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STRUCTURAL CONTROL OF SOME MINING DISTRICTS IN CENTRAL IDAHO

6

by

Thor H. Kiilsgaard

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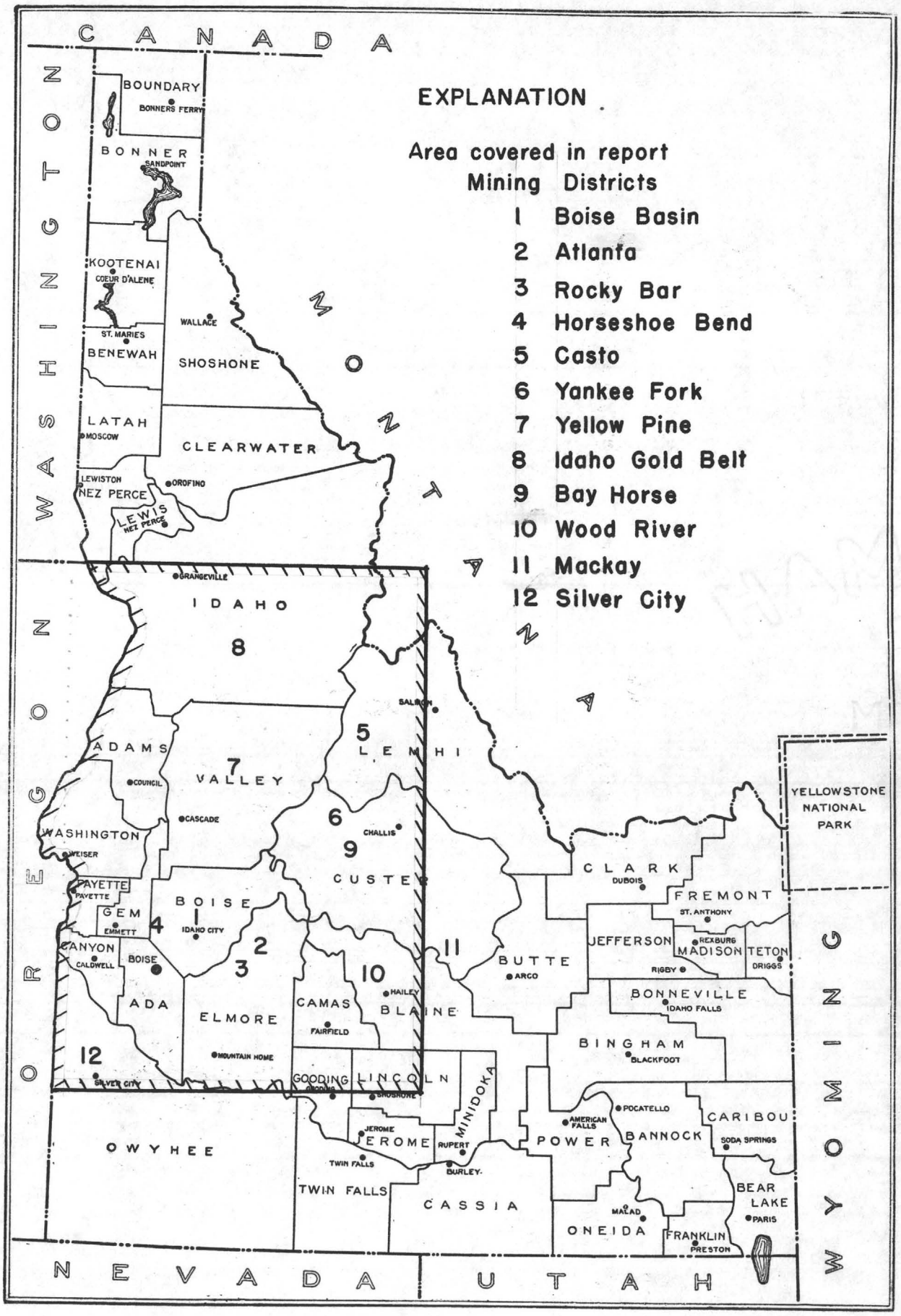
ABSTRACT

This report is concerned with the factors resposible for ore deposition within certain mining districts underlain by or adjacent to the Idaho batholith, see Plate (6). These districts are of economic value due chiefly to two types of ore deposits: 1) base metal deposits related to Mesozoic intrusives and; 2) precious metal deposits related to Tertiary intrusives. Of the two types, the precious metal deposits are the most important and occur throughout a greater portion of the area, see Plate (6), consequently they have received the greatest amount of attention.

The precious metal deposits which are associated with the Tertiary intrusives, chiefly porphyritic dikes, have been guided to their present locations by major north-east trending fracture patterns. These fracture patterns have resulted from antithetic faulting which has roughly paralled a north-east trending dome or arch. This great dome, the exact magnitude of which is not known, is Miocene or early Pliocene in age and has resulted from vertical forces acting from within the batholith.

Plate No. 1


CANADA
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Area covered in report
Mining Districts
1 Boise Basin
2 Atlanta
3 Rocky Bar
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5 Casto
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7 Yellow Pine
8 Idaho Gold Belt
9 Bay Horse
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MONTANA
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KOOTENAI
COEUR D'ALENE
ST. MARIES
BENEWAH
WALLACE
SHOSHONE
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OWYHEE
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CLARK
DUBOIS
FREMONT
ST. ANTHONY
YELLOWSTONE NATIONAL PARK
JEFFERSON
REXBURG
MADISON
TETON
DRIGGS
RIGBY
BONNEVILLE
IDAHO FALLS
BINGHAM
BLACKFOOT
POCATELLO
AMERICAN FALLS
POWER
BANNOCK
CARIBOU
SODA SPRINGS
BEAR LAKE
PARIS
MALAD
ONEIDA
FRANKLIN
PRESTON

INTRODUCTION

The state of Idaho has long been recognized as one of the West's foremost mining states. Mining operations have been active, at various times, in almost every portion of the state. The central part of the state, see Plate (6), that part underlain by the Idaho batholith, has been the site of more mineral discoveries than any other individual sector. These mineralized areas are located throughout the batholithic region but are especially predominant near the perimeter or bordering areas.

PURPOSE

The purpose of this paper will be to analysize the features relating to ore deposition, in the above mentioned areas, and to attempt an interpretation of the factors which have controlled the deposition. With this thought in mind, geologic information on a number of the better known mining camps will be analyzed. This analysis, together with a study of the more important structural features of the area, will perhaps shed some light on a problem which has here-to-fore received a minor amount of attention.

DESCRIPTION OF THE AREA UNDER CONSIDERATION

The Idaho batholith[1], now exposed over about 16,000 square miles, extends from the vicinity of Boise northward through the central portion of Idaho into the western part of Montana. It comprises a more or less solid rock body of quartz monzonite composition. Some facies, mainly marginal, are granodiorite with other types of granitic rocks included.

Most of the western, all of the southern and much of the eastern borders of the batholith are rimmed with Tertiary strata, mainly Miocene volcanic rocks. Near its southeastern end, the batholith intrudes a thick series of Paleozoic strata. In this vicinity, isolated granitic masses, probably satellites, cut Paleozoic strata ranging in age up to Pennsylvanian. Farther north, on the east border of the batholith, the inclosing formations are mostly Algonkian Belt rocks and Tertiary volcanic flows.

Age of the Idaho batholith

The age of the batholith has been listed, by numerous writers, to range from Archean to Eocene. However, recent workers[2] in the field have narrowed this range down to be definately post-Triassic and pre-Miocene. Further research has placed the age as upper Jurassic or lower Cretaceous. Since batholiths of such magnitude are generally related to major disturbances, it is reasonable to regard the batholith as one of the products of widespread diastrophism which occured in the Cordilleran region near the end of the Jurassic period.

Relation of Tertiary Granitic Rocks to the batholith

In the central and south-eastern parts of the batholith there are numerous masses of granitic rock, clearly younger in age than the host rock. The largest of these bodies occurs along the Middle Fork of the Salmon River, where it is exposed along the axis of a broad anticlinal or domal arch.

In addition to the larger masses of Tertiary granitic rocks there are several large discontinuous belts of Tertiary dikes which trend along shear zones cutting through the batholith. Most of these belts have a definate northeast trend and appear to have resulted from structural readjustment within the batholith.

Challis volcanics

In addition to Tertiary granitic intrusives there occurs, in the central and south-east section, a large series of volcanic flows, mainly andasites and rhyolites of Oligocene (?) age. In places these flows completly cover the older batholith, but other locations, where the upper-most flows have been eroded away, show that the structural deformation which has accounted for dike injection throughout the batholith has also effected the Challis volcanics and allowed the Miocene dikes to penetrate the lower lying flows.

SUMMARY OF THE GEOLOGY

Pre-Cambrian Time

The occurrence of Belt rocks as cappings and roof pendants throughout the higher regions in the batholithic area suggests that in pre-Cambrian time all of the present exposed area was the depositional site of a tremendous thickness of sediments. Evidence also points to orogenic disturbances at the close of that period.

Paleozoic Time

The deposition of Paleozoic sedimentary beds in the south-eastern section, proves that Paleozoic seas were present in some parts of the area. It is not known how far to the north these seas advanced, since all evidence was destroyed by the later intrusion. In the northern part of the region large flows of Permian volcnics give evidence to extensive volcanic activity during this period.

Mesozoic Time

During Jurassic or early Cretaceous time, enormous masses of magma invaded the underlying rocks of the area and formed the Idaho batholith.

This intrusive mass was associated with great disturbances in the surrounding rocks and resulted in large scale uplift of the entire region. Following the uplift, vigorous erosion set in and by early Tertiary times had reduced the area to one of relatively gentle topography.

Tertiary Time

The exact orogenic disturbances which have transpired in Tertiary time are highly controversive, many writers having different opinions on this subject. The complexity of the situation is further augmented by the small amount of detailed field mapping that has been done in the region. The general consensus of opinion is that the batholithic area was rejuvenated[4] in early Tertiary time as a result of the structural disturbances caused by the Laramide revolution. These disturbances were followed by the out-pouring of great thicknesses of Challis volcanics in the central and south-eastern sectors.

During or shortly after the volcanism, granitic magma again invaded the batholithic area, although on a smaller scale than the previous intrusion. This intrusion was accompanied by regional uplift in the form of a broad north-easterly striking arch or dome. Erosion along the axis of this dome has exposed large areas of these mid-Tertiary, probably Miocene, granitic rocks, in the Casto quadrangle. Countless numbers of smaller intrusions, chiefly in the form of dikes, occur throughout the entire area. These granitic intrusives follow zones of shearing, and evidence indicates that these shear zones, while they may have been pre-Miocene in age, were reactivated in Miocene time by the deformation, thus providing avenues for the migration of material which formed the above mentioned dikes. In places the dikes were accompanied by mineralization forming many of the well known Idaho mining districts.

In a general way these dike-shear zones follow definite trends in a north-easterly direction, in some localities they may strike north or north-west but the regional trend is to the north-east. They do not occur as a continuous belt but rather in an En-echelon fashion. Individual dikes and faults may vary in trend but taken as a group they comprise definite patterns which may be traced over long distances.

In addition to the Miocene intrusives, there occured in upper Miocene time, a tremendous outpouring of Columbia River basalt around the western and north-western borders of the batholith. The effusion of the basalt was followed by a period of quiescence during which the region was again eroded to a moderate level.

In Pliocene time there occured another period of uplift with structural disturbances expressed mainly by normal and block faulting along already established fractures. The uplift may have continued with diminishing vigor until fairly recent times. This uplifted, so-called "Idaho peneplain", has been the site of intense erosion, which has resulted in the extremely rough topography characteristic of the area at the present time.

Concurrent with the Pliocene uplift and continuing into Pleistocene times was a vast effusive flow of Snake River lavas around the southern border of the batholith. This thick series of flows, according to Kirkham[5], resulted in a depression or the Snake River downwarp, whose axis roughly parallels the trend of the Snake River across the southern part of Idaho.

MINERALIZATION

C.P. Ross, one of the well known workers in Idaho geology list the ore deposits of the batholithic area in two broad classes based on a genetic classification[6]. These are:

1. Deposits related to Mesozoic Igneous Rock
   A. Deposits in shear zones in siliceous rocks.
   B. Irregular replacement deposits in calcareous rocks.
   C. Contact Metamorphic Deposits.
   D. Pegmatite Veins

2. Banded Veins in Tertiary Igneous Rock
   A. Lodes without sharp boundaries in Tertiary rock.
   B. Contact Metamorphic Deposits.
   C. Deposits related to Tertiary dikes.

In addition to the above mentioned types of ore deposition, Ross postulates a rough zonal theory in which he notes the presence of precious metal ores within the borders of the batholith and the occurrence of base metal ores in the sedimentary zones surrounding the batholith. This theory will be referred to in a later paragraph.

PRECIOUS METAL MINING DISTRICTS

In a discussion of the following mining districts, the writer will attempt to summarize the various characteristics and similarities which exist between the different districts. Perhaps a summation of these characteristics will yield some clues on the factors which controlled the ore deposition.

Boise Basin (see Plate No. 6)

Introduction

The Boise Basin, one of the most famous mining districts in Idaho, due to its early day placer gold production, is located in the central part of Boise County, Idaho[7]. It is underlain by the Idaho batholith, which is cut locally by related aplite, lamprophyre and pegmatite dikes. Younger porphyritic dikes, many accompanied by mineralization, also cut through the area.

The "Porphyry belt"

The most striking geologic feature in the area is the "porphyry belt".

This belt is composed of six varities of Miocene dike rocks listed below in order of age; dacite porphyry, rhyolite porphyry, granophyre porphyry, and granite porphyry. Diabase and diorite porphyry are of doubtful age but are definately later than the more acidic dikes. All but the last two dikes were intruded before deposition of the Miocene mineralized lodes.

Ross, dates the dikes as Miocene in age largely by:

1. The close accord between the dikes and fissures that are structurally discordant with the Idaho batholith but correspond to fissures of known Tertiary age eleswhere.

2. The petrographic dissimilarity between most of the dikes and any known to be related to the Idaho batholith.

3. The petrographic resemblance between many of the dikes and rocks eleswhere in Idaho that are known to be of Miocen age.

Mapping in the Boise Basin plus reconnaissance in neighboring areas reveals that the belt, as a whole, trends about N 60°E. It was traced along a strike length of 35 miles and was commonly found to be 1 to 2 miles in width. Most of the dikes, although irregular, curved and branching, have an average trend of N 70°E. Some dikes vary in trend, especially the younger more basic ones.

Relations of Structure to Mineralization

Most of the ore deposits in the basin are found to be associated with the porphyry belt. In attitude, like the dikes, they closely approach the general trend of the belt but rarely coincide with that of the zone as a whole. The size and persistance of the zone of fracturing followed by the dikes shows that it is one of the major components of the regional structure. The fracturing, that furnished the openings for the mineralizing solutions subsequent to the intrusion of the dikes, is probably due to recurrent movement along this zone of major structural weakness.

Some of the ore deposits do not comply with the regional N 70° E trend; two subordinate fracture systems are noted, both of minor size and with

irregular trends. The first set strikes N 30° to 60°W with a near vertical dip or slightly inclined to the south-west. The second set comprises small discontinuous seams, jagged in detail, which lie at slight angles to the second set of fractures. Evidence indicates that all these sets of fracures are pre-mineral and have controlled the localization of the deposits.

The ore deposits are of economic value cheifly due to their precious metal content. Some mines contain base metal sulfides but of such a low concentration as to be of no economic importance. The lodes are classed as mesothermal in type.

Horseshoe Bend District (see Plate No. 2.)

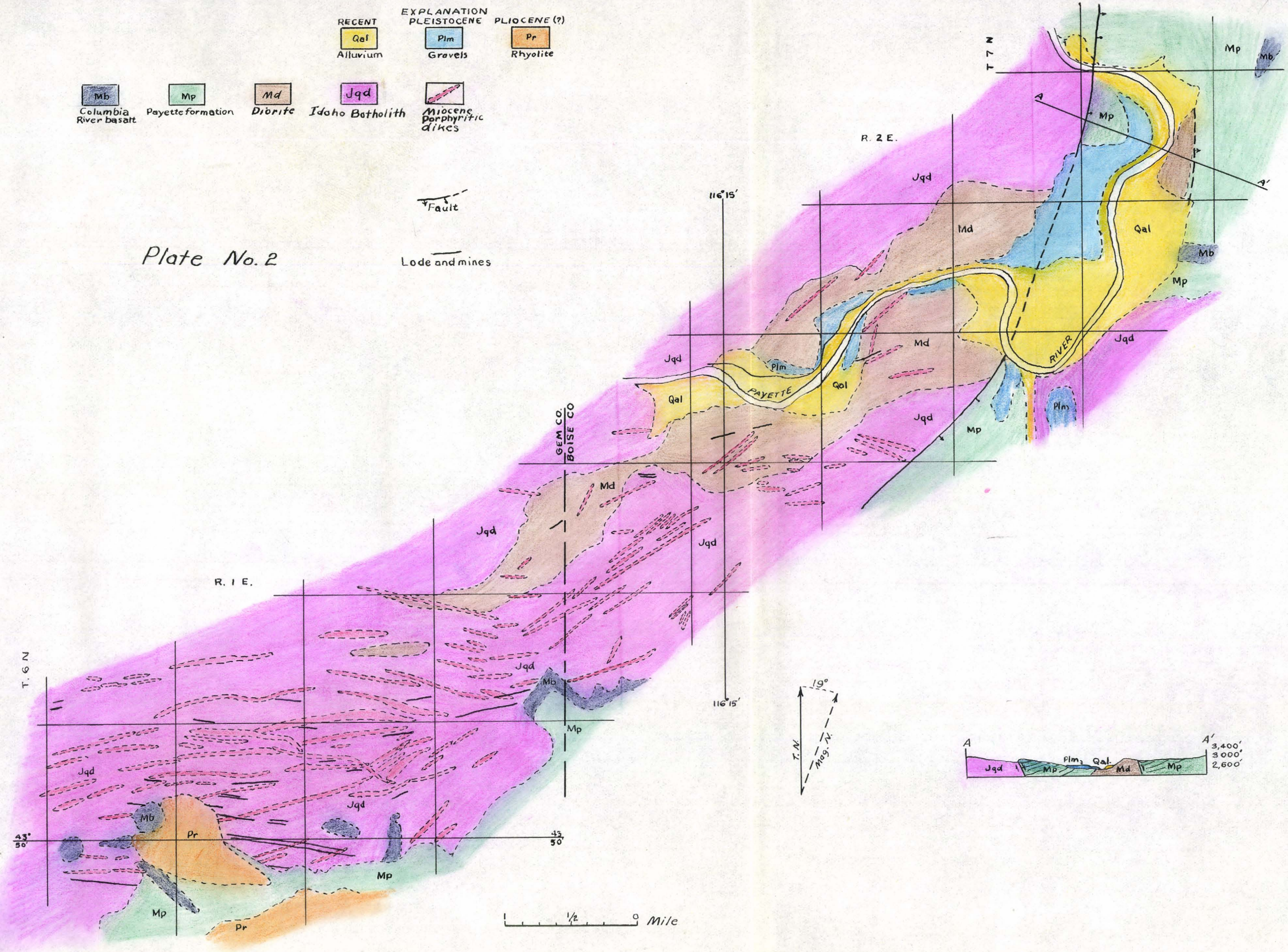
Introduction

The Pearl-Horseshoe Bend gold belt lies partly in Gem County and partly in Boise County, about 18 miles north-northwest of Boise, Idaho.

Geology

The geology of the Pearl-Horseshoe Bend gold belt is much like that of the Quartzburg, Grimes Pass and Boise Basin districts a few miles to the east. Each district has a prominent dike swarm or "porphyry belt" controlled by zones of structural weakness in the older batholithic rock and each contains mineralized lodes in association with the younger dikes.

At Horseshoe Bend the Tertiary porphyry dikes are numerous, complex in composition, and occur throughout the entire area. The dikes range from dacite porphyry to lamprophyre and are concentrated in a belt of east-northeast trend. They vary in size from those too small to map to others 400 feet in width and 8,000 feet in length. The belt covered in Anderson's report is approximately 2 miles in width and 9 miles long.



Geologic sketch map of the Pearl-Horseshoe Bend gold belt.
(After Anderson)

While the general trend of the belt is east-northeast, individual dikes vary in strike and often cut obliquely across the belt.

Near the close of the dike intrusions, mineralization action was prevalant, the depositional sites being controlled by the fracture patterns which preceeded the dikes. In a few places lamphrophyre dikes have been intruded, following the mineralization, and some of these dikes have cut across the veins.

A close accordance exists between the dike and lode patterns. The strikes of the largest and most persistent of the mineralized fractures, like those of the dikes, approach but rarely coincide with the zone as a whole. The lodes are more or less parallel to the dikes in their immediate vicinity, see Plate (2). Some dikes as well as veins and small faults have a definite north-west strike almost at righ angles to the general trend of the belt. This would indicate that other component stresses were active during the period of structual adjustment which gave rise to the belt. The fracturing that furnished the channels for the ore bearing solutions is doubtless to be attributed to a recurrence of movement along this zone of major structural weakness which earlier provided for the intrusion of the dikes.

Anderson, believes the age of the porphyry intrusives to be Miocene. He bases this assumption partly on field information within the district and partly on known information on similar dikes in other parts of the state. He also notes that the character of the ores indicates that mineralization is of the Mesothermal type, and that the source of mineralization is related to the Tertiary intrusives and not to the older Idaho batholith.

The Atlanta District (see Plate 6)

Introduction

The Atlanta district is located in Elmore County about 80 miles north of Mountain Home, the county seat[15].

The district has an interesting history which began with the discovery of rich gold-silver ores in 1864 by placer miners, who where prospecting the streams in the area. However, due to the regions remoteness, cost of mining operations and erratic deposition of the ore, the district has had an intermittent mining history. The total production values are listed at somewheres near $6,000,000.

Character of the Deposits

The ore deposition is characteristically epithermal and features an abundance of finely crystalline quartz and minute particles of sulphides, enclosed by granitic country rock. The deposits have been extensively brecciated and recemented by later deposition of quartz and sulphides.

The main ore bearing veins have a general N 50 - 70°E strike, dipping to the north-west. Some minor veins transverse the major structure striking north-west and dipping to the north-east.

Structure

The Atlanta district appears to lie along a broad zone of marked structual weakness in which the Idaho batholith has been thoroughly and repeatedly shattered. The zone has a general north-east trend and appears to have originated from two major periods of structual adjustment. The first period was initiated during the early stages of magma consolidation and is evidenced by the present dike pattern of aplites and pegmatites, which accompanied this period of crustal failure.

At a later date, after the emplacement of the aplite and pegmatite dikes, the region was again subjected to shearing stresses of regional extent. These shear and fracture zones, in the main, conform with the earlier pattern both in strike and dip, but may be differentiated by the presence of mineralized lodes and porphyry dikes which locally trangress and displace the older aplites and pegmatites.

The major shear zone, which varies from 40 feet to 120 feet in width, has been traced along a strike length of several miles. It is composed of a multitude of fractures, the more prominent trending parallel to the general strike. Smaller fractures cross at oblique angles and conform with a general north-west trend.

Perhaps the most prominent features of the district are the porphyry dikes which have accompanied mineralization. These dikes, described by Anderson as a "broad porphyry belt" composed chiefly of pink granophyre, others having the composition of granite porphyry and dacite porphyry. They have been traced along a strike length for over 10 miles and may extend for an indefinate distance into the unmapped areas on either side of the Atlanta district. Most of the dikes are from 50 to 300 feet thick and vary from several hundred to several thousand feet in length. Anderson reasons that these mid-Tertiary porphyry dikes have resulted from regional structural adjustment along the longitudinal axis of a broad north-east trending dome. He explains that the collapse of such a dome could account for the zone of fracture and subsequent dike intrusion.

Rocky Bar District

Introduction

The Rocky Bar district is located in northern Elmore County, a few miles south-west of the Atlanta mining district. This small gold-silver producing district, formerly an important mining camp, is now abandoned. As a mining camp it was typical of the early day "boom towns". High grade ore was mined right up to the "grass roots" but the deposits did not prove to be economical as mining went down to lower levels.

Geology

Ballard[9], in his report on the district, was impressed by the close relationship between the trend of the quartz veins, the igneous dikes and the major faults, all of which made up a belt whose general strike varied from N 60°E to due east and which dipped to the north. Cutting across this dike belt, at intervals, are a series of minor north-west trending faults, which in a few places, have been mineralized, forming small ore bodies. Ballard calls attention to the number and magnitude of dikes, which vary in composition from acidic to basic and he points out evidence which indicates that quartz vein deposition occured concurrent with dike intrusion and possibly even before the more basic dikes. He roughly sums up the dike and vein relationship as: "basic dikes and veins both occupy fissures of the same period of diastrophism, that is, of nearly contemporaneous age and thus are structually related." He further reasons that, during dike intrusion, magmatic differentiation had proceeded to such a point that at one extreme there was a basic segregate available for dike intrusion and at the other extreme an acid segregate available for vein filling.

The "Gold Belt" Region

Introduction

An interesting region, the so-called "Gold Belt", is located in Idaho County, Idaho. It is composed of the Elk City, Orogrande, Buffalo Hump, Warren, Florence and other smaller mining districts. These districts have, in past times, been the sites of intense placer mining activities, the placer gold being derived from near by lodes.

Geology

The area has never been throughly investigated and detailed information such as time relationship, structural control, ect. is lacking. The strucure of the area is exceedingly complex and only partly understood, many of the geologic problems remain to be solved[10].

The rocks of the region are chiefly north-west trending pre-Cambrian, metamorphosed sediments and intrusive granitic rocks of the Idaho batholith. Cutting obliquely across the regional trend of the older rocks, is a major north-south trending fracture system which is accompanied by several types of igneous dikes and occasional gold bearing quartz veins. Many of the quartz veins do not conform with the general north-south trend. A few quartz veins strike almost due east, dipping both to the north and south at steep angles.

The "Gold Belt" is roughly 35 miles in length and 3 to 4 miles in width. In a general way it represents a pre-mineral fracture system which, at a later date, presumably mid-Tertiary time, has been intruded by igneous dikes with accompanying mineralized quartz veins. These veins are typically epithermal in character.

The Yellow Pine District

Introduction

A district which is becoming increasingly important in the Idaho mining industry is located near Yellow Pine in northern Valley County, Idaho.[11] Within recent years large deposits of antimony, tungston, and low grade gold ores have been brought into production in this area.

Geology

The area is underlain by granitic rocks of the Idaho batholith, however, locally there are large exposures of pre-Cambrian metamorphosed sediments. These pre-Cambrian exposures occur as roof pendants above the underlying granitic rocks. The region is cut by several, large, pre-mineral, north-south trending, east dipping shear zones. One of the faults in this zone, the Meadow Creek fault, has been traced along the strike for several miles. Following the trend of the regional shear zones and of later age are two and possibly more distinct sets of fractures; one striking N 15°E, and dipping 40-80° east, the other striking N 2-32°E and dipping steeply west. Both of these fracture zones contain minor amounts of gouge and show evidence of inter-mineral and post-mineral faulting.

The ore deposits occur along complex fracture patterns following major shear zones in the granitic batholith. The mineralization occurs in two ways; as small high grade lenticular veins and as disseminated deposits, both of epithermal character. Two periods of mineralization are represented in the area; the first by pyrite, arsenopyrite and gold, the second by antimony and silver. The two periods are believed to be genetically related and to have been deposited in mid-Tertiary time.

Casto Quadrangle

Introduction

This region is located, for the most part, in north-western Custer County, Idaho. During the early days in western mining history it was the site of several"mining booms", none of which lasted for more than a few years. Due to the regions remoteness and inaccessability, it has received very little attention from mining men during recent years.

Geology

The quadrangle,[12] is located along the south-eastern side of the Idaho batholith; however, the dominent rocks within the quadrangle are a complex series of Miocene intrusives and Oligocene (?), Challis volcanics. The entire region has been repeatedly faulted and folded until an exact time relationship of the various structures is rather difficult to determine.

The most interesting geologic features of the area are the complex Miocene intrusives and the structual deformation which these intrusives have imparted to the region during the time of their implacement. The Miocene intrusives vary widely in composition, in direct contrast to the more stable and uniform batholith. This would imply that conditions, during intrusion of the two rock types, were fundamentally different. The batholith must have been intruded and cooled under conditions that permitted the mass to attain uniform composition and textures throughout. On the other hand, the wide range of composition and texture of the Miocene intrusives would point to comparatively rapid and irregular movement during intrusion. This would indicate lower pressures and shallower depth at the time of formation.

The movement and deformation effect of these Miocene intrusives is further emphasized by the manner in which they have deformed the overlying Challis volcanics. These volcanics have been warped into broad folds, striking to the north-east. The major structure is a broad arch or dome whose axis roughly parallels the north-eastward trend of the Middle Fork of the Salmon River, and whose outer flanks lie well beyond the limits of the quadrangle. Paralling the longitudinal trend of this regional dome are ~~are~~ a discontinuous series of Miocene dikes and large normal faults, most of whom dip to the northwest. Transversing the broad dome are a series of north-west trending faults of minor size and displacement. The two sets of faults appear to be complimentary and to have formed a fracture system, which has given relief to tensional stresses that were active during the period of mid-Tertiary deformation.

Mineralization

Two broad types of ore deposits are recognized in the area: 1) shear zones containing copper and lead sulphides with minor amounts of gold and silver in a gangue containing large amounts of siderite; 2) veins and breccia zones characterized by the presence of fine grained ribbon-banded quartz, valuable for their gold-silver content. Type 1 is thought to be genetically related to the intrussion of the Idaho batholith. The deposits occur mainly as replacements in Paleozoic sediments. Type 2, occurs along shear zones in the volcanic extrusives and are, for the most part, associated with the Miocene dikes.

Yankee Fork District

Introduction

During the summer of 1947, the writer, while employed by the Idaho Bureau of Mines and Geology, was a member of a field party, which made a geological examination of the Yankee Fork Mining district in northwestern Custer County, Idaho. This region, the scene of many eary day "mining booms", has produced an estimated $15,000,000 in gold-silver values.

Geology

The area is entirely underlain by Challis volcanics. It is cut in several places by strong shear zones whose strikes varies from N 60°E to due east. These shear zones are locally accompanied by porphyritic dikes, whose strikes closely follows the trend of the shear zones. These shear zones, due to their striking red-brown colors, are the most outstanding geologic features within the area. When viewed from a commanding vantage point they may be visually traced for miles across the country side. The rock within these shear zones is highly altered and oxidized, thus accounting for the unusual colors.

All of the mines and prospects that were visted, occured either within or adjacent to the zones of shearing, and all were similar in their characteristics. They were narrow, ribbon-banded quartz lenses and veins of short strike length, steep dip, and had been mined to shallow depths. The deepest working place encountered, in the district, was 900 feet, measured down the dip. The positions of profitable ore shoots are unpredictable, in these epithermal "bonanza like" deposits, and no definite structural control has so far been established. Suffice it to say that, mineralizing solutions have migrated along these zones of fracture and where the proper temperature-pressure conditions and openings were encountered, at the correct time, have resulted in mineral deposition.

No means of determining the age of the faults or the dikes was available within the Yankee Fork district; however, by comparing the observed structural features with those of similar character in other, better known districts, some tenative classifications were made. It was decided that the fault zones, both the major easternly and the minor northward trending zones, were mid-Tertiary in age and had resulted from some type of structural adjustment. An attempt was made to determine the direction of movement along the fault planes; however, due to the lack of "marker beds" and the uniform similarity of the volcanic country rock, the effort was unsuccessful. That the faulting was pre-mineral, thus providing channelways for the migration of the subsequent mineralizing solutions, is proven by the present position of the ore deposits.

BASE METAL MINING DISTRICTS

The following districts are typical of the base metal producing districts located in the area under consideration, (see Plate 6). These districts differ from those previously discussed in several ways, among others are: types of ore, structural control, and composition of the enclosing country rock.

The Bay Horse District

Introduction

The Bay Horse district is located in the upper drainage basin of the Salmon River, in Custer County, Idaho. The district formerly was one of the most important base metal mining districts in the state of Idaho.

Geology

The region is underlain by a thick sequence of Paleozoic sedimentary rocks which are intruded from the west by the Idaho batholith.

The Paleozoic strata are complexly folded, the folds having a general north-northwest trend. The folds have been highly distorted by thrust and normal faults. Ross,[16] believes that the Idaho batholith played an active part in the deformation and that folded and faulted structure resulted from igneous intrusion.

The overlying Tertiary strata are only gently folded and are locally displaced by north-east trending normal faults that dip to the north-west. The general dip of the Tertiary strata is a few degrees to the south-east suggesting that the strata has been subjected to some broad regional warping. Some smaller north-west and north-south faults also displace the Tertiary strata. They appear to be complimentary to and of the same approximate age as the major north-east faults.

Mineralization

The Bay Horse region contains several mines that formerly were important producers of lead, silver, copper, zinc, gold, and antimony. A study of these mines reveals two interesting features: 1) the high base metal content of the ores, 2) the irregular trend and disposition of the lodes within the Paleozoic host rocks. Field evidence indicates that these deposits are directly related to the intrusion of the Idaho batholith. Among other characteristics the deposits show, irregular attitudes, massive replacement "kidneys" of diverse shapes and sizes, abundant siderite gangue, and the presence of galena, sphalerite, chalcopyrite and other sulphides not found, in commercial quanities, in the precious metal bearing districts. The location of the deposits appear to have been controlled by two factors; 1) those deposits formed by replacement of more calcareous members of the host rock, and 2) deposits which roughly follow the complex folded structure developed during intrusion. Another interesting feature of the area

is the relatively deep zone of oxidation as compared to other nearby areas. At Bayhorse, oxidation has progressed to depths of several hundred feet, in some mines. In the near by precious metal districts, oxidation has rarely progressed more than a few feet below the surface.

In the Bayhorse region, no important commercial deposits are found in the Challis volcanics. In places the volcanics contain small quartz veins but these veins do not contain any ore.

Wood River District (see Plate 6)

Introduction

The Wood River region, located in Blaine County, Idaho, is one of the oldest base metal producing mining camps in the state of Idaho. This region, like the Bay Horse district to the north-east and the Mackay district to the east, is underlain by Paleozoic sediments. These sedimentary formations have been folded and faulted into very complex fracture patterns. Some of these fracture patterns have controlled the location of the ore deposits. Westgate[17], notes the presence of five distinct periods of faulting within the district, most of which have resulted from structural deformation caused by the intrusive force of the near by Idaho batholith.

Structure

The batholithic intrusion has resulted in folding and overturning of the Paleozoic rocks with a general northwest trend of the folded axis. The overturning has resulted in thrust and reverse faults of a large size.

Mineralization

The base metal mineralization is associated with the intrusion of the Idaho batholith. The solutions were guided to their present positions by fracture resulting from structural deformation. Inter-mineral and post-mineral faulting are common in the area and have increased the complexity of the structure, thus creating difficult exploration problems.

The Mackay District

Introduction

Another well known mining district in Idaho is the Mackay district. This district has received close attention from Umpleby,[9] resulting in a well written U.S.G.S. Prof. Paper. Since the area is to complex to be adequately described in this paper, only the broad regional characteristics will be discussed.

Geology

The region is underlain by pre-Cambrian and Paleozoic sediments that are locally intruded by Mesozoic granite, Idaho batholith, and younger Tertiary rocks. Three major periods of deformation are observed in the area: 1) near the close of the Algonkian period; 2)during the Mesozoic period, probably as a result of the batholithic intrusion; 3) during Tertiary times.

Umpleby classes the mineralization in two ways; pre-Oligocene and post-Oligocene. All the important mineral deposits in the district are pre-Oligocene. They are valuable for their base-metal content and appear to be genetically related to the intrusion of the Idaho batholith. The deposits have varying trends, many of them being of contact-metamorphic type. Umpleby reasons that structural readjustment of the Paleozoic rocks, due to the Mesozoic intrusion has set up the fracture pattern allowing the mineralizing solutions to migrate into the Paleozoic rocks, thus forming the deposits.

OTHER MINING DISTRICTS

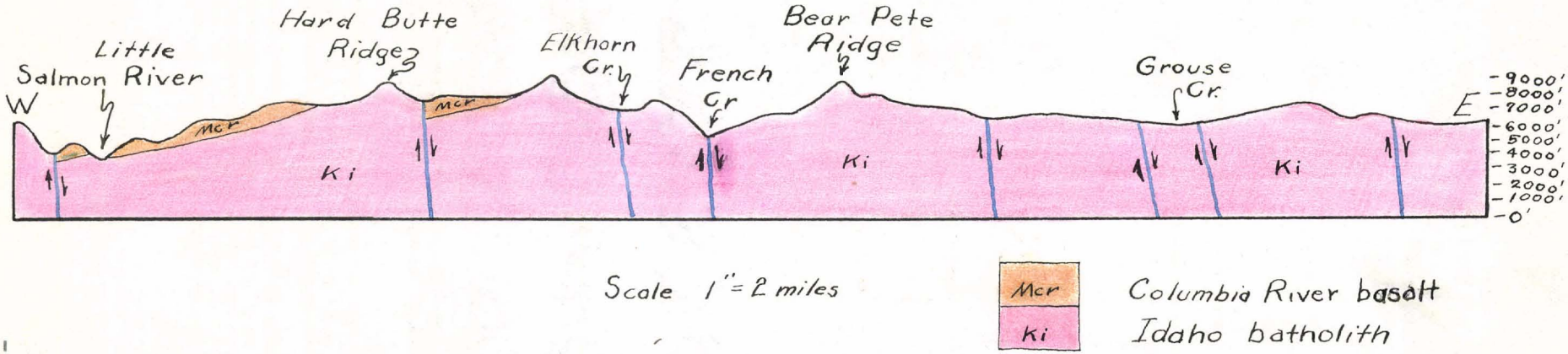
Other mining districts, located within the area under consideration, have been studied but not presented in this discussion. Such a presentation would only be a repetition of data already observed. Among others, these would include; Shoup, Leasburg, Venice, Silver City, Hailey Gold Belt, Blackbird, and Sea Foam.

REGIONAL STRUCTURAL DEFORMATION

A review of the various mining districts immediately points out many of their similar characteristics. One of the common geologic features noted in practically all of the precious metal districts was the occurrence of porphyry dikes. In almost every case, these dikes have occured in belts or dike zones, which have had a constant regional trend. Further examination reveals that these dike zones have followed major zones of shearing, whose regional trend has been in a general northeast direction. These discontinuous shear zones indicate that the deformation which originally caused the shearing was not of a local nature but has extended over a large part of the batholithic area. Several workers have advanced theories attempting to account for the deformation within local areas, papers dealing with this subject have already been discussed, e.g., Ross (12), and Anderson (15). Other workers have attempted a more regional explanation for the deformation.

Capps, (13), in his paper on faulting in western Idaho, notes the presence of several periods of active faulting and uplift during Tertiary times. The major fault zones, one of which has been traced along a strike length of 150 miles, occurs along the western border of the Idaho batholith. These zones of shearing have north-west to northerly strikes and dip to the east, (see Plate 3). Capps places the most active period of faulting in late Miocene or Pliocene times, when large scale domal uplift of the Salmon and Clearwater Mountains resulted in large north-south, east dipping block faults with the down thrown side to the east. One of these, the Long Valley fault, has a measured displacement of 3000 feet. He notes that these faults disrupted the drainage system and accounted for the present occurrence of high level placer deposits.

Plate No. 3



Cross Section across the Salmon River Mountains taken a few miles south of the Salmon River, West Central Idaho

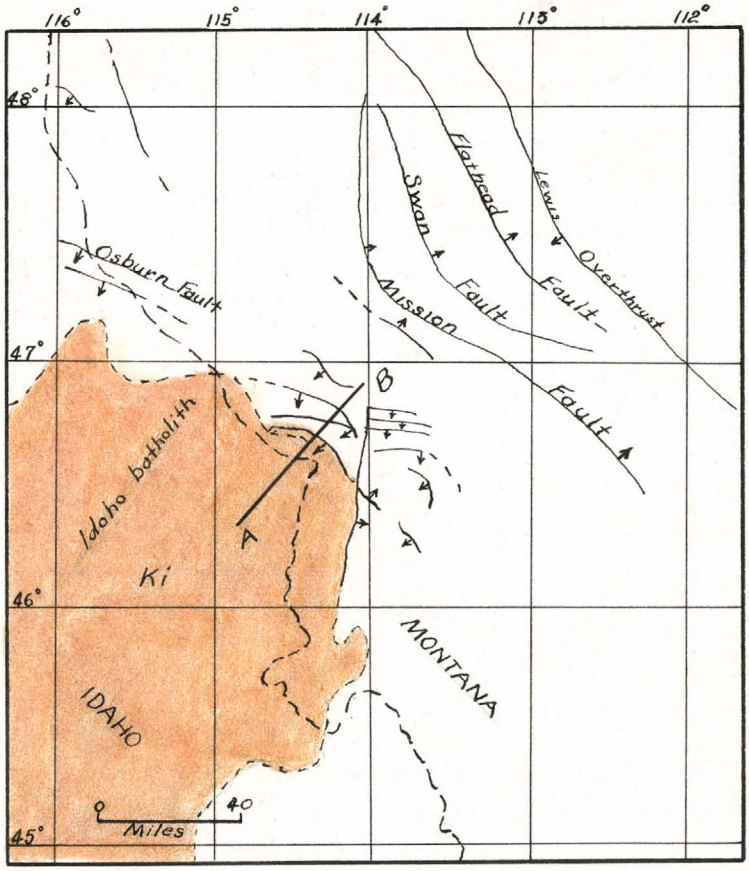
The Section illustrates the "block faulting" common in that area

As a partial explanation to this period of structural readjustment, Capps, points out that during a period of mountain growth, the borders of the batholithic area would yield to stress before the center portion; however, he further notes that the central portion must also have suffered by faulting during the uplift.

Moving to the north-eastern side of the batholith, and momentarily stepping outside the area under consideration, we find an interesting paper by C.M. Langton[14], in which he discusses the structure of a region in western Montana, (see Plate 4). Of special interest is the occurrence of a series of large curved overthrust faults which are concentric about the batholith. These faults dip towards the south-west, the western side in each case, being the upthrown side. Related to these thrust faults are a series of intrusive dikes which in places conform closely with the fault planes and in other places have been sheared and displaced, indicating that dike intrusion was concurrent with faulting. Closely connected with, and resulting from the thrust faulting, is an irregularly folded area, many of the folds being nearly closed or overturned to the north-east. Langton attributes the folding and thrusting to intrusive action by the batholith. From a correalation of these observations, together with other field data, he dates the age of the batholith as upper Cretaceous or Eocene.

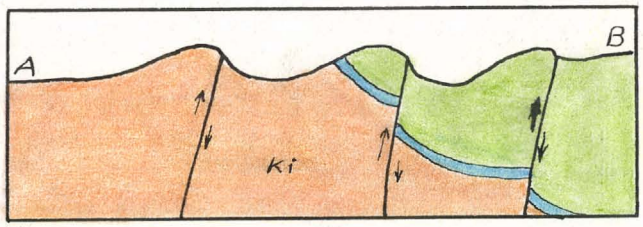
The writer doubts Langton's age classification of the batholith. His deductions as to the thrusting forces initiating from within the batholithic area are undoubtedly true. However, from his descriptions on the faulting and on the intrusive dikes, one cannot help but wonder if the thrusting hasn't resulted from large scale domal uplift in Tertiary times and has no relation to the initial intrusion of the batholith.

Plate No. 4

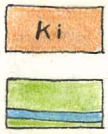


Index Map showing major fault patterns of Western Montana

(taken from Langton)



Diagrammatic cross section showing how faults could have originated from uplift within the batholithic area.



Idaho batholith

Undifferentiated

The type of faulting which Langton describes may be tied in very closely with crustal disturbances in other parts of the batholith and one wonders if further field investigations might not show a close relationship to the mid-Tertiary disturbances previously discussed. To go one step farther, if the longitudinal axis, of a domal upwarp, which may have caused the thrust faulting is traced to the south-west, it may be tied in with the broad arch described by Ross in the Casto Quadrangle. An arch of such a trend and magnitude could very easily account for the constant trend of the regional fracture patterns.

A THEORY CONCERNING STRUCTURAL DEFORMATION

On Plate 5, the writer has diagrammatically attempted to depict a type of structural deformation which could have resulted in the fracture patterns and accompanying intrusions that occur in the area under consideration. The diagram is not drawn to scale but merely to illustrate the type of forces which could have produced the structural features located throughout the area.

The most important forces involved have been those which have produced vertical uplift. These vertical forces have resulted from the action of the igneous intrusions, occurring in Miocene or early-Pliocene times. The force exerted by the intrusions has been regional in extent and has resulted in a broad elongated domal arch whose longitudinal axis trends north-east. The arch is not symmentrical but contains many irregularites. Present information indicates that the northeastern end of the arch has been uplifted to higher elevations than has the south-western end, thus giving the dome a slight plunge to the southwest. In some local areas, the configuration of the dome has been further distorted by minor north-west trending transverse folds and faults. The exact size of this domal arch cannot be determined from present available information; however, its longitudinal axis probably extends from western Montana into south-western Idaho. The limbs of the arch are extended to include most of the present exposed batholithic area.

The effects of Tensional Forces

The tension which was developed during crustal stretching of the arched area has exceeded the elastic limit of the rocks within this area and has resulted in fracture. These fractures have not formed as continuous faults but as discontinuous shear zones, in an en-eschelon manner, paralleling the longitudinal axis of the domal arch. In almost every case the faults dip towards the axial plane, i.e., the site of maximum stress. Several factors are responsible for the distribution of the shear zones. A factor of prime importance is the location of the sites of maximum stress created by the intrusion. The more highly stressed areas would create more fractures within their adjacent areas. Another factor which should be considered is the composition of the affected rocks. Incompetent beds tend to yield to plastic flow before they rupture. Competent rocks, such as the granitic rocks in the batholithic area, would fracture before they would flow. Thus, the occurrence of sheared areas along the margin of the dome would be expected. Still another factor which governs the position of fractures, is the attitude of pre-fracture joints and faults. Jointing undoubtedly exerts a control on fractures in certain localites; however, there is such a limited amount of information on jointing in this area that it has been ignored. The continuous trend of the mid-Tertiary shear zones suggests that they may have followed older and already established belts of structural weakness. If such is the case the mid-Tertiary uplift has reactivated these shear zones as evidenced by the present presistant fault patterns.

The attitude of the master shear zones, on both sides of the dome, indicates that the faults are probably antithetic in type. They have resulted from the effects of vertical stresses. These stresses have uplifted the rocks, producing crustal stretching. When the crustal elongation has exceeded the elastic limit of the rocks, rupture has occurred and the center blocks, lying between the fault planes have been down-dropped, see Plate 5. The actual fault displacement is hard to determine, due to the uniform nature of the rocks and the lack of distinctive marker beds. The down-dropped blocks may not have moved directly down the dip of the fault planes. Evidence in some localities indicates strike slip faulting on some master fault planes. Such occurrences are easily explained by a consideration of the forces which have controlled faulting. If a faulted block, in moving down the dip of a northwestward dipping fault plane, encountered frictional resistance, it would move toward that direction offering the least resistance. Thus the block might move either to the northeast or the southwest, in either case leaving evidence of oblique strike slip faulting.

The consistant appearance of minor northwest trending fracture systems suggest that these faults are complimentary to the master, northeast trending faults. They appear to be contemporaneous with the master faults and to have resulted from the same stresses. In most cases they show little recognizable displacement and a small amount of gouge. Many of these faults are quite permeable and have provided sites for ore deposition.

Association of intrusive dikes with fracture patterns

The fact that mid-Tertiary uplift was concurrent with igneous intrusion is suggested by the continuous repetition of Miocene dikes occurring in and along the shear zones.

In places these dikes conform closely with the shear zones, in other places they are cut and displaced by the faulting. The dikes, even in widely separated districts, show similar characteristics.

1. They are structurally controlled by zones of shearing.
2. Their porphyritic textures and other petrographic features indicate irregular periods of crystallization and movement.
3. They exhibit the same time order of deposition; i.e., acidic dikes followed successively by more basic dikes.
4. Within mining districts, they are invariably related to mineralized deposits, especially the precious metal deposits. In most cases ore deposition has been preceded by the more acidic dikes and followed by the more basic dikes.

MINERALIZATION RELATED TO STRUCTURAL DEFORMATION

As previously noted, page (7), Ross places the ore deposits of the region in two broad classes:

1. Deposits related to Mesozoic intrusives.
2. Deposits related to Tertiary intrusives.

The writer doubts Ross' theory on ore zoning in which he advocates a zonal control for the deposition of precious metals within the batholithic area and base metals in the surrounding sedimentary rocks. It is difficult to imagine any genetic connection between base metal ores of Mesozoic age and precious metal ores of mid-Tertiary age, both separated, in most cases, by miles of barren country rock. It seems more probable that these two types of deposits represent deposition in two distinct and different metallogenetic epochs.

The older Mesozoic deposits are probably directly related to the batholith. That they have resulted from deeper sources and at higher temperatures is evidenced by:

Their mineral associations, galena, sphalerite, copper sulphides, siderite, ect; the coarseness and uniformity of grain size; the lack of fine banding; their lack of characteristics commonly found in epithermal deposits.

The younger mid-Tertiary precious metal deposits are related to the "porphyry dikes" and have no relationship to the older batholith. These epithermal deposits have originated from mineralizing solutions which initially had lower temperatures. The solutions, in their vertical ascent, have had to travel farther before the overlying pressures have been decreased enough to permit boiling to occur.[19] Once the boiling point has been reached, the volume and the thermal gradient has been increased. Since the function of boiling will be to drive off a certain percentage of the rising solutions as steam, supersaturation of the remaining solutions and resulting mineral deposition will follow. The above mentioned functions result in the features so typical of the epithermal deposits located in the area, e.g., fine banding, the presence of mineralized vugs and drusy cavities, variation in mineral grain size, presence of chalcedony and other micro-crystalline forms of silica, a preference in the deposition of precious metal minerals, and relatively shallow depth of mineralization.

CONCLUSIONS

The following conclusions are based on research of the publications listed in the bibliography of this paper plus actual field studies within the area under consideration.

1. Regional uplift has resulted from vertical stresses acting from within the batholithic area.
2. The regional fault patterns are chiefly of the antithetic type, resulting from rock failure due to surface tension. They dip towards the area which has been subjected to the greatest vertical forces.
3. The fracture patterns are of mid-Tertiary age, probably upper Miocene or Pliocene. They have resulted from a regional uplift or a broad doming effect, see Plate (5).
4. Fracture patterns following definate regional trends have provided the openings which were later filled by igneous intrusives. These intrusives, in local cases, were accompanied by mineralization.
5. The "porphyritic dikes" represent products of magmatic differentiation. This fact is brought out by their time order of deposition, i.e., acidic dikes followed by progressively more basic dikes.
6. Hydrothermal mineralization has accompanied dike injection, usually deposition has followed the more acidic dikes and preceeded the more basic dikes.
7. The epithermal precious metal deposits located in or near the "porphyry dike" zones are related in origin to the igneous dikes and not to the older Idaho batholith.
8. The deposits of precious metals, associated with the "porphyry dikes", are structurally controlled by the regional fracture patterns whose trend is almost always to the northeast.

Deposition of these metals has occurred when openings were present at a time when the physico-chemical conditions were suitable for ore deposition.

9. The characteristics of the epithermal "bonanza deposits", within the Idaho area, are similar in all respects to epithermal deposits in other mining districts throughout the western states. In none of these precious metal epithermal districts has mining proved profitable beyond the depths of a few hundred feet. For this reason it is doubtful if continued deep level exploration, in the Idaho districts, will reveal any downward extension of the present precious metal ore bodies. Deep level exploration may reveal profitable base metal ore bodies but the continuence of the precious metal ores beyond their present non-profitable limits is doubtful.

10. Only minor amounts of post-mineral faulting has occurred in the epithermal deposits. This is in disagreement with most of the prospectors in the area who contend that the termination of ore deposits has resulted from"faulting". As previously mentioned ore deposition has been guided by the major fracture patterns and in some areas containing heavy ground, a false impression of the time relations between ore deposition and faulting has resulted.

11. Future precious metal exploration work should pay close attention to the master northeast trending faults and their minor, complimentary northwest faults. All available field evidence indicates that these fracture patterns have been the dominent controlling factors in precious metal ore deposition.

BIBLIOGRAPHY

1. Ross, C.P.; Mesozoic and Tertiary Granitic Rocks in Idaho, Jour. of Geol. Vol. 36, No. 8, 1928.

2. Reed, J.C. Jr.; Geology and ore deposits of the Warren mining district, Idaho County, Diaho. Idaho Bureau of Mines and Geology, Pamphlet 45, 1937.

3. ———————— ; " " " " " " " " "

4. Ross, C.P.; Geology and Ore Deposits, Casto Quadrangle, Idaho. U.S.G.S. Bull. 854, 1934.

5. Kirkham, V.R.D.; Snake River Downwarp, Jour. of Geol. Vol. 39, No. 5, 1931.

6. Ross, C.P.; Lode deposits of South-Central Idaho, Econ. Geol. Vol. 26, 1931.

7. ————————; Lode deposits of the Boise Basin, Idaho. U.S.G.S. Bull. 846 D, 1934.

8. Anderson, A.L.; Geology of the Pearl-Horseshoe Bend Gold Belt, Idaho. Idaho Bureau of Mines and Geology, Pamphlet No. 41.

9. Ballard, S.M.; Geology and Ore Deposits of the Rocky Bar Quadrangle, Idaho Bureau of Mines and Geology, Pamphlet No. 26.

10. Shenon, P.J. & Reed, J.C. Jr.; Geology and Ore Deposits of the Elk City, Orogrande, Buffalo Hump and Tenmile districts, Idaho County, Idaho. U.S.G.S. Circular No 9.

11. White, D.E.; Antimony Deposits of a part of the Yellow Pine district Valley County, Idaho. U.S.G.S. Bull. 922 I.

12. Ross, C.P.; Geology and Ore Deposits of the Casto Quadrangle, Idaho. U.S.G.S. Bull. No. 854, 1934.

13. Capps, Stephen,R. Faulting in western Idaho and its relation to the high placer deposits. Idaho Bureau of Mines and Geology, Pamphlet No. 56.

14. Langton, C.M.; Geology of the northestern part of the Idaho batholith and adjacent regions in Montana. Jour. of Geol. Vol. 43, Part 1, 1935.

15. Anderson, A.L.; Geology and Ores of the Atlanta district, Idaho Bureau of Mines and Geology, Pamphlet No. 49.

16. Ross, C.P.; Geology and Ore Deposits of the Bayhorse Region, Custer County, Idaho. U.S.G.S. Bull. No. 877.

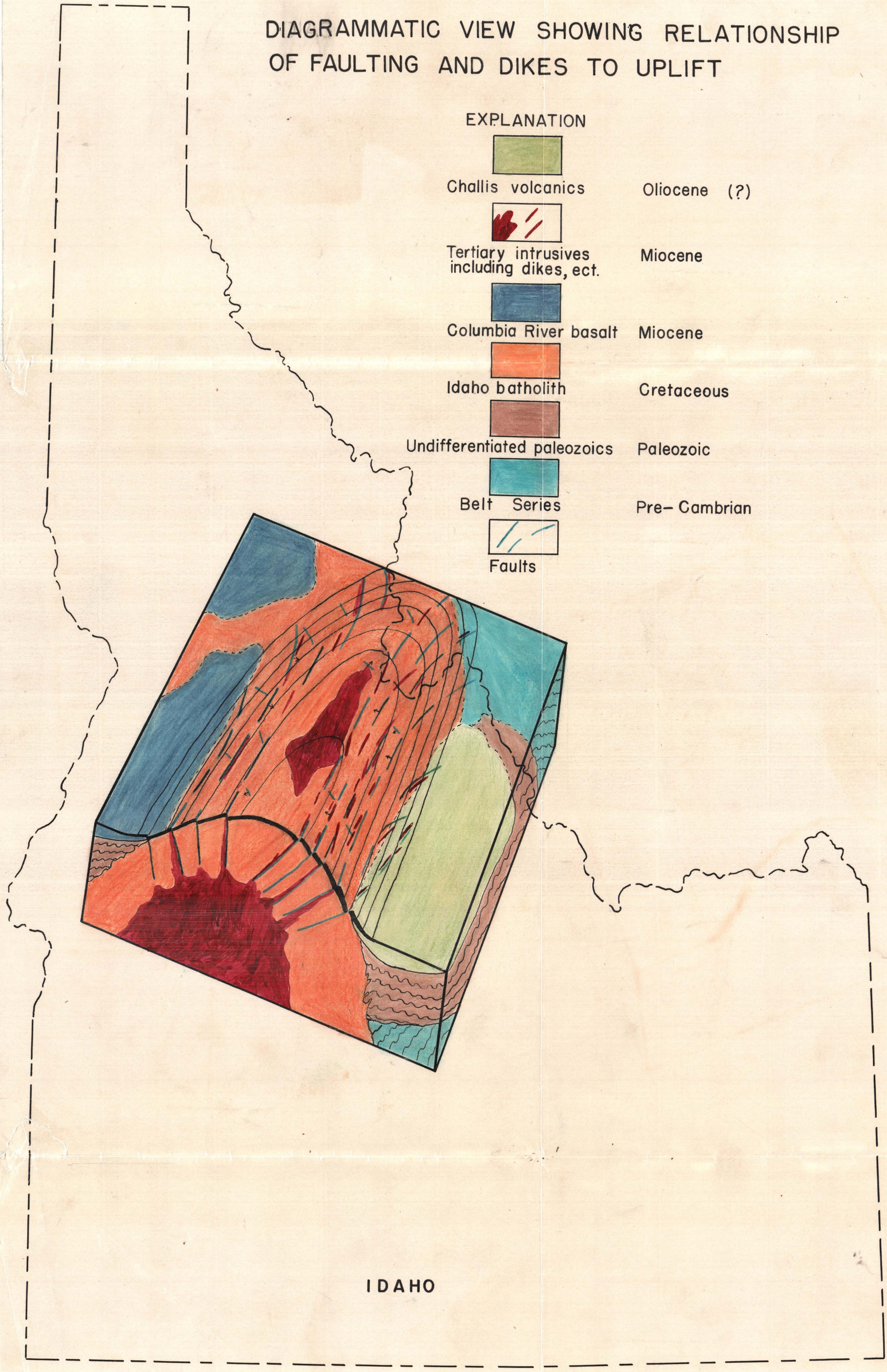
17. Umpleby & others; Geology and Ores of the Wood River Region, Idaho. U.S.G.S. Bull. 814, 1930.

18. Lindgren, Waldemar; U.S.G.S. 20th Annual Report, Part 3, 1900.

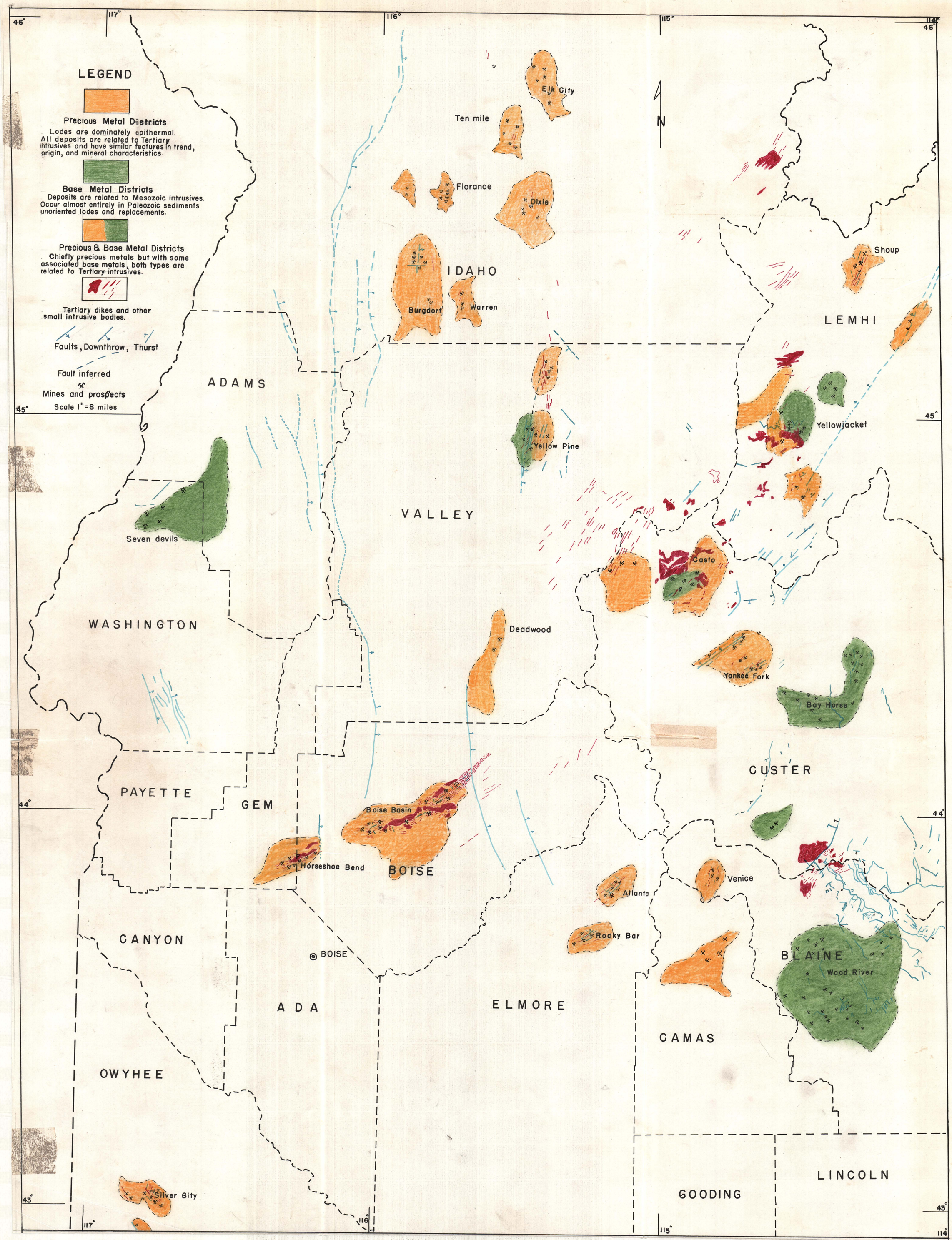
19. Hulin, C.D.; Lecture Notes.

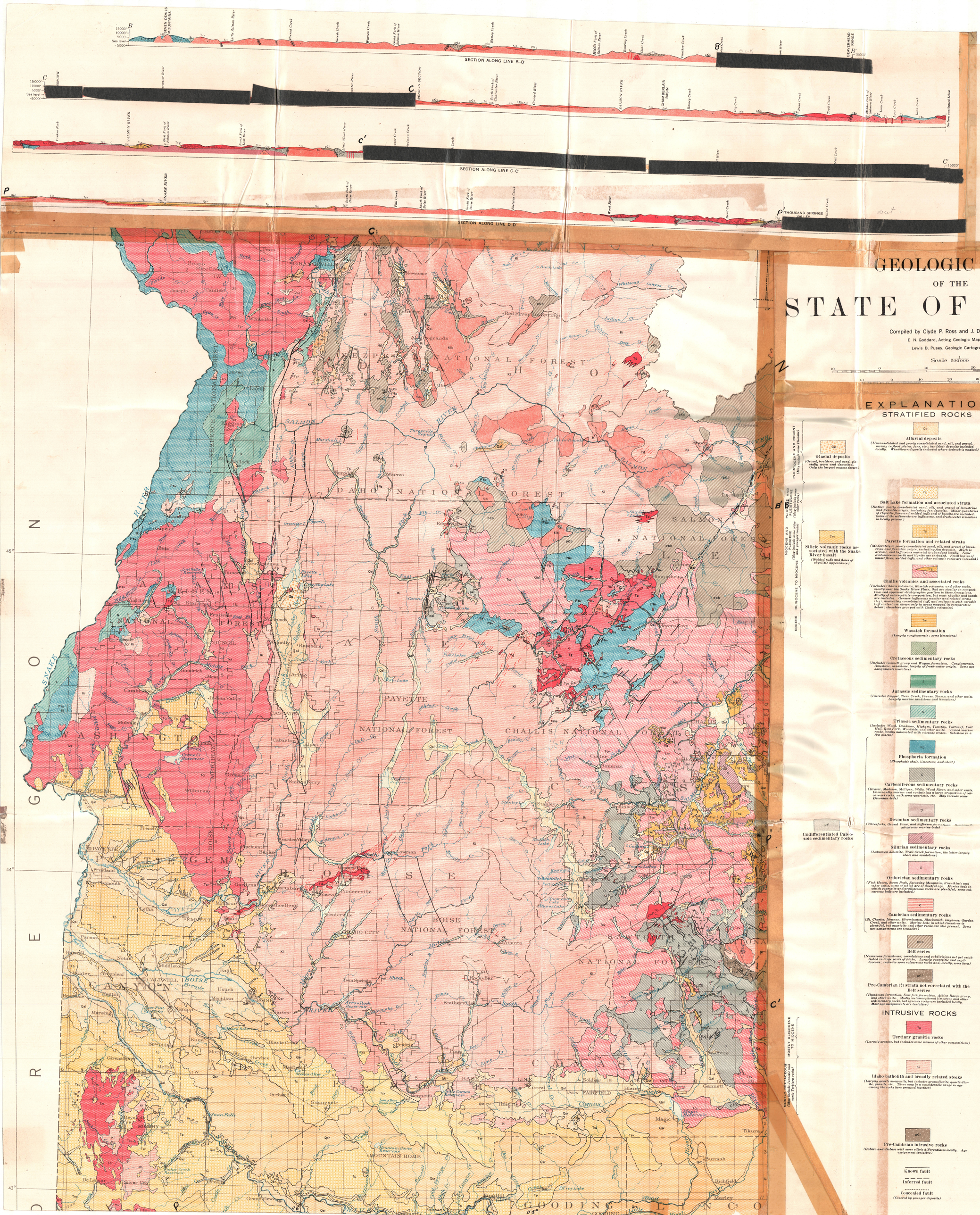
Wisser, E. Lecture Notes.

DIAGRAMMATIC VIEW SHOWING RELATIONSHIP OF FAULTING AND DIKES TO UPLIFT



OVERLAY SHEET
FOR
GEOLOGIC MAP OF IDAHO




SECTION ALONG LINE B-B'
SECTION ALONG LINE C-C'
SECTION ALONG LINE D-D'
SEVEN DEVILS MOUNTAINS
BEAVERHEAD RANGE
CHAMBERLAIN BASIN
THOUSAND SPRINGS VALLEY
SALMON RIVER
SNAKE RIVER
Sea level
GEOLOGIC MAP
OF THE
STATE OF IDAHO
Compiled by Clyde P. Ross and J. Donald Forrester
E. N. Goddard, Acting Geologic Map Editor
Lewis B. Pusey, Geologic Cartographer
Scale 1/500000
Miles
Kilometers
EXPLANATION
STRATIFIED ROCKS
Glacial deposits
Alluvial deposits
Late lake sediments
Snake River basalt
Salt Lake formation and associated strata
Silicic volcanic rocks associated with the Snake River basalt
Payette formation and related strata
Columbia River basalt
Challis volcanics and associated rocks
Wasatch formation
Cretaceous sedimentary rocks
Jurassic sedimentary rocks
Triassic sedimentary rocks
Permian and Triassic volcanic rocks
Phosphoria formation
Carboniferous sedimentary rocks
Devonian sedimentary rocks
Silurian sedimentary rocks
Ordovician sedimentary rocks
Cambrian sedimentary rocks
Belt series
Pre-Cambrian (?) strata not correlated with the Belt series
Undifferentiated Paleozoic sedimentary rocks
INTRUSIVE ROCKS
Tertiary granitic rocks
Tertiary dikes and other small intrusive bodies
Idaho batholith and broadly related stocks
Border zones around the Idaho batholith and related bodies
Pre-Cambrian intrusive rocks
Known fault
Inferred fault
Concealed fault
(Covered by younger deposits)
QUATERNARY
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
PERMIAN
CARBONIFEROUS
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRE-CAMBRIAN