would have allowed for later rebrecciation of the sulfide deposits in response to Early Tertiary deformation. Although the above evidence is not conclusive, a Middle to Late Cretaceous age assignment for the metallic sulfide deposits of the area fits the available data better than an Early Tertiary age.

## Genesis of the Deposits

An understanding of the genesis of the ore deposits is of great importance as the search for additional deposits consists largely of locating similar environments of deposition.

Deposits enclosed by argillaceous rocks are so similar in age, mineralogy and spatial distribution to those enclosed by carbonate rocks that they are confidently thought to have shared a similar mode of origin, although perhaps separated slightly in time.

It was previously demonstrated that the Juliette Creek intrusive complex and the major lodes of the area are spatially and temporally related. As special conditions are necessary to account for the deposition of the vein material, it does not seem unreasonable to assume a genetic relation between the two. However, the intrusive phases presently exposed within the area do not appear to have been the direct source of the metals or the ore-bearing solutions because they appear to have been relatively dry magmas upon emplacement and the intrusive rocks themselves are cut by mineralized fractures. The general pervasive alteration of the intrusive phases and the igneous textures indicative of post-emplacement cataclastic deformation suggest that a younger intrusive phase might well exist at depth and could be the source of the mineralizing fluids. As the deposits correspond closely in space and time with the Juliette Creek intrusive complex, the depth of formation of the deposits is thought to be similar to the depth of emplacement of the intrusive complex; approximately 20,000 to 25,000 feet. The deposits are thought to have formed within the 200 to 300 °C interval of Lindgren's mesothermal temperature range. Although this estimate is highly speculative, it does not seem unreasonable based on the assumed proximity of the cooling mass of the intrusive complex.

There is abundance evidence that the deposits were formed from aqueous solutions. The deposits were formed by open space filling. The dominant control in localizing the mineralizing solutions was the permeability of the country rocks as determined by the physical properties of the host rocks. The media of transport of the mineral substances must have been rather tenuous in order to penetrate the tiny openings provided by the clay gouge of fault zones in the argillaceous rocks, and to produce the intricate intermingling of original and introduced material. The lack of zoning in the deposits, and the immobility of the various cations derived from the adjacent country rocks, indicate that the fluids retained a rather stable character over a remarkable vertical extent. The mineralizing solutions were concentrated and trapped by enclosing impermeable rocks. The localizing structures do not appear to have been throughgoing, but rather served essentially as "dead ends" for the migrating solutions. A closed, nearly static system of this character would explain the vertical and lateral continuity of the deposits.

Economic Potential and Exploration Criteria for Sulfide Ore

From the standpoint of exploration and development, here, as in many other regions, the days of easily located, mined and treated ore are past. The history of the mines in the area shows that hypogene sulfide ore of sufficient size and grade to repay the costs of mining and to provide a reasonable profit for the early mine operators were deposited in a variety of places throughout the area. Falling metals' prices in the late 1920's necessitated leaving behind important quantities of rich ore in the larger mines (Umpleby, 1913, p. 68; Michell, 1939; Chambers, 1966, p. 98). The concentration of ore grade material in the early days of the district most certainly did not meet levels obtainable with modern technology and the waste rock of the early mine and mill operations provide possibilities for economic small scale leaching or reconcentration operations. In addition, it is not unreasonable to expect that deposits of similar character might still remain undiscovered.

It has already been shown that the level of erosion has only recently intersected the upper parts of a former hydrothermal system. Therefore, the possibilities for undiscovered ore at depth are encouraging. However, this also suggests that future exploration in the area is likely to be costly and difficult, and the expected size and grade of individual ore bodies may not warrant the cost of their exploration and development. In addition to locating suitable sulfide deposits, there are several other factors that influence the economic potential of the area and these include the design of mining operations which are compatible with the rugged topography, limited space and winter weather conditions, and the resolution of problems associated with the environmental impact of a mining operation on not only the immediate area, but the influence it would have upon nearby population centers as well. The availability of electric power, the necessity of improving the roads in the immediate area with the possibility of constructing a major bridge, the long truck hauls and the distance from the nearest railheads to smelting centers further complicate possible mining operations in the area. Nonetheless, a simple evaluation of the area based upon the extrapolation of structural and lithologic factors that demonstrably control known sulfide ore bodies can quickly eliminate large areas as unlikely to contain sulfide ore of economically mineable size and grade.

The known sulfide deposits of the area have been shown to occur in two discrete groups; those occurring in argillaceous rocks and those occurring in carbonate rocks.

Potential for Additional Deposits in Carbonate Rocks

In the past, the individual deposits localized in carbonate rocks have represented discontinuous small tonnages of high grade ore. Umpleby (1913) presented average analyses of 13 shipments of hand-sorted ore from the several mines located on and near Pacific Mountain that were operating during the early 1900's and they are as follows:

| | Au oz/ton | Ag oz/ton | %Pb | %Cu | %Fe | %Zn | % S | $\%SiO_2$ |
|---|---|---|---|---|---|---|---|---|
| Average | 0.041 | 69.90 | 57.34 | 1.76 | 1.29 | 2.59 | 4.92 | 21.17 |
| High | 0.075 | 92.5 | 63.30 | 3.06 | 3.16 | 3.40 | 7.40 | 29.50 |
| Low | 0.016 | 44.7 | 47.85 | 1.80 | 0.58 | 1.86 | 0.91 | 15.00 |

Total tonnage: 553

Judging from the variation in sulfur values, the hand-picked ore contained considerable oxidized material, however, the grade of the ore is not greatly different from that of the unoxidized ore shipped during later periods and it is believed to be fairly representative of the higher grades of ore obtainable in undiscovered deposits. The ore zone of the Pacific Mine is described in detail by Chambers (1966, p. 125 - 133) as are the ore zones of the Beardsley-Excelsior and Riverview Mines, which are the larger mines of interest from the standpoint of possible remaining ore. From 1945 to 1949 and later from 1957 to 1958, the Pacific Mine and Beardsley-Excelsior Mine areas were intensely explored by ASARCO and the Bunker Hill Company. Small tonnages of mineralized material were encountered and commonly averaged less than two percent lead and two ounces of silver per ton. Some zones, however, averaged slightly higher; 4.2 percent lead, 5.3 percent zinc and 6.9 ounces of silver per ton. Ore was mined under a small lessee operation from 1947 to 1948 from a small area in the Pacific Mine that ranged from five to seven percent lead, 7.5 to 10.5 ounces silver per ton, plus considerable zinc.

The sulfide ore localized in carbonate rocks occurs where near vertical, generally east-west trending fault zones intersect zones of bedding-plane brecciation. The extent of bedding-plane brecciation and the spacing of intersecting fault zones controls the horizontal and vertical limits of the ore. Narrow mineralized fissures were easily detected by early miners and were commonly followed in from the surface to where the ore zone spread along the breccia horizons. The sulfide ore zone of the Pacific Mine is the most extensive of the area. Significant tonnages of low-grade fluorspar ore also occur with the low-grade sulfide mineralization. The combined metal content may support a moderate mining operation in the future. Although considerable work was done in the Beardsley-Excelsior area, the sulfides encountered were not encouraging. Ross (1937, p. 133) indicates that there is still good ore in the lower workings, but they are now inaccessible. Salisbury (cited in Chambers, 1966, p. 137) showed that the ore ranged from 19 to 47 percent lead, and that the ratio of ounces of silver to percentage of lead varied from 2 to 0.5. Chambers (1966, p. 125 to 140) has suggested several possibilities for additional detailed exploration in the Pacific and Beardsley-Excelsior area but regards them as largely speculative.

All totalled, there is thought to be a small tonnage of "commercial" grade sulfide ore remaining in the deposits localized by carbonate rocks. However, the sulfides occur as irregular veinlets and scattered pods in equally irregular and scattered ore shoots and horizons. Consequently, blocking out large tonnages of ore is difficult and large scale mining of these kinds of sulfide occurrences would be expensive. Although the grade and size of the deposits do not warrant large-scale operations, they are ideally suitable to smaller scale lessee development, which has been the practice in recent years.

Certainly the greatest hope for future mining in the area lies with discovering new deposits. There is no reason to believe that deposits which may exist elsewhere in the carbonate rocks would differ significantly in character from the other deposits known in the area. The intersection of pre-mineral faults with zones of bedding plane brecciation might expectedly have localized irregular discontinuous ore shoots varying in shape from 400 x 400 x 40 feet near horizontal tabular zones to 300 x 30 x 15 feet elongate shoots depending upon the relative control of brecciation and faulting. The tenor of the ore would vary from high grade pods averaging 45 ounces of silver per ton, 40 percent lead, $\pm$ 3 percent copper and zinc to lower grade disseminated veinlets in intervening ground of 5 ounces of silver per ton, 5 percent lead, $\pm$ 1 percent copper and zinc.

Several features of the deposits localized in the carbonate rocks suggest that near surface ore may have been overlooked by the early prospectors. Quartz gangue and pyrite are largely absent from the deposits and, consequently, the easily recognizable iron-stained float does not accompany outcropping vein material. Instead, the earthy and crumbly oxidation products of lead and silver offer the only readily visible clue to the existence of these deposits. The distinctive oxidation products of copper, however, make it likely that fewer of the copper-rich deposits have been overlooked. Consequently, as the north-facing slopes of the Bayhorse Creek valley are heavily timbered, the likelihood of undiscovered deposits of this type is perhaps greatest in this area.

More importantly, a consideration of the structural characteristics of the area rapidly limits the available ground favorable for exploration. Moreover, it emphasizes three highly promising areas of investigation. Although pre-mineral faults are of a relatively small displacement, are not easily recognized, and do not bear any consistent relationship to the regional structure, the bedding plane breccia zones which are needed for development of the larger ore bodies can definitely be correlated with predictable zones of tension within the developing Bayhorse Anticline. All of the major known sulfide deposits, and most of the smaller veins are localized above the interbedded slate in the upper part of the fifth unit of the Bayhorse Dolomite and at or below the contact with the overlying Ramshorn Slate. This is reasonably explained by the existence of tensile stress in the upper parts of the competent unit and compressive stress in the lower parts as the Bayhorse Anticline developed. However, the tensile stress was not everywhere uniform. It tended to be localized along the eastern hinge line of the initial fold (Fig. 27c, p.188 ).

Emplacement of the Juliette Creek intrusive complex subjected the fold to additional deformation. The upward facing part of the concave bend in the anticline was intensely brecciated along its entire north-south length and it was to later localize the

the extensive ore zone of the Pacific Mine. A continuation of regional west to east compressive stress and the development of a stress couple overturned the anticline by shoving the upper beds over the lower. The newly formed hinge-line breccia zone was accentuated and additional zones of bedding-plane slippage were formed where the upper beds moved between the lower dolomite beds and the overlying incompetent slates. Longitudinal breccia rolls were created along the eastern limb of the anticline that were to later localize the Riverview ore body. The more transverse breccia rolls of the Beardsley-Excelsior Mines were a natural consequence of the irregular local stress field and the resultant purckering of the beds. Small pre-mineral faults were superimposed upon the area during the last stages of emplacement of the complex, and provided the channels by which the ore-bearing solutions were guided to the larger breccia zones.

This interpretation of the available data then indicates that roughly the stratigraphic top 300 feet of the Bayhorse Dolomite offers a good chance of containing additional ore along a narrow zone on the eastern limb of the anticline from roughly three miles south of the study area to a little north of the intersection of Kelly and Beardsley Gulches (Area 1, Fig. 30). The Riverview Mine in the southeast corner of the study area and the Turtle Mine one mile farther south are both located in this zone at the only two places where the

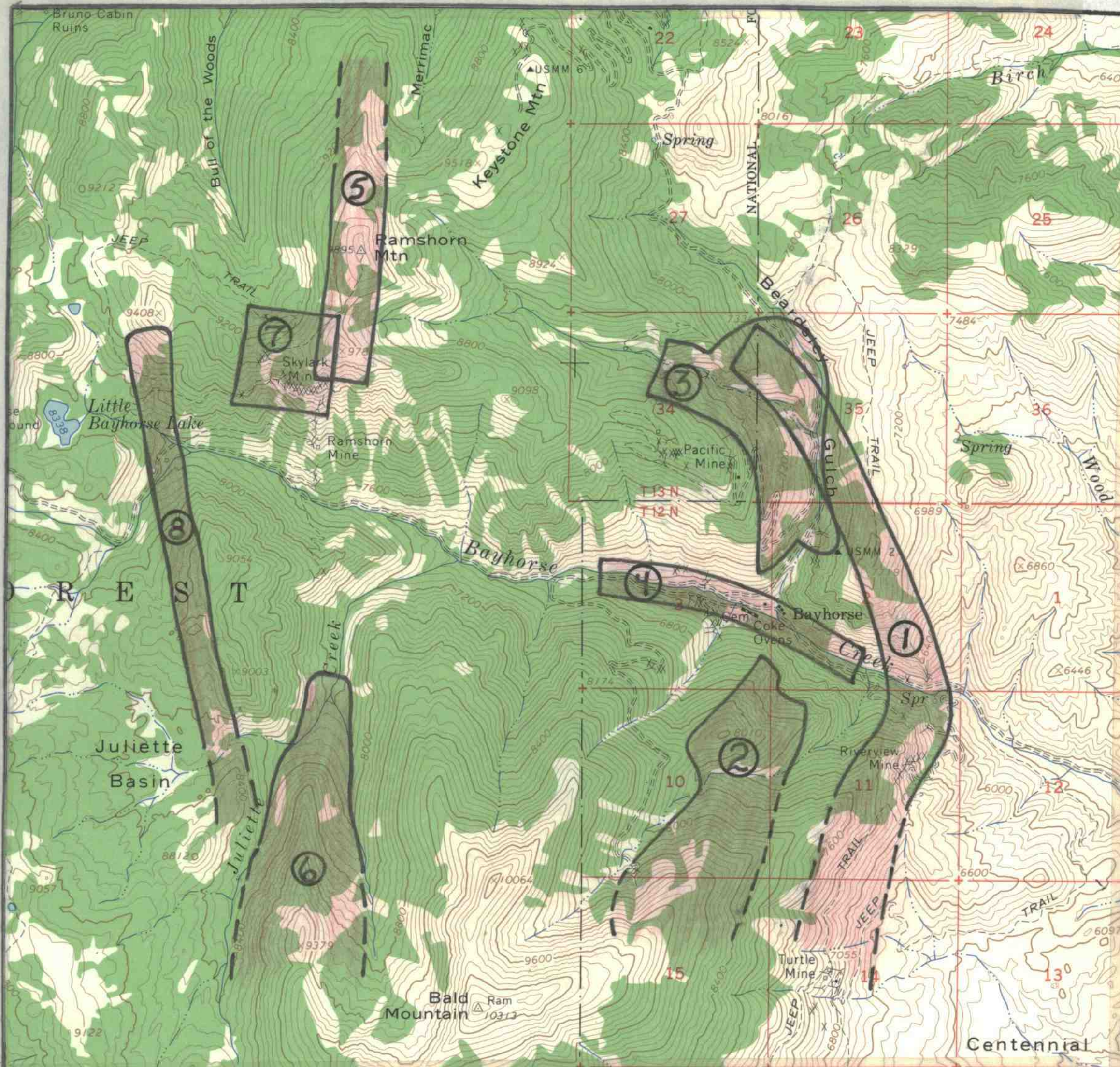



Figure 30. Areas of exploration interest

Bayhorse Dolomite is exposed. Unfortunately, the potential ore zone is tabular in shape and parallels the steeply dipping eastern limb of the anticline and thus presents a discouragingly small target to a vertical drill hole. Outcrop of dolomite is largely non-existent along this zone and the impermeable character of the overlying slate makes it doubtful that any trace of the underlying mineralization is detectable visually or geochemically. The cover of slate in this area is nearly 500 feet thick and the irregularly segmented character of the suspected sulfide ore makes it doubtful that geophysical techniques would be of much use in locating targets for drilling.

A second zone offering a favorable structural environment for ore deposition extends along the postulated trend of the old eastern hinge of the anticline and is roughly coincident with the trace of the present day Mill Fault. The major post-ore Mill Fault corresponds quite closely to this postulated old line of weakness and quite possibly plays a major roll in offsetting and concealing major ore deposits identical to those of the Pacific Mine beneath the area one mile south of the Bayhorse townsite (Area 2, Fig. 30). If the basic tenants of the controlling features of this model are accepted, then there is reason to believe that the overlying Ramshorn Slate in this area might conceal a sizeable quantity of ore similar in every way to that of the Pacific deposit. The presence of sulfides and fluorspar on the cliffs northeast of Smith Canyon lend direct support to this possibility. In addition, small tonnages of sulfide ore have been developed on the east side of the Mill Fault towards the lower end of Beardsley Gulch. Some of these deposits could conceivably be faulted off extensions of the Pacific Mine ore horizons. They may be indicative of yet additional deposits located beneath the Ramshorn Slate east of the Mill Fault, but west of Beardsley Gulch (Area 3, Fig. 30). Additionally, this same block of ground, on the eastern slope of Pacific Mountain, especially the northern part of the block, offers potential in that it is located at the intersect of not only two favorable structural features, but three; the eastern limb breccia zone, the old hinge line zone and the projection of closely spaced east-west fault zones that aided in localizing the Pacific Mine deposit.

That part of the anticline to the west of the old hinge line zone offers little in the way of exploration potential. The paucity of visible breccia zones together with the near absence of even small sulfide veins common on the eastern side of the anticline offer direct support for the postulated lack of favorable mineralization in this area. This is in full accord with the theoretical structural development of the area in that the west to east compressive strain overturning the anticline would tend to squeeze the beds together on the western limb against the core of the anticline, and the overlying beds would undergo simple bedding plane shear without the accompanying development of large fracture zones. Fracturing in this area is not nearly as distinct and intense as it is in the eastern area, which is thought to have undergone appreciable structural readjustment upon emplacement of the quartz-feldspar porphyry intrusive phase.

The area east of the eastern limb of the anticline is underlain by volcanics and a considerable thickness of Ramshorn Slate. The depth to the Bayhorse Dolomite in this area is unknown and there is no indication as to how far it may be beneath the surface. Regional deformation associated with the emplacement of the Idaho Batholith may have produced minor bedding plane brecciation in this area as an accompaniment to folding, but this offers little encouragement to exploration. Also, this area probably did not receive the structural overprint from the local deformation associated with the emplacement of the intrusive complex that is necessary for the development of fracture zones.

The potential of two additional areas is much more difficult to evaluate, but deserves brief mention. As previously discussed, Kelly Gulch is the locus of several enigmatic features indicative of a marked structural discontinuity that may have localized significant mineralization. In addition to the structural trough, two prominent lineaments cross the area, together with two major faults. Small concentrations of sulfide minerals, as well as significant showings of fluorite are scattered over the dip-slope of dolomite on the northern flank of Pacific Mountain.

The second area of possible interest lies to the west of the exposures of Bayhorse Dolomite. Several attempts have been made to reach the Bayhorse Dolomite below the Ramshorn Mine in hopes that the Ramshorn structures would cut the dolomite and sulfide mineralization would "blossom out". Exploration attempts to date have been frustrated by deep holes and poor drilling conditions in the Ramshorn Slate. The dolomite that has been intersected is apparently little distorted and the open spaces necessary to develop large concentrations of sulfide minerals are absent. This supports the contention that the Ramshorn vein system is not a large through-going structure. Rather, it is related solely to features directly associated with the development of the Ramshorn Anticlinorium.

Significant zones of fracture may have been created along the lower hinge line of the western flank of the Bayhorse Anticline and may have localized sulfide minerals. This area is also the locus of several large north-trending fault zones indicative of possible structural complexities at depth. The depth to the Bayhorse Dolomite in this area is probably not as great as it is farther to the east as fault segments of dolomite are present at the surface. Elsewhere in this general area, the dolomite is probably much too deep to be of interest.

In connection with the central part of the study area, it should be noted that Chambers (1966) presents the results of considerable exploration in the Hoosier-North Star area (Area 4, Fig. 30). Although sulfides and fluorite are present, they are generally restricted to fault zones and small zones of breccia that are of comparatively limited distribution within the Garden Creek Phyllite and Dolomite. The extent of mineralization does not warrant development at present. This area participated directly in the emplacement of the quartz-feldspar porphyry phase of the complex. Although breccia zones would be expected to be large and continuous with fractures continuing upward into the phyllite, the zones encountered to date are narrow, discontinuous fractures. Some of the veins may have fed mineralized zones in the overlying Bayhorse Dolomite.

<u>Potential for Additional Deposits in Argillaceous Rocks.</u> The second group of sulfide deposits known to occur in the area have been localized in the Ramshorn Slate and account for 95 percent of the production from all the mines within the study area. The search for similar deposits elsewhere within the slate offers the greatest potential return for the investment. Over the combined life of the Skylark and Ramshorn Mines, nearly 80,000 tons of ore were

produced. Although the tonnage of the deposits was relatively low, the grade of ore was fairly high; the average from 1902 to 1926 in the Ramshorn Mine was 45 ounces of silver per ton, 4 percent lead, 0.74 percent copper, 0.26 ounces of gold (Ross, 1937, p. 118). These averages are indicative of the high grade unoxidized ore that future exploration may encounter elsewhere. The ore bodies have been relatively discontinuous tabular masses localized along near vertical shear zones in the Ramshorn Mine and, conversely, along near horizontal breccia zones in the Skylark Mine. The ore shoots are reported to have continued down dip for as much as 400 feet at widths of up to 140 feet and thicknesses averaging 16 inches.

Michell (1937) presents a detailed account of the possibilities for additional ore within and near the Ramshorn and Skylark Mines and they will not be restated here. However, in light of the structural evolution of the area as previously discussed, several old possibilities should be emphasized and new ones suggested.

The strong development of the Ramshorn vein system along the axial plane zone of the Ramshorn Anticlinorium accentuates the close association of ore-bearing solutions for this pre-existing zone of weakness in an otherwise impermeable host. The extension of this zone to both the north and south provides good possibilities for additional ore (Areas 5 and 6, Fig. 30). However, the development of axial plane shear zones is directly related to the intensity of compressive strain during the last stages of emplacement of the Juliette Creek intrusive complex, and to the interaction of well-developed slaty cleavage and hornfels. The greatest development of compressive strain would have been in close proximity to the stock-shaped protuberances of the intrusive complex. The vein system is then likely to rapidly lose its identity with increasing distance from the intrusive complex. The possibility that a similar set of coinciding factors may exist elsewhere to the southwest could be tested with a detailed aeromagnetic survey of the area.

There is no reason to believe that the Ramshorn vein system does not continue northward for a considerable distance beneath the north-south ridge of the Ramshorn Mountain summit area (Area 5, Fig. 30). The continuation to the south is not as promising as the intrusive mass of the Nevada Mountain stock partially intrudes this zone and the development of hornfels in other parts of the zone restricts the formation of the intense shearing that characterizes the intersection of the outer contact of the hornfels with the axial plane of the anticlinorium and well-developed slaty cleavage. However, sporadic mineralization and intense red staining of the slate is known to occur along this zone in the vicinity of Juliette Creek, east of Nevada Mountain. This area is reported to have been intensely prospected in the early days of the district (Area 6, Fig.

30). The cover of alluvium and poor outcrop in the area suggests exploration possibilities at depth. Perhaps the best chance of discovering additional sulfide ore along this southern extension is to the south of the map area. Interestingly, the U. S. Geological Survey (Hobbs and others, 1975) has mapped a large normal fault coincident with this proposed zone of weakness that is traceable from two to eight miles south of Nevada Mountain. The projected trend of this zone, if carried another mile farther, would intersect the old Silverbell Mine similar in character to the Skylark Mine. However, specific drill targets along this zone are difficult to define because of the poor outcrop expression, the abundance of mobile talus and the scarcity of vegetation. These factors render a geochemical expression to any concealed ore bodies unlikely or slight.

A continuation of the Ramshorn vein system at depth has been regarded as a good possibility in the past. Drilling in Bayhorse Creek below the Ramshorn Mine has demonstrated the lack of controlling structure with depth as the hornfels grade increases. The presence of disseminated blebs of sulfide suggests that where small fractures do exist in the hornfels, minerals may be concentrated, but the probability of large tonnages of high grade ore at depth is doubtful in this area. Rather, it is believed that the zone of intersection of the lower grade contact of the hornfels with the axial plane of the anticlinorium and well-developed slaty cleavage will produce the optimum environment for potentially major ore discoveries in the future. This coincidence of several factors does indeed indicate the possibility of ore at depth, however, not to the south as previously believed, but to the north along the projected northern slope of the hornfels line (Fig. 31). The zone of favorable ground could be viewed as a narrow wedge with its apex to the south and opening northward.

A second area, of perhaps greater promise, lies in a consideration of the Skylark-type vein system. As previously delineated, this system is noteably different in its controlling structural features and mode of development. The gently westward-dipping veins roughly parallel the relic bedding planes in the hornfelsed Ramshorn Slate. These zones are thought to have opened through the action of a stress couple on the country rocks in direct response to the emplacement of the Skylark stock. The possibility for undiscovered ore horizons parallel to the upper Skylark veins at depth is relatively great (Area 7, Fig. 30). The opening of relict bedding planes could conceivably go to the base of the intrusive complex several thousand feet below. As in other ground within the area, the geochemical expression is likely to be poor. However, the near-horizontal tabular habit of the potential ore zones is amenable to relatively easy testing by drilling from the ridge overlying the Skylark Mine. The possible continuation of

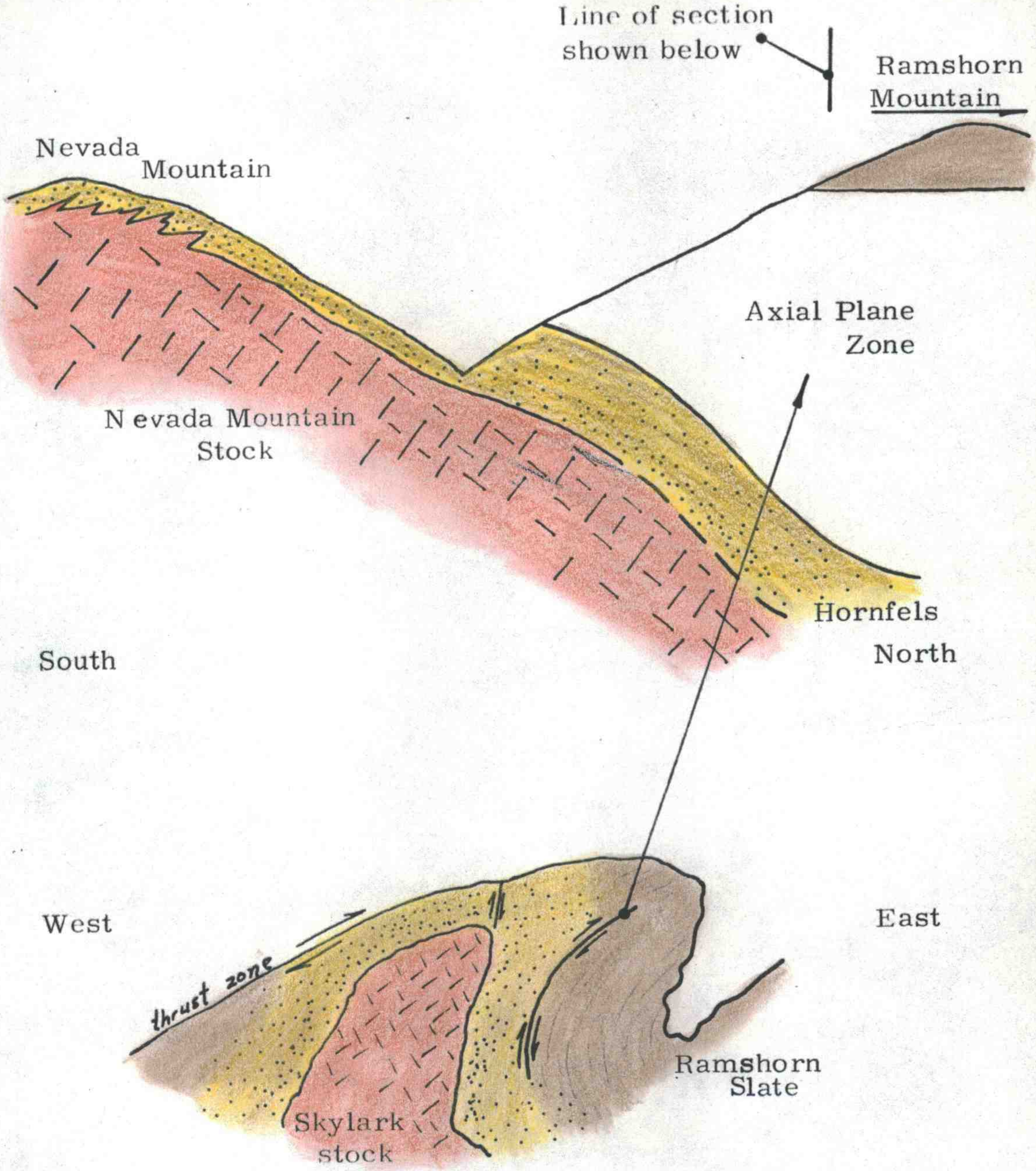



Figure 31. Diagrammatic sections showing the possible continuation of the Ramshorn vein system with depth.

Skylark-type ore horizons with depth has already been suggested by mining company personnel and the mode of development proposed herein strengthens the argument for such a reoccurrence with depth. If the bedding planes are mineralized in closely-spaced intervals, the area may have potential as an open pit deposit.

The Nevada Mountain Fault also invites investigation (Area 8, Fig. 30). The fault zone is closely associated with intense hydrothermal alteration and geochemically anomalous concentrations of silver, lead, zinc and copper over its traceable extent. Small breccia bodies, localizing concentrations of sulfide minerals and siderite similar to the Ramshorn-type mineralization, are known along the fault zone. The fault has had a long history of periodic movement dating from before the major period of metallization and ending in Late Tertiary time. The fault is now largely obscured by a veneer of post-mineral volcanic rocks and alluvium. As the necessary pre-requisite for Ramshorn-type sulfide mineralization is the development of fracture zones, this major pre-mineral fault zone offers good possibilities for having localized significant lead-silver mineralization.

The area to the west of the Nevada Mountain Fault offers little incentive to exploration. The known sulfide deposits are all pre-Tertiary in age and are unrelated to the Challis Volcanics. Although mineralization may be concentrated beneath the cover of

Tertiary volcanics, there are no obvious targets worthy of being drilled.

However, there is one possibility that deserves mention. Although the thrust plate of quartzitic rocks has been removed from the area by erosion, it is possible to speculate on the effects this thrust zone may have had upon the localization of mineralizing fluids. After passing through the largely impermeable Ramshorn Slate along fractures developed in response to the folding of the slate, the hydrothermal solutions might well have spread beneath the overlying quartzite, migrated laterally along the zone of thrusting, and deposited their ore minerals before trickling upwards through minor faults in the quartzite sequences. Indeed, minor mineralized faults are present in exposures of the mixed lithology sequence.

The remaining north-south strip between the axial plane zone of the Ramshorn Anticlinorium and the western limb of the Bayhorse Anticline is enigmatic from an exploration standpoint. Several large normal faults cross the area. This is reasonable as the synclinal area between the two major anticlinal structures would be a comparative zone of weakness tending to localize such structures. The faults are believed to be largely post-mineral in character because of their trend and strength of development. However, they may have been formed by the coalescence of several smaller pre-mineral faults as small showings of sulfides occur at intervals along their traces. The transition from one anticline to the other is not precisely known as the outcrop expression is very poor in this area. The interaction of the intrusive complex with the Bayhorse Dolomite and the Ramshorn Slate, and the possible mineralization at depth is unknown. The absence of mineralization at the surface is not necessarily a deterrent to prospecting in the area, especially in light of the long history of movement thought to be possible along the fault zones.

## Tertiary Fluorspar Deposits

Although the settlement of the Bayhorse region began in 1877 with the discovery of several lead-silver lodes, the fluorspar deposits of the district went largely unnoticed until shortly after World War II, when fluorspar was added to the list of strategic minerals. The old literature on the area mentions the presence of fluorspar only as a minor gangue mineral accompanying the sulfide deposits localized in the carbonate rocks. It was not until 1947 when the fluorspar occurrences of the area attracted the attention of A.E. Chambers that the local deposits received recognition. From 1947 to 1949, the fluorspar deposits of the district were intensely investigated by Chambers (1966), and have since been more briefly examined by Anderson (1954). These investigations were primarily concerned with several occurrences of fluorspar to the north of the study area. The largest concentration of fluorspar is apparently on Keystone Mountain, but important deposits are also known from the ridges bordering Garden Creek, Daugherty Gulch and Mill Creek.

Since the recognition of fluorspar in the district, emphasis has been largely on exploration. Large tonnages of fluorspar reserves have been blocked out, but production has been relatively small as competition from low-cost foreign sources, chiefly Mexico, renders the deposits uneconomical at present.

The only significant tonnages of fluorspar known to occur within the study area are associated with the sulfide ore zones of the Pacific Mine. Fluorite also occurs in the Hoosier-North Star Mine area, although in much smaller quantities. The reports previously mentioned describe in detail the geologic and structural occurrence of the known fluorspar deposits. The general relationships of the deposits within and to the north of the study area will be summarized here in an attempt to correlate characteristics of the known deposits with features of the district geology that ultimately may lead to the discovery of additional deposits within the district.

## Host Rock and Structural Characteristics

The fluorspar mineralization is totally unrelated to the sulfide mineralization in both time and space. The fluorspar was apparently introduced after and largely superimposed upon the base-metal deposits of the district. In general, the fluorspar occurs as separate bodies, independent of the sulfide deposits but spatially related to zones of weakness along the margins of the base-metal lodes. The dominant control of the fluorspar deposits is also structural, but it is not as well defined as for the base-metal lodes previously discussed. Presumably this is because the tectonic events of Tertiary time were of a smaller magnitude and less precisely defined.

The Bayhorse Dolomite is the most widely mineralized rock in the district and in addition to localizing significant concentrations of sulfide minerals, it is also the primary host rock for the known deposits of fluorspar. Small quantities of fluorspar have been encountered in diamond drill holes in the area just west of the Bayhorse townsite in both the phyllitic and dolomitic members of the Garden Creek Phyllite and are similar in character to the larger and more abundant deposits within the Bayhorse Dolomite.

The fluorspar is predominantly a filling of a variety of open spaces and generally shows little evidence of replacement. The filling is generally incomplete and openings lined with well-formed fluorite crystals abound. To date, fluorspar has not been found within any other rock units in the district. Chambers (1966, p. 71) separates the fluorspar occurrences into three different types on the basis of structural control and texture: (1) boxwork fillings; (2) fissure-fillings; and (3) replacements.

Although traces of fluorspar can be found in much of the dolomite over the area, it is found in substantial amounts only where the dolomite has been fractured or brecciated. Not all parts of the dolomite appear to be equally favorable for the development of open spaces. Although the structural control of the fluorspar deposits is not as pronounced as it is for the sulfide deposits, a predictable relationship is discernible.

The structural control of the fluorspar deposits is similar to that displayed by the sulfide deposits. The fluorspar concentrations are dependent largely on the extent of favorable structural openings which are in part fault controlled by subhorizontal zones of brecciation. The boxwork filling deposits, best developed on Keystone Mountain and in areas to the north, show a marked tendency to be located in the upper beds of the Bayhorse Dolomite and particularly just below the Ramshorn Slate. Brecciation of the dolomite near this contact was largely in response to structural adjustments during the regional deformation that accompanied the extrusion of the Challis Volcanics. The breccia zones show no great movement but do exhibit a considerable amount of crackling of the rock and an apparent independence of major fissuring. The contact zone was flooded with silica cementing the dolomite fragments and bleaching and silicifying the slate near the contact. Subsequent dissolution of the dolomite left a network of thin silica portions upon which fluoritizing solutions deposited a thick crust of fluorite crystals. The overlying impermeable silicified slate apparently aided this process by impounding the solutions in the upper parts of the anticline allowing ample time for solution and deposition.

Fissure-filling deposits are more clearly fault related and are less predictable in occurrence. They may accompany box-work deposits as apparent near-vertical solution channels or occur separately. The faults are generally of small size and displacement and have created zones of shearing, brecciation and simple fissuring. The fluorspar bodies may be confined between definable walls and may be of solid, nearly homogeneous fluorspar, or they may represent incomplete filling of fissure zones and abound in openings lined with well-developed fluorite crystals. Shear zones in the Garden Creek Phyllite in the area just west of the Bayhorse townsite are characterized by small, reticulating veinlets that have filled post-sulfide mineral fractures. The restricted development is caused by a lack of open spaces following the disturbance of the incompetent phyllite. The known fissure-filling deposits are small but may intersect more favorable zones of brecciation at depth. Although the mineralized faults are too few to establish a definite pattern, they generally trend 10° to 20° west of north and dip steeply to both the east and west.

The replacement type of fluorspar deposit is best developed on Keystone Mountain and in the Pacific Mine. This type of deposit is characterized by open space filling and replacement of finely-brecciated sandy-dolomite. The deposits are lenticular in shape, subparallel to bedding and display irregular and embayed contacts with adjacent undisturbed dolomite. This type of deposit represents large tonnages of moderate grade fluorspar. In hand specimens, much of the higher grade fluorspar is commonly so finely crystalline as to escape recognition.

The deposits show a considerable range in size. The fissure veins range from a few inches to several feet in thickness, and from tens to hundreds of feet in length. The breccia deposits measure from a few feet in thickness up to 30 feet, and may be traced for as much as 200 feet in outcrop. Replacement deposits are generally very large and average several hundreds of feet square in area and tens of feet in thickness.

Wall Rock Alteration

The hydrothermal solutions that accompanied fluorite deposition affected the wall rock to only a limited extent. The principal alteration effects were caused by solutions related to the earlier sulfide mineralization. Alteration of the carbonate host rock was important in physically preparing the ground prior to the periods of structural adjustment that opened the rock preceding sulfide deposition and later fluorite mineralization. After the initial brecciation of the dolomite caused by structural adjustment to compressive stress, the dolomite was recemented by sulfide minerals, carbonate and quartz. Silicification was more intense towards the top of the Bayhorse Dolomite and the introduction of carbonate was greater towards the base of the formation. Considerable recrystallization and coarsening of the upper beds of dolomite accompanied silicification and ankerite was formed where iron was leached from the overlying Ramshorn Slate or from the dolomite bands and lenses. The district was subjected to a later period of deformation associated with the tectonism accompanying the eruption of the Tertiary volcanic sequence. The previously silicified areas of the dolomite were not only associated with pre-existing zones of weakness, but also behaved in a more brittle manner than the enclosing dolomite and served to localize stress created during Tertiary deformation. These areas, then, were reopened to the fluorite-bearing solutions.

## Mineralogy

The fluorspar deposits are characterized by a very simple mineral assemblage. Other than fluorite, only trivial amounts of quartz and carbonate are present. Many of the fluorspar occurrences contain small quantities of broken sulfide and quartz crystals as small inclusions or breccia fragments. Dolomite is the principal gangue mineral and occurs as brecciated wall rock fragments. Quartz is usually sparingly present and has its greatest development in association with earlier formed sulfide deposits as thin inconspicuous layers and angular fragments coated by fluorite crystals. Quartz is also well developed in boxwork deposits which are characterized by thin partitions of quartz encrusted with fluorite crystals.

The fluorite is mineralogically distinctive. It is commonly milky white or colorless, although some smaller crystals can be transparent. Only the more massive, fissure-filling deposits contain fluorite that shows any coloration and even in these occurrences only very faint tinges of gray, purple and green are discernible. The fluorite localized by the Garden Creek Phyllite and Dolomite is distinctively more colored than the fluorite found elsewhere in the district and is usually a translucent green.

The cause of color in fluorite has been extensively investigated (Deer et. al., 1962, p. 350). White to colorless fluorite is apparently indicative of chemically pure and structurally ordered crystals. Coloration arises when the crystal structure is physically disturbed through heating or increased pressure, radioactive emanation from inclusions or nearby radioactive material, or contamination from rare-earth elements, carbonaceous material, iron, manganese, etc. The green coloration of the fluorite associated with the Garden Creek Phyllite formation is probably due to the incorporation of ferrous iron (Serra, 1947) derived from the adjacent iron-rich argillaceous units. Purple fluorite can be found elsewhere in association with the phyllitic formation and is probably colored by trace amounts of manganese. The majority of the fluorite found within the district is nearly colorless and suggests that the hydrothermal system responsible for the formation of the deposits was relatively free of contaminating elements and permitted a high degree of order in the crystal structure.

The fluorite does show some variation in its textural characteristics depending upon the size and the completeness of filling of the open space available. As expected, the larger, more crystalline open-space is commonly lined with coarsely crystalline fluorite while the smaller incompletely filled open space is usually lined with finely crystalline fluorite. Banding is relatively rare, but faint concentric bands around brecciated wall rock fragments and parallel to fissure walls are locally present. Fluorite of the replacement deposits is invariably very finely crystalline. Some fluorite has been brecciated and recemented by fluorite and is indicative of syntectonic deposition.

Where open-space filling was incomplete, solutions were free to precipitate well-formed crystals of cubic habit that are never larger than 2 cm square and most are less than 1 cm. Elsewhere, open space fillings are more complete and structureless fluorite, largely free of inclusions and impurities, are characteristic and break along well-defined octahedral cleavage planes.

Calcite is ubiquitous as a late-stage open-space filling mineral and fills fractures in sulfide and fluorspar deposits alike.

The paragenesis of the fluorite deposits is quite simple. The mineral succession appears to be quartz, fluorite and calcite with a minimum of overlap. The sequence is fairly well defined by cross-cutting and encrustation relationships. Commonly, the fluorite is present without quartz or calcite.

Tenor of the Ore

Three grades of fluorspar are generally recognized; metallurgical, ceramic and acid. The different grades are commonly related to the silica concentration in the ore or concentrate by reducing the $CaF_2$ in the rock by 2.5 percent for each percent of $SiO_2$ present to arrive at the effective $CaF_2$ content. Metallurgical grades commonly contain from 60 to 73 percent effective $CaF_2$, ceramic grades from 85 to 96 percent and acid grades more than 97 percent. For metallurgical uses, fluorspar is generally desired in the form of small lumps or gravel. Ceramic and acid grades are usually finely ground powders.

There are only small amounts of fluorspar ore presently known within the district that meet the metallurgical-grade standard without benefication. The tenor of the fluorspar varies widely over the area with the fissure-filling ores generally containing low tonnages of high grade ore, boxwork deposits with moderate tonnages of moderate grade ore and with replacement deposits containing large tonnages of lower grade ore. The highest grade ore ranges from 55 to 80 percent $CaF_2$. The lower grade ores generally range from 10 to 30 percent $CaF_2$.

## Secondary Enrichment

Once fluorite is deposited, it is stable under a wide variety of conditions. Some secondary enrichment of the deposits seems to have taken place, but is due more to solution-weathering and removal of carbonate gangue minerals and subsequent physical concentration of the remaining fluorspar than to any chemical change in the primary fluorite.

## Age of the Deposits

Thin coatings of chalcedony and calcite locally coat fluorite crystals but otherwise fluorite is everywhere the last mineral to be deposited. It is commonly found filling post-sulfide fractures and as coatings on sulfide minerals. Metallic minerals are locally found as inclusions within fluorite. In addition, brecciated sulfide and fluorite ore is recemented by fluorite. Formation of the fluorite deposits, then, post-dates the deposition of the base-metal minerals and by some time interval as Shannon (1926, p. 176) mentions fluorite encrusting calamine, the oxidation product of sphalerite. Anderson (1954, p. 9) reports that fluorspar was introduced into rocks of the Challis Volcanics sequence in a deposit north of the study area near Daugherty Spring. K-Ar age determinations on basalt near the base of the local volcanic stratigraphic section in the same area give ages of 49.2 ± 1.8 m.y. and 48.7 ± 1.8 m.y. (R. L. Armstrong, 1974, cited in Hobbs, 1975). The age of fluorspar deposition is then post early-Middle Miocene and is similar in age to the deposits at Meyers Cove 32 miles north-northwest of the Bayhorse townsite which are entirely within rocks of the Challis Volcanics. McIntyre (oral comm., 1975) has suggested that deposition of the Challis Volcanics may bracket in time the formation of the fluorspar deposits and that the possibility exists that a volcanic time-stratigraphic marker horizon above which no fluorspar was deposited may be present.

Genesis of the Deposits

Fluorite was introduced into fissured and brecciated country rock by solutions which originated in some deep magmatic source, presumably the same source that supplied the materials of the Challis Volcanics. The fluorite bearing solutions probably escaped at a high temperature, ascended through the crust and spread widely through the fractured country rock and, in places of exceptional brecciation, considerable concentrations of fluorspar were deposited. In common with most fluorite deposits, low temperature and low pressure conditions are thought to have prevailed during formation of the fluorspar in which warm aqueous solutions remote from their magmatic source permeated abundant open spaces near the surface and deposited their mineral constituents.

The temperature at which the deposits were formed could be more precisely determined by studying the abundant fluid inclusions in the fluorite. However, the temperature is probably within the range of 80°C to 200°C as determined for a wide variety of similar fluorspar occurrences elsewhere in the world.

Although a great variety of chemical and physical factors may have acted to control deposition of fluorite, there is evidence to suggest that its formation was in large part governed by the rate of solution movement. At the time of deposition there was probably a great variety of open space present in the easily fractured dolomite, yet it is only where the solution movement was slowed or restricted that chemical reactions were allowed to proceed to completion. Whereever the boxwork deposits are found, they are beneath the impermeable Ramshorn Slate. Similarly, the fluorspar occurrences in the Garden Creek Dolomite are beneath the impermeable phyllite unit. The replacement deposits of the Pacific Mine are beneath the silicified zone that accompanied lead-silver mineralization which may have acted as an impermeable barrier to later ascending fluorite-bearing solutions.

Some post-sulfide, pre-fluorite faults have acted to localize fluorspar. Conversely, others have acted to restrict fluoritization. Chambers (1966, p. 85) reports such a fault zone where fissures were opened, cemented by silica, and apparently were not later rebrecciated and acted to effectively seal off the fluorite-bearing solutions to follow.

The fault zones with greater movement would be prone to develop more finely grained gouge zones and succeeding silicification would effectively seal the zone to migrating solutions. In all cases, ore-bearing solutions were impounded by impermeable layers which controlled deposition in adjoining brecciated or fractured rock. The key association in controlling ore deposition is apparently fractured or brecciated dolomite in proximity to impermeable argillaceous rocks or gouge filled fracture zones.

The channels for circulation of the fluorite-bearing solutions were largely independent of those which directed the earlier quartz-sulfide mineralization. Some fluorite concentrations are totally unrelated to older base-metal concentrations as they occur in post-sulfide zones of fracturing and brecciation. Others are quate closely related. In such cases, the fluorspar generally occurs peripherally to the sulfide deposits and suggests that structural movements preceding the introduction of the fluorite-bearing solutions found the earlier zones of weakness too strongly restricted by the earlier silicification. Thus, the bordering dolomite was forced to take up the deformation and failed by fracturing and fissuring.

Economic Potential and Exploration Criteria

The present exposures of fluorspar within the region indicate that significant amounts of fluorite were deposited in structurally favorable locations over a wide area in the Paleozoic and Early Tertiary country rocks.

Although mineable reserves of fluorspar are known to occur within the region, several factors work against possible commercial operations within the area. In addition to the problems bearing on mining of the base-metal deposits, the economic development of fluorite is hampered by the competition from a large production of low-cost foreign fluorspar, mainly from Mexico.

The distribution of the fluorspar appears entirely dependent on the location of structurally favorable fissures and breccia zones within the Paleozoic and early Tertiary country rocks. The known deposits show a marked preference for the Bayhorse Dolomite, although fluorite is also known from the Garden Creek Dolomite. It is doubtful that significant quantities of fluorspar will be found in the argillaceous Ramshorn Slate or the Garden Creek Phyllite as these formations respond incompetently to deformational strain and are not prone to localizing a great deal of open space for the deposition of ore. The search for additional fluorspar is, therefore, best confined to the Bayhorse Dolomite with some attention given to the lower dolomite of the Garden Creek Formation.

The sulfide deposits have been shown to be closely dependent upon well-defined zones of brecciation that vary in a predictable manner over the area. The structural controls of fluorite deposition however, do not bear the same well-defined relationship to the regional structure as do the sulfide deposits. Thus, the occurrence of features of exploration significance are not as obvious.

The deformation accompanying the eruption of the Challis Volcanics was not characterized by profound unconformities or extreme disruption of the country rock. Rather, broad tuminescence of regional extent accompanied by tensional fractures and gentle warping are more characteristic. The most highly mineralized fractures are generally of small displacement and appear to trend slightly west of north. The more easily traceable faults of large displacement were either post-mineral or served as impermeable barriers aiding in impounding ore-bearing solutions. Where small pre-mineral faults intersect bedding plane breccia zones beneath impermeable layers the fluorite-bearing solutions spread laterally to deposit their load. The most extensive zone of brecciation appears to be in the upper parts of the Bayhorse Dolomite, but their location bears no consistent relationship to more easily recognizable features. There is evidence that the sulfide ore bodies of the peripheral zones localized stress and produced breccia zones beneath which fluorite minerals were deposited. The predictable location of sulfide ore bodies with respect to the structural interpretation of the area, and the possible association of both high grade sulfide ore with large tonnages of fluorite mineralization, make such targets doubly attractive. To the extent that fluorite mineralization is dependent upon pre-existing zones of weakness, it is predictable. The zones of greatest exploration potential, as outlined for the sulfide deposits in the carbonate rocks, then would be equally applicable to the search for deposits of fluorite. As significant fluorspar is already known, the direct search for additional reserves unrelated to sulfides should wait until economic conditions warrant. The suggestion is made that future exploration should be concerned primarily with the location of sulfide ore, as it offers the greatest potential initial return, and that the fluorite ore possibly encountered by developed contemporaneous with or at a later date after the price of fluorite and/or mining costs are more equitable.

The exploration for fluorite is likely to be costly within the district as the easily recognized exposures of fluorspar are already known and underground exploration will be required to prove the extent of mineralization. However, the extremely finely crystalline character of the large tonnage of low to moderate grade fluorspar makes it likely that some exposures have been overlooked. It is suggested that a semiquantitative geochemical analytical technique, conveniently employed in the field, be used by geologists in future prospecting. In addition, the heavily timbered areas south of Bayhorse Creek offer particularly good exploration ground as the likelihood of "blind" deposits is good. Geobotanical techniques or soil sampling for sulfides, as well as fluorite, might have some application in this area.

## Possible Mineralization Directly Associated with the Juliette Creek Intrusive Complex

The recognition of a stockwork molybdenum deposit in the Pat Hughes Creek stock has recently invoked interest in the possibility of a similar hydrothermal system in the Bayhorse area associated with the Juliette Creek intrusive complex. Evidence for a deep hydrothermal system of this character is very meager, and based solely upon pervasive alteration effects of the various intrusive phases. Conclusions drawn herein from such features must be regarded as highly speculative.

### Hydrothermal Alteration

Hydrothermal alteration affects all lithic phases of the Juliette Creek intrusive complex and the surrounding country rocks. Alteration associated with the vein deposits in the argillaceous and carbonate country rocks has already been discussed. Alteration associated with the phases of the intrusive complex is local in extent and similar in character. Quartz, kaolin group clays, sericite and carbonate are essentially the only alteration minerals associated with the intrusive complex. They vary erratically in relative abundance along a zone marked by the Nevada Mountain fault and in the quartz-feldspar porphyry from drill core in the area just west of the Bayhorse townsite.

Nevada Mountain Fault Zone. The granodiorite phase of the Juliette Creek intrusive complex has been pervasively altered in proximity to the Nevada Mountain fault. A zone of alteration extends approximately 500 feet into the intrusive phase from the fault contact. The adjacent volcanic and sedimentary rocks appear to have been less affected, but exposures of these rocks are poor in this area. The alteration mineral assemblage is simple and consists predominantly of quartz and sericite with carbonate and kaolinite in slightly variable proportions. An altered sample of granodiorite was analyzed for its major oxide constituents and is compared to the average of four unaltered samples of granodiorite in Table 13. Sericite occurs as a finely crystalline groundmass intergrown with quartz, in coronas around quartz phenocrysts, and as coarsely crystalline replacements of feldspar. Carbonate may be present in amounts up to 10 percent as fillings of hairline veinlets and as scattered crystalline aggregates. Kaolinite is locally present and occurs as a pervasive alteration product of feldspar and is intricately intergrown with sericite. Mineral proportions vary only slightly over the altered zone and they do not show any systematic trends.

The only sulfides present in the intrusive phase in significant amounts are associated with this zone of alteration, and they include trivial amounts of pyrite, chalcopyrite and molybdenite. The sulfides are all fracture controlled and are disseminated in trace amounts along thin quartz veinlets in the highly altered host.

Table 13. Chemical and modal analyses of an altered granodiorite sample compared to the average of four unaltered granodiorite samples.

| Chemical Analyses (percent) | | | Modal Analyses (percent) | | |
|---|---|---|---|---|---|
| | 7-23-75-11H | Average of four ** granodiorite samples | | 7-23-75-11H | Average of four ** granodiorite samples |
| $SiO_2$ | 73.5 | 67.8 | Quartz | 39 | 14.6 |
| $Al_2O_3$ | 15.2 | 15.2 | Orthoclase | 3 | 12.2 |
| FeO** | 4.9 | 4.1 | Andesine | 7 | 60.6 |
| MgO | 0.3 | 1.1 | Biotite | Tr | 5.0 |
| CaO | 0.2 | 2.7 | Hornblende | Tr | 3.6 |
| $Na_2O$ | 0.2 | 4.4 | Accessories | 2 | 3.2 |
| $K_2O$ | 3.95 | 3.10 | Sericite | 33 | -- |
| $TiO_2$ | 0.45 | 0.49 | Carbonate | 7 | -- |
| MnO | ---- | ---- | Kaolinite | Tr | -- |
| $P_2O_5$ | ---- | ---- | Epidote | Tr | -- |
| | | | Opaques | 9 | 0.9 |
| | 98.70 | 98.99 | | 100 | 100 |

*From Table 2, p. 80
**Total iron reported as FeO

Quartz-Feldspar Porphyry. The quartz feldspar porphyry exposed in drill core from the area just west of the Bayhorse townsite is thoroughly altered to an assemblage of sericite, kaolinite, quartz and carbonate. The deepest hole penetrated more than 850 feet of the intrusive phase and was bottomed in highly altered quartz-feldspar porphyry that had changed little in character from its upper contact with the Garden Creek Phyllite. Kaolinite and quartz are intricately intergrown in a finely crystalline groundmass surrounding embayed quartz phenocrysts, and as replacement rims of feldspar phenocrysts. The cores of the feldspar are commonly replaced by finely crystalline sericite. Sericite also fills microfractures and is commonly intergrown with kaolinite and quartz. Carbonate is abundant and occurs as scattered, coarsely-crystalline aggregates. The alteration is remarkably pervasive and continuous over the length of the drill core. The only change noticed was a slight increase in kaolinite over carbonate with depth. The character of this alteration assemblage is very similar to the assemblage just described for the alteration products of the Nevada Mountain fault zone, but the vertical extent is much greater. As three dimensional data are lacking for the quartz-feldspar porphyry assemblage, it may also be related to fault controlled hydrothermal solutions of minor extent related to the intense fracturing of the immediate area. Conversely, it may represent the upper parts of a peripheral alteration zone to a much larger hydrothermal system. The continuity of the well-developed alteration effects over a great vertical range suggests the circulation of large quantities of hydrothermal fluids. In either case, more data are needed on the geometry, character, and extent of this alteration pattern.

Two samples of altered quartz-feldspar porphyry were analyzed for major oxide content and the results were previously presented in Table 5, p. 84 along with modal analyses of six samples of similar character. Sample DPW 150 was taken from two feet below the contact with the Garden Creek Dolomite, and sample DPW 1012 was taken from the bottom of the drill hole 862 feet deeper. The original character of the rock has been obliterated by intense hydrothermal alteration. $K_2O$, $SiO_2$ and $Na_2O$ show a slight increase with depth as $Al_2O_3$, FeO, MgO and CaO decrease slightly. This parallels the observed mineralogic trend with sericite, kaolinite and quartz increasing slightly relative to carbonate with depth.

Economic Potential and Exploration Criteria

The possibility of a "disseminated" or stockwork molybdenum porphyry-type orebody localized within the Juliette Creek intrusive complex is not high. The absence of potassic alteration minerals, the apparent compact character of alteration patterns in close proximity to fault zones, the marked absence of close spaced fracturing, all indicate a small-sized hydrothermal system. Iron sulfides are scarce and structurally controlled. Molybdenum and copper are present only in geochemically anomalous amounts. They were not observed to occur as megascopically discernible sulfides within the intrusive complex. However, only scattered exposures afford a view of the upper parts of what is apparently only a slightly deeper but much larger intrusive mass.

The upper parts of an extensive hydrothermal system may be in evidence, but the precise character of the system can not be known with certainty without more extensive underground exploration. Although probably not sufficiently interesting to warrant specific exploration, holes drilled for sulfide or fluorite targets in the vicinity of the projected intrusive contact should be deepened to provide more information on the possibility of this ore-type.

## X. THE ROLE OF DISSOLUTION IN CREATING OPEN SPACE

As previously demonstrated, sulfide and fluorite mineralization were accomplished through the filling of open spaces. The creation of this open space is thought to have been controlled largely by fractures and faults created by the interaction of the varied physical response of the different host lithologies to stress fields of regional and local distribution. The structural development of the Bayhorse district is clearly a dominant factor controlling mineral deposition and this characteristic has been emphasized throughout this report. The interpretation of the various features of structural significance, previously presented, accounts for the observed characteristics of the mineral deposits in a reasonable manner consistent with both regional and local considerations. The proposed structural development of the district is important to the search for additional mineral deposits as it lends a certain degree of predictability to their location. In addition to the tectonic processes known to have been operative, however, there are features present within the Bayhorse Dolomite which suggest that dissolution of this reactive host may have contributed significantly to the creation of open space.

The proportion of dissolution versus tectonism for the dominant control forming the open spaces is an important consideration, because it adds another dimension to the problem of predicting where additional mineral deposits might be located within the Bayhorse Dolomite. If dissolution occurred after the major structural deformation of Middle Cretaceous time, following pre-existing zones of weakness related to this deformational period, then the predictability of the foregoing structural model is not damaged. However, the conclusions drawn from the proposed structural history of the district would be significantly changed if these structural controls were superimposed upon the effects of an earlier dissolution event related to the development of a paleokarst topography upon the eroded surface of the Bayhorse Dolomite during Latest Cambrian or Earliest Ordovician time. The latter may have been the overriding factor in the formation of open spaces within the carbonate formation.

The following discussion will show that although the processes of dissolution were operative within the Bayhorse Dolomite on an important scale, they were totally unrelated to the major periods of mineralization, and actually were associated with the last stages of Early Tertiary volcanism, rather than with an earlier paleokarst topography. In addition, it will be shown that the prevalence of the effects of dissolution do not detract from the proposed structural development of the district, but actually support it.

Two large and quite distinctive breccia bodies, referred to in the following discussion as the breccia plume and the breccia pipe, are located within the upper parts of the Bayhorse Dolomite.

Obvious structural control for both breccia bodies is absent and both display features difficult to account for by processes other than extensive dissolution. The character and possible mode of formation of the breccia plume is discussed first.

Breccia Plume

The breccia plume is exposed high on a cliff face toward the top of the Bayhorse Dolomite section. It is located on the north side of Bayhorse Creek approximately 2600 feet east of the Bayhorse townsite

Description. The breccia plume derives its name from the inverted tear-drop shape of the exposure on the cliff face (Pl. 34). It is approximately 50 feet high and 50 feet wide in maximum dimensions. The geometry of the cliff face provides a three dimensional view of the breccia body and shows that the plume shape, as viewed in two dimensions, is actually the cross-sectional profile of a nearly horizontal rod-shaped breccia body at least 100 feet long. The outer edges of the breccia plume are regular and well-defined. At no place along the perimeter of the body does it pass into throughgoing structures of any kind. Except for narrow joints and small fractures, the adjacent dolomite is undisrupted. The breccia body is composed of angular blocks and fragments of dolomite, identical to the surrounding carbonate, cemented by a distinctive very coarsely

Plate 34. Breccia Plume

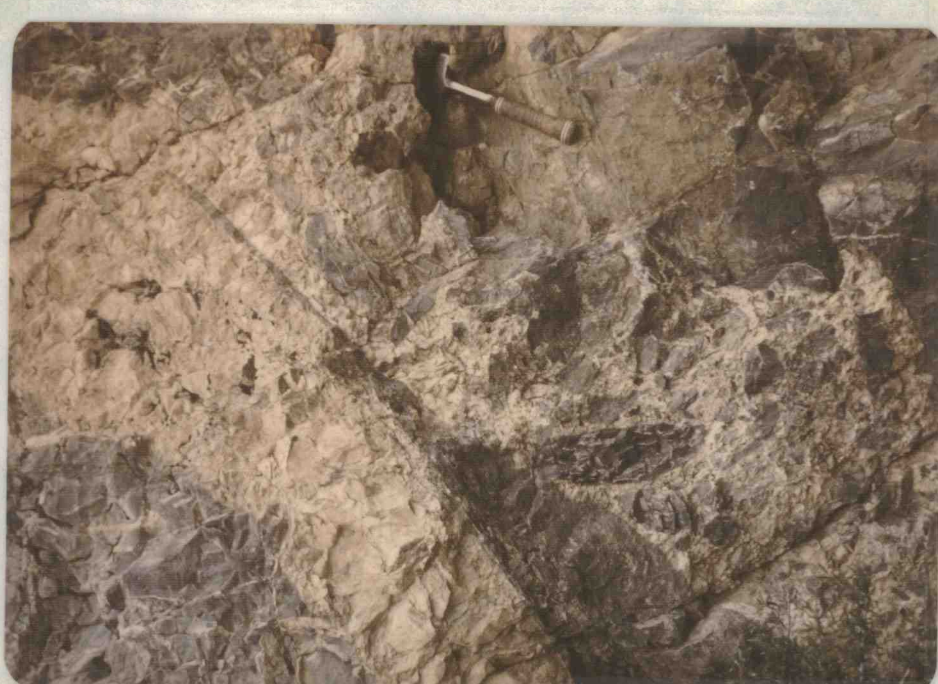


Plate 35. Narrow sliver of dolomite in breccia body.

crystalline, cream-colored calcite.

The breccia plume is associated with other forms of open space of a similar character that are filled with the coarsely crystalline calcite. Where the Bayhorse Anticline bulges eastward, coarsely crystalline calcite fills large vertical fissures with very little apparent displacement that range up to ten feet in width toward the middle parts of the dolomite section. So large and abundant are the calcite vein fillings that they were mined for smelter flux in the early mining days of the district. The calcite-filled fissures give way toward the top of the Bayhorse Dolomite to breccia bodies similar in character to the breccia plume. They differ from the breccia plume in that the clasts commonly consist of narrow slivers of dolomite and are usually associated with highly jointed country rock (Pl. 35). The distinctive character of the calcite in all of these open space fillings, the absence of sulfide or fluorite mineralization, and the restriction of the calcite bodies to anomalously deformed parts of the original Bayhorse Anticline suggest a common mode of origin for all occurrences of the calcite.

Mode of Formation. Because the writer cannot account for the characteristics of the breccia and fissure zones through tectonic processes alone, he is forced to conclude that some other process was operative. Several features suggest that the processes of dissolution contributed significantly to the formation of the calcite deposits.

It is difficult to imagine how the delicate clasts of dolomite common to the breccia bodies, could develop through dynamic deformation. In addition, the development of the very wide fissure zones with the concomitant absence of any apparent offset is also difficult to envision through tectonic processes alone. These features collectively suggest that dissolution was the dominant process in enlarging the small fractures and joints that were probably created within the Bayhorse Dolomite as a result of structural deformation related to the emplacement of the Juliette Creek intrusive complex.

Apparently, the processes of dissolution and subsequent calcite deposition were superimposed upon the area at a later date as sulfide mineralization is not associated with the calcite fillings, except where the distinctive coarsely crystalline calcite cross-cuts sulfide mineralization. In addition, sulfide mineralization was not characterized by deposition of large quantities of coarsely crystalline calcite. If calcite deposition was somehow related to sulfide mineralization, then the later structural adjustments that uniformly rebrecciated the sulfide deposits would have similarly affected the large calcite fillings.

Tertiary deformation that was contemporaneous with the eruption of the Challis Volcanics was probably responsible for rebrecciation of the sulfide deposits. This event would have enhanced any small joints and fractures initially created by the emplacement of the Juliette Creek intrusive complex. The restricted development of the secondary calcite suggests that parts of the original Bayhorse Anticline that were refolded must have accomodated most of the deformation and responded by brittle failure and the creation of large amounts of open space. However, the central bulge in the newly formed structure was only to the point of developing small joints and fractures that were later to be accentuated by Tertiary deformation and dissolution.

As previously noted, the near absence of rebrecciation in the fluorite deposits suggests that they were formed after deformation that accompanied the eruption of the Challis Volcanics. Likewise, effects of rebrecciation are absent from the calcite deposits and a similar mode of development is implied. However, field evidence indicates that the fluorite deposits are spatially and temporally separate from the coarsely crystalline calcite deposits. The difference in degree of rebrecciation and the few cross cutting relationships observed suggest that calcite deposition followed fluorite mineralization.

It is concluded that the major period of calcite dissolution and deposition occurred contemporaneously with the end stages of fluoritization or at a slightly later date in connection with the last stages of Tertiary volcanism.

During subsequent periods of ground water activity, the calcite-filled spaces were prime areas for resolution of calcite and the formation of carbonate caves. The few subsurface water courses and solution cavities that are present within the district are found in this anomalously deformed area in association with these calcite deposits. The colloform and banded calcite and chalcedony found lining the solution cavities are totally different from the earlier coarsely crystalline calcite that completely filled the breccia bodies and fissure zones.

## Breccia Pipe

A breccia pipe has been mapped on the northern slope of Pacific Mountain and is located entirely within the Bayhorse Dolomite (Pl. 1, back pocket). The breccia pipe was first recognized and subsequently investigated through geophysics and diamond drilling by N. L. Industries, Inc.

Description. The overall shape of the breccia pipe is that of a rod approximately 200 feet in diameter and of undetermined length. It plunges to the southeast at about 30° into the carbonate country rock. The pipe is spatially associated with the northwest edge of the main sulfide and fluorite-bearing zones of the Pacific Mine, but it is not itself mineralized. It consists of uniformly finely-broken (1 to 3 mm) fragments of dolomite and shale cemented by finely crystalline (1 mm) calcite. The constituents are highly altered and the liberation of iron, presumably from the argillaceous fragments, has stained the rock with tinges of red and brown. The edges of the body are regular and well-defined. The adjacent dolomitic country rock is cut by small randomly oriented joints and fractures but is otherwise undisturbed.

The breccia pipe differs from the breccia plume and related structures in several important ways. Clasts of the breccia pipe are much more finely broken and consist of fragments of both shale and dolomite. The breccia pipe is also significantly larger than the plume; and is apparently an isolated occurrence as other bodies of a similar character are not known within the district.

Mode of Formation. The breccia pipe apparently is related to processes active at a late stage within the district; as was the case for the breccia plume. Although it is in close proximity to highly mineralized zones of both sulfides and fluorite, the breccia pipe is not mineralized. In addition, the breccia pipe has not been rebrecciated. The breccia pipe is apparently the product of a one-stage event that occurred after the two major periods of deformation and mineralization.

The shale fragments may have been derived from shale units interbedded with the lower units of dolomite. If this interpretation is correct, then the fragments would be indicative of upward transport. However, the surface exposure of the breccia pipe is nearly a stripped structural surface and it is possible that the overlying Ramshorn Slate may have contributed the shale fragments from above. The relative abundance of shale fragments cannot be used to determine transport direction as either very little Ramshorn Slate could have been added from above or quite a lot could have been contributed from below. The finely broken character of the clasts adjacent to undisturbed country rock is very difficult to account for solely through tectonic processes, and this again would suggest some kind of dissolution process. However, some other process than simple static dissolution regulated by pre-existing joints and fractures as proposed for the calcite fillings would be required to produce the uniformly, finely broken clasts. The process may have involved a dynamic system, wherein turbulence coupled with dissolution and perhaps initially controlled by a pre-existing zone of weakness, would easily account for the finely ground character of the constituents. Such an event can be readily related to the late stages of Tertiary volcanism involving high gas pressures in an unstable near-surface environment. As previously described, calcite deposition is thought to have been prevalent during the late stages of this period and would explain the carbonate cement of the breccia pipe.

# XI. GEOLOGIC SUMMARY

The central part of the Bayhorse Mining District contains a thick sequence of Early Paleozoic sedimentary lithologies that were deposited in an elongated marine embayment. These rocks have not been greatly affected by the processes of regional metamorphism, but have undergone significant structural deformation as a result of the emplacement of the Idaho Batholith and outlying plutons. The Juliette Creek intrusive complex is the local representative of Middle Cretaceous magmatism, and is presumably such an outlying pluton related to the last stages of igneous activity associated with the Idaho Batholith. The emplacement of the intrusive complex was of major importance in preparing the ground for two later mineralizing episodes by significantly altering the pre-existing local structure and lithologic characteristics of the sedimentary rocks. The first mineralizing episode closely followed the emplacement of the intrusive complex and resulted in the deposition of significant quantities of lead and silver in open spaces created in the adjacent country rocks. These lodes apparently represent the upper parts of a large hydrothermal system that may be associated with stock-work molybdenum or porphyry-copper type mineralization at depth. After this major period of magmatic, tectonic and hydrothermal activity the rocks of the district were again affected by a similar series of events that culminated in the eruption of the flow and pyroclastic deposits of a thick sequence of volcanic rocks and the deposition of important fluorspar mineralization in middle Eocene time.

The stratigraphic succession within the Bayhorse area consists of a series of alternating pelitic, carbonate and quartzite units that range from Latest Cambrian to Middle Ordovician in age. The Garden Creek Phyllite of Late Cambrian age forms the base of the local stratigraphic section and consists of a lower dolomite unit and an upper phyllite unit. The Garden Creek Formation is conformably overlain by the Bayhorse Dolomite of Latest Cambrian or Earliest Ordovician age. The greater part of the formation consists of thickly-bedded, featureless dolomite and limestone that are locally intercalated with thin beds of shale. Oncolitic and stromatolitic algal remains and scattered chert lenses are common toward the middle of the section. The Ramshorn Slate of Early Ordovician age overlies the Bayhorse Dolomite with slight angular discordance. Within the district, the Ramshorn Slate is composed exclusively of a thickly-laminated featureless slate that is locally intercalated with small sandy and calcareous beds. The contact of the Ramshorn Slate with the overlying mixed lithology sequence and Clayton Mine Quartzite of Middle Ordovician age is an angular unconformity and/or a thrust fault. Within the area, the mixed lithology sequence and Clayton Mine Quartzite consist of feldspathic quartzite interbedded with siltstone and shale.

The lithologic and textural varieties of the Lower Paleozoic rocks, combined with regional considerations collectively indicate that the Bayhorse area was transitional between marine shelf areas to the west, north and east and deeper miogeosynclinal areas to the south for most of Paleozoic time.

The entire Mesozoic sedimentary section is missing from the Bayhorse region. This is thought to be due largely to non-deposition, rather than to erosion.

Central Idaho was affected by magmatic activity continually from Late Jurassic to Middle Cretaceous time. Synchronous with the onset of batholithic scale magmatism was folding and thrust faulting of the Paleozoic sedimentary rocks. This magmatic-tectonic event corresponds with the Nevadan Orogeny, which affected the type area in western Nevada from Middle Jurassic to Middle Cretaceous time. The magmatic activity culminated in the formation of the Idaho Batholith and related outlying plutons, one of which is locally represented by the Juliette Creek intrusive complex.

The Juliette Creek intrusive complex represents the upper parts of a much larger and somewhat deeper plutonic mass that was forcefully emplaced into the surrounding sedimentary rocks at depths ranging from four to five miles along anticlinal axes that paralleled the north-south structural grain of the region.

Radiometric K-Ar age determinations on magmatic biotite indicate that the age of the intrusion is $95.9 \pm 3.3$ m.y.

The effects of thermal metamorphism were variably imposed upon the adjacent sedimentary rocks and the resulting changes in the lithologic characteristics of the country rocks aided in the modification of the pre-existing local structure by the forceful emplacement of the intrusive complex.

The relative timing of emplacement of the varied igneous lithologies that form the Juliette Creek intrusive complex tends to parallel a normal calc-alkaline petrogenetic trend. The intrusive complex consists of at least three separate, but genetically related intrusive phases, namely; quartz diorite, granodiorite and quartz-feldspar porphyry. Intrusive relationships indicate that the quartz diorite was the first phase to be emplaced, followed at a somewhat later date by the granodiorite phase. The chemical and mineralogical variation within the granodiorite indicates that the processes of magmatic fractionation were operative on a small scale within this phase. The position of the quartz-feldspar porphyry phase in the emplacement sequence cannot be determined with certainty from field relationships. However, K-Ar dating of hydrothermal sericite and the intrusive lithology suggests that the porphyry phase is closely related in time to the other intrusive phases of the complex.

Throughout most of Mesozoic time the Bayhorse region was located within an area of epeirogenic uplift and was certainly subject to erosion during the Nevadan orogeny from Middle Jurassic to Middle Cretaceous time and again during the Lavamide orogeny at the close of the Cretaceous. During intervening periods, low forelands undergoing erosion may have given way to shallow, limey-bottomed seas.

The predominant structural feature of the district consists of two parallel elongate folds that have been enhanced in the Paleozoic sedimentary rocks by eastwardly directed compressional movement related to the emplacement of the Idaho Batholith. The Ramshorn Slate reacted incompetently to deforming strain and was folded into an eastwardly-overturned anticlinorium. The Bayhorse Anticline developed parallel to this structure in response to similar regional strain. The Bayhorse Dolomite reacted more competently and formed a less irregular anticline asymmetric to the east. The emplacement of the Juliette Creek intrusive complex increased the asymmetry of the Ramshorn Anticline and pushed the structure to the point of brittle failure along predictable zones of weakness related to the development of a thermal metamorphic aureole adjacent to the complex. The emplacement of the complex also acted to reshape the central part of the Bayhorse Anticline and resulted in the local development of a broad box-shaped anticline from the pre-existing structure. The modification of the Bayhorse Anticline accentuated pre-existing zones of weakness within the original structure. These folds have been subsequently modified by thrust faulting and high-angle normal faults of various displacements.

Hydrothermal alteration and sulfide metallization are spatially, temporally and probably genetically related to the Juliette Creek intrusive complex. All the lithologic types of the intrusive complex and the surrounding country rocks display the effects of hydrothermal alteration.. Alteration associated with the lode deposits in the argillaceous and carbonate host rocks is greatly restricted in development. It consists large of the effects of $H^+$ metasomatism, which is represented by base ion leaching from a zone generally coincident with the lode deposits, and deposition of these base ions as gangue minerals within the deposits. In addition, silicification and dolomitization are prevalent. Hydrothermal alteration associated with the various phases of the intrusive complex is local in extent and similar in character. Quartz, kaolin group clays, sericite and carbonate are essentially the only alteration minerals associated with the intrusive complex. They vary erratically in relative abundance along a zone marked by the Nevada Mountain Fault and within a pervasively altered zone at depth that is coincident with quartz-feldspar porphyry phase of the intrusive.

Sulfide metallization within the more highly altered intrusive phases of the complex is typified by disseminations of pyrite and trace amounts of chalcopyrite and molybdenite localized by scattered veinlets. Vein and breccia body fillings within the country rocks are closely controlled by predictable zones of weakness and are characterized by galena, tetrahedrite and pyrite with generally insignificant quantities of sphalerite, arsenopyrite and chalcopyrite. Sulfide metallization is distinctly epigenetic and probably was derived from an underlying source, perhaps from the much larger crystallizing igneous mass indicated at depth.

The region underwent extreme erosion during most of Cretaceous time and was reduced to a near peneplain toward the close of this period. The mature erosion surface was deeply incised by youthful V-shaped stream valleys by Early Tertiary time as a result of renewed uplift preceding the eruption of the Challis Volcanics in middle Eocene time. This erosion cycle succeeded in exposing the upper parts of the magmatic-hydrothermal system that had been active during Middle Cretaceous time and initiated the processes of supergene enrichment which were later interrupted by extrusion of the volcanic sequence.

The Challis Volcanics sequence forms a relatively thin veneer that covers the flanks and caps the ridges of the structural and superimposed topographical highs within the district. The unit consists mainly of separate flows and flow breccias ranging in composition from latite to andesite in which thin flows of basaltic composition, silicic pyroclastic deposits, and sedimentary deposits are locally interbedded.

Fluorspar mineralization accompanied the extrusion of the volcanic deposits and was accomplished by filling open spaces created in the Paleozoic country rocks and the earlier volcanic units by structural adjustment to stress associated with the eruption of the volcanic sequence. This period of deformation was largely independent of the first period that was related to the emplacement of the Juliette Creek intrusive complex. New zones of weakness were opened and older zones, largely restricted to the easily fractured carbonate units were reopened. To the extent that middle Eocene deformation followed pre-existing zones of weakness related to the Middle Cretaceous period of deformation, the fluorspar deposits are relatively predictable. Fluorite was essentially the only mineral deposited although it was accompanied by silicification and remobilization of carbonate .

Following deposition of the Challi Volcanics, an erosion cycle commenced that proceeded far toward maturity by Pliocene time. In early Pliocene time the district was uplifted (Ross, p. 93) and stream valleys that had developed in the peneplained volcanic surface were superimposed upon the underlying Paleozoic rocks of the area with little control exerted on the drainage pattern by pre-existing structure in the basement. This process has continued to the present as stream valleys are youthful and characteristically V-shaped.

The rugged topography of the central part of the Bayhorse Mining District has been only slightly modified by surficial processes of Quaternary age. These processes include glacial erosion above 7600 feet, coupled with water and frost action, snowslides and rockslides at all elevations.

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# APPENDIX

## Laboratory Techniques

Modal analyses of approximately 130 thin sections were obtained. Selected samples, including all modal analyses listed in the text, were point counted (800 points) using a mechanical stage. Visual analyses were made on the other thin sections by estimating mineral percentages at approximately 15 selected sites per slide. Plagioclase feldspar compositions were determined using extinction angles on polysynthetic twins normal to (101).

Potassium-bearing minerals were detected by staining rock slabs with potassium cobaltinitrate.

X-ray diffraction studies of phyllosilicates were performed on a Norelco diffractometer at the Department of Geology, Oregon State University. $Cu_{K\alpha}$ radiation was used, data was recorded on strip charts, and the mineral types were determined by comparing results obtained in the laboratory with data listed in the ASTM X-ray diffraction data card file. Clay samples were prepared as smears on glass slides. Determinations of phyllosilicates were used largely as support for hand-sample and microscopic identification of alteration products. Sericite was identified as fine-grained white mica; kaolin group minerals are clay-size, colorless, weakly birefringent and low in relief; chlorite was distinguished by its green color in plane light and anomalous blue interference colors. X-ray diffraction results did not contradict mineral identifications based on the criteria listed above.

Whole-rock chemical analyses for $SiO_2$, $Al_2O_3$, FeO (total iron), CaO, $K_2O$ and $TiO_2$ were done by the X-ray fluorescence technique at Oregon State University. The rock powders were ignited and fused with anhydrous lithium tetraborate flux and cast into buttons. Polished faces of these buttons were analyzed using a Cr target X-ray source with appropriate analyzing crystals and detection systems. Analyses for Mg and Na were done on a model 103 Perkin-Elmer atomic absorption spectrophotometer by Dr. E. M. Taylor. Analytical accuracy estimated for analyses on U. S. Geological Survey rock standards includes the following:

| Oxide | | Accuracy | |
|---|---|---|---|
| $SiO_2$ | wt. % | $\pm$0.5 | wt. % |
| $Al_2O_3$ | wt. % | 0.25 | wt. % |
| FeO | wt. % | 0.05 | wt. % |
| CaO | wt. % | 0.05 | wt. % |
| MgO | wt. % | 0.1 | wt. % |
| $Na_2O$ | wt. % | 0.1 | wt. % |
| $K_2O$ | wt. % | 0.025 | wt. % |
| $TiO_2$ | wt. % | 0.025 | wt. % |

Specific gravities for samples from the plutonic complex were measured on a jolly balance (accuracy - 0.015 units).

Scale of Stratification Thickness (after Ingram 1954)

| | |
|---|---|
| Very thickly bedded | Thicker than 1 m |
| Thickly bedded | 30-100 cm |
| Medium bedded | 10-30cm |
| Thinly bedded | 3-10cm |
| Very thinly bedded | 1-3 cm |
| Thickly laminated | 0.3-1 cm |
| Thinly laminated | Thinner than 0.3 cm |