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GEOLOGICAL SURVEY

GEOLOGY OF THE MACKAY 30-MINUTE QUADRANGLE, IDAHO*

By

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The geology of the Mackay thirty-minute quadrangle, Idaho

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Abstract

The Jefferson Dolomite, Grand View Dolomite, and Three Forks Limestone, all of Devonian age, are the oldest rocks exposed in the quadrangle. Rocks that range from Mississippian to Permian in age are widespread; they are represented by the White Knob Limestone in the eastern part of the quadrangle and the Copper Basin Formation in the western part. The Copper Basin Formation, which is composed of non-carbonate detrital rocks, is interlayered with the White Knob Limestone near the middle of the quadrangle. This interlayering is herein interpreted to be the result of depositional interbedding, but it could be in part due to juxtaposition by faulting. The Challis Volcanics, of Tertiary age, cover much of the quadrangle, and except for a conspicuous basal conglomerate, lack distinctive subdivisions similar to those in neighboring areas. Alluvial deposits which may be in part as old as Pliocene are scattered through the quadrangle. Glaciation affected all the higher parts of the quadrangle, and locally glacial deposits of at least three ages can be distinguished. The latest two of these are probably of late Wisconsin Bull Lake and Pinedale ages. Basalt flows of probable Recent age extend into the southernmost part of the

quadrangle and originate in part from vents there.

Intrusive rocks, including plutons and related dikes of Tertiary age, are scattered throughout the quadrangle. They range from granite to quartz diorite in composition. The intrusive rocks seem to be related to the Challis Volcanics.

The rocks of the quadrangle were strongly deformed and eroded prior to the deposition of the Challis Volcanics. No thrust faults have been recognized although such faults are plentiful in the adjacent region. Deformation has continued until recent times.

All or parts of five mining districts are included in the quadrangle and the total production probably exceeded $10,000,000. Mining has been quiet since World War II but activity has been renewed at times in the past and possibilities for the discovery of substantial new deposits seem promising. The mineral deposits formed largely by replacement, partly in areas of contact metamorphism. The metals present are varied but copper has been the main product. All of the deposits are believed to be related to the intrusions of Tertiary age.

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Introduction

The Mackay quadrangle lies mainly in the drainage basin of the Big Lost River in south-central Idaho. It is largely in Custer County but parts of Blaine and Butte Counties are included. The Mackay quadrangle contains all or large parts of the Copper Basin, Alder Creek, Little Wood River, and Lava Creek mining districts (Ross, 1941). The eastern border of the Alto district is included.

The locations of most of the features described and discussed in this report, as well as the fossil localities cited, are shown on the geologic map of the Mackay quadrangle (Nelson and Ross, 1969). The work on which the geologic map of the quadrangle and this report is based, was part of a series of studies undertaken by Ross in central Idaho. Field mapping was done at a scale of 1:96,000 during the summers of 1956, 1957, and 1958, with brief visits in 1959, 1960, and 1961. Ross did the largest part of the field mapping with Nelson participating in the field during 1958. Nelson took over completion of the report and developed many of the ideas presented here after Ross' death early in 1965. Emphasis of this study was mainly on major features of the Paleozoic stratigraphy, but other aspects of the general geology received attention. The scale of the available base map and the time devoted to the fieldwork prohibited detailed study of the quadrangle as a whole, but stratigraphic details were obtained in selected areas, mainly by B.A.L. (Betty) Skipp and Willis Nelson. A map of the part of the Alder Creek mining district that centers around the Empire mine was made by Nelson. In the course of this work he gathered significant data on metamorphism and on the character and age of the intrusive activity in relation to ore genesis; summaries of the work are included in this report. In the summer of 1961, Thor Kiilsgaard studied the mines close to Mackay, using Nelson's detailed areal map as a guide, and some of his ideas on the ore deposits are included.

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Everyone encountered during the course of the field-work was cordial and cooperative, contributing greatly to the pleasure and speed with which the work was done. In the summer of 1956, Ronald Kistler acted as field assistant. During the following summer, Betty Skipp spent about two weeks in an intensive study of Carboniferous strata in the southeastern part of T. 7 N., R. 22 E. (Skipp, 1961a, 1961b), and in other incidental work in the quadrangle. Much of the areal mapping in 1958 was done by Robert Lester and Betty Skipp, who have contributed also in the subsequent office work. Verl Potts owned and managed the pack train used in 1957 and 1958. The skill and energy displayed by himself and his horses were indispensable in providing access to the more remote parts of the quadrangle. Valuable aid in the office was rendered by George E. Ulrich, mainly in connection with the petrographic work.

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Devonian rocks

Rocks of Devonian age are recognized only in the Lost River Range in the northeast corner of the quadrangle. They constitute an extension southeastward of the three Devonian formations mapped in the adjacent Borah Peak quadrangle (Ross, 1947, p. 1107-1112). In ascending order, the units are the Jefferson Dolomite, Grand View Domomite, and Three Forks Limestone. The extensive exposures in the Borah Peak quadrangle have yielded more data on all three than could be obtained in the Mackay quadrangle.

A few hundred feet of Jefferson Dolomite are poorly exposed in a small area on the lower slopes of the Lost River Range, where it consists of dark-bluish-gray dolomite, nearly black in most outcrops. Evidence of the former presence of organisms is discernible but few identifiable fossils remain. One (collection 4474-SD, map location 1) was determined by Jean M. Berdan (written communication, November 27, 1957) as "Favosites" cf. "F." limitaris Rominger, of Middle or Late Devonian age.

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The Grand View Dolomite extends southeastward from the northern border of the Mackay quadrangle past the gorge of Lower Cedar Creek. Detailed measurements on the timbered slopes are impracticable but the thickness is roughly 2,000 feet. The dolomite is similar to that in the Jefferson Dolomite below, but it is somewhat thinner bedded and weathered surfaces tend to be more rusty colored. In places near the top, thin limestone beds may represent gradation into the overlying Three Forks Limestone. Two scanty collections (MI 3 and MI 4, map locations 2 and 3) from the Grand View Dolomite in unsurveyed sec. 29, T. 8 N., R. 24 E., in the Lost River Range, were examined by R. S. Boardman (written communication, February 4, 1957). The first (MI 3) contains a species of the ramose stromatoporoid genus Amphipora of Middle or Late Devonian age. The other, from a short distance down slope, contains a species of a ramose stromatoporoid closely related to Amphipora but probably belonging to the poorly understood genus Dendrostrana. It is presently known in this country only in the Middle Devonian of Michigan.

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The Three Forks Limestone overlies the Grand View Dolomite throughout its exposure in the northeastern corner of the quadrangle. The formation consists of calcareous shale and limestone in thin beds. Most of the rock is fairly light gray on fresh fractures but it weathers yellowish to reddish brown. Fossils collected east of Lower Cedar Creek in unsurveyed sec. 2, T. 7 N., R. 24 E. (collection 4475-SD, map location 4) were found by Jean M. Berdan to include Cyrtospirifer sp, Schizophoria sp, Pugnordis sp, Carnarotoechia? sp, Nudirostra? sp, and bryozoa, regarded by her as typical of the Three Forks Formation (Upper Devonian). In the vicinity of this fossil collection the formation is about 75 feet thick but the thickness increases northwestward. The beds are deformed and locally poorly exposed, but the thickness may be 200 to 300 feet. According to J. T. Dutro (written commun., March 1961), a fossil collection, S-5 (map location 5) contains elements typical of the highest Devonian faunules in the Canadian Rockies and is similar to collections from the southern part of the Lemhi Range (Ross, 1961a, p. 213-214). Dutro also reports that collection S-3 (map location 5) contains Cyrtospirifers and Nudirostra ventricosa like those in the faunule from the 4-foot limestone bed at the top of the Three Forks green shale in some parts of southwestern Montana; and collection S-2 (also map location 5) most closely resembles the faunule of the Three Forks green shale itself.

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S-5. About 210 feet above base of Three Forks Limestone near the Milligen contact:

echinoderm debris, indet.
Schizophoria aff. *S. striatula* Schlotheim
Camarotoechia cf. *C. nordeggi* Kindle
Pugnoides cf. *P. minutus* (Warren)
Nudirostra sp.
Cyrtospirifer aff. *C. animasensis* Girty
Cyrtospirifer aff. *C. whitneyi* (Hall)
"*Cleiothyradina*" cf. "*C.*" *devonica* (Raymond)
Athyris aff. *A. angelica* Hall

S-3. Same map location as S-5; about 160 feet above base of Three Forks Limestone:

echinoderm debris, indet.
massive bryozoan, undet.
ramose bryozoans, undet.
Schuchertella sp.
Productella aff. *P. coloradoensis* Kindle
Canarotoechia sp.
Nudirostra ventricosa (Haynes)
Cyrtospirifer aff. *C. monticola* (Haynes)
Cyrtospirifer sp.
"*Spirifer*" cf. "*S.*" *notabilis* Kindle
Crurithyris? sp.
pectinoid pelecypod, indet.
nautiloid cephalopod, indet.

S-2. Same map location as S-5; about 60 feet above base of Three Forks Limestone:

echinoderm debris, indet.

ramose bryozoans, undet.

Schuchertella sp.

Schizophoria cf. _S._ _striatula_ Schlotheim

Productella aff. _P._ _coloradoensis_ Kindle

"_Productella_" sp.

Camarotoechia sp.

Nudirostra sp.

Cyrtospirifer cf. _C._ _whitneyi_ (Hall)

Cyrtospirifer sp.

"_Spirifer_" cf. "_S._" _notabilis_ Kindle

"_Cleiothyradina_" cf. "_C._" _devonica_ (Raymond)

orthoceratid cephalopod, indet.

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Carboniferous and Permian rocks

Milligen Formation

The stratigraphic unit herein designated the Milligen Formation occurs in and extends north and east of the northeastern part of the Mackay quadrangle. It is separated from the rocks at the type locality of the Milligen Formation, in the Hailey quadrangle to the west, by wide areas underlain by other rocks, including the Copper Basin Formation. The lower part of the Copper Basin Formation locally includes dark-gray argillaceous rock, which may be the same age as the Milligen Formation, but none of the argillaceous rocks in the Copper Basin Formation can be traced into either the Milligen Formation of the Lost River Range or the rocks at the type area of the Milligen Formation in the Hailey quadrangle.

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An additional reason for questioning the correlation of the rocks mapped as Milligen Formation of the Lost River Range with the Milligen Formation in the type locality in the Hailey quadrangle is the suggestion by Roberts and Thomasson (1964) that the Milligen Formation in the type locality may have been deposited in a basin that was separate from the basin in which the Copper Basin Formation was being deposited. See the section on the regional relationships of the Copper Basin Formation below for further discussion of this problem.

All of the rocks mapped as Milligen Formation in the quadrangle are dominated by dark, nearly black argillite. Some beds are calcareous shale. The formation yields few exposures and in steep slopes it is commonly covered by abundant talus from the overlying White Knob Limestone. The formation is everywhere so poorly exposed that detailed sections could not be measured in it. Within the quadrangle, the thickness is probably less than 500 feet, although farther northwest in the same range the thickness has been estimated as about 1,000 feet (Ross, 1947, p. 1113).

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In the Mackay quadrangle, the Milligen Formation grades downward through a narrow zone into the Three Forks Limestone (Upper Devonian) and is overlain by White Knob Limestone of which at least the lower part is of Late Mississippian age, as shown below. In this quadrangle, therefore, the Milligen Formation is clearly of Mississippian age, as it is in the Borah Peak quadrangle to the north (Ross, 1947, p. 1113). We have found no diagnostic fossils in the formation in this quadrangle, although a few plant fragments have been noted. Sandberg, Mapel, and Huddle (1967) report on a conodont fauna, which indicates an Early Mississippian (Kinderhook) age, for rocks 13 feet above the base of the Milligen Formation, near the mouth of Cedar Creek Canyon, 4 miles northeast of Mackay.

Copper Basin Formation

Name and description

The name Copper Basin Formation was introduced by Ross (1962) for the thick assemblage of dominantly non-carbonate clastic rocks that underlies much of the western part of the Mackay quadrangle; the name is taken from the major topographic depression in the western part of the quadrangle.

The Copper Basin Formation consists of quartzite, sandstone, siltstone, argillite, mudstone, conglomerate, and limestone in proportions that vary from place to place. These rocks range from light gray to nearly black on fresh surfaces, and weather various shades of brown. These various rock types are interbedded on a scale that ranges from individual beds to sequences many hundreds of feet in thickness that are dominated by a single rock type. Where aggregates of argillite or limestone within the formation are large enough, they have been mapped as subdivisions of the formation.

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Fine-grained quartzite and quartzitic siltstone are the most common rocks in the formation. They consist of well-cemented quartz grains as well as minor amounts of mica and finely disseminated carbon. The quartzite and siltstone occur in beds that commonly range from 1 to 3 feet in thickness. Individual beds are commonly separated from adjacent beds by shaly layers, and some have obscure internal cross-bedded structures, and others have laminated structures.

Sandstone is less abundant than quartzite from which it differs principally in degree of cementation. Some of the sandstone contains considerable calcium carbonate as the principal cementing agent.

The argillite is commonly fairly dark in color, and consists of very fine-grained micaceous minerals mixed with various amounts of very fine-grained quartz and locally carbonate minerals. It grades on one hand into siltstone and on the other into mudstone. Most of the argillite weathers readily first to small platy chips and then to very dark-gray soil. Bedding is commonly not conspicuous, but locally some of the argillite shows pronounced laminations as a result of variations in composition between laminae.

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The conglomerate consists of well-rounded pebbles and cobbles in a groundmass similar to the associated quartzite and sandstone. The pebbles and cobbles are predominantly quartzose rocks that commonly range from granules to pebbles one inch across; at the head of the Right Fork of Iron Bog Creek, some of the conglomerate contains cobbles 6 inches across.

The limestone in the Copper Basin Formation is similar to, but it is commonly thinner bedded and contains more noncarbonate detritus than the White Knob Limestone. Except for the masses of limestone shown as members of the formation on the geologic map of the quadrangle (Nelson and Ross, 1969), limestone is very sparsely distributed in the Copper Basin Formation.

Some of the sandstone, siltstone, argillite, and the matrices of some of the conglomerate contain a significant amount of carbonate; these rocks are commonly more susceptible to weathering than similar rocks with less carbonate in them and they commonly weather to a more brownish color.

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The lower 650 feet of rock exposed at Timbered Dome is dolomite (see p. 31), which differs so much from other rocks of Carboniferous age in the quadrangle that the possibility that it belongs to some older unit naturally arises. However, these rocks are exposed over a limited area, and within that area no evidence for an older age assignment has been discovered. In the absence of any evidence for a different assignment, the dolomite is included in the Copper Basin Formation.

The stratigraphic section on Timbered Dome described below and located on the geologic map of the quadrangle, was measured by Betty Skipp and Robert Lester and is shown diagrammatically by Skipp (1961a). This section includes rocks that are assigned to both the Copper Basin Formation and the White Knob Limestone.

Section of Carboniferous rocks at Timbered Dome

(Thicknesses marked by asterisks calculated by means of Kelsh plotter)

(Fossils listed were determined tentatively by Betty Skipp)

(Color designations are from "Rock-color Chart," Goddard and others, 1948)

	Thickness feet
Sequence interrupted at top by small fault which is overlain by Challis Volcanics	
Limestone and sandstone, interbedded; limestone, dark-gray and grayish-red (10R 4/2), fine- to coarse-grained, abundantly fossiliferous (reefoid) in places, medium- to thick-bedded, resistant, weathers light-brown and medium-gray; sandstone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4), fine-grained, quartzose, calcareous, cherty, unfossiliferous, medium-bedded. Bryozoa, productid brachiopods and corals--------------	100*

Gradational contact

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Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Limestone and siltstone, interbedded; limestone, dark-gray, very fine grained, sparsely fossiliferous, thin- to medium-bedded, nonresistant, weathers grayish-orange; siltstone, grayish-orange, fine-grained, thin- to medium-bedded. Unidentifiable brachiopods. No microfossils----------------------	220*
Jasperoid, dark-gray to medium-dark-gray, very fine grained, fossiliferous near base, massively bedded, resistant, weathers light-olive-gray (5Y 6/1) and light-brownish-gray (5YR 6/1); interbedded with secondarily silicified sandstones. Gastropods and brachiopods poorly preserved---------------------	1,080*

Contact masked by silicification

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Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Sandstone, light-gray to medium-light-gray, very fine to fine grained, quartzose, very clean, well compacted, breaks across grain, mostly medium-bedded, some thick-bedded, top 10 feet fossiliferous, resistant, lower 200 feet secondarily silicified, weathers grayish-orange (10YR 7/4) to light-brown (5YR 5/6); interbedded in upper 10 feet with limestone, medium-gray, fine-grained, impure, thin to very thin bedded, weathers yellowish-gray (5Y 8/1)----------------	430*

Abrupt contact

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Section of Carboniferous rocks at Timbered Dome--Continued

Thickness feet

Limestone, medium-gray to dark-gray, medium- to coarse-grained, largely calcarenite, fossiliferous, middle portion thin-bedded and very cherty, upper beds medium-bedded with some grayish-black and light-olive-gray nodular chert, some graded bedding and banding. Brachiopods--*Spirifer pellaensis* Weller, *Productus*, several species, *Girtyella* sp. Corals--several genera including *Triplophyllites* sp. Fenestellate bryozoa. *Plectogyra* sp.------------ 645

Gradational contact

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Section of Carboniferous rocks at Timbered, Dome--Continued

	Thickness feet
Limestone, grayish-black to medium-gray, fine- to medium-grained, fossiliferous, massive- to thick-bedded, weathers medium-gray, in places weathered surface has meringuelike peaks. Corals-- *Syringopora sucularia* (Girty), *Amplexus* sp., *Caninia torquia* (Owen). Foraminifera--*Plectogyra* sp., *Paramillerella circuli* (Thompson). *Ammodiscus* sp. Brachiopods noted in field but not collected--spirifers, *Dielasma* sp., *Composita* sp.----------	80

Gradational contact

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Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Limestone, medium- to medium-dark-gray, very fine grained to fine grained, fossiliferous, medium- to thick-bedded, weathers medium-dark-gray to light-olive-gray (5Y 6/1). Corals--*Ekvasophyllum* sp., *Triplophyllites* sp., *Amplexus* sp., *Caninia* sp. Fenestellate bryozoa--*Tabulipora* sp. Brachiopods--*Composita trinuclea* Hall, *Productus inflatus* McChesney, *Productus burlingtonensis* Hall, *Spirifer pellaensis* Weller, *Gigantoproductus brazerianus* (Girty). Foraminifera--several kinds including *Plectogyra* sp.--	970

Gradational contact

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Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Limestone, olive-gray to medium-dark-gray, some pale-grayish red (10R 5/2), fine- to coarse-grained, dolomitic(?) near base, fossiliferous, medium to massively bedded, weathers gray and pale yellowish-brown (10YR 7/2), resistant near base where coarse-grained limestone is dominant; intercalated with a few beds of sandstone, very fine grained, quartzose, pale-light-brownish-gray (5YR 7/1). Bryozoa, crinoid fragments, brachiopods--*Cliothyridina sublamellosa* (Hall), *Composita laevis* Weller, *Girtyella* sp.; corals--*Triplophyllites* sp. *Paramillerella tortula* (D. Zeller), *Plectogyra* sp.------------------------	55

Variable contact

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Section of Carboniferous rocks at Timbered Dome--Continued	Thickness feet
Jasperoid, medium-gray to medium-dark-gray, very fine grained, brecciated in places, angular medium-dark-gray fragments in medium-gray matrix, edges of fragments indistinct in places, banding common, thin- to medium-bedded (1 inch to 2 feet); extremely resistant, ridge-forming; minor slickensiding subparallel to bedding, prominent vertical jointing common--------------	1,200

Abrupt contact

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Section of Carboniferous rocks at Timbered Dome--Continued	Thickness feet
Siltstone and limestone, interbedded. Percentage of siltstone decreases up section. Siltstone, pale-red (5R 6/2) and very pale-yellowish-brown (10YR 6/2), quartzose, calcareous, thin- to medium-bedded, slope-forming. Limestone, dark-gray to grayish-black, very fine to medium grained; very fine grained limestone is dominant and is characterized by dark color, stylolitic structures, and a very pale-yellowish-brown (10YR 7/2) weathered crust composed of silty material; medium-grained limestone is oolitic, has sparry calcite cement, microfossiliferous, *Plectogyra* sp.; forms steep slope below jasperoid contact----------------------------------	780

Gradational contact

Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Sandstone, varicolored, light-grayish-red (5R 4/2), light-gray, pale-yellowish-brown (10YR 6/2), very fine to fine grained, quartzose, calcareous in places, medium-bedded, graded bedding in places, no crossbedding; basal beds form resistant ridge; weathers pale-brown (5YR 5/2), moderate brown (5YR 4/4)----------------------------	640

Gradational contact

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Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Siltstone, varicolored, light-pale-brown (5YR 6/2), light-olive-gray (5Y 6/1), medium-light-gray, and light-grayish-red-purple (5RP 5/2), quartzose, fossiliferous, thin-bedded, slope forming; thin zone of intraformational conglomerate occurs in talus through upper 30 feet--fragments are silt-stone, medium-gray, angular, maximum size approximately 30 mm, siliceous cement, outlines of fragments are indistinct in places. Pelecypod, *Deltopecten* sp. Brachiopod, *Leiorhyncus carboniferum* var. *polypleurum* Girty-----------------------------------	520

Gradational contact

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Section of Carboniferous rocks at Timbered Dome--Continued

	Thickness feet
Argillite, grayish-black, fissile, saddle-forming, interbedded with siltstones and very fine sandstones, light-pale-brown (5YR 6/2), light-grayish-red-purple (5RF 5/2), and medium-light-gray, quartzose, some carbonate cement, fossiliferous; sandstones become dominant toward top, slope forming; a limestone, dark-gray, very fine grained, unfossiliferous, thin (5-10 feet), occurs 10-20 feet below the top, weathers medium-light-gray and very pale-orange. Brachiopod, *Leiorhynchus carboniferum* var. *polypleurum* Girty in upper siltstones----------------------------------	400

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Section of Carboniferous rocks at Timbered Dome--Continued	Thickness feet
Sandstone, medium-gray to medium-dark-gray, very fine to medium grained, conglomeratic near base, grades into siltstone near top, medium bedded up to 2 feet; weathers light-olive-gray (5Y 6/1), moderate yellowish-brown (10YR 5/2), moderate brown (5YR 4/4) and gray; blocky resistant outcrop near base. Conglomerate present 50 feet above base, maximum pebble size 10 mm, rounded pebbles. Internal cast of brachiopod and wood impressions about 5 feet above base----------------	340
Abrupt contact	

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Section of Carboniferous rocks at Timbered Dome--Continued — Thickness feet

Dolomite, light-olive-gray (5Y 6/2) and medium-gray, very fine grained, unfossiliferous, banded in places, floating sand grains and sandy streaks common (sand averages 1/4 mm, subround), thick (10 feet) to massively bedded, resistant, characteristic rough-weathered surface with prominent chert veins standing in relief, weathers very pale-yellowish-brown (10YR 7/2); interbedded with quartzite, light-gray, medium-grained, thin- to medium-bedded, and sandstone (found only near top of interval), medium-dark-gray, medium-grained, quartzose, $CaCO_3$ and $MgCO_3$ cement, graded bedding present on small scale, weathers dark-gray. A sample of the dolomite of this unit contains 35.75 percent calcium carbonate and 13.3 percent magnesium carbonate, according to an analysis by James A. Thomas of the Geological Survey, made Feb. 19, 1959-- 650

Base not exposed. Total-------------8,110 feet

The beds assigned to the Copper Basin Formation aggregate 3,300 feet in thickness.

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Age and paleontology

All of the diagnostic fossils so far obtained from the Copper Basin Formation are of Late Mississippian age. However, some collections contain forms that may be as young as Middle Pennsylvanian and some contain forms that may be as old as Early Mississippian. Also near Cabin Creek a thick section of the Copper Basin Formation underlies limestone of Early Mississippian (Osage) age. Ross (1962, p. 386 and 387) reasoned that the uppermost part of the Copper Basin Formation was likely to be of Permian age because the Copper Basin Formation interfingers with the White Knob Limestone and the uppermost part of the White Knob Limestone is of Permian age. However, there is no evidence that any of the Copper Basin Formation is as young as the Permian part of the White Knob Limestone.

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The most intensively studied section of the rocks of the Copper Basin Formation is on Timbered Dome. There the rocks that can be assigned to the Copper Basin Formation, without hesitation, are overlain by a thick sequence of limestone that contains a layer of sandstone several hundred feet in thickness, see pages 18 to 31. The limestone is all assigned to the White Knob Limestone and the included sequence of sandstone is interpreted to be an eastward-extending wedge or lense of the Copper Basin Formation. Dutro and others (written commun., March 20, 1961) believe that the fossil in collection 18137-PC (map location 6) from the sandstone layer in the limestone definitely indicates an Upper Mississippian Chester age whereas, Skipp, on the basis of endothyrids, would place the Mississippian-Pennsylvanian boundary in the limestone below the sandstone (see the discussion on p. 76 and Skipp, 1961a). The _Sulcatopinna_ cf. _S. inexpectans_ Walcott in collection 18137-PC was originally described by Walcott from beds near Eureka now thought by Mackenzie Gordon to be approximately equivalent to the _Goniatites granosus_ zone (early Chester). A similar species of _Sulcatopinna_ also occurs in the Batesville Sandstone in Arkansas.

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Fossils indicate that the main part of the Copper Basin Formation, below the lower jasperoid, is of Upper Mississippian Meramec age. Betty Skipp (1961a) reached this conclusion on the basis of endothyrids, and Dutro and others (written communication, March 20, 1961) noted the presence of *Leiorhynchus* aff. *L. carboniferum* Girty in the Copper Basin Formation below the lower jasperoid.

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Collection 18454-PC, from the south flank of Timbered Dome (map location 7), was studied by Dutro (written communication, March 14, 1961). It came from beds that probably correspond to those below the lowest jasperoid unit in the measured section. Their age significance is in some doubt. The most probable inference is that they are of Meramec age. Dutro, however, remarks that similar fossils were reported by Sando, Dutro, and Gere (1959) from rocks in Laketown Canyon, northeast Utah, thought to be of late Osage age. On the other hand, he points out that a flattened ammonite in connection 18454-PC is tentatively identified by Gordon as Cravenoceratoides?, a genus found in rocks of late Chester age. The fossils found in the collection are listed below.

18454-PC: Chonetes aff. C. choctawensis Girty
Leiorhynchus cf. L. carboniferum polypleurum Girty
Crurithyris? sp.
Cravenoceratoides? sp.

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Anderson's lot 4 (1929b, p. 11) came from the southwest slope of Timbered Dome in sec. 11, T. 3 N., R. 24 E. (map location 8). Lot 4 was regarded by Girty as of Late Mississippian age and reported by him to contain

Orbiculoidea sp.

Productella hirsutiformis

Leiorhynchus carboniferum var. polypleurum

Spirifer martiniformis?

Deltopecten caneyanns

Deltopecten sp.

Bembexia sp.

Anderson (1929b, p. 12) collected fossils from the black shale (his lot no. 7, map location 9) of the Copper Basin Formation west of Dry Fork Creek, which seem to underlie the White Knob Limestone. Girty reported that this collection contained Leiorhynchus carboniferum var. polypleurum. This fossil is regarded as indicative of Mississippian age.

Collection 18147-PC, along the Right Fork of Iron Bog Creek (map location 10), contains, according to Dutro, Yochelson, Duncan, and Sando (written communication, March 20, 1961), *Quadratia*? sp., *Spirifer* sp. aff. *S. ankansanus* (Girty) and *Dimegelasma*? sp. and is of probable Mississippian age.

Collection 18451-PC from near Dry Fork Creek (map location 11) contains (Dutro, written communication, March 14, 1961) *Leiorhynchus* cf. *L. carboniferum* Girty and is of probable Late Mississippian age.

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Collection CPR 865 (map location 12) came from sec. 25, T. 8 N., R. 21 E., immediately north of the quadrangle from rocks that were previously mapped as belonging to the Wood River Formation (Ross, 1947, pl. 1). T.J. Dutro and W.J. Sando (written communication, March 15, 1961) note that collection CPR 865 contains brachiopods that are of generalized types ranging from Chester through Middle Pennsylvanian at least. The *Pentremites* by itself would suggest a Chester age although similar forms are known from the Morrow. The corals are most like Early Pennsylvanian forms and are compared to species described under *Hapsiphyllum* by Moore and Jeffords from the Lower Pennsylvanian of Texas. Thus, the rock is regarded as probably of Early Pennsylvanian age, possibly a Morrow equivalent.

CPR 865:

- horn corals, indet.
- echinoderm debris, indet.
- *Pentremites* sp.
- rhynchonelloid brachiopod, indet.
- *Wellerella*? sp.
- leiorhynchoid brachiopod, indet.
- *Spirifer* aff. *S. rockymountainus* Marcou
- *Composita* cf. *C. sulcata* Weller
- *Cleiothyradina* sp.
- *Crurithyris* sp.

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Dielasma? sp.

enomphalacean gastropod, indet.

small high-spired gastropods, indet.

Thomasson (1959, p. 39-40) found ostracods in limestone in or near sec. 20, T. 4 N., R. 22 E. These include Glyptopleura sp. Polytylites sp. and Kirkbyella sp., very close to Kirkbyella quitkei Creneis and Bristol. Thomasson regards this fauna as indicative of Early to Middle Pennsylvanian age. The ostracods were determined for him by Kesling and Sohn.

Regional relation

The Copper Basin Formation is flanked on the west by rocks that have been mapped as Milligen and Wood River Formations in the Hailey quadrangle, and on the east it is in part overlain by, and in part interlayered with, White Knob Limestone. Some of the aspects of the relationship of the Copper Basin Formation to these formations on either side of it will be discussed in the following paragraphs.

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The rocks that characterize most of the Copper Basin Formation are similar to and adjoin rocks that have been mapped as Wood River Formation in the eastern part of the Hailey quadrangle, and argillaceous parts of the Copper Basin Formation are similar to and adjoin rocks that have been mapped as Milligen Formation in the eastern part of the Hailey quadrangle (Umpleby, Westgate, and Ross, 1930). A zone of reversed faults intervenes between the rocks along the western edge of the Mackay quadrangle and the type localities of the Milligen and Wood River Formations in the Hailey quadrangle to the west. (Umpleby, Westgate, and Ross, 1930, pl. 1). West of this zone of faults the distinction between the Milligen and Wood River Formations is based on differences in lithology and especially on the presence of conglomerate above the Milligen Formation at or near the base of the Wood River Formation. East of this zone of faults, in the Mackay quadrangle and the eastern part of the Hailey quadrangle, the distribution of lithologies, including conglomerate, is too erratic for the rocks to be consistently subdivided.

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Roberts and Thomasson (1964), based in part on analogies they have drawn between the geology of northern Nevada and that of central Idaho, have suggested that the rocks on either side of the zone of reversed faults in the Hailey quadrangle may have been deposited in separate basins and that the rocks that were deposited in these separate basins were subsequently brought together by faulting. If this supposition is true, then the use of the names Milligen and Wood River Formations is not justified east of the zone of reversed faults.

The Copper Basin Formation locally contains lenticular masses of limestone and near the middle of the quadrangle rocks of the formation are interlayered with rocks of the White Knob Limestone. Some of this interlayering of rock types may be the result of low-angle faulting, but we have chosen to interpret it to be intertonguing of different facies. The mixing of sandstone and siltstone with limestone at Timbered Dome (see p. 18 to 31, and Skipp, 1961a) is believed to be due to such interfingering. The limestone within the Copper Basin Formation between Copper Creek and Muldoon Canyon is considered to be a lens of limestone that is related to but not connected with, the main part of the White Knob Limestone to the east. Alternately, this limestone may be part of a wedge that extends westward from the main mass of the White Knob Limestone. The limestone between Fish and Dry Fork Creeks is interpreted to be part of a westward-extending wedge of White Knob Limestone. The sandstone, siltstone, and conglomerate, which are interlayered in the White Knob Limestone near Cabin Creek, are considered to be parts of wedges and lenses that extend eastward from the main mass of the Copper Basin Formation to the east.

At Timbered Dome, east of Cherry Creek, and near Cabin Creek where the Copper Basin Formation and White Knob Limestone occur together in more or less equal amounts, the upper part of the sequence is dominated by limestone and the lower part by noncarbonate detrital rocks. If these rocks are in depositional contact their distribution suggests that the domain of noncarbonate detrital deposition became restricted during the later part of the deposition of these two formations.

Thickness

The Copper Basin Formation may be about 18,000 feet thick, based on inspection of the geologic map of the quadrangle (Nelson and Ross, 1969). Direct measurement of the thickness is not possible because there are no continuous exposures that include the top and bottom of the unit and no known horizons within the formation that would permit adding partial sections together so as to provide an idea of the total thickness. Probably lateral variations are so prevalent that key horizons useful for such a purpose do not exist.

White Knob Limestone

Name and description

South-central Idaho east of longitude 114° contains great thicknesses of strata that are almost exclusively calcareous. When these were first encountered in the course of the long series of investigations under Ross' direction, of which the study of the Mackay quadrangle was one of the latest, they seemed so similar to the Brazer

Limestone of northern Utah and southeastern Idaho, commonly considered to be of Late Mississippian age, that this name was applied to them (Ross, 1934a, p. 977-985). Recent studies (Scholten, 1957a and b; Blackstone, 1954; Ross, 1961a, p. 222-228) show that limestone of this character in south-central Idaho ranges in age from Mississippian into Permian. The Brazer Limestone in the type locality has been found, when restudied (Sando, Dutro, and Gere, 1959), to be dolomite instead of limestone, 850 feet thick, and of Early to Late Mississippian age. It seems desirable, therefore, to restrict the name Brazer to the dolomite of Mississippian age in the Crawford Mountains, Utah, where Brazer Canyon is situated, and Ross (1962) has introduced the name White Knob Limestone for the assemblage of rocks heretofore called Brazer in the vicinity of the Mackay quadrangle. This assemblage is well exposed in the White Knob Mountains in the northern part of the Mackay quadrangle. The name is especially appropriate because the most detailed petrologic and stratigraphic study yet made of any part of the assemblage was done in these mountains (Skipp, 1961a and b).

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Most of the White Knob Limestone is very pure limestone with chert nodules and laminae in many of the beds. Table 1 presents chemical analyses of specimens from the formation. Most of the limestone is medium to thick bedded, although thin-bedded limestone is locally common, especially near the base of the formation. In the Lost River Range the lower 300 to 500 feet of the formation is thin bedded. Conspicuously thin-bedded limestone is also present near Black Daisy Canyon and near Lupine Creek.

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Table 1.--Chemical analyses of White Knob Limestone from near Mackay

	No. 59N 1 From 2,750 ft. N. 49° E. of the Grand Prize Mine	No. 59N 2 From 750 ft. S. 56° E. of the Blue Bird Mine
SiO_2	4.77	5.47
Al_2O_3	.17	.12
Fe_2O_3	.03	.09
FeO	.06	.03
MgO	.48	.39
CaO	52.58	52.34
Na_2O	.01	.02
K_2O	.03	.02
H_2O+	.05	.11
H_2O-	.04	.02
TiO_2	.01	.01
P_2O_5	.04	.03
MnO	.02	.01
CO_2	41.53	41.31
Cl	.00	.00
F	.01	.07
	99.83	99.98

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Locally sandstone, quartzite, siltstone, mudstone, argillite, and conglomerate similar to those in the Copper Basin Formation are interlayered in the White Knob Limestone as isolated beds and as sequences that range from a few feet to several hundreds of feet in thickness. These sequences of noncarbonate clastic rocks in the limestone are most common in a zone that extends northward through the middle of the quadrangle. These layers of noncarbonate clastic rocks may be either layers whose deposition alternated with the deposition of the limestone, or layers that were brought into juxtaposition with the limestone by low-angle faulting. We interpret them to be interbedded wedges and lenses of rocks akin to the Copper Basin Formation that extends eastward into the White Knob Limestone. The presence of limestone layers in the Copper Basin Formation to the west, described above, are interpreted to be further manifestations of this interfingering.

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Four stratigraphic sequences that contain rocks of the White Knob Limestone were studied in detail. The location of these sequences are shown on the geologic map of the quadrangle (Nelson and Ross, 1969); two of these are close together north and east of the junction of Antelope and Cherry Creeks; one is near Cabin Creek, east of Copper Basin; and the fourth is at Timbered Dome. The sequences at Timbered Dome are described in the section of this report on the Copper Basin Formation, and the other three will be described in the order that they are listed above. The details of these sections are also shown graphically by Skipp (1961a). The sections near the junction of Antelope and Cherry Creeks are dominantly limestone; the one near Cabin Creek contains a little sandstone, siltstone, and conglomerate similar to rocks in the Copper Basin Formation; and the section at Timbered Dome contains much rock that is assigned to the Copper Basin Formation.

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The first stratigraphic sequence north and east of the junction of Antelope and Cherry Creeks is in secs. 28, 32, and 33, T. 5 N., R. 24 E. In this area the limestone rests on the Copper Basin Formation, which includes near the top a thick lens of fissile, carbonaceous argillite lithologically like much of the Milligen Formation. It includes fine- to medium-grained gray to black, locally cherty limestone in beds ranging from a few inches to 2 feet in thickness. The contained fossils indicate a Chester age.

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Stratigraphic section in secs. 28, 32, and 33, T. 5 N., R. 24 E.

	Thickness feet
Jasperoid (silicified limestone below the Challis Volcanics)	
White Knob Limestone	
Limestone, pink, coarse-grained, somewhat metamorphosed-------------------------	100
Limestone, dark-gray, fine-grained, medium-bedded; chonites, brachiopods Echinoconchs, Paramillerella cf. P. cooper (D. Zeller) 1953, Plectogyra sp.------------------------------------	1,050
Limestone, medium-grained and medium-bedded, with much black chert. Fossil hash, corals, bryozoa, Endothyra cf. E. Symmetrica (E. Zeller) 1957-----------	100
Limestone, mostly medium-gray, massive, with a layer of chert nodules and a few thin shale layers. Fossil hash, crinoid stems, corals, Plectogyra sp.-	450
Limestone, medium-gray, fine-grained, thick-bedded, with some chert. Corals, brachiopods, Plectogyra sp.-----------	150

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Stratigraphic section in secs. 28, 32, and 33, T. 5 N., R. 24 E.--Continued

	Thickness feet
Limestone, medium-gray, fine-grained, in part laminated, cherty, with corals----------------------------------	200
Limestone, dark-gray, fine-grained, with crinoid stems-------------------------	250
Limestone, medium-dark-gray, fine-grained, non-fossiliferous--------------------	20
Copper Basin Formation	
Siltstone and quartzite with interbedded argillite. Quartzite is light-gray and weathers dark-yellow-brown. A lens of conglomerate 200 feet from the top has quartzite and chert pebbles up to 1.5 inches in diameter. The proportion of argillite decreases upward. Probable worm tracks 100 feet above base of unit. *Leiorhynchus carboniferum* var. *polypleurum* Girty--------------------------------	750
Argillite, fissile, dark-gray to black with sandy layers-------------------	60

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Stratigraphic section in secs. 28, 32, and 33, T. 5 N., R. 24 E.--Continued

	Thickness feet
Sandstone, medium-gray, medium-bedded, weathering dark-yellow-brown----------	150
Argillite, fissile, with sandy layers, dark-gray to black-------------------------	20
Total----------------------------------	3,300

Of this 2,320 feet belong to the White Knob Limestone.

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The second stratigraphic sequence north and east of the junction of Antelope and Cherry Creeks is in secs. 2, 3, and 4, T. 4 N., R. 24 E. The sequence contains fossils at intervals but most of these appear not to be diagnostic. Numerous crinoid stems and cup corals and some gastropods, corals, and brachiopods are present. The contact with the Copper Basin Formation ~~is~~ seems to be gradational. The limestone is mostly dark-gray on fresh fracture and in beds a few inches to 5 feet thick. The thickness of the beds tends to increase upward in the section. Some of the limestone in the lower part of the section weathers to thin sheets. At fairly close intervals throughout the section chert, in part rusty, is plentiful in nodules and layers. Some limestone beds include abundant closely spaced, thin chert laminae. A few beds are sandy. In several places the limestone is silicified and brecciated in the manner common beneath the Challis Volcanics but the volcanic rocks have been removed by erosion.

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Stratigraphic section in secs. 2, 3, and 4, T. 4 N., R. 24 E.

	Thickness feet
Top of formation not reached.	
Limestone, massive, in beds 1 to 6 feet thick. In most beds chert is inconspicuous but some are ribboned with it. Fossils are rare and poorly preserved----------------------------------	340
Limestone, massive, with some beds over 10 feet thick. Many beds have closely spaced chert laminae and nodules. Some beds are soft where weathered---	245
Limestone, mostly thick-bedded but some is fissile. Chert in nodules and laminae. Silicified brachiopods and corals----	470
Limestone, mostly in beds less than a foot thick. Chert laminae plentiful------	380
Limestone, massive, dark, in beds up to 5 feet thick. Chert not abundant------	460
Limestone, poorly exposed, in beds up to 3 feet thick. There are some chert layers and some chert nodules up to 3 feet long--------------------------	200

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467-100

Stratigraphic section in secs. 2, 3, and 4, T. 4 N., R. 24 E.--Continued

	Thickness feet
Largely covered limestone in beds up to 5 feet thick, with some chert----------	190
In part covered. Limestone in beds 1 to 5 feet thick. Scanty and irregular chert nodules. Poorly preserved gastropods--	350
The rock in this interval is poorly exposed and in part covered by limestone breccia interpreted to be of Tertiary age. Mostly thin-bedded limestone, with some chert layers. Float indicates some beds are sandy------------------------------	370
Mostly covered. Limestone with chert laminae and nodules---------------------------	235
Limestone, in part brecciated. Chert laminae up to 6 inches thick------------------	120
Limestone, thin-bedded, with closely spaced chert laminae locally. One exposure has about 5 chert layers, an inch thick, per foot of limestone. Crinoid stems are plentiful. Poorly preserved non-diagnostic corals---------------------	69

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Stratigraphic section in secs. 2, 3, and 4, T. 4 N., R. 24 E.--Continued

	Thickness feet
Limestone in 4- to 20-inch thick beds, with sparse chert, interbedded with sandstone represented only by chips---	60
Limestone in beds about an inch thick, sparse chert-------------------------	180
Limestone, thin-bedded, in part dark, in part light-colored. Crinoids. Some beds are siliceous and there may be some shale---------------------------	95
Sandstone, calcareous, with interbedded limestone, some of which is nearly black--------------------------------	300
Thin, fissile black shale-----------------	20
Top of shaly beds of Copper Basin Formation	4,445

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987-100

The stratigraphic sequence near Cabin Creek is in and near unsurveyed sec. 14, T. 6 N., R. 22 E. Here the limestone of the basal part of the formation contains thin argillaceous and cherty beds similar to some in the underlying Copper Basin Formation. The limestone in the lower 2,500 feet is fine grained and contains clay and silt, mainly in thin laminae. At higher horizons the limestone is more nearly pure calcium carbonate, and is more richly fossiliferous. It is composed mainly of clastic calcium carbonate particles cemented by lime mud. Bryozoan biostromes are present. The upper part of the formation in this area contains beds of conglomerate and sandstone intercalated in the limestone. The limestone throughout is essentially free from magnesium. Additional details of the rocks of this section have been published elsewhere by Betty Skipp (1961a and b).

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Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.

	Thickness feet
Challis Volcanics	
Limestone, dark-gray to medium-gray, fine- to medium-grained, fossiliferous, thin- to thick-bedded, upper beds cliff forming; weathers medium-gray to light-gray with a smooth surface; contains a lens of sandstone, olive-gray, conglomeratic, grains largely chert, weathers to resistant ledge; *Paramillerella designata* (D. Zeller) 1953, corals and brachiopods----------	495
Conglomerate, medium-light-gray to light-brownish-gray, chert and quartzite groundmass, resistant, lenticular; lichens give dark-gray appearance; some sandstone and siltstone interbeds, quartzose, thin-bedded----------------	220

Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Limestone, olive-gray, mottled dark-gray and orange near base, medium to very coarse grained, fossiliferous, limonitic, weathers grayish-orange; brachiopods, corals, crinoids, ostracodes, Foraminifera, fish plates-----	75
Sandstone, greenish-gray to pale brown, quartzose; graded bedding; slope forming------------------------------	55
Conglomerate, medium-gray to grayish-red, chert and quartzite groundmass, weathers grayish-red and pale brown, resistant; sandstone interbeds, light-gray, coarse-grained, chert grains, crossbedding-------------------------	10

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Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Limestone, medium-dark-gray to dark-gray, fine- to medium-grained, fossiliferous, medium-bedded, ledge-forming near base; weathers medium-light-gray to grayish-orange with rough surface: <u>Plectogyra</u> sp. bryozoa, corals, brachiopods, crinoids, ostracodes, conodonts--------	340
Conglomerate, medium-dark-gray and grayish-red, chert and quartzite groundmass, resistant; sandstone interbeds--------	20
Limestone, dark-gray to medium-gray, fine- to medium-grained, fossiliferous, somewhat argillaceous, massive- to thick-bedded, black chert lenses common, cliff forming near base; weathers light-olive-gray to medium-gray: <u>Plectogyra</u> sp. brachiopods, bryozoa, gastropods, corals, crinoids----------	620

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667-100

Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Sandstone, medium-dark-gray to grayish-red, quartzose, very coarse grained, crossbedded; limestone interbeds, medium-gray, oolitic, very coarse grained----------------------------------	50
Conglomerate, dark-grayish-red to moderate yellowish-brown, chert and quartzite groundmass, lenticular, resistant, foreset bedding, weathers dark-reddish-brown; sandstone interbeds, medium-dark-gray, medium- to coarse-grained, quartzose----------------------------	190
Sandstone, medium-gray, quartzose, medium- to coarse-grained, siliceous and calcareous; limestone interbeds, medium-gray, sandy, fossiliferous, some coquinoid, some calcarenitic; conglomerate, poorly sorted, quartzose, at base and in lenses: brachiopods--	140

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Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Limestone, dark-gray to grayish-black, fine- to medium-grained, fossiliferous, some organic matter; conglomerate lenses, poorly sorted: brachiopods, gastropods, bryozoa, ostracodes, Foraminifera----------------------	75
Conglomerate, light-olive-gray to medium-light-gray, poorly sorted, chert and quartz groundmass, non-resistant, weathers medium-gray and light-yellow-orange---------------------	20
Limestone, dark-gray to medium-gray, medium-grained, fossiliferous, argillaceous in places, thick-bedded, microcoquina common, sandy and coarse-grained near top, lower beds resistant, weathers light-gray, light-brownish-gray and yellowish-gray: <u>Plectogyra</u> sp. brachiopods, crinoids, bryozoa, corals, Foraminifera, conodonts-----	590

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Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Conglomerate, light-olive-gray to pale brown, chert and quartzite groundmass, weathers moderate yellowish-brown; sandstone interbeds, locally conglomeratic; limestone interbeds, grayish-black to medium-light-gray, largely coarse-grained, sandy, silty, fossiliferous, some microcoquina: brachiopods, crinoids, echinoids, conodonts, bryozoa-------------------	145
Limestone, dark-gray to light-olive-gray, medium- to coarse-grained, fossiliferous, microcoquina and sandy streaks common, some oolitic beds, argillaceous in places, thin- to medium-bedded; conglomerate, quartzose at top: Plectogyra sp. Granuliferella? sp. crinoids, brachiopods, bryozoa, trilobites, gastropods---------------	190

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867-100

Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Limestone, medium-light to medium-dark-gray, medium-grained, fossiliferous, silty, oolitic, weathers medium-dark-gray: corals, echinoids, bryozoa------	50
Siltstone, light-yellow-brown to light-yellow-gray, quartzose, resistant; limestone, light to medium gray, coarse-grained, cherty------------------------	45
Limestone, dark-gray to medium-gray, medium-grained, fossiliferous, medium-bedded, reefoid bed at 3,200 feet; lower beds resistant, medium-gray chert nodules common, weathers medium-gray: <u>Plectogyra</u> sp., <u>Granuliferella</u> sp., brachiopods, corals, crinoids, Foraminifera--------------------------	1,040
Siltstone, quartzose----------------------	150
Limestone, medium-dark-gray, medium-grained, fossiliferous, silty, some microcoquinas, non-resistant, weathers medium-light-gray; bryozoa, Foraminifera-----------------	75

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Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Limestone, medium-gray to grayish-black, fine- to medium-grained, coarser grained in upper beds, fossiliferous in places, reefoid bed at 2,200 feet, clay, silt and black chert abundant in upper beds, bedding irregular, massive at base, banded in places, weathers medium-gray to light-olive-gray; siltstone interbeds, calcareous: Granuliferella sp. Plectogyra sp., bryozoa, corals, ostracodes, crinoids, echinoids, Foraminifera---------------	1,880

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887-100

Stratigraphic section in and near unsurveyed sec. 14, T. 6 N., R. 22 E.--Continued

	Thickness feet
Limestone, dark-gray to grayish-black, finely crystalline, clayey, silty in places, unfossiliferous, thin-bedded, laminated, weathers medium-gray to light-olive-gray with a crust; siltstone interbeds, dark-gray and light-grayish-orange, quartzose, calcareous; mudstone interbeds, grayish-black, some siliceous, some carbonaceous------	740
Measured thickness of White Knob limestone above Copper Basin Formation	7,365

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867-100

Age and paleotology

Fossils have been collected from numerous areas in the quadrangle underlain by the White Knob Limestone. These fossils indicate that the formation ranges in age from the lower Mississippian Osage through the Mississippian and Pennsylvanian into the Permian at least as high as the Leonard and probably into the Word. The areas from which diagnostic fossils have come, and their indicated ages, are listed below in the order that they are treated in more detail in the following paragraphs. The order of presentation is in general that of decreasing age. Briefly rocks just north of Cabin Creek have yielded fossils that indicate an age range of from Osage into Chester, those from in and near the bight of Dry Creek a range from Meramec into Chester, those from on and near Timbered Dome a range from Meramec into Late Pennsylvanian, and those from near Antelope Creek east of Cherry Creek a range from Chester into Leonard and probably Word.

Fossil collections from the Lava Creek and the Leadbelt Creek-Dry Canyon area are also listed and discussed below.

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Fossils from the vicinity of Cabin Creek were collected from the measured stratigraphic section that is presented on pages 57 to 65. Betty Skipp studied endothyrids from this section (Skipp, 1961a) and has concluded that the rocks there range in age from Osage, through Meramec into Chester. T. J. Dutro and W. J. Sando (written commun., March 20, 1961) have studied megafossils from this section and their conclusions concerning the age of the rock are in accord with those of Skipp. They comment that comparisons between this section and the one on Timbered Dome are difficult, apparently because of different facies involved in the two areas. Under the stratigraphic scheme adopted in the present report, based primarily on lithologic map units, the section near Cabin Creek belongs to the White Knob Limestone and much of that at Timbered Dome belongs to the Copper Basin Formation, which is in accord with the idea of facies differences advanced by Dutro and Sando. They suggest that the top of the section at Cabin Creek correlates approximately with the top of the Copper Basin Formation at Timbered Dome, which there appears to interfinger with the basal part of the White Knob Limestone. They regard collections 18129-PC and 18130-PC (map locations 13 and 14) near the top of the Cabin Creek sequence as of probable Chester age.

As noted below, beds high in the White Knob Limestone at Timbered Dome are definitely of Pennsylvanian age. Dutro and Sando say that collections 18122-PC, 18123-PC, 18124-PC, and 18126-PC (map locations 15, 16, 17, and 18) at Cabin Creek are of Meramec or at the youngest early Chester in age. The presence of Inflatia in these and higher collections suggests that all these beds may be Chester equivalents. However, they note that the occurrence of the small coral Rotiphyllum? in 18121-PC (map location 19) suggests a fauna that has been noted elsewhere just below the Faberophyllum beds in Utah (Sando, Dutro, and Gere, 1959, p. 2761). This statement seems to imply a possible Osage age. The bryozoan-rich rocks in the lower part of the sequence at Cabin Creek could be of Meramec or possibly older Mississippian age. Taking the various bits of evidence into account, Dutro and Sando would tentatively place the Chester-Meramec boundary somewhat less than 1,200 feet below the top of the section of White Knob Limestone measured near Cabin Creek.

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Collection of megafossils from the measured section near Cabin Creek.

18118-PC (map location 20):

algae?, indet.

echinoderm debris, indet.

<u>Fenestella</u> spp.

<u>Cystodictya</u>? sp.

18119-PC (map location 21):

echinoderm debris, indet.

<u>Fenestella</u> spp.

rhomboporoid bryozoans, indet.

18120-PC (map location 22):

sponge spicules, indet.

echinoderm debris, indet.

<u>Fenestella</u> spp.

<u>Polypora</u> sp.

<u>Cystodictya</u>? sp.

rhomboporoid bryozoans, indet.

?brachiopod fragments, indet.

18121-PC (map location 19):

echinoderm debris, indet.

<u>Rotiphyllum</u>? sp.

large horn corals, indet.

rhomboporoid bryozoan, indet.

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18122-PC (map location 15):

echinoderm debris, indet.

Fenestella sp.

Cystodictya? sp.

rhomboporoid bryozoan?, indet.

Chonetes sp. (small)

Inflatia cf. *I*. *inflatus* (McChesney)

"*Avonia*" sp. (cf. "*P*." *moorefieldanus* Girty)

Flexaria? sp.

Spirifer aff. *S*. *pellaensis* Weller

Torynifer? sp.

punctate spiriferoid, indet.

Eumetria sp.

cf. *Rhineoderma* sp.

phillipsid trilobite, indet.

18123-PC (map location 16):

echinoderm debris, indet.

Fenestella spp.

rhomboporoid bryozoans, undet.

Chonetes sp. (as in 18122)

Quadratia cf. *Q*. *hirsutiformis* (Walcott)

Inflata cf. *I*. *inflatus* (McChesney)

Spirifer aff. *S*. *pellaensis* Weller

Torynifer sp.

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18124-PC (map location 17):

Michelinia sp.

echinoderm debris, indet.

Fenestella spp.

Cystodictya sp.

lamellar fistuliperoid, undet.

ramose trepostome, undet.

Spirifer cf. *S*. *haydenianus* Girty

18126-PC (map location 18):

sponge spicules, indet.

horn coral, indet.

echinoderm debris, indet.

Fenestella spp.

rhomboporoid bryozoans, indet.

Cystodictya sp.

bryozoan fragments, indet.

Echinoconchus aff. *E*. *genevienvensis* Weller

Spirifer cf. *S*. *bifurcatus* Hall

Composita sp.

Cleiothyradina cf. *C*. *sublamellosa* (Hall)

Reticulariina? sp.

Girtyella? sp.

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18127-PC (map location 23):

small horn coral, indet.

echinoderm debris, indet.

Fenestella spp.

Penniretepora sp.

trepostome bryozoans, undet.

Inflatia? sp.

18128-PC (map location 24):

large horn corals, indet.

echinoderm debris, indet.

Orthotetes cf. *O*. *kaskaskiensis* McChesney

Chonetes sp.

Undaria? sp.

Inflatia sp.

Spirifer aff. *S*. *Leidyi* Norwood & Pratten

Composita cf. *C*. *subquadrata* (Hall)

"*Punctospirifer*" cf. "*P*." *transversus* (McChesney)

Dielasma? sp.

18129-PC (map location 13):

Caninia sp.

18130-PC

Caninia sp.

Inflatia? sp.

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Several fossil collections were obtained from the White Knob Limestone in and near the bight of Dry Fork Creek. Collections 18152-PC through 18155 (map locations 25 to 28), listed below, were examined by Dutro and Sando (written communication, March 20, 1961). They note that collection 18152-PC represented the *Faberophyllum-Striatifera* fauna referred to above and is of probable Meramec age while collection 18155-PC contains *Caninia* and brachiopods like those above that faunal zone at Timbered Dome. This collection could be of early Chester age.

18152-PC (map location 25):

Carruthersella? sp.

Faberophyllum sp.

springoporoid coral, cf. *Kueichowpora*

small horn corals, indet.

Antiquatonia? sp.

Striatifera cf. *S*. *brazeriana* (Girty)

Composita sp.

18153-PC (map location 26):

ramose bryozoans, undet.

Cystodictya? sp.

18154-PC (map location 27):

Rhopalolasma? sp.

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18155-PC (map location 28):

Caninia sp.

crinoid columnals, indet.

ramose bryozoans, undet.

Cystodictya sp.

Inflatia? sp.

Spirifer aff. *S. pellaensis* Weller

Cleiothyradina sp.

Eumetria sp.

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The fossils from Timbered Dome listed below came from limestone that is interbedded with sandstone, siltstone, and mudstone. As described on pages 18 to 31 and shown diagrammatically by Skipp (1961a), the section there consists of an intermediate limestone mass that overlies sandstone, siltstone, and mudstone, and that is separated from an upper limestone mass by an intervening mass of sandstone. This sequence of rocks is interpreted to result from two westward-extending wedges of White Knob Limestone interfingering with two eastward-extending wedges of the Copper Basin Formation. As thus interpreted, both the intermediate and upper masses of limestone are considered to be parts of the White Knob Limestone. The megafossils in collections 18131-PC through 18136-PC and 18138-PC (map locations 29 through 35) have been examined by Dutro and Sando (written commun., March 20, 1961) with the results listed below. They regard the lower part of the limestone above the lower jasperoid as of probable Meramec age. High in this limestone assemblage they recognize the Faberophyllum-Striatifera fauna that is quite widespread in the northeastern Utah-southeastern Idaho region. Beds containing that fauna are thought to be of late Meramec age and are generally found in the lower part of the Great Blue equivalents south of the Snake River Plain. The relation of these equivalents to other upper Paleozoic units is summarized by Carr and Trimble (1961).

Dutro and Sando remark that collections 18132-PC through 18134-PC are characterized by a large Caninia and brachiopods suggestive of an early Chester age. These three collections correspond to an assemblage like that of the faunal zone above the Faberophyllum-Striatifera zone south of the Snake River Plain. Dutro and Sando think the Meramec-Chester boundary at Timbered Dome would be at or below the middle of the limestone between the two jasperoid bodies in the measured section. Collection 18137-PC (map number 6) from beds of the Copper Basin Formation below the upper jasperoid mass is, as noted on page 33, definitely indicative of a Chester age.

The upper part of the limestone in the measured section is regarded by Betty Skipp (1961a), on the basis of the endothyrid content, as of Pennsylvanian age. Dutro and Sando, on the contrary, say that, because the brachiopods in the highest collection in the measured section (18138-PC) (map location 35) are like those from lower beds, there is no apparent reason for considering that rocks younger than Chester occur in the section. Collection 19667-PC (map location 36) was obtained by Ross from the White Knob Limestone fairly near but probably stratigraphically above collection 18138-PC. Dutro and Yochelson (written commun., March 14, 1961) regard this collection as definitely of Pennsylvanian age and probably Late Pennsylvanian.

Collection CPP 700 (map location 37) listed below was described by Dutro (written commun., March 23, 1961).

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List of fossils in White Knob Limestone at Timbered Dome

18131-PC (map location 29):

large horn coral, indet.
fenestrata bryozoans, indet.
ramose bryozoans, undet.
Cystodictya sp.
Avonia? sp.
Echinoconchus aff. E. genevievensis Weller
Spirifer aff. S. pellaensis Weller
Composita sp.
Cleiothyradina aff. C. sublamellosa (Hall)
Reticulariina? sp.
Eumetria? sp.
pelecypod, indet.
Loxonema sp.

18132-PC (map location 30):

Caninia sp.
echinoderm debris, indet.
ramose bryozoans, undet. (small)
Ovatia sp.
gigantoproductid brachiopod, indet.
Composita sp.
pleurotomariacean gastropod, undet.

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18133-PC (map location 31):

Caninia sp.

Ovatia sp.

Flexaria? sp.

Spirifer cf. *S. peilaensis* Weller

Composita sp.

18134-PC (map location 32):

Caninia sp.

Pseudodorlodotia? sp.

Hayasakaia? sp.

Ovatia sp.

18135-PC (map location 33):

small horn coral, indet.

echinoderm debris, indet.

ramose bryozoans, undet.

Echinoconchus sp.

Inflatia? sp.

Spirifer aff. *S. haydenianus* Girty

Composita sp.

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18136-PC (map location 34):

fenestrate bryozoans, undet.

ramose bryozoans, undet.

Inflatia sp.

Spirifer? sp.

Reticulariina? sp.

brachiopod fragments, undet.

18138-PC (map location 35):

fenestrate bryozoans, undet.

ramose bryozoans, undet.

Inflatia sp.

Flexaria? sp.

productoid fragments, indet.

Reticulariina? sp.

19667-PC (map location 36):

Linoproductus sp. (large)

Cancrinella sp.

Juresania aff. J. nebrascensis (Owen)

productoid brachiopod, indet.

"Nuculana obesa" White

Nuculoid pelecypod, indet.

Glabrocingulum (Ananias) cf. G. (A.) welleri (Newell)

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CPR 700 (map location 37):

horn coral fragment, indet.

echinoderm debris, indet.

echinochonchid brachiopod, indet.

<u>Spirifer</u> aff. <u>S.</u> <u>leidyi</u> Norwood and Pratten

<u>Composita</u> sp.

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Fossils from the White Knob Limestone were collected from several localities north and east of the junction of Antelope and Cherry Creeks. On the bases of the study of endothyrids, Betty Skipp (1961a) has concluded that the rocks from the measured section described on pages 49 to 51 are Meramec and Chester in age. Collection 18148-PC (map location 38) is from the eastern or stratigraphically high end of one of these measured sections. Collections 18150-PC and 18151-PC (map locations 39 and 40) are from east of and stratigraphically above the measured section. Collection 18151-PC, according to Yochelson's analysis of the mollusca (Dutro, Yochelson, Duncan, and Sando, written communication, March 20, 1961), is definitely Permian, it is certainly post-Wolfcamp and could be either Leonard or Word equivalent, with a slight preference for the latter. According to the report just cited, collection 18150-PC is of Middle Pennsylvanian age or younger. Collection CPR-486 (map location 41) is from between the two measured sections north and east of the junction of Antelope and Cherry Creeks, and according to Dutro (written communication, March 23, 1961) is of Mississippian age. Collection SK58125 (map location 42) is from south of Antelope Creek, and is regarded as of Middle Pennsylvanian age, probably from the early part of the Middle Pennsylvanian (Douglas, written communication, October 23, 1958, and Yochelson, written communication, November 4, 1958). The fossils from the five collections commented on in this paragraph are listed below.

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18148-PC (map location 38):

small horn corals, indet.

echinoderm debris, indet.

Fenestella sp.

ramose bryozoans, indet.

worm tubes, indet.

Schizophoria sp.

Derbyia sp.

Lissochonetes sp.

Antiquatonia? sp.

"*Marginifera*" sp.

Linoproductus sp. (large)

productoid fragments, indet.

Spirifer cf. *S. occidentalis* Girty

Spirifer aff. *S. rockymontanus* Marcou

Composita sp.

Reticulariina? sp.

Hustedia sp.

dielasmid brachiopod, undet.

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18150-PC (map location 39):

Fenestella sp.

rhomboporoid bryozoans, indet.

Chonetes sp.

Antiquatonia? sp.

"*Marginifera*" sp.

productoid fragments, indet.

Cleiothyradina sp.

Hustedia sp.

punctate spiriferoid, undet.

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887-100

18151-PC (map location 40):

small horn coral, indet.

Tabulipora sp.

Rhombotrypella sp.

rhomboporoid bryozoans, indet.

stenoporoid bryozoan, indet.

Antiquatonia? sp.

Linoporductus sp.

Juresania? sp.

echinoconchid brachiopod, indet.

"Marginifera" sp.

punctate spiriferoid, indet.

Nucula sp.

Promytilus? sp.

Astartella sp.

astartellid pelecypod(?), undet.

Aviculopecten sp.

Permophorus aff. P. albequus (Beebe)

parallelodontid pelecypod, undet.

Schizodus sp.

Euphemites cf. E. batteni Yochelson

Knightites (Retispira) cf. K. (R.) fragilus Yochelson

Bellerophon sp.

Colpites? sp.

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18151-PC (map location 40)--Continued

aff. Baylea sp.

Callitomaria? sp.

Platyworthenia? sp.

Glabrocingulum sp.

Apachella? sp.

cf. Peruvispira sp.

pleurotomariacean gastropod A, undet.

pleurotomariacean gastropod B, undet.

Straparollus (Euomphalus?) sp.

Planotectus sp.

Anomphalus sp.

Platyceras (Strophostylus?) sp.

Naticopsis spp.

Taosia sp.

Girtyspira? sp.

aff. Auriptygma sp.

Meekospira? sp.

"Strobeus" sp.

cf. Orthonema sp.

subulitacean gastropod A, undet.

subulitacean gastropod B, undet.

loxonematid gastropod, undet.

Pseudozygopleura sp.

Donaldina? sp.

~~Worm tube, cf. Spirorbis sp.~~

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SK 58125 (map location 42):

Fusulinella sp. or "Profusulinella" sp.

The silicification has destroyed the detailed structure of these small fusulines making it impossible to make a positive identification. In addition to fusulinids, this sample contains the cross section of a bellerophontiform gastropod, possibly Bellerophon, and several external impressions of crinoid stems which closely mimic high-spired gastropods.

CPR 486 (map location 41):

fenestrate bryozoans, indet.

ramose bryozoans, indet.

Derbyia aff. D. cymbula Hall and Clarke

Linoproductus cf. L. platyumbonus Dunbar and Condra

Spirifer cf. S. occidentalis Girty

Composita cf. C. subtilita Hall

Reticulariina? sp.

pectinoid pelecypod, undet.

pelecypod fragments, indet.

gastropod borings, indet.

proetid trilobite, undet.

spindle-shaped borings, indet.

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Fossils from the vicinity of Lava Creek are contained in collections 18142-PC, 18144-PC and CPR 699 (map locations 43, 44, and 45). T. J. Dutro, E. L. Yochelson, Helen Duncan, and W. J. Sando (written communication, March 20, 1961) consider collection 18142-PC to be of probable Meramec age; the other collections, although not closely diagnostic, are probably of Late Mississippian age.

18142-PC (map location 43):

Cystodictya sp.

Moorefieldella cf. M. *eurekensis* (Walcott)

18144-PC (map location 44):

ramose bryozoans, indet.

shell fragments, indet. (perhaps brachiopods)

CPR 699 (map location 45):

small horn corals, indet.

echinoderm debris, indet.

encrusting bryozoan, indet.

Composita sp.

pectenoid pelecypod, indet.

shell fragments, indet.

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Fossils obtained from the mass of White Knob Limestone that extends from Leadbelt Creek to Dry Canyon are listed below. T.J. Dutro (written communication, March 23, 1961) considered the fossils in collection CPR 681 (map location 46) from Leadbelt Creek to be of Middle(?) Pennsylvanian age. Collection CPR 662 (map location 47) from Dry Canyon indicates a Mississippian age, according to Dutro (written communication, March 23, 1961). The fossils listed below from collections 18140-PC and 18141-PC (map location 48) from Dry Canyon were determined by T.J. Dutro, E.L. Yochelson, Helen Duncan, and W.J. Sando (written communication, March 20, 1961). The fossils in lot 6 (map location 49) collected by Anderson (1929b, p. 12) were determined by Girty.

CPR 681 (map location 46):

Syringopora sp.
small amplexoid horn coral, indet.
echinoderm debris, indet.
fenestrate bryozoans, indet.
Polypora sp.
ramose and encrusting bryozoans, indet.
Spirifer cf. *S. occidentalis* Girty
Composita sp.
moderately high-spired gastropod, indet.
gastropod(?) fragment, indet.

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CPR 662 (map location 47):

Sponge spicules, indet.

echinoderm debris, indet.

fenestrate bryozoans, undet.

small ramose bryozoans, undet.

stenoporoid bryozoans, indet.

Rhysidomella sp.

Chonetes sp.

Inflatia? sp.

Cleiothyradina sp.

Reticutariina? sp.

Hustedia? sp.

18140-PC (map location 48):

ramose bryozoan, indet.

"Marginifera" sp.

Reticulariina? sp.

Hustedia sp.

18141-PC (map location 48):

Fenestella sp.

ramose bryozoans, undet.

productoid shell fragments, indet.

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Lot 6 (map location 49):

Wewokella? sp.
Triplophyllum sp.
Chaetetes radians
Productus ovatus
Diaphragmus elegans?
Spiriferina spinosa?
Sulcalipinna sp.
Aviculipecten sp.
Levidentalum sp.
Bellerophon sp.
Pleurotomaria sp.
Griffithides sp.

Regional relations

Wherever the base of the White Knob Limestone can be observed in the quadrangle, the limestone of the formation lies with apparent conformity on rocks of the various types that make up the Copper Basin Formation. In the Lost River Range, in the northeastern corner of the quadrangle, the rocks of the White Knob Formation grade downward into very dark-gray argillaceous rocks that are similar to but cannot be correlated with any specific part of the Copper Basin Formation. These dark argillaceous rocks have been considered to be part of the Milligen Formation; here this assignment is questioned as explained in the section of this report entitled Milligen Formation. Elsewhere in the quadrangle all the rocks that are exposed beneath the formation can reasonably be assigned to the Copper Basin Formation.

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Rocks that are assigned to the White Knob Limestone are locally interlayered with rocks that are assigned to the Copper Basin Formation. The pertinent discussion of the relationships between the rocks of these two formations has been presented in the section of this paper on the Copper Basin Formation.

At most places in the quadrangle the White Knob Limestone is unconformably overlain by Challis Volcanics. East of Fish Creek, however, the rocks that are assigned to the formation are conformably overlain by rocks of the Copper Basin Formation.

Thickness

The 7,365 feet thickness of White Knob Limestone measured near Cabin Creek and described on pages 57 to 65 is the thickest section of the formation that has been recognized in the area of the Mackay quadrangle. In the Lost River Range north of the quadrangle, Ross (1947, p. 1116) estimated the formation to be probably more than 6,000 feet in thickness.

Early Tertiary rocks

Challis Volcanics

The Challis Volcanics comprise a thick and widespread assemblage of volcanic rocks, with some intercalated sedimentary rocks, that once covered much of south-central Idaho. According to a recent revision of the originally broad definition (Ross, 1961b), the formation consists of dominantly volcanic strata of early Tertiary age within the part of central Idaho north of the Snake River Plain and south of the westward-flowing segment of the Salmon River (near latitude 45°30'). That region also contains younger volcanic rocks now excluded from the Challis Volcanics.

The Challis Volcanics cover nearly half of the Mackay quadrangle. They are a heterogeneous assemblage of lava flows, volcanic breccia, sandstone, siltstone, and conglomerate. These rocks are various shades of reddish gray, brownish gray, and greenish gray. They range in composition from andesite to rhyolite. Analyses of typical specimens are given in table 2. Most of the assemblage corresponds with the latite-andesite member of the formation in the Bayhorse region (Ross, 1937, p. 50-53). It differs from that member in that fragmental rocks of various kinds are more abundant than in the Bayhorse region. No basalt has been found in the Challis Volcanics in the Mackay quadrangle, although it is reported in the Wood River region (Umpleby and others, 1930, p. 53-57).

Lava flows seem to be the most abundant material in the formation in the Mackay quadrangle, and andesite is the most common flow rock. The typical andesite of the flows contains phenocrysts of pyroxene, hornblende, and biotite either singly or in various combinations. Most of the andesite also has plagioclase phenocrysts that range from calcic oligoclase to calcic andesine. Some of the flows contain a little potassium feldspar (commonly sanidine) and some contain quartz; in these flows the plagioclase is commonly more sodic than that in the typical andesite flows. In most of the flow rocks the phenocrysts are less than 2 mm long and most of the groundmass is partly devitrified glass.

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Breccias composed of volcanic detritus are about as abundant as lava flows and are of the same range of composition as the lava flows. Most of these breccias occur as massive lenticular or tongue-shaped masses that seem to be mudflow deposits, although stream-deposited breccias, air-laid breccias, and auto-brecciated parts of lava flows are undoubtedly also present.

Volcanic sandstone and siltstone are widely distributed but nowhere in large enough aggregates to map at the scale of the present study. The recognizable constituents include plagioclase (commonly oligoclase to andesine), and locally sanidine and quartz, but most of the detritus is glassy volcanic rocks, commonly somewhat devitrified. These rocks are sufficiently altered to hinder identification of their components. Much of the material in these rocks is pyroclastic material; some has been aerial deposited with little or no subsequent sorting or transportation, and some is clearly water-laid.

Conglomerate, confined mostly to the base of the formation, is locally several hundred feet thick. It consists of rounded fragments that range from a fraction of an inch to as much as one foot in size, and include volcanic rocks, quartzite, siltstone, and chert, as well as sparse limestone and Challis Volcanics.

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One noteworthy exposure 3,700 feet N. 11° W. of the junction of Sawmill Canyon and the North Fork of Alder Creek consists largely of rounded pebbles, cobbles, and boulders of igneous rock. Farwell and Full (1944, p. 9) interpreted these fragments to be granite and from this concluded that the granite, to be described below, was already in place and exposed to erosion before the volcanic rocks were being deposited. The rounded rock fragments are composed of phenocrysts of plagioclase and biotite, and locally a little quartz and sanidine. Most of the quartz and feldspar phenocrysts are rather intensely broken, and some of the quartz is rounded and resorbed. The groundmass of these rocks is glassy and some includes laminated glass fragments that look like pumice. Some of these fragments may be xenoliths of plutonic rocks which have had their groundmasses melted and locally inflated, or, as seems more likely, they may all be fragments of volcanic rocks. If any are xenoliths of plutonic rock, then their presence shows that the plutonic rocks from which they were derived had crystallized, probably below the surface, before the enclosing volcanic rocks were extruded.

Some of the Challis Volcanics near Lake Creek, south of Copper Basin, are altered to the extent that they resemble the Casto Volcanics as described by Ross in the Casto quadrangle to the north (1934b, p. 28-35, 45-54). The granitic mass in the vicinity of Lake Creek intrudes and seems to be the cause of this alteration, which diminishes away from the granitic mass. The alteration produced chlorite, epidote, actinolite, carbonate, sericite, and some quartz. The original mafic

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minerals, perhaps largely pyroxene, have been more extensively altered than the feldspar. Apparently at a late stage the rocks were kaolinized.

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The maximum thickness of the Challis Volcanics that is indicated by comparing the surface topography with contours drawn on the base of the Challis Volcanics is in sec. 18, T. 3 N., R. 23 E., and is a little more than 1,700 feet. In many areas underlain by the formation, there is no evidence as to the elevation of the base of the formation, and in these places the thickness is indeterminable but may exceed 1,700 feet. In the Mackay quadrangle, the upper limit of the Challis Volcanics is everywhere an erosion surface so that the maximum thickness of the remaining parts of the formation at any place is less than the original thickness of the formation at that place.

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Direct stratigraphic correlation between the part of the Challis Volcanics in the Mackay quadrangle and the parts of the formation in adjacent areas is impossible. However, the rocks in the Mackay quadrangle resemble the latite-andesite member which makes up the lower part of the formation in the Bayhorse area to the north (Ross, 1937, p. 50). The implication that only the lower part of the formation is present in the Mackay quadrangle is strengthened by the fact that no correlative of the Germer Tuffaceous Member, which overlies the latite-andesite member in the area to the north, has been recognized in the Mackay quadrangle.

The Challis Volcanics within the Mackay quadrangle have not yielded diagnostic fossils. Fragments of fossilized coniferous wood are widespread but too poorly preserved to be of value in establishing the age of the formation (R.A. Scott, , and L. I. Doner, , written commun., October 17, 1958).

Ross (1961b, p. C179) presented evidence which shows that the Challis Volcanics range in age from Eocene into, at youngest, early Miocene, and probably is mostly Oligocene in age. Fossils from the Germer Tuffaceous Member southwest of Challis, northwest of the Mackay quadrangle, were examined by J. A. Wolfe (written report, October 7, 1960), who concluded that all the species in these collections are known from middle Eocene floras of the Rocky Mountains Region. As noted above, the part of the Challis Volcanics in the Mackay quadrangle seems to be older than the Germer Tuffaceous Member and is therefore probably Eocene in age.

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The volcanic rocks are, as noted below, intruded by granitic bodies and dikes that are 40 to 50 million years old. As the intrusions are presumed to belong to the same general period of magmatic activity as the eruptions, the volcanics within the quadrangle are older but probably not greatly older than the intrusions. On this basis, much of the Challis Volcanics in the Mackay quadrangle is probably of Eocene age.

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Intrusive rocks

Intrusive rocks, probably all products of a single period of igneous activity, are conspicuous features of the Mackay quadrangle. They include several plutons and numerous dikes. The compositions, distribution, and relationships of the intrusive rocks and ore deposits in the north-central part of the quadrangle are presented in a separate paper (Nelson and Ross, 1968), and only a summary of this information is included here.

The rocks of the plutons range in composition from granite to quartz diorite; table 3 gives the chemical and normative compositions of some of these rocks. The rocks are holocrystalline, commonly porphyritic, and range from fine to medium grained; they are composed of quartz, potassium feldspar, plagioclase that ranges from An_{20} to An_{30} in composition, hornblende, biotite, locally pyroxene, and various accessory minerals.

All of the plutons within the Mackay quadrangle seem to be intrusive; their contacts are sharp, and locally cross cutting, the country rock is commonly metamorphosed for a short distance beyond the contacts, the grain size of the plutonic rocks near the contacts diminished toward the contacts, and locally dikes extend out from the plutons into the country rock.

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The pluton that lies a short distance west of Mackay is called the Mackay Granite, and the outermost part of it on the northeast is composed of light-colored granite rock that we termed leucogranite porphyry in our paper on the Alder Creek mining district (Nelson and Ross, 1968). The leucogranite porphyry is so consistently different from the rest of the Mackay Granite that we believe that it is the product of a separate intrusive surge. The leucogranite porphyry is of special interest because the most valuable ore deposits that have been found in the quadrangle are associated with skarn that borders and lies within it. The relationship of the leucogranite porphyry to skarn and of skarn to concentrations of ore minerals is discussed in more detail in the section of this paper on ore deposits.

Lead-alpha age determinations made by T. W. Stern from zircon from two samples of the Mackay Granite both gave an age of 40 ± 10 million years. One sample came from near the Champion mine. Its chemical composition is shown by the fourth analysis in table 3. The other sample is from the SW cor. sec. 13, T. 6 N., R. 23 E. A sample of the leucogranite porphyry from the NW¼ sec. 1, T. 6 N., R. 23 E., was determined by the lead-alpha method to be 50 ± 10 million years old (Stern, 1959, written communication). An age determination by the same method, from the pluton along Lake Creek, gave an age of 50 ± 10 million years.

The pluton that lies west of Copper Basin underlies about 4 square miles of the Mackay quadrangle, and is part of a larger complex of granitic rock that underlies about 50 square miles of the area west of the quadrangle. Within the quadrangle these rocks are somewhat variable in appearance and composition, but they all have granitoid textures and seem to be intrusive. In the area west of the quadrangle this complex includes gneissose rocks that Cook (1956, p. 13) concluded were metamorphosed sedimentary rocks.

The pluton that extends southward across the southern boundary of the Mackay quadrangle at Iron Mountain is presumably the northern end of a much larger mass described by Anderson (1929b, p. 22-23), who speaks of Iron Mountain as Boyle Mountain.

Dikes cut all the rocks of the quadrangle older than the Snake River Basalt. They are most numerous in a zone that trends northeastward through the center of the northern half of the quadrangle. A second less dense concentration of dikes forms another zone that passes through the headwaters of Iron Bog Creek. Not many dikes have been recognized in the Challis Volcanics. This is in part due to the difficulty of distinguishing the dike rocks from the similar appearing volcanic rocks. It may, however, be that fewer dikes cut the Challis Volcanics than cut the older rocks, because the Challis Volcanics and dike rocks probably were emplaced during about the same interval of time.

The rocks that make up the dikes range from fine to coarse grained, most are porphyritic, but a few are not. They are composed of quartz, potassium feldspar, plagioclase, mostly oligoclase, hornblende, biotite, locally pyroxene, and various accessory minerals.

The most common dikes are composed of light-colored, fine-grained rhyolite that contains dipyramid phenocrysts of quartz, in part smoky, as well as phenocrysts of oligoclase and(or) orthoclase. The phenocrysts in these dikes seldom exceed one-fourth inch in size. Specimen 16, table 3, is a typical appearing rhyolite.

Rhyolite porphyry with abundant large phenocrysts is the second most abundant type of rock that occurs in dikes in the quadrangle. The phenocrysts in these dikes include oligoclase, orthoclase, and quartz. The oligoclase and orthoclase phenocrysts are commonly larger than the quartz phenocrysts, and locally they attain lengths of one inch. Specimens 17 and 18, table 3, are typical rhyolite porphyry.

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Metamorphic rocks

The metamorphic rocks include marble and associated rocks, skarn, and jasperoid, which will be described in order below. Of these rocks, only the jasperoid is sufficiently widespread to be shown on the geologic map of the quadrangle (Nelson and Ross, 1969). More detailed descriptions and discussions of the metamorphic rocks will be found in Nelson and Ross, 1968, Farwell and Full, 1944, and Umpleby, 1917.

Marble and associated isochemically metamorphosed rocks

Marble occurs at the contact between limestone and the various intrusive rocks, notably the granitic pluton west of Mackay known as the Mackay Granite. The most conspicuous development is in White Knob, a gleaming white mass of marble that constitutes a landmark in sec. 3, T. 6 N., R. 23 E. Somewhat less conspicuous zones of marble are plentiful. They vary in width and in places extend hundreds of feet into the limestone from the contact with igneous rock. Locally the marble includes layers and masses of scapolite, diopside, tremolite, wollastonite, and garnet (largely grossularite). These are interpreted to be the results of recrystallization of pre-existing rock components without addition of material from other sources; some seem to have originally been beds of argillaceous and siliceous limestone and beds and nodules of chert.

Where the granitic rocks intrude sandy and silty beds of the Copper Basin Formation, isochemical metamorphism has resulted in recrystallization of quartz into mosaics that tend to conceal original sedimentary textures, and also the formation of muscovite, biotite, and diopside. All these changes may have been brought about without addition of outside material.

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Skarn

Skarn is of outstanding interest because all the larger ore bodies are within skarn. Skarn occurs locally along all the contacts between granitic rocks and limestone. At most places the skarn is discontinuous and no more than a few feet thick. Adjacent to the leucogranite porphyry along the northeast edge of the pluton west of Mackay, however, skarn is extensively developed and locally attains a thickness of several hundreds of feet.

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Some patches of skarn, in part associated with limestone, are surrounded by leucogranite porphyry. These patches of skarn are believed to be parts of roof pendants and engulfed blocks of limestone that have been altered to skarn. The skarn consists of garnet and diopside with subordinate amounts of epidote, actinolite, scapolite, wollastonite, and fluorite. Garnet makes up about three-quarters of the skarn; most is brown and is about midway in composition between andradite and grossularite. A small amount of it is yellow and is dominantly grossularite. According to analyses presented by Umpleby (1917, p. 64), the diopside contains considerable magnesium and a little iron. In some places the skarn consists almost entirely of magnetite and hematite, and skarn of this character about 1,000 feet northwest of the Grand Prize mine is in large enough bodies to be of economic interest. In addition to the minerals just listed, Umpleby (1917, p. 49-55) mentions eight that are thought to be components of the skarn: apatite, augite, custerite, hedenbergite, plagioclase, and vesuvianite. Ilvaite in rather large masses was found in contact metamorphosed limestone near Navarro Creek. The skarn seems to have been formed by fluids from the granitic magmas reacting with pre-existing rocks--mostly by metasomatism of limestone or marble.

A little of it seems to have formed from granitic rocks, and locally veins of skarn extend as much as 100 feet into granitic rock. Sulfide minerals and their alteration products are associated with the skarn, and concentrations of these within skarn constitute the most important ore bodies in the area. These minerals and their relationship to the skarn are described in greater detail under the description of the Empire mine in the ore deposits section of this paper.

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Jasperoid

The jasperoid consists of fine-grained, somewhat ferruginous silica that commonly has been in part brecciated and recemented by fine-grained quartz. All the jasperoid in the quadrangle is associated with limy rocks, principally limestone, and much of it occurs at and near depositional contacts of the Challis Volcanics on limy rocks. Where jasperoid caps hills of limy rock, the geologic setting indicates that these hills were once capped by volcanic rocks that have been removed by erosion. Although this relation strongly suggests that much of the jasperoid developed by replacement of limy rocks by fluids derived from the Challis Volcanics, it is less clear whether or not some of the plutons were sources of fluids that also caused jasperoidization. Jasperoid also occurs along faults that seem to have been avenues for the movement of silica-bearing fluids that caused jasperoidization.

Quaternary deposits

Snake River Group

Relatively unmodified basalt flows, which are some of the youngest parts of the Snake River Group, occur in the southernmost part of the Mackay quadrangle. These include lava flows that are slightly older than the flows of the Crater of the Moon and virtually non-weathered flows, that are probably correlative with those at Craters of the Moon National Monument. These flows will be described below; the older first and the younger second.

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Basalt flows which are older than the flows of the Craters of the Moon, but still young enough to be little modified by erosion, occur in both the southeastern and southwestern parts of the quadrangle. Those that crop out along Friedman Creek are believed to be the upper of two sets of flows that extend from the Snake River Plain, up the valley of the Little Wood River, into the lower reaches of Copper Creek, and into the valley of Friedman Creek. South of the quadrangle these two sets of flows are separated by old alluvium and at the southern edge of the quadrangle they are obscured by an extensive cover of young alluvium. The basalt flowed in the channel of Friedman Creek where it locally overlies old alluvium and is locally overlain by young alluvium. Chilled lava laps a short distance up the sides of the valley of Friedman Creek.

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The basalt flows in T. 3 N., R. 25 E., are not so clearly related to present topography as those just described. All that can be stated positively as to their age is that they are more weathered and eroded and therefore probably older than the lava in the valley of South Lava Creek, which is related to lava in the Craters of the Moon. They are, however, fresh in comparison with most of the basalt of the Snake River Plain farther south and they preserve many lava tunnels and other fragile features. They end abruptly a few miles east of the quadrangle, where they overlie lava of more ancient appearance, which is probably rather high in the thick sequence of flows that underlies the northern part of the Snake River Plain.

Young basaltic rock regarded as akin to that in and near the Craters of the Moon National Monument (Stearns, 1928; Stearns, Crandall, and Stewart, 1938, p. 93-100) is present in the southeastern corner of the quadrangle. It emerged from orifices in secs. 5 and 8, T. 2 N., R. 24 E., and occupied parts of the valleys of Dry Fork Creek and Lava Creek.

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These young rocks comprise lava flows and cinder masses which are so much fresher in appearance than the older flows of the Snake River Group previously described that they can be distinguished on the most casual observation. They are mostly black but locally they are colored brown or red by iron oxides. The flows generally have irregular upper surfaces that consist of broken, vesicular, and spiny blocks of basalt, consolidated while the lava beneath was still in motion. Exceptionally, they have ropy, pahoehoe type surfaces. They stand higher at their borders than in their median portions probably because the central parts of the flows partly drained away after the edges had chilled against the valley sides. The lava is sparsely covered by grass and brush, although little soil is visible except in holes where it has been carried in by water and, perhaps, by wind.

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The recent lava in the Lava Creek drainage includes two or more separate flows and issued from at least two closely spaced vents, one of which retains a visible crater. At both vents the material is fragmental ejectamenta, in part cinders and blocks, less commonly rounded bombs. Anderson (1929a, p. 16-17) reports that the lava is ophitic and contains labradorite, augite, and glass. Magnetite is conspicuous but olivine is absent. A flow from Lava Creek entered the valley of Dry Fork where it covered detrital material, largely alluvium. It dammed the valley of Dry Fork Creek and forced the water to escape underground through sink holes in the limestone of the valley floor. Springs north of the mouth of Cold Spring Canyon probably are fed by water from above the lava dam, although some water now escapes around the toe of the flow.

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The entire assemblage of dominantly basaltic flows and associated rocks that underlies the Snake River Plain was formerly termed the Snake River Basalt (Russell, 1902, p. 58) and originally regarded as Miocene to Recent in age. In current studies, Malde and Powers (1962) restrict the term Snake River Group to rocks of late Pleistocene and Recent age, the upper part of the Snake River Basalt of previous usage. Stearns (1928, p. 98-100) concluded that the last volcanic eruption in the Craters of the Moon National Monument probably occurred more than 250 years ago but perhaps not more than 1,000 years ago and that the earliest flows may be Pleistocene in age. Most are surely Recent. Anderson (1929a) thought that the lava within the Mackay quadrangle belonged to the earliest of the succession of eruptions related to the great rift in the area of the Craters of the Moon, but evidence on this point is scanty. The young flows in the Mackay quadrangle, particularly those in the Dry Fork Creek drainage, seem to be younger than Wisconsin glaciation and, therefore, Recent.

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Glacial deposits

Glacial erosion has been widespread and U-shaped valleys and cirques are common in all of the higher parts of the Mackay quadrangle. Glacial deposits are scattered over much of the quadrangle, but are most abundant in the northern part where the higher altitudes were favorable for the development of glaciers. Water-sorted glacial outwash merges with alluvium, mainly the old alluvium, and the boundaries between different kinds of surficial deposits cannot be drawn with precision.

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The glacial deposits in the Mackay quadrangle are divisible into a group of older deposits that occur well above the present streams, and a group of younger deposits that occur in and near the present stream valleys. The older high-level deposits are inferred to be either early- or pre-Wisconsin in age, and although none of them are shown on the geologic map of the quadrangle (Nelson and Ross, 1969), some of them will be described below. In Copper Basin the younger deposits, which are in harmony with the present drainage, can be further subdivided locally into older deposits, which are inferred to be of Bull Lake age, and younger deposits, which are inferred to be Pinedale in age. In the following paragraphs, the older deposits and the two subdivisions of younger deposits will be described in order from oldest to youngest.

High-level deposits, consisting of masses of glacial boulders and, more commonly, sparsely distributed erratics, are fairly plentiful in the higher parts of the quadrangle but none of these deposits are shown on the geologic map of the quadrangle (Nelson and Ross, 1969). Places where such material has been noted include slopes along the North Fork of Alder Creek below the mouth of Stewart Canyon, the ridge crest south of Cliff Creek in the SE¼ sec. 6, T. 6 N., R. 24 E., slopes between Corral Creek and the West Fork of Navarro Creek at altitudes near 8,000 feet, ridges near Bear Creek up to about 8,900 feet in altitude, the ridge that rises over 8,500 feet above sea level between the Right Fork of Iron Bog Creek and Smiley Creek, ridges above Cherry Creek above an altitude of 8,500 feet and almost to the divide

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with Copper Basin, saddles above Wood Canyon mostly below 7,500 feet, ridges along the East Fork of the Big Lost River near the western border of the quadrangle, and additional localities in which widely scattered boulders remain.

At some of these places the high-level glacial deposits include granitic fragments, although the drainage basins they are in do not contain granitic bedrock. None of the glaciation in the region is believed to have produced glaciers large enough to have crossed major drainage divides. Therefore, the presence of granitic erratics in drainage basins that do not contain granitic bedrocks is considered clear evidence for substantial changes in the drainage pattern subsequent to the deposition of these high-level glacial deposits. The fact that most of these deposits are now well above the present valley bottoms also indicates that there has been considerable downcutting since the glaciation that produced them.

It is clear that the presently recognizable high-level deposits are only remnants of once more extensive deposits, which were probably concentrated along old stream valleys where they were vulnerable to modification or removal by subsequent stream and glacial erosion. Most of the remaining high-level deposits probably owe their continued existence to fortuitous locations away from the sites of active stream and glacial erosion.

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The relation of the high-level deposits to present topography is reminiscent of that in the Bayhorse region where widespread glacial drift occurs some 1,000 feet above the present streams (Ross, 1929, 1937, p. 93-96). In the Bayhorse region the well-displayed early glaciation was tentatively assigned a Nebraskan age. While this remains possible, the evidence at hand for all such features in central Idaho indicates merely that the early glaciation was either early- or pre-Wisconsin in age.

By far the greater part of the deposits of glacial origin in the quadrangle is relatively young material that is related to the present drainage; it consists of slightly weathered irregular blankets of bouldery material on the floors and lower slopes of mountain valleys and canyons up to a height of several hundred feet above the streams.

In most of the quadrangle these young glacial deposits cannot be separated into material of different ages. In Copper Basin, however, the deposits of two glacial maxima can be locally distinguished, and where possible these have been shown separately on the geologic map of the quadrangle (Nelson and Ross, 1969). Differentiation of these young deposits was done with advice by Gerald M. Richmond.

The oldest of the young glacial deposits that are related to the present topography occupy an area of more than 4 square miles southwest of benchmark 7705, at the mouth of Cabin Creek. These deposits are somewhat weathered in comparison to the younger deposits to be described, and because of this, as well as their spatial relation to other glacial deposits, they are inferred to be of Bull Lake age.

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The younger part of the young moraine in Copper Basin lies to the west of, in part adjacent to, and presumably in part upon the deposits just described. On the east side of Star Hope Creek, this younger moraine underlies an area named the Potholes, from the kettle topography that occurs on it. On the west side of Star Hope Creek, the younger moraine makes up parts of ridge spurs, and the moraine attains a thickness of about 1,500 feet in the end of the ridge north of Broad Canyon. This younger moraine is inferred to be of Pinedale age on the basis of its freshness and its relationship to the other glacial deposits in the area.

Throughout the quadrangle the cirques do not contain mappable quantities of moraine and their surfaces tend to be bare rock. Talus piles and thin alluvium in hollows in the cirque floors were not mapped.

No remnants of glacial ice or of drift young enough to be attributed to the "little ice age" (Matthes, 1942) have been noted in the Mackay quadrangle, but it is plausible to suppose that glaciation occurred in the highest parts of the quadrangle at that time. This suggestion is based on the presence in the rugged parts of the Lost River Range to the east of snow banks with blue ice in their interiors (Ross, 1947, p. 1149). None of this ice can be considered a modern glacier, but it might be remnants of glaciers of the little ice age.

Old alluvium

The streams throughout the quadrangle are bordered by unconsolidated or, at most, poorly cemented alluvial material. The larger masses of alluvium probably record a long complex history of erosion and deposition, but for mapping and descriptive purposes they are divided only into old alluvium, terrace alluvium, and flood-plain alluvium. Only the larger masses of alluvium are shown on the geologic map of the quadrangle (Nelson and Ross, 1969).

The old alluvium corresponds essentially to the "older alluvium" in the Bayhorse region (Ross, 1937, p. 70-72) except that it is not believed to include glacial deposits, other than glacio-fluvial outwash. Corresponding deposits are plentiful in the Borah Peak quadrangle (Ross, 1947, p. 1125), but the alluvium there was not subdivided in mapping. No alluvial deposits old enough to be correlated with the Donkey Fanglomerate of Pliocene(?) age in the Borah Peak quadrangle (Ross, 1947, p. 1122-1124) were recognized in the Mackay quadrangle, but it is conceivable that some exist.

The old alluvium is above modern flood plains and even above terrace deposits that border the flood plains. It lies on low ridge crests and high terraces and fans formed well before the present erosion cycle and it generally shows some cementation.

The largest masses of old alluvium occur as fans that occupy much of the Big Lost River valley and that are now incised by the river and its tributaries. These fans are composed mainly of fairly coarse gravel and sand, derived from the mountains under conditions different from those of the present. The material of the fans is rather poorly cemented, in large part by calcium carbonate. It is firm enough to maintain low, steep bluffs, but it crumbles readily under a pick. The lower ends of the fans are truncated along fairly continuous bluffs where the old alluvium is incised by the Big Lost River.

The old alluvium in the valley of the Big Lost River near Mackay is very thick; the alluvium of the modern flood plain and adjacent terraces is relatively thin. Gravity traverses were conducted in the valley of the Big Lost River by J. Jacobson and D. Hill. According to D. P. Hill (written commun., October 15, 1959), and David Strait (written commun., December 6, 1960), who interpreted the data, a traverse across the valley along the southern boundary of the northern tiers of sections in T. 5 N., R. 25 E., indicates that the alluvium there attains a maximum thickness of about 3,000 feet. Another traverse along the eastern boundaries of sec. 31, T. 7 N., R. 25 E., and sec. 6, T. 6 N., R. 25 E., a mile west of the eastern border of the quadrangle, gives an inferred depth of 6,000 feet. A traverse north from near the dam at the Mackay reservoir suggests that a shallowly-buried ridge of dense rock extends east from the dam, and that the alluvial fill north of the dam is thicker than that over the buried ridge. Scattered outcrops of White Knob Limestone indicate that the buried ridge may be composed of this rock. The data are not sufficient to indicate whether this buried ridge is continuous across the valley; presumably the ancestral Big Lost River passed through it.

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In Copper Basin the smooth surface that extends westward from Copper Basin Ranger Station for a distance of about 4 miles is underlain by gravel, sand, and silt, somewhat doubtfully included in the old alluvium. The material here may be somewhat younger than most of the old alluvium. It is sufficiently well sorted and rounded to indicate deposition by water rather than ice. The small glaciers that once filled the neighboring mountain valleys, or their ancestors, must have yielded detritus to the lowland as they melted and the material here described may include products of this run-off.

Patches of loose gravel, which are not shown on the geologic map of the quadrangle (Nelson and Ross, 1969), occur on ridge crests along the lower reaches of Dry Fork Creek at altitudes up to 400 feet above present creek level. These represent terrace gravel laid down by the Dry Fork Creek or its tributaries early in its history. The amount of erosion that has occurred since this gravel was deposited suggests that it may have been deposited during the Pleistocene epoch.

Terrace alluvium

The terrace alluvium is in general intermediate in age between the old alluvium and the flood-plain alluvium. Most of it is probably fairly young; some of it may be as young as some of the flood-plain alluvium; and a little of it may be as old as some of the old alluvium.

Two sets of alluvium mantled terraces are present along the valley of the East Fork of the Big Lost River beyond where it emerges from Copper Basin. The lower set is fairly continuous but the upper set is discontinuous. Two sets of gravel mantled terrace also occur along

Copper Creek in the southwestern corner of the quadrangle; these two sets are about 20 feet and 100 feet above the flood plain of Copper Creek. The valley of Fish Creek is also terraced but the terrace deposits were not delineated on the geologic map of the quadrangle (Nelson and Ross, 1969).

Flood-plain alluvium

The flood-plain alluvium of the present report corresponds to the "younger alluvium" and "flood-plain alluvium" of the Bayhorse region (Ross, 1937, p. 72-73) and to the younger part of the alluvium mapped in the Borah Peak quadrangle (Ross, 1947, p. 1125). Alluvium is present on the flood plains of most streams in the Mackay quadrangle but, as in the Bayhorse region, it was mapped only in large valleys.

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Thin beds of nearly white, pulverulent volcanic ash occur in at least four places in the quadrangle. All are in unconsolidated material allied to the young alluvium. One is in a bench cut in the flood plain of the Big Lost River at the border of Mackay Reservoir. One is in unmapped grav l along the West Fork of Navarro Creek, downstream from and probably younger than the large glacial deposit farther south. Another ash bed is in torrential fill in a gully in sec. 32, T. 2 N., R. 21 E. This fill has been dissected by recent erosion to expose the ash beds. Another is in the fill of a minor gully tributary to Antelope Creek in sec. 11, T. 4 N., R. 24 E. Probably all the fill that contains ash is rather old flood-plain alluvium. Ash deposits in broadly similar environments have been reported from numerous places in the Northwest (Horberg and Robie, 1955; Riggs and Gould, 1957) and most appear to be from a single eruption 6,700 years ago. The ash in the Mackay quadrangle seems identical to those listed in the two reports cited (Powers, H. A., 1961, oral communication).

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Landslide deposits

Landslides and landslips are plentiful but few have been mapped. One conspicuous mass of landslide debris, in and near sec. 19, T. 7 N., R. 25 E., is shown on the geologic map of the quadrangle (Nelson and Ross, 1969).

Structure

Faults

Although no low-angle faults have been recognized in the Mackay quadrangle, the prevalence of such faults in the area to the west suggest that low-angle faults may be present here also. The reader will realize that much of the interlayering of the various rock types of the Copper Basin Formation and the White Knob Limestone, which is herein attributed to depositional interbedding, could equally well be the result of juxtaposition by faulting. Recognition of low-angle faulting is hindered by the scarcity of useful marker horizons within the Copper Basin Formation and White Knob Limestone, as well as by the widespread cover of volcanic rocks.

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Many steep faults have been recognized in the Mackay quadrangle, and doubtless many more are present but unrecognized, especially in areas underlain by the Challis Volcanics. Many of the faults shown on the geologic map of the quadrangle (Nelson and Ross, 1969) are inferred from the presence of steep straight scarps either in the present topography or in the surface at the base of the Challis Volcanics. Part of the surface at the base of the volcanics is shown by contours on the geologic map (Nelson and Ross, 1969); it is a composite of the topography before the eruption of the volcanics and the modifications of that surface by later deformation. Commonly steep straight slopes in the surface beneath the Challis Volcanics coincide with modern escarpments. At most places there is insufficient evidence to determine whether these are fault-line scarps that existed as steep hillsides prior to the deposition of the volcanic rocks, or whether they are fault scarps that formed after the volcanics had been laid down. probably some are one, some the other, and some a combination of both.

At least some of the volcanic rocks along the fault that crosses the heads of Navarro Creek seem to have been deposited subsequent to the movement on that fault, because the volcanic rocks extend across the fault and into canyons cut in the scarp.

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On the other hand, the movement on the fault that extends south-southwestward from the vicinity of Mackay seems to have occurred after at least part of the volcanic rocks had been deposited. Here jasperoid, in part brecciated and recemented by jasperoid, occurs in the Challis Volcanics along the fault. The straightness of this contact and the fact that the volcanic rocks are in contact with Paleozoic rocks along it also suggests that it is a fault that was active after at least some of the volcanism. At the northern end of this fault, old alluvium has been deposited against the fault scarp. There is no evidence that any movement has occurred on this fault during or after the time that the old alluvium was deposited.

The straightness of the fault contact between volcanic rocks and Paleozoic rocks, which extends northward from Copper Creek, suggests that this fault was active during and perhaps after, the deposition of the Challis Volcanics.

Within the Paleozoic rocks there are few recognizable stratigraphic markers that can be used for determining structures. In the southwest part of the quadrangle in the vicinity of Argosy Creek, however, limestone beds in the Copper Basin Formation are truncated by a fault.

The steep southwest-facing front of the Lost River Range, along with the abrupt change in stratigraphic level between the mountains and the isolated outcrop at the SW cor. sec. 4, T. 7 N., R. 24 E., indicate that a major structure, probably a fault, exists at this mountain front.

Many of the centers of eruption in the Craters of the Moon National Monument area, south of the Mackay quadrangle, are along a fracture zone

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that trends about N. 40° W. and has been named the Great Rift zone (Stearns, 1928, p. 7-9). As Anderson has noted (1929a, p. 18-19; 1929b, p. 26-27), a northwestward projection of the rift zone lines up with the eruptive centers of young basalt near Lava Creek.

Folds

Throughout the quadrangle the Paleozoic rocks are folded, and the major folds that can be delineated trend between about due north to about N. 45° W. Major folds that have been recognized include those in the Lost River Range in the northeastern corner of the quadrangle, the anticline that extends with possible interruptions from Corral Creek southeast past Cherry Creek and probably to Timbered Dome, the anticline that extends south between Star Hope and Copper Creeks, and the anticline that lies west of Dry Fork Creek.

Superimposed on the major folds are many minor folds which were not delineated at the scale of the mapping for this report. In the limestone many of the minor folds are intricate, nonsymmetrical, and of a type that seems to be common in limestone. Some of the deformation in the limestone seems to be associated with the emplacement of the masses of intrusive rocks in the quadrangle. Many of the attitudes of the beds near the intrusive rocks west and southwest of Mackay are based on work of summer students of the University of Idaho, School of Mines, and were furnished through the courtesy of Professor George Williams.

The Challis Volcanics have been folded but less intensely, and apparently less systematically, than the older rocks.

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Geologic history

Although no rocks older than Devonian are exposed in the Mackay quadrangle, data from neighboring areas suggest that the quadrangle was the site of deposition of sediments in the Precambrian epoch. Probably, though not unquestionably, no sedimentation occurred in Cambrian time. Siliceous sands were probably deposited in late Ordovician time, as quartzite of this age is extensive in nearby parts of the Lost River Range. Some of the more argillaceous Ordovician rocks known to be abundant farther west (Umpleby, Westgate, and Ross, 1930, p. 17-23) may be present below the surface, but their absence in the Borah Peak quadrangle suggests that they may not have extended across the Mackay quadrangle. Carbonate rocks of Ordovician and Silurian age were almost certainly deposited, but they are not now exposed. Marine carbonate rocks, largely dolomitic, of Devonian age, are the oldest rocks that are now exposed in the quadrangle.

During much of Mississippian, Pennsylvanian, and part of Permian time, sequences of rock thousands of feet in thickness were being deposited in the region. In and east of the eastern part of the quadrangle, these are largely carbonate rocks; whereas, in and west of the western part of the quadrangle, they seem to be largely noncarbonate clastic rocks. The White Knob Limestone is the principal component of the carbonate sequence in the east, and the name Copper Basin Formation is applied to the noncarbonate sequence in the west. Near the middle of the quadrangle, rocks typical of these two formations are interlayered. As already noted, some of this interbedding probably is

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depositional, but some of it may have resulted from low-angle faulting. These sequences of rocks are several times thicker than rocks of comparable age to the east in Montana, which suggests that these rocks in the area of the quadrangle were deposited in an actively subsiding basin, perhaps a geosyncline; whereas, the rocks to the east seem to have been deposited in a more stable environment, perhaps a shelf. The dominance of noncarbonate clastic rocks in the western part of the quadrangle suggests that there may have been an actively rising area, or geanticline, near the western edge of the quadrangle.

The major deformation of rocks in the area seems to have occurred after the deposition of the White Knob Limestone and before a considerable period of erosion that occurred prior to the eruption of the Challis Volcanics in early Tertiary time. Deformation of this general age in the Northern Rocky Mountains region is generally ascribed to the Laramide orogeny which took place in the later part of Mesozoic time. The Idaho Batholith is considered to have been emplaced during the Laramide orogeny, but none of the intrusive rock in the quadrangle is believed to be that old.

No Mesozoic strata have been found anywhere in or near the Mackay quadrangle, and the region is thought to have been dry land throughout the Mesozoic era.

The next episode for which there is clear evidence was a period of Tertiary igneous activity. This activity began with the eruption of volcanic rocks, which continued throughout the episode. Penecontemporaneous intrusion of granitic plutons and associated dikes occurred over

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a span of time, which, however, seems to have begun after the volcanism was well under way. By the time this igneous activity had ceased, the entire area of the quadrangle was probably buried beneath lava flows and associated pyroclastic rocks of the Challis Volcanics. Locally some crumpling and faulting of the older rocks seems to have accompanied the emplacement of the intrusive rocks.

Since the eruption of the Challis Volcanics, erosion has been dominant, but the presence of alluvium of several ages indicates that down-cutting by streams hesitated, at least locally, several times. The alluviation may have been due in part to climatic fluctuation, and in part to local interference of drainage by structural sagging or faulting. The regional seismicity, and large local differences in altitude in the area, attest to continuing deformation in the region.

During Pleistocene time, glaciers sculptured the higher parts of the quadrangle, and at least three glacial maxima are recorded in deposits in the quadrangle.

During late Pleistocene and Recent time, basalt flows, which are among the youngest parts of the Snake River Group, flowed into several of the valleys in the southernmost part of the quadrangle.

Mineral deposits

The Mackay quadrangle contains the Alder Creek and Copper Basin mining districts, large parts of the Little Wood River and Lava Creek mining districts, and the easternmost edge of the Alto district (Ross, 1941, pl. 1). All of these have been productive and all continue to be sporadically active, although on a reduced scale compared to past activity.

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Copper has been the principal product but the quadrangle has also yielded precious metals, lead, zinc, tungsten, barite, and iron. Molybdenum and fluorspar are known. Each of the mining properties for which information is at hand is described below. The descriptions are based on published and other reports and on visits made in the course of the present investigation, but this investigation did not include systematic study of the mineral deposits.

Alder Creek mining district

The Alder Creek district lies immediately west of Mackay. It has an area of over 70 square miles and extends south to Alder Creek and on the west includes the drainage basins of Navarro Creek and Stewart, Mammoth, and Sawmill canyons. Nearly 50 properties, mostly on separate lodes, have been worked at one time or another, but most of the production has come from the Empire, Horseshoe, White Knob, Blue Bird, and Champion mines, especially the Empire. Much of the larger part of the production has been in copper.

The Empire mine, in sec. 36, T. 7 N., R. 23 E., produced continuously from 1902 through 1930, and sporadically since then, first under the White Knob Copper Company, and later under the Empire Copper Company, the Idaho Metals Company, the Mackay Metals Company, the Mackay Exploration Company, and, finally, the Lost River Mines Incorporated. Umpleby (1917, p. 94) estimated the production through 1913 at $2,500,000, mainly in copper, and Ross (1930, p. 8-9) presented production figures from the beginning of 1914 through April 1929 that total over $6,000,000 in large part from leasing operations. Farwell and Full (1944, p. 5) show the production of metals by weight from 1902 through 1942. In 1956 a sulfide ore body was discovered in an adit that was driven more than 1,500 feet from the surface at approximately the 1,100-foot level of the mine. Exploration has continued since then and in 1960 ore was shipped from this adit. In 1961 a mill was constructed at the portal. Some iron oxide from open cuts above the principle old workings was shipped in 1958.

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Most of the ore that has been shipped from the Empire mine has been oxidized material not susceptible to concentration by methods available at the time the mining was done. This ore is reported to have contained 4 to 5 percent copper. Concentrates of sulphide ore averaging about half this much copper were shipped (Ross, 1930, p. 15), and some shipped in the early days contained as much as 6 percent (Umpleby, 1917, p. 49). At least one carload of tungsten ore containing 2.08 percent WO_3, was mined below the 1,000-foot level, and was shipped in 1942 (Farwell and Full, 1944, p. 1, 11). During the most active part of the history of the property, only fairly rich copper ore or material easily concentrated by gravity methods could be handled. Presumably much copper-bearing material that could be profitably produced using modern techniques remains in the mine and some may be in the dumps.

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The Empire mine has open pit and underground workings in a north-trending arcuate zone (Farwell and Full, 1944, p. 12) about 3,500 feet long with a maximum width of 400 feet. The horizontal workings have an aggregate length of over 60,000 feet on more than 9 levels, scattered through a vertical range of over 1,500 feet. The lowest exploration is in the 1,600-foot level, also termed the Cossack tunnel. The main portal of the mine is at the 700-foot level, which is also the longest level. Most of the ore so far mined came from stopes above this level through a vertical range of roughly 500 feet, but ore was mined long ago from stopes extending 300 feet below the 700-foot level.

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The concentrations of ore minerals in the Empire mine and some of the neighboring mines are intimately associated with skarn, which is described in the section of this paper on metamorphic rocks. The skarn occurs along the contact between limestone and the leucogranite porphyry. Various ideas as to the nomenclature, relationships, and age of the intrusive rocks and the skarn have been expressed by previous investigators (Kemp and Gunther, 1908; Umpleby, 1917; Farwell and Full, 1944; Leland, 1957). In the present discussion nomenclature and concepts concerning the rocks are based on the work of Nelson (Nelson and Ross, 1968), done in connection with the present investigation, and on that of Thor Kiilsgaard (in U.S. Geol. Survey, 1962), who visited the mine in 1961. Most of the ore shoots are in skarn adjacent to marble; some are entirely within skarn; and some are at the contact between skarn and leucogranite porphyr. Umpleby (1917, p. 45) stated that most of the ore shipped came from ore shoots within the granite porphyry, 100 to 800 and in one case 1,200 feet from the contact. Probably most of these shoots were in skarn that had formed by replacement of roof pendants and engulfed blocks of limestone, but in places intrusive rocks contain skarn minerals, some of which seem to be replacements of the intrusive rocks and some to fill fissures.

The mineralized shoots in the Empire mine are irregular pipelike bodies (Farwell and Full, 1944, p. 10) that commonly are elliptical in plan, with their long axes at various different attitudes but usually steeply pitching. In horizontal cross section the long axes range in length from 15 to 200 feet and the short axes from 5 to 55 feet. One

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shoot has been mined almost continuously through a vertical distance of 600 feet but most are less persistent. Some ore bodies strike northwest; others northeast. Most pipes pitch northeast, east, or southeast in directions nearly at right angles to their strikes. Some pipes branch upward; a few branch downward. A few ore bodies, mostly under marble hanging walls, are flat. Stope maps show more irregularities in trend than systematic arrangement. There is a tendency for stopes to be radial with respect to the main mass of the leucogranite porphyry but some of the larger stopes nearly parallel the boundary of that body. Dikes of various shapes and trends traverse the skarn, adding complexities to the form and distribution of ore bodies. The mine contains various fractures and shear zones and some of these have proved to be useful guides in the search for ore (Ross, 1930, p. 15). The fractures and shear zones are not sufficiently well shown on available maps to permit generalizations on their distribution and origin. Umpleby (1917, p. 45) has called attention to one gouge-lined fracture with a strike of N. 20°-30° E., and a dip of 50°-60° SE. He regarded this as a product of minor post-mineral movement along a pre-mineral fault. Farwell and Full (1944, maps and sections) show numerous faults whose trends average near N. 45° E., and whose dips are southeast. Their structure sections show these faults traversing dikes and skarn bodies without displacement. The limestone is tightly and irregularly folded but details on the structure of limestone near the ore bodies are not available.

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Kiilsgaard (U.S. Geological Survey, 1962, p. A3-A4) found that in the lower levels of the Empire mine steeply plunging irregular pipe-like bodies of primary ore have formed where northeast-trending premineralization faults cut the skarn. He reasons that the jointed and fractured skarn was more permeable to mineralizating solutions ascending along the faults than were the limestone and granitic rocks. His conclusions support, in part, the earlier conclusions of Umpleby (1917, p. 44-49).

The hypogene minerals in the ore bodies in the Empire mine (Umpleby, 1917, p. 49-55) include chalcopyrite, pyrite, pyrrhotite, magnetite, scheelite, molybdenite, sphalerite, specularite, galena, tetrahedrite, bornite, calcite, quartz, fluorite, in one place siderite, and the minerals of the enclosing skarn. The sulphide body in the tunnel started in 1956 contains pyrrhotite, pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, covellite, malachite, and possibly scorodite. Much of the ore is oxidized and this contains such minerals as azurite, brochantite, calamine, chalcanthite, chrysocolla, native copper, copper pitch, covellite, cuprite, gypsum, hematite, limonite, kaolinite, malachite, opal, pyrolusite, smithsonite, and tenorite. Chalcocite has been noted but is nowhere abundant. There is no evidence that secondary enrichment of economic significance has occurred anywhere in the mine.

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The distribution of supergene and hypogene ore minerals in the Empire mine has not been studied in any detail. Unoxidized sulphide remains within 50 feet of the surface in a few places but oxidized metallic minerals are encountered in ore shoots hundreds of feet underground. It seems that surface water was able to penetrate readily into fractured ground throughout the mountain in which the workings are situated. Wherever this water reached, sulphides were oxidized but no stable zone was established at which secondary enrichment could take place.

The mines and prospects in the area surrounding the Empire copper mine have yielded mainly lead and zinc ore, although copper is also present. They include the White Knob, Grand Prize, Blue Bird, Champion, Horseshoe, and smaller properties. The deposits in these properties differ from those of the Empire mine in that skarn is less abundant or absent in them, and the mineralized bodies are irregular veins rather than pipes. The properties named above have all been productive at one time or another but available records of production are incomplete.

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From 1916 through 1928, the Horseshoe mine yielded 8,869 tons of crude ore, 90 tons of concentrates, 63.57 ounces of gold, 94,901 ounces of silver, 20,334 pounds of copper, 2,488,503 pounds of lead, and 39,571 pounds of zinc (Ross, 1930, p. 9). At the Horseshoe mine, the principal fracture zone trends about N. 30° W., and is in marble. The production from this mine has been mainly lead carbonate ore containing some gold and silver, although bodies of sulphide containing pyrite, sphalerite, chalcopyrite, and galena occur in the mine. The sphalerite contains so much iron that it has been unmarketable. The workings extend to 350 feet below the surface and oxidized material to more than 200 feet.

The Champion mine has been known since early in the history of the district but little mining was done there until after 1931. J. L. Ausich (1961, written commun.) reports that 5,947,132 pounds of crude ore has been produced since then. The overall average of this ore is 12.45 percent lead, 2.86 percent copper, 26.16 percent iron, and 3.18 ounces silver. This mine is mostly in White Knob limestone but the workings extend into granitic rock. Some skarn is reported (Umpleby, 1917, p. 101). Available data on the Grand Prize, White Knob, Blue Bird, and other small mines in the vicinity of the Empire mine are too scanty to warrant inclusion here.

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The Copper Queen workings on the East Fork of Navarro Creek are held by L. D. and H. H. Lindburg and E. G. Pence. They consist of short tunnels and shallow cuts. No production is on record. The bedrock is White Knob Limestone, cut by dikes of several kinds. The limestone is somewhat marmorized and contains small masses of skarn composed of garnet, ilvaite, and magnetite. The mineralized material is in fracture zones, in part on dike boundaries. The metallic minerals seen were oxidized. Scheelite is reported to occur in skarn in these workings (Cook, E. F., 1956, p. 29).

Mine workings have been noted near the head of Mammoth Canyon, along Stewart and Sawmill Canyons, Cliff Creek, and near Sheep Canyon (T. 6 N., R. 25 E.). All are small and most have had little work done on them for some time. Several of the lodes in this part of the district contain tungsten (Cook, E. F., 1956, p. 27-29). These include the Phoenix property near the head of Mammoth Canyon in which powellite and scheelite occur in skarn, the Vaught property close to Cliff Creek in which powellite and scheelite have been found, the Hanni mine near the head of Cliff Creek from which 11 tons of ore assaying 1.60 percent WO_3 were shipped in November 1953.

Copper Basin mining district

The Copper Basin district embraces the mountains surrounding Copper Basin. It contains the Copper Basin, Cornhusker, Star Hope, and smaller properties. The Copper Basin mine, which has also been called the Reed and Davidson mine, is in unsurveyed sec. 35, T. 6 N., R. 22 E. Adits, shafts, and cuts are scattered over a rather large area of hillside through a vertical range between 7,800 and 8,600 feet in altitude. Some of the workings are still open but in our inspection no stopes were reached that might have given some measure of past production. A shaft 265 feet deep, with workings off of it, is reported (Umpleby, 1917, p. 102-105) to have been sunk on a ridge at an altitude of about 9,500 feet. This was not seen during the present investigation. The deposits were first located in 1888 and much of the activity was in the following few years, although there have been revivals since then, notably in 1918 to 1920. A smelter was set up in 1900, but does not appear to have been successful. The total output has been estimated at $230,000 (Ross, 1930, p. 10), mostly in copper, although some lead has been obtained. From 1912 through 1919, the mine produced 88.56 ounces of gold, 16,227 ounces of silver, 696,060 pounds of copper, and 2,662 pounds of lead with an aggregate value of $185,404. The mine workings are in argillaceous, calcareous, and quartzitic rocks, near the contact between the White Knob Limestone and the Copper Basin Formation, and are cut by various dikes. There are zones of silicified breccia. The calcareous beds in the mine contain lime silicate minerals like those in the Empire mine. So far as is known, all the ore mined was oxidized. Ore seen in these workings by Ross in 1929 is in tabular replacements along the bedding in quartzite.

The Cornhusker property is high on the northeastern slope of Muldoon Canyon. It is owned by Harvey Beverland and was discovered about 1880 by the owner's grandfather. It has been worked intermittently since then but all the workings are shallow and widely spaced. Some lead carbonate ore was shipped in 1957 and some shipments may have been made in the early days. The bedrock is Copper Basin Formation including some intercalated limestone. The mineralization is in long fractures, mostly in calcareous rock, but the bodies are both small and widely scattered so far as can be judged from observations made by Ross in 1957. An adit was started that year in a prominent limestone ledge but the result of this exploration is not known.

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The Star Hope mine, which has been known also as the Starr Hope and Star of Hope mine, is on Star Hope Creek. It was discovered about 1880 and worked actively for some 10 years with some revivals of interest since then. The workings are close to a small tributary on the northeast slope of the valley of Star Hope Creek and were reached by a switchback road that ascends from an altitude of about 8,400 feet to one of over 9,400 feet, passing several portals on the way. This road was only a few years old but it was impassable to vehicles in 1956. The dumps indicate that they result from somewhat less than 3,000 feet of workings in all, but the adits were not safely accessible in 1956. Umpleby (1917, p. 105) found a total of 1,500 feet of workings at the time of his examination in 1912. He spoke of a production of $50,000 from rich lead-silver ore. The bedrock belongs to the Copper Basin Formation which here is carbonaceous and contains intercalated limestone. The rock is intricately contorted. The dumps show that the vein matter was vuggy quartz containing pyrite and galena. There are numerous dikes and one of these is sheeted and altered by mineralization.

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At the southwestern border of the alluvium of Star Hope Creek some workings of recent appearance were noted in 1956. These consist of short adits and a small stope, holed through to the surface. The vein matter here is chalcopyrite, galena, and calcite in granular vein quartz. Boundaries with the quartzitic wall rock are irregular. Mineralization resulted from replacement of the rock and only subordinately from fissure filling.

There are several prospects west of Copper Basin. The principal one noted during the present investigation is the Red Rock prospect in the mountains south of Ramey Creek. It is owned, according to a claim notice on the ground, by B. A. Miller and V. A. Johnson. The principal adit, probably a few hundred feet long, was caved at the time of a visit by Ross in 1957, but a hole about 25 feet above it showed recent work. This excavation is on a poorly defined zone of fracture in chloritized and silicified rock mostly originally granitoid. Some of the altered rock contains pyrite and galena.

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Little Wood River mining district

The Little Wood River district is an irregular area that is about half in the Mackay quadrangle and about half in the Hailey quadrangle. The district derives its name from the principal stream that traverses it, whose head-waters are in the Hailey quadrangle. The principal mining activity in the district has been in the Mackay quadrangle in and close to the eastern part of T. 3 and 4 N., R. 21 E., and the western part of T. 3 and 4 N., R. 22 E. This part of the district, sometimes called the Muldoon district, is drained by Copper Creek, a tributary of the Little Wood River. Copper Creek was formerly called Muldoon Creek, and a town called Muldoon and two smelters were once situated at the confluence of Copper Creek and the tributary now called Muldoon Creek, formerly the East Fork of Muldoon Creek (Umpleby, 1917, fig. 14). Almost no trace of the old town and the smelters remain and most of the mine workings have long been caved. Ore was discovered in the district in 1881 and major activity continued until about 1910 (Finch, E. H., <u>in</u> Umpleby, 1917, p. 106-110). By 1913, when Finch visited the area, many of the workings were already inaccessible. There have been only minor intermittent revivals since then.

The Muldoon mine, which is the principal mine in the district, is reported to have produced about $200,000 from silver-lead ore. The mine had about 4,000 feet of drifts and crosscuts (Finch in Umpleby, 1917, p. 109-110) plus several stopes. The vertical range of the main workings was fully 400 feet and exploration has been carried through a vertical distance of about 1,200 feet (Anderson and Wagner, 1946, p. 21). The deposit is reported by Anderson to be a replacement along the bedding of quartzitic and slaty rocks, with an igneous rock on the hanging wall in places. The latter is probably one of the many dikes in the area. The beds strike northward and dip northeast, with numerous variations in attitude. Ore was found in diverse rocks, including the dike rock. The ore minerals included argentiferous galena, pyrite, sphalerite, and chalcopyrite, with some quartz.

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The Idaho Muldoon mine, not to be confused with the Muldoon mine, has almost surely been productive although records of production are unknown. The principal working of the mine is an adit in limestone, which, with its branches, has a length of over 400 feet. There is a shaft or winze 160 feet from the portal. This is 40 feet deep and has a 40-foot drift at its bottom. (Anderson and Wagner, 1946, p. 20-21, fig. 4.) The principal vein follows a fault of variable attitude. This fault strikes northeast and in most places dips 65°-70° NW., but near the shaft dips 80° SE. When seen by Anderson, calcite stringers and scattered grains of galena were visible along the fault in the part of the workings near the portal. Farther in he noted an ore shoot that dips steeply southeast with a northeasterly plunge. The shoot is about 40 feet long and up to at least 3 feet wide. It contains galena, pyrite, chalcopyrite, and sphalerite, with oxidation products in surface exposures. The fracturing throughout the workings is complex. One persistent fracture zone is followed southward by a drift nearly 100 feet long. The trend is somewhat west of north and the dip is about 67° E. The rock is altered on this fracture, but no sulphides were seen by Anderson and Wagner. In addition to the deposits just described, the mine has a replacement deposit on the bedding of limestone that strikes N. 20° W. and dips 35° NE. This is exposed in cuts for a distance of about 100 feet. It contains the sulphides already noted plus much arsenopyrite. Oxidation products are present. The sulphides are sporadically distributed, mostly in a layer less than 10 inches thick.

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The dumps of old workings are plentiful along both sides of Muldoon Creek but, apart from the two mines described above, essentially no information is available in regard to them.

During the late 1950's the Muldoon Barium Co. prospected for barite along Copper and Muldoon Creeks and has mined in sec. 12, T. 3 N., R. 21 E. Some shipments have been made but work was halted in 1960. The workings here consist of an adit with branches, totalling about 600 feet with an open cut above, and various prospect openings. The bedrock belongs to the Copper Basin Formation, which here includes limestone lenses in somewhat calcareous quartzitic beds. The mine is close to one of the major faults of the region, and the rocks are intricately contorted. They have been bent into overturned folds and displaced by minor overthrusts. Tertiary dikes cut the beds. The principal barite body has been followed underground for over 200 feet. It is roughly accordant with the contorted bedding and has been broken by slumping and perhaps also by recent faulting. Much of it has been crushed. Some of the transverse fractures are lined with quartz containing galena and sphalerite. The summary above is based on maps and descriptions furnished by the company (Z. A. Franciskovic, written communications, March, October, and December 1960) for use in this report, supplemented by observations on the property.

Exploration by the Muldoon Barium Co. has revealed barite in several places along Muldoon Creek, mostly near the old Idaho Muldoon mine. The presence of some barite on old dumps is reported by the company, but the amount found in mining for silver and lead must have been small as the mineral is not mentioned in published reports.

The Eagle Bird mine near the head of Garfield Canyon is reported to have yielded 3,380 tons of ore with a net value of $62,775 between 1948 and 1953 (McGowan, V. L., October 1959, written communication). Various other workings are scattered over the 21 claims of the property but these were not examined in the present investigation. Probably little work has been done in them for some years. The Eagle Bird adit, with its branches, is about 800 feet long and has stopes that reach the surface. It is entirely in limestone and explores a mineralized fracture zone that trends about N. 20° W. and dips 40° and less to the northeast. The zone is controlled by irregular, in part poorly defined, fractures but conforms approximately to the bedding of the limestone. The various other workings scattered widely over the property were driven to explore other mineralized zones, presumably like those of the Eagle Bird. The ore at the latter contains galena, pyrite, pyrrhotite, sphalerite, arsenopyrite. According to Cook (1956, p. 12), it also contains scheelite. Samples were found to carry 0.02 to 0.69 percent WO_3. The limestone is silicified and dolomitized and contains sparsely disseminated sulphide grains. Smelter returns furnished by the lessees show that the ore shipped contained 4.6 to 16.2 percent lead, 1.7 to 10.1 percent zinc and 7.6 to 17.9 ounces of silver to the ton.

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The Silver Spar property is on Black Spar Creek, and was formerly known as the Black Spar mine. It includes 20 patented claims, some of which were patented in 1891, as well as some unpatented claims. Except for part of a drainage adit, the workings were inaccessible at the time of the present study. They are in the Challis Volcanics. Most of the data summarized here was furnished by Dr. Dwight Lenzi, President of the Silver Spar Mining Co. (written communications, with maps, November 1959, February 1960). A map prepared in 1923 shows an adit with its portal close to Copper Creek that extended a total of about 1,100 feet to tap workings from a shaft on Black Spar Creek. The shaft is reported by Dr. Lenzi to be 200 feet deep with a drift at the bottom and another at the 100-foot level, probably connected with the adit. There are various other adits on the property. In 1957 an attempt was made by prospectors to enter the adit but was promptly abandoned because of the large volume of water encountered. Ore specimens at the shaft contain tetrahedrite, galena, sphalerite, and pyrite, in a quartz, carbonate, and barite gangue. The carbonate is probably ankerite but the amount collected is too small for precise identification.

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The old workings along Little Copper Creek are reported (Finch *in* Umpleby, 1917, p. 109) to include those on the Drummond claim near the head of the creek. Unlike most deposits in the district, this was valued mainly for copper. Finch noted that the ore was in calcareous rock containing wollastonite, diopside, garnet, and epidote, under a hanging wall composed of a granitic porphyry dike. The ore minerals included galena, anglesite, and small crystals of oxidized copper sulphides. The ore mined was reported to contain 6 percent copper and $5 to $6 a ton in gold.

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Lava Creek mining district

The Lava Creek district is an irregular area mostly in T. 2 and 3 N., R. 24 E. Most of it is within the Mackay quadrangle but part is south of the quadrangle boundary. The Era district of Umpleby (1917, p. 14 and 120) is the northern part of the Lava Creek district, as the term is used here. The town of Era, founded on Champagne Creek during the 1880's, has long been abandoned. Mining began in the district in 1883 but was halted in 1887 after known bodies of rich oxidized silver ore were exhausted. During the eighties a mill at the Hornsilver mine is estimated to have yielded $300,000 from several mines. Of this $250,000 came from the Hornsilver mine (Anderson, 1929b, p. 30). Umpleby (1917, pl. 1) shows the Hornsilver mine to be in the SW¼, sec. 11, T. 3 N., R. 24 E. The Hub mine, in the southwestern corner of sec. 9, T. 2 N., R. 24 E., is supposed to have yielded $90,000, most of it during the eighties and early nineties of the past century. The northwestern part of the district, known as the Lead Belt, was found during the early prospecting but active development did not begin until 1905 and was never very productive. Umpleby (1917, p. 14) credits the mines in the Lead Belt with a yield of $25,000. During the 1920's the district had a revival of activity in an attempt to utilize sulphides. The production during this revival has not been recorded in

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detail but general statements by Anderson (1929b, p. 31) suggest that it was less than $100,000. Interest was renewed in 1943 and continued for a few years. At that time the Last Chance mine (Anderson, 1947, p. 453), which is at the western edge of sec. 14, T. 3 N., R. 24 E., yielded 1,174,506 pounds of lead, 2,007,769 pounds of zinc, and about 31,000 ounces of silver. The annual volumes of the Minerals Yearbook of the U.S. Bureau of Mines show that the district was active in 1937 into 1946 and yielded about 17,000 tons of ore during that period. Their statistics as to metal content are not directly comparable to those given by Anderson. They show that the major production was that of the Era Mining and Development Co. from the Horn-silver mine between 1943 and March, 1946. Presumably that production is the same as that credited by Anderson to the adjacent Last Chance mine of the same company.

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Most of the mineral deposits of the Lava Creek district are in the Challis Volcanics, which are cut by several intrusive masses, themselves locally mineralized. The deposits are in fissures and breccia zones and formed in part by filling of open spaces, in part by replacement. Anderson (1929b, 1947) described over 20 deposits of which two are in the Lead Belt. Deposition seems to have taken place in several pulses, with successive changes in the composition of the solutions and perhaps with progressive lowering of the temperatures of deposition. About 20 primary metallic minerals and 11 gangue minerals are reported. In addition to the common sulphides, according to Anderson, the deposits contain ruby silver, tetrahedrite, wurtzite, aikinite, hubnerite, pyrrhotite, and arsenopyrite. The more significant gangue minerals include calcite, dolomite, rhodochrosite, alunite, barite, clay minerals, sericite, chlorite, and epidote. The secondary products are those to be expected from the primary assemblage. They include 23 minerals, comprising sulphides, oxides, and carbonates. Cook reports (1956, p. 11) the Sam and Tom property in the south-central part of sec. 12, T. 2 N., R. 23 E., contains powellite disseminated in contact-metamorphosed limestone.

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