STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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Geology and Physiography
of the
Northern Wallowa Mountains
Oregon

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Frontispiece

WALLOWA LAKE AND THE VALLEY OF THE WEST FORK FROM THE AIR
(Courtesy of the U. S. Forest Service)

FOREWORD

One of the more important duties of the Oregon State Department of Geology and Mineral Industries, as outlined in the law that created the Department in 1937, is the carrying out of a State Geological Survey. This particular work is pointed toward the ultimate completion of a detailed geological map of Oregon. Only a small part of the State has thus far been covered geologically in anything like the detail contemplated under the present program. Many years will be required for the job, but a good start has been made and available data are being assembled by the Department as rapidly as possible toward the production of a preliminary State geological map.

The Department's activities that come under the heading of Geological Survey are divided into two types. The first is the regular summer field work - the Oregon Geological Survey - carried out by carefully selected young geologists and geological students under the direction of older heads. The second comprises continuous work throughout the year by staff and field geologists of the Department in their regular duties of giving geologic service to mine operators, property owners, and outside inquirers.

For the work of the Oregon Geological Survey a specific area or quadrangle is selected for mapping and study each summer. In the selection of an area, attention is given to both economic and scientific aspects.

For the first work of the new Oregon Geological Survey under this Department, the area of the northern Wallowa Mountains was selected. The Wallowas were known to contain, among others, deposits of molybdenum and tungsten, both of which were expected to be important in connection with the industrial development of the lower Columbia River area. Not very much was known, however, of the economic importance of the deposits mentioned. There seemed to be a movement also to create a National Park or Primitive Area of the Wallowas without advance knowledge of whether or not substantial mining development could be expected in this hitherto little-known country.

With the idea then of obtaining and publicizing factual information on the Wallowas, the Department carried out surveys during the summer of 1938 and a portion of 1939. A preliminary geologic map of a portion of the area was issued.

Final results of the Wallowa study and a map of the quadrangle are published in this bulletin. With the exception of some substantial deposits of a beautiful type of black marble, we can not prophesy that the northern area of the Wallowas may be expected to experience any such mineral production as has the southern Wallowas, particularly in the vicinity of Cornucopia. The Wallowas themselves nevertheless have great scenic resources, and a chapter on this phase by Dr. W. D. Smith has been added to the general study of geology and physiography.

Earl K. Nixon
Director

Portland, Oregon,
April 1941

PLATE II

Figures 1-3 Sagenites (Trachysagenites) herbichi Mojsisovics-(Locality AA) This is a characteristic ammonite of the Tropites subbullatus Zone (Karnic Stage) - Upper Triassic.

1. side view showing the ornamentation (spines or knots).
2. side view showing the suture (etched on the specimen).
3. view showing the outline of the whorl.

Figures 4-5 Juvavites sp. (Locality AB) This ammonite commonly occurs in the upper part (the Juvavites Subzone) of the Tropites subbulatus Zone, Karnic Stage, Upper Triassic. This specimen of Juvavites cannot be identified specifically as it represents an incomplete (immature) individual. Furthermore at this particular stage the genus Juvavites is practically indistinguishable from Griesbachites. The latter genus when it attains the size of about twice the size of the present specimen shows prominent, oblong nodes at the ventral terminations of the ribs. The genus Griesbachites occurs in Nevada in the beds above the Tropites subbullatus Zone - in the so-called Karnic-Noric transition beds, and in other parts of the world it has been reported even from the Noric stage.

4. view showing the aperture - the cross-section of the whorl.
5. view showing the umbilicus and the branching ribs on the sides.

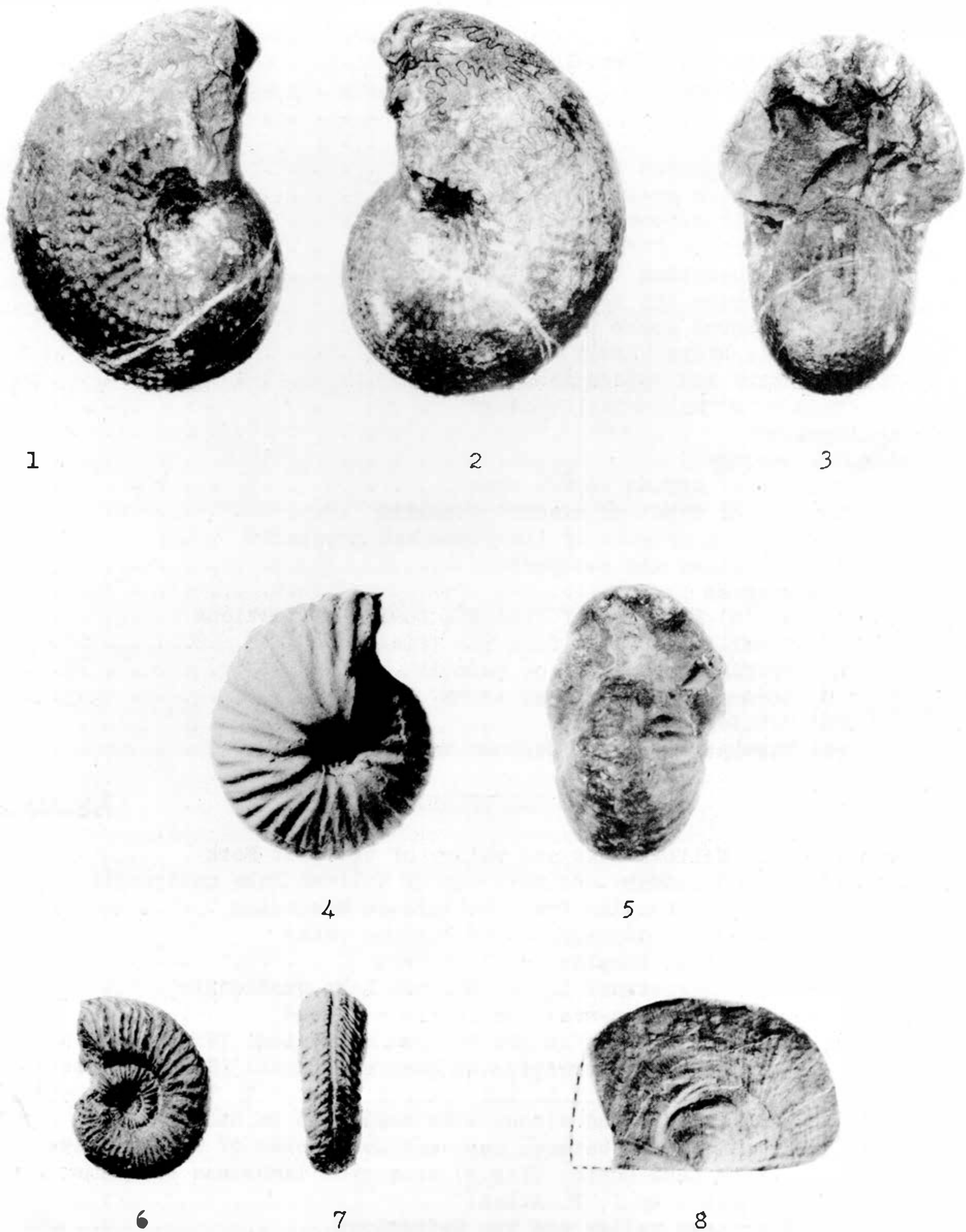
Figures 6-7 Clionites (Traskites) fairbanksi Hyatt and Smith-(Locality: "Probably from near the Black Marble Quarry"). This ammonite is characteristic of the lower part (the Trachyceras Subzone) of the Tropites subbullatus Zone (Karnic Stage), Upper Triassic.

6. side view showing the umbilicus and the ornamentation on the sides.
7. view of the venter showing the ventral groove where the branching ribs terminate.

Figure 8. Halobia oregonensis Smith (Locality AC)

8. a characteristic pelecypod of the Karnic and Noric Stages of the Upper Triassic.

PLATE II



TRIASSIC FOSSILS FROM THE WALLOWA MOUNTAINS
(Photographs by S. W. Muller)

CONTENTS

ILLUSTRATIONS

ABSTRACT

The Wallowa Mountains rise above the mile-high plateau of northeastern Oregon to an elevation of 10,000 feet. They are bounded on the east by the Snake River Canyon, and on the north, west, and south by the valleys of the Wallowa, Grande Ronde, and Powder rivers.

Altered greenish lavas, tuffs, and sediments of probable Permian age are the oldest rocks of the area, from 3000 to 5000 feet in thickness. These are found at the northern edge of the range around Wallowa Lake and in the southeastern portion of the mountains along the Imnaha and Snake rivers.

A thick sequence of altered upper Triassic sediments overlies the greenstones. The lower series of shales and hornfels (0-2000 feet thick) is followed upward by 2000-3000 feet of the Martin Bridge formation, largely crystalline limestone, and the upper Hurwal formation made up of 1000-3000 feet of shales and sandstones.

These rocks were extensively folded and intruded in middle Mesozoic time by batholithic masses of granodiorite. The sedimentary rocks to the north of the main Wallowa batholith were folded into a northwest trending downwarp. To the south of this batholith they were even more highly folded and crumpled into a complicated series of northeast trending folds.

Extensive erosion during Cretaceous and early Tertiary times stripped off much of the cover of sedimentary rocks overlying the granodiorite and reduced the mountains to a rolling plain. Today the Wallowa batholith is exposed in the western half of the range over 175 square miles; the Cornucopia batholith, which lies five miles southeast of the border of the main mass, occupies about eleven square miles.

Basalts correlated with the great Columbia River lava flood were extruded from north-south cracks in the crust during the middle Tertiary and apparently covered the entire area. Remnants of lava today cap the crests of some of the highest peaks in the range. Faulting occurred in the late Tertiary and was most pronounced along the northern front of the mountains. The range was elevated at this time to its present average height of over 8000 feet. Deep radial valleys were developed, which were widened and deepened during the Pleistocene by the great glaciers coming down them from the ice cap that covered the center of the area.

Metallic minerals deposited during the intrusions of granodiorite are mined in the southern Wallowas, but so far have not been found in economic amounts elsewhere. Tremendous reserves of limestone and marble exist on the north side of the range. They have been mined at one locality and may be further developed in the future.

CHAPTER I
INTRODUCTION

Field Work and Acknowledgements

A geologic reconnaissance of the northern Wallowa Mountains was carried out by the Oregon Department of Geology and Mineral Industries in order to determine areas or zones most suitable for prospecting; to eliminate certain localities as being unfavorable prospecting ground; to prepare a reconnaissance geologic map illustrating results; and to carry northward the geologic work of C. P. Ross (38)*.

The survey parties were in charge of Earl K. Nixon, Director of the Department, who kept in close touch with the progress of the work by field inspection and by correspondence. During the 1938 season, five geologists and four student assistants were in the field from July 12th to August 13th, and an additional week was spent in the southern portion of the area by two geologists and two assistants. Dr. Warren D. Smith was geologist in charge of field parties. He was assisted by Ray C. Treasher and John Eliot Allen of the Oregon Department of Geology and Mineral Industries, and Lloyd Ruff and Wayne R. Lowell, assistant geologists. Fred Hoffstaed, Wilbur Greenup, James Weber, and Herbert Harper were student assistants. Parties were in the field again in 1939 from August 5th to September 9th, during which time the molybdenum properties on Hurricane Creek were sampled and mapped by Nixon, Treasher, Lowell, Ford Young, and Hiram Wood. Additional trips were also made by Smith, Allen, and Lowell to complete areas not reached the season before.

The area covered includes most of the central portions of the Wallowa Lake Quadrangle. The topographic base was the Forest Atlas of the U. S. Forest Service; sheets 8, 9, 12, and 13 of the Wallowa National Forest, and sheets 4 and 5 of the Minam Division of the Whitman National Forest were used. While the topography is reconnaissance, these maps made it possible to cover the area in fair detail. Special thanks are due C. J. Buck, Regional Forester; J. F. Erwin, Supervisor of Wallowa National Forest; Lester Moncrief, Supervisor of Whitman National Forest; V. H. Flack, in charge of Maps and Surveys, as well as to members of the Forestry field staff, for enthusiastic cooperation.

Traverses were made from the valley bottoms to the crests of the ridges at intervals of one to two miles or less. All major streams were traversed, and while it was found impossible to follow along all the serrated ridges, most of these were covered for considerable distances. Within the area of granitic rocks the traverse network was larger; the features noted were large inclusions, dikes, or physiographic phenomena. Dashed-line contacts should be accurate within the accuracy of the topography, which shows numerous errors of up to several hundred feet. Dotted-line contacts are largely inferred. The NE$\frac{1}{4}$ of the NW$\frac{1}{4}$ and much of the NE half of the Wallowa Lake quadrangle was not mapped, but consists of Columbia River basalt, overlain by glacial deposits, and alluvium. The area south of the Imnaha river and east of the crest of the ridge between Main and East Eagle Creek was mapped by Ross (38).

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* Numbers in parenthesis are references to the bibliography (Appendix E)at the end of the bulletin. The first number refers to date of publication; the number after the colon (where two numbers appear) to the page.

In the field, Messrs. Joseph LaGore, Jack Baxter, G. T. Green, Clint Haight Jr., and Charles Seeber gave much needed assistance.

The rocks of the area have been studied in the laboratory by Dr. Lloyd W. Staples, who has written all the petrographic descriptions incorporated in this report. He was assisted by Robert Brooks, who ground the thin-sections and assisted with the photomicrographs.

The section on glaciation was written by Wayne Russell Lowell.

Identification of the fossil specimens and the determination of age relationships was made by Dr. Seimon W. Muller of Stanford University, who also kindly furnished the plate of photographs of fossils.

Previous Work:

The earliest report on the geology of the "Eagle Creek Mountains" was by Waldemar Lindgren (01:580) who described the Triassic calcareous shales and limestones with interbedded volcanic breccias on Eagle Creek. On his map all the pre-Tertiary formations within the southern Wallowas are included in the Triassic, and the granodiorite on Middle and West Eagle creeks was overlooked. Swartley's report (14:67-96) includes thirty pages of text with numerous photographs showing the geology and ore-deposits within the northern Wallowa Range. He refers to the Wallowa Batholith as being the "same instrusion seen at Cornucopia" but recognized the main features of the area and gave a description of nearly all of the known mineralized localities. Parks (14:30-35) discusses the "black marble" quarry and the Wallowa fault escarpment and draws a rough cross-section of the relationships exhibited in that district. The Frazier prospect is described both by Swartley (above) and by Hess and Larsen (21:308), who mention it as containing scheelite. In the summer of 1927, Dr. W. D. Smith (28:158-194) conducted a summer camp for geology students at Wallowa Lake, made a topographic map of the lake region and a generalized cross-section through the range. One of the students, James Stovall (29) wrote a Master's Thesis on the Pleistocene geology and physiography of the Wallowa and Hurricane Canyons. Another thesis problem was undertaken by Louise Stevens (32), who studied a quartz-plagioclase dike at Aneroid Lake.

Only within the last decade has any detailed work been done in the Wallowa Mountains. Goodspeed (33:160 and 39) has made an intensive study of the rocks around Cornucopia in the southern Wallowas and has also referred to some of the pegmatites near Aneroid Lake. Evidences of large scale "granitization" as noted by Goodspeed in the southern Wallowas have not been seen in the northern area. The geologic history of the region south and southwest of the quadrangle has been studied by Gilluly (37) and by Ross (38), who have published maps of the Baker and portions of the Pine quadrangles. A reconnaissance survey of the northern Wallowas was made in 1930 and 1931 by Moore (37:119-132) and a small scale geologic map of the area published in 1937. Moore recognized most of the main structural features of the northern part of the range, and his conclusions have in nearly all cases been borne out by the present more detailed study of the area.

CHAPTER II

GEOGRAPHY
by Warren D. Smith

Location

The area covered by the survey during the summers of 1938 and 1939 occupies the central portion of the Wallowa Lake quadrangle, from N. lat.117° to 117°30' and W. long. 45° to 45°30'. It lies for the most part on the north side of the Wallowa Range, and is bounded on the north by Wallowa Valley, on the west by the north fork of the Minam river, on the east by the Lick Creek forest road, and on the south by the northern boundaries of the survey by C. P. Ross (38) on Eagle Creek and the Imnaha River. The total area mapped is about 350 square miles.*

The territory covered by field survey is located in southern Wallowa County, the extreme eastern extension of Union County, and a very small portion of northern Baker County. It includes portions of twps.2, 3, 4, 5, and 6 S., Range 43, 44, and 45 E. in the extreme northeastern part of the State of Oregon. Its boundaries approximate those of the so-called Eagle Cap Primitive Area in the Wallowa and Whitman National Forests. It includes the drainage of Lostine River, Hurricane Creek, west and east forks of Wallowa River on the north; and main Eagle Creek on the south.

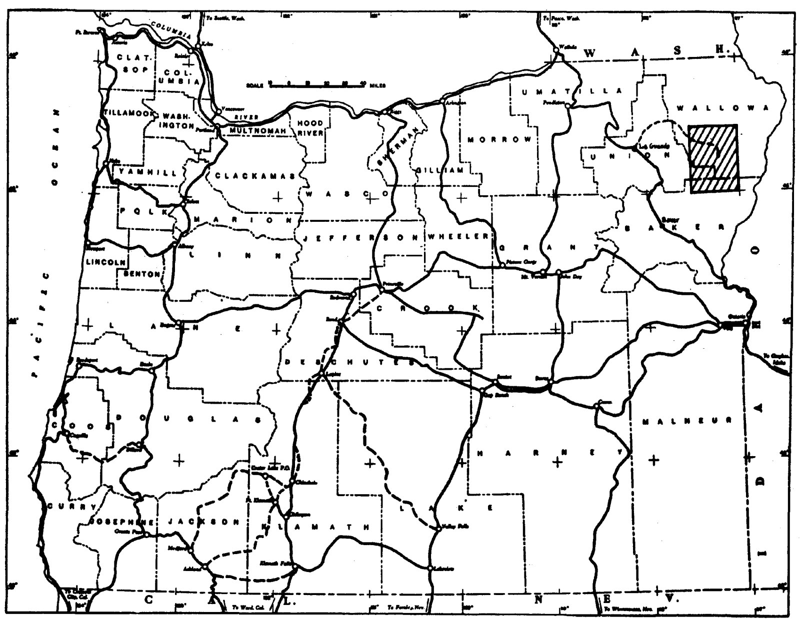


Fig. 1. Index Map.

* For more complete details concerning the general geography and human history of this region, the reader is referred to the excellent map and description by the U. S. Forest Service, and to the chapter on Wallowa County in Physical and Economic Geography of Oregon, by Warren D. Smith -- Commonwealth Review, vol. X, no. 1 (January, 1928).

Accessibility

Wallowa Lake, near the center of the quadrangle, lies 360 miles east of Portland, about 60 miles northeast of Baker, and about 100 miles south of Lewiston, Idaho.

The area mapped is reached by way of the towns of Enterprise and Joseph by both railroad and highway. The railroad terminus is at Joseph, five miles north of Wallowa Lake. State Highway 82 connects with the Oregon Trail highway (U.S.30) at La Grande, and ends at the lake, a distance of 73 miles.

A good forest road about 19 miles long leads south from Lostine into the mountains, and there are several excellent forest trails which traverse the region from north to south. Of these, the best two are the Wallowa Lake-Aneroid-Tenderfoot-Cornucopia trail and the Minam Lake trail. A few trails cross from east to west. Trails also extend up the Imnaha and the various forks of Eagle Creek. The interior of the mountain area, therefore, is readily accessible but only by mountain trail.

Topography

The area studied is extremely rugged with a maximum relief of nearly 6000 feet. Wallowa Lake lodge is situated at 4411 feet and Sacajawea Peak is 10,033 feet in elevation.

In general, the region consists of sharp ridges radiating in all directions from Eagle Cap (9,675 ft.) as a center and separated by steep-walled canyons several thousand feet deep. The topography is dealt with in greater detail under the chapter on "Physiography".

Hydrography

Several main streams with gradients from 100 to 250 feet or more to the mile flow north from the center of the range. The principal ones are Lostine River, Hurricane Creek, and the east and west forks of the Wallowa River. In late summer, most of the streams can be forded on foot, but in the spring crossing is difficult and dangerous.

The largest lake of the area is Wallowa Lake, slightly over three miles long and three-fourths of a mile wide. It is 283 feet deep by the deepest sounding (1927). In the higher portions of the area, particularly in that part known as the Basin, are many small glacial lakes varying from mere ponds to lakes one-half mile in length. More than fifty lakes lie within the quadrangle. Next to Wallowa Lake, the largest is Steamboat Lake near the north fork of the Minam.

Climate

The climate is that of typical mountain country of the continental interior. The rainfall varies from 10 to 30 inches, and is concentrated in short periods during convectional storms. Electrical storms of considerable violence occur in the hot summer months. There is a heavy winter snowfall, amounting at Joseph to 55 inches during the period from December to April.

As in many other mountainous areas, this region is characterized by a very high ratio of sunny days to cloudy ones. According to the Koppen's climatic scheme, the following types are represented here:

Dsf and Ds climates
D -- Humid, January mean less than 32° F.
S -- Summer drought
sf - Three summer months with not less than .75" precipitation

Vegetation

The north side of the Wallowa Mountains is fairly well covered with timber and underbrush. Above 7500 feet scarcely any timber is found, but small alpine plants are abundant in the meadows and even on some of the less sharp ridges.

A list of typical trees and shrubs found in this region was supplied us by Mr. Louis Henderson, Curator of the Herbarium at the University of Oregon. This list is based upon collections made by Mabel S. Miller, and is included as Appendix F.

Animals

Deer, elk, bear, cony, beaver, and porcupine have been seen in this area, and mountain sheep have been reported from time to time, although none of the members of this survey saw any of them.

Sheep from the lowland ranches are driven into the high mountain meadows every summer. The region is famous for its fishing, the lakes being continually restocked. Eastern brook trout are said to thrive best.

Population

Within the area mapped there are no settlements south of Wallowa Lake, with the exception of summer camps at Aneroid Lake and on the Lostine River. A hiker following a trail may occasionally find a prospector's cabin, but these are mainly abandoned. Although the Nez Perce Indians once ranged the Wallowa Mountains, they are now gone.

One of the difficulties of field work in this area is that one must "pack in" his camp if he goes in any distance from the tourist resorts at the foot of the mountains. It was necessary for the Department's survey of 1939 to establish five base camps, one on the Lostine River, one at Aneroid Lake, another at Wallowa Lake, a fourth on East Eagle Creek, and a fifth at the forks of the Imnaha River.

CHAPTER III

GEOLOGY

by John Eliot Allen and Warren D. Smith

General Features

The central and western portions of the Wallowa Lake quadrangle are occupied by the Wallowa granodioritic batholith, the eastern extension of which, the McCully prong, divides the older sedimentary rocks into two series. These are the northern, which occupies the lower drainages of the Lostine, Hurricane and Wallowa Rivers, and the southern, which occupies the upper drainage of the Imnaha and extends over into the Eagle Creek drainage on the south.

The older sedimentary rocks, ranging in age from Permian to Upper Triassic, in the northern area form a great northwest plunging syncline, cut off abruptly on the south by the McCully prong. In the southern area they form a series of more or less compressed folds, trending northeast, parallel to the edge of the McCully prong.

Overlapping all older formations on all sides except the south are the Miocene basalt flows, which on some of the highest peaks in the central part of the range remain as remnants.

The great northwest-striking Wallowa fault escarpment forms the north face of the range overlooking Wallowa Valley.

The following tabulation gives generalized sections of the sequence and thicknesses of the formations appearing within the quadrangle, and outlines the major geologic events which have taken place within this part of the State.

Epoch	Formation	Thickness	Events
Recent	Alluvium, mainly derived from glacial deposits	0 - ?	Slight erosion.
Pleistocene	Moraines, glacial outwash	0-900	Glaciation.
Pliocene Miocene Oligocene Eocene	Columbia River basalt dikes and flows Stream gravels	0-1500 0-50	Folding, faulting, uplift and erosion. Intrusion and extrusion of basalts Long continued erosion, with development of mature topography.
Cretaceous	Diaschistic dikes and veins.		Minor intrusions.
Jurassic	Granodiorite.		Granodioritic intrusions. Intense folding, uplift?
Upper Triassic	Hurwal formation. Martin Bridge (grey, black ls. formation (white, pink ls.	1500+ 200-2000 0-300	Shallow-sea deposition. Uplift and erosion.
	Lower sedimentary series	0-2000	Folding and metamorphism. Minor intrusions.
Permian	Clover Creek greenstone.	3000-5000	Intense volcanism and near shore sedimentation

Fig. 2. Geologic Formations in the Northern Wallowa Mountains.

Clover Creek Greenstone

Distribution and relationships. A thick series of altered lavas containing small amounts of pyroclastic rocks and interbedded sediments has been mapped by Gilluly (37) and Ross (38) in the Baker and Pine quadrangles as "Clover Creek greenstone". Greenstones in the Wallowa Lake quadrangle are similar in lithology, thickness, and stratigraphic position. The Clover Creek greenstone is the oldest formation mapped in the quadrangle. Its base has not been observed, and although its internal structure is obscure, it seems to be conformably overlain by the Lower Sedimentary series. On the middle fork of the Imnaha River, however, the sedimentary series is lacking, and the Martin Bridge formation appears to cut across the folded structures in the greenstone with strong unconformity. Around Wallowa Lake, greenstone occupies the lower slopes of Tunnel Mountain and Signal Point. For miles along the Imnaha River east of Marble Mountain the sides of the valley are largely greenstone.

Thickness. The section in Tunnel Mountain must have a minimum thickness of at least 3000 feet, and in the Imnaha valley the series may be as much as 5000 feet thick. Similar estimates of thickness of the greenstone series in adjacent areas have been made by Gilluly (37:21) and Ross (38:25). The total thickness in the quadrangle is not known, as the base is not exposed.

Lithology: According to Staples, "the term greenstone has been used in the Wallowas for dense, fine-grained metamorphosed igneous rocks, chiefly lavas, although in places there are pyroclastics and sediments included in the formation. A sample of a characteristic phase of the greenstone was taken from the road north of the lower Imnaha River at an elevation of 5400 feet (NW$\frac{1}{4}$ sec.17 T.5 S., R.47 E.) This specimen (R 1425) is a black porphyrite containing green feldspar phenocrysts up to four or five centimeters in length. Megascopically the plagioclase phenocrysts show both polysynthetic twinning and zonal structure. They also show rosette grouping and forking. Frequently they are broken and embayed by the matrix. The rock, which can be classified as andesite porphyry, contains about 70% of andesine with 20% as phenocrysts and 50% as groundmass. Index of refraction studies on the phenocrysts indicate that they are andesine-labradorite. The groundmass consists of 15% augite along with the feldspar, and magnetite is the chief accessory. The secondary minerals are chlorite, antigorite, sericite and kaolinite. Some of the magnetite is possibly the result of exsolution phenomena. The chlorite, which has very low birefringence, is an important constituent since it accounts for part of the color of the rock. It not only seems to replace the augite, but also fills the spaces formerly occupied by the feldspar. In regard to a similar rock, Ross (38, p.22) says, 'Near the Imnaha River most of the lavas are different shades of green; others are gray, bluish gray, purple and black. Some are amygdaloidal, many are porphyritic, having in places numerous feldspar phenocrysts as much as an inch or even more in length in dense groundmass. Probably these large, forked phenocrysts result in part from accretion after the consolidation of the rock rather than from original crystallization'. The writer found no evidence to indicate that the phenocrysts were formed in any other than the normal manner, in the specimen examined".

Greenstone-breccia and conglomerate boulders are common in the Hurricane Valley and are derived from outcrops in the east side of the valley. Limestone in pods and lenses occurs within the greenstone near the contact on the west canyon wall of the west fork of the Wallowa River two miles south of Wallowa Lake. The "greenstone" on Eagle Creek appears megascopically to be a dark-green, granular, gabbroid rock, composed mainly of pyroxene. It represents a contact metamorphic phase of the Hurwal sediments.

Analyses of samples taken by Gilluly (37) from the greenstone series in the Baker quadrangle show that the rocks are in large part quartz keratophyres and spilites.

Age and correlation. Gilluly (37:26) reports a fossil collection of Permian age from the northeast quarter of the Baker quadrangle, and fossils from a limestone lens in the greenstone near Homestead have been determined by Lupher (2) as being Permian. Another collection from this general locality is reported by Ross (38:26) as being the same age as the Permian Phosphoria formation. No fossils were found associated with the greenstone series in the Wallowa quadrangle.

Lower Sedimentary Series

General Features. A group of shales, sandstones and minor lenses of limestone which have been more or less altered to pyritized hornfels, schist, and crystalline limestone, apparently overlies conformably the Clover Creek greenstone and with apparent strong unconformity underlies the Martin Bridge formation. This series separates the above formations under Point Joseph and west of Marble Mountain, and it occurs along the entire southern and western border of the northern area, where it lies between the Martin Bridge formation and the granodiorite. In this region it has consequently been considerably altered and assimilated, with development of large and small xenoliths and roof pendants. On Middle Mountain and south of Wallowa Lake, however, the sedimentary series is very thin and in the Hurricane drainage and on the middle fork of the Imnaha it appears to be absent altogether.

A roof pendant in the south wall of Wilson Basin is probably made up of rocks of this formation. The upper portion of Tunnel Mountain above the greenstone has been mapped as belonging to this series. Here 1000 feet of fossiliferous shales, capped by a massive bed about 500 feet thick of fine-grained, green sandstone, underlies pink limestone of the Martin Bridge formation.

In the southern area, the formation lies between the Martin Bridge formation and the granodiorite and again occurs to the east in the folded structures west of Marble Mountain, although it is absent in the next ridge to the north.

A limestone band occurs directly overlying greenstone on Hurricane Creek and in the Imnaha drainage. If this is a basal phase of the Lower Sedimentary series, a part of the area on Hurricane mapped as Hurwal formation should be reclassified.

Thickness. The maximum thickness of the Lower Sedimentary series exposed in Point Joseph is not over 2000 feet. Elsewhere it is usually much less and on lower Hurricane Creek and the middle fork of the Imnaha it appears to be absent. In both of these localities, this may be the result of faulting, but is more likely due to disconformity with the Martin Bridge formation. The great variation in thickness is also due in part to the fact that except on Tunnel Mountain and west of Marble Mountain on the Imnaha the series is found in direct contact with the granodiorite. In the valleys of both forks of the Wallowa River two miles south of the lake there is a thickness of a few hundred feet of limestone between the series and the granite. Here the sediments themselves average less than 200 feet in thickness, and are bounded on the north by the greenstone.

Lithology. According to Staples, "the lower Sedimentary Series shows the effects of both contact and regional metamorphism. This is as might be expected, since it is known that granite and granodioritic intrusives deform their walls much more than do basic magmas. Hornfels, schists, and quartzites, with some sandstones and shales, are widely disseminated. Bedding is usually apparent, and platy jointing is common.

"Numerous hornfels have been examined, showing all degrees of variation from a true hornfels to a schist. Especially along the granodiorite contact is there a good development of the metamorphic sediments. In sec.23, T.3 S., R.43 E., there are small areas of hornfels (R 1322) with a granular appearance and containing quartz, feldspar and some diopside. There is a slight alignment of the quartz grains and there is also evidence of the introduction of quartz after the formation of the hornfels. There are granodiorite-aplite and quartz stringers closely associated with the hornfels.

"In the case of many of the schistose rocks within the Lower Sedimentary Series it is very difficult to determine their origin. There are all gradations from hornfels to schist indicative of the differences in the types of metamorphism. On Silver Creek in sec.15, T.2 S., R.43 E., there is a fine-grained, slightly schistose rock (R1327) that is on the line between a true hornfels and a quartz mica schist. The rock is probably a meta-sediment and is composed chiefly of quartz, diopside, and muscovite with a slight alignment of the mica.

"A well-developed schist is found in the S$\frac{1}{2}$ of sec.10, T.4 S.,R.44 E. on the southwest face of the Matterhorn. This reddish gray schistose rock (R 1473) with green porphyroblasts contains over 50% of aligned quartz grains with the schistosity being emphasized by the alignment of the biotite, which is somewhat leached. The rock also contains tremolite which occurs both as porphyroblasts, often showing polysynthetic twinning and as an important constituent of the groundmass. This is a metasedimentary rock, but the exact identity of the parent rock is uncertain. The rock is a quartz tremolite schist.

"On the Francis Lake trail at Falls Creek in the center of sec.24, T.3 S., R.43 E., is a quartz biotite schist (R 1353) which contains in addition to a predominance of biotite and quartz, considerable actinolite, muscovite, plagioclase, magnetite and pyrite. This is probably a metasedimentary rock and is reported to be in close proximity to quartzite and granite."

Age and correlation. Fossils collected from the Lower Sedimentary series (see Appendix A-C, locality 10) indicate an upper Triassic (middle Karnic) age. The unconformity between this series and the Martin Bridge formation, however, led Ross (30:29) to place rocks in the southern Wallowas with a similar stratigraphic position but lacking fossils in the "Carboniferous (?)".

Martin Bridge Formation

General Features. The most conspicuous formation of the area, next to the great granodiorite intrusion, is the Martin Bridge formation which covers within the Wallowa Lake quadrangle over 25 square miles in the northern and about the same in the southern area. It is comprised of a variety of more or less metamorphosed limestones. These rocks make up the precipitous white faces on the east wall of the Lostine River at Lapover, on Hurricane Creek at the Matterhorn and Sacajawea, and of Cusick and Marble Mountains, on the Imnaha River. Limestone always separates the Lower Sedimentary series from the Hurwal formation and, in some places, small lenses are intercalated within the latter.

On lower Hurricane Creek and on the Middle Fork of the Imnaha as well as on Boner Flat, limestones lie directly upon the Clover Creek greenstone, the Lower Sedimentary series being missing.

Thickness and subdivisions. The Martin Bridge formation has been so intensely folded and deformed over large parts of the area that the apparent thickness of 3000 to 5000 feet in the Hurricane and Upper Imnaha drainages is undoubtedly excessive. Judging from the less contorted exposures on the lower Lostine and Wallowa Rivers, the maximum thickness is probably less than 2000 feet, and the average is substantially less, perhaps 500 feet.

On the Upper Imnaha River and near the crest of Point Joseph, the base of the formation is composed of from 100 to 300 feet of fine-grained, nearly pure, white crystalline limestone, which under the basalt on Point Joseph has been stained pink. The main body of the formation (from 200 to 2000 feet) is grey to black, crystalline limestone, which towards the top is both intercalated with and grades into the argillaceous Hurwal formation.

Basic dikes. Within the Martin Bridge formation are found dikes which are older than the granite since they have been broken and pulled apart by the movements that folded and distorted the limestones. These dikes occur in the Lostine Valley east of Lapover on Marble Point; on the face of the Matterhorn; at Ice Lake east of the Matterhorn; at Aneroid Lake; and in several other localities. The flow-banding in the crystalline limestone follows evenly around the isolated, more or less, angular fragments and blocks of fine-grained igneous rock. Many of the latter are andesitic in nature and frequently contain abundant, fine sulphides. In Marble Point some of these are so highly mineralized that they have in the past been prospected for copper. Just west of Ice Lake a 1½-inch dikelet originally 10 feet long has been broken into some 25 parts which were pulled apart so that they are now traceable along a distance of 55 feet. Staples examined samples of dark inclusions up to 5-6 feet in width, from the crystalline limestone east of Lostine River near Lapover. He states, "This (R 1372) is a fine-grained, allotriomorphic rock with plagioclase, diopside, tremolite, and remnants of leached biotite. The inclusions probably represent a lamprophyre - possibly approaching spessartite".

Lithology. The Martin Bridge formation shows a great variety of limestone types, of which the coarse-grained (up to 3mm.), bluish-white or grey variety is the most common, and the dense black type, locally known as "black marble" is perhaps the most beautiful. Of the types of rock shown, Staples reports that:

> "The limestone shows many different states of recrystallization, proportional to the amount of metamorphism experienced by the rock. A specimen from near Point Joseph (R 1432) taken at an elevation of 8900 feet is

fine-grained (0.07mm.) and light gray with red banding. The rock is almost pure calcite, completely crystalline, and with only a small amount (less than 1%) of quartz. The reddish color is due to ferric oxide stain. In contrast to this rock, a specimen (R 1416) taken from the SE. part of the area in the N$\frac{1}{2}$ of sec.4, T.5 S., R.45 E., is a dark-gray, fine-grained, laminated calcareous rock. A petrographic study of this shows it to contain carbonaceous matter which frequently outlines fossil remains and accounts for the dark coloration. The recrystallization of the calcite proceeded to a less degree and less uniformly than in the former specimen, and secondary veins of calcite are present. There are minor amounts of pyrite and quartz present in the rock. This rock would be classified as a carbonaceous fossiliferous limestone, with only a small amount of recrystallization.

"An example of advanced metamorphism in the limestone is shown by a specimen (R 1386) taken from the SW$\frac{1}{4}$ of sec.18, T.3 S., R.43 E. from a thin band of limestone near granodiorite. The rock is medium grained (0.64mm.), gray, with considerable carbonaceous matter. This crystalline limestone not only shows recrystallization of the calcite, but the effect of dynamic metamorphism is noted by an alignment and flattening of the calcite grains producing a slight schistosity. The interference figure of the calcite grains indicates the stress to which the rock has been subjected. There is an alignment of carbonaceous matter, probably indicating former bedding at almost right angles to the newly developed flattening of the grains."

Well-developed bedding due to layers of more highly carbonaceous material is sometimes prominent, but more commonly the banding is due to the intense dynamic metamorphism which caused the rock to crumble and flow. The banding is especially well-developed near the contacts with more competent rocks or near inclusions, around which the banding passes and then regains its original trend.

Age and correlation. All fossils found in this calcareous series were from Upper Triassic horizons, and most of them were upper Karnic in age. Collections from nine localities were submitted for identification to Dr. Seimon W. Muller of Stanford University.

The location and stratigraphic position of these and other localities cited in the literature are given in Appendix A-B.

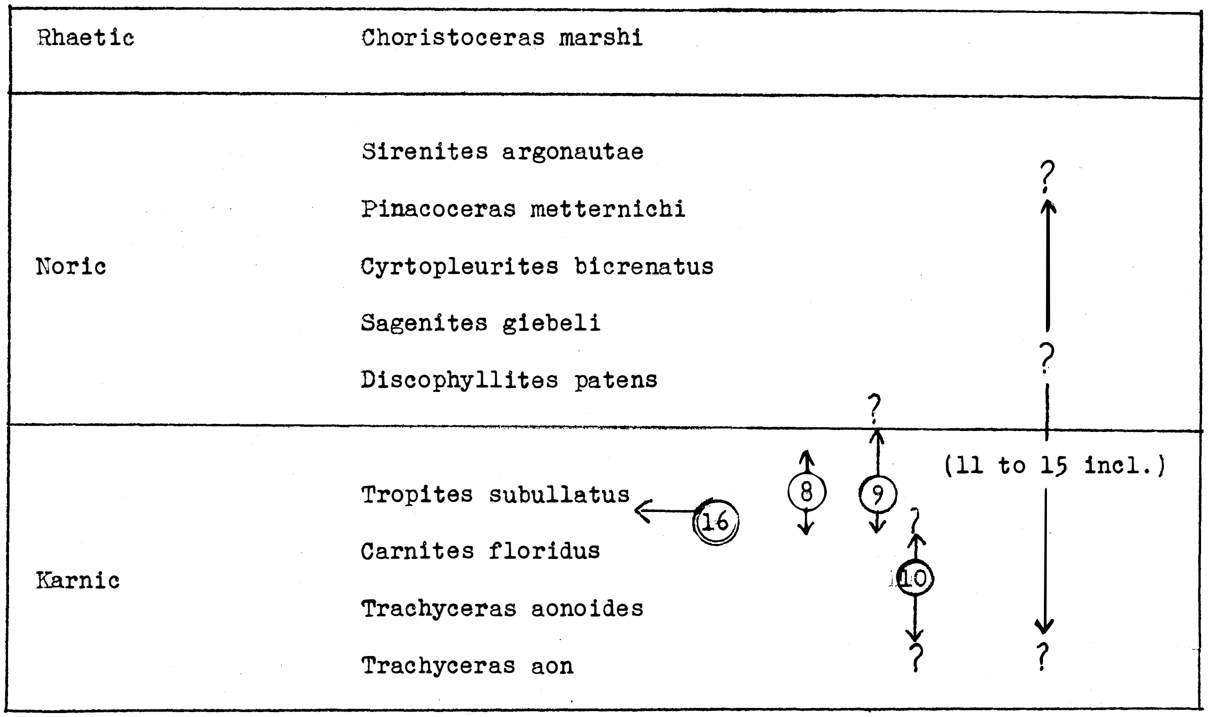


Fig. 3. Standard Section of Upper Triassic with location of Wallowa fossils (see Appendix B)

No fossils were found in other than crystalline limestones or in hard dense slates. The slates seemed to contain more forms of the pelecypod Halobia than anything else, though some small and generally imperfect ammonites were also present. The larger ammonites came principally from B. C. Basin, at locality #16. The corals (Thecosmila) were abundant at the so-called "Black Marble" quarry. The sponge (Steinmannia) is also common here. Owing to the hardness of the matrix in which many of these fossils were found, collecting was not easy. In the slates deformation had badly distorted some of the forms.

The limestone series can be definitely correlated, not only with the "Martin Bridge formation" of Ross (38:32-36), but with the "Hosselkus limestone" of northern California. It reaches the top of the Karnic, and the boundary with the Hurwal formation must closely approximate the boundary with the Noric.

Hurwal Formation

Definition and general features. The conformable series of essentially argillaceous sediments which makes up many of the crests of the ridges and peaks within the Wallowa Lake quadrangle and lies both stratigraphically and topographically above the predominantly calcareous Martin Bridge formation, is here named the Hurwal formation, after the divide of that name lying in the center of the quadrangle. The base of the formation is about 50 feet in elevation above the point from which a large fossil collection of Karnic age has been derived. (Appendix A, no.9).

The formation grades within a few tens of feet from the underlying Martin Bridge limestone through argillaceous limestone and calcareous shale, to shale and hornfels. It sometimes contains intercalated limestone bands as on the west walls of Hurricane Creek, Francis Lake Basin, and Sentinel Peak.

Within the northern area the Hurwal formation not only forms the crest of the divide east and north of the Matterhorn, but it also occurs in residual patches on Sacajawea Peak and over a considerable area along the Hurricane Divide especially east of Twin Peaks and around Francis Lake. It appears between the limestone and the granite and basalt in the east wall of the Lostine Valley below Lapover. In the southern area it makes up most of the ridge which runs south from Aneroid Lake to Sentinel Peak and beyond, as well as the crests of the ridges north and south of Tenderfoot Basin and north of Hummingbird Mountain.

If the sediments which form the west wall of Hurricane Creek belong to the Hurwal formation, the limestone band which appears high on the wall just below Sawtooth Peak would occupy the highest stratigraphic position of any of the pre-Tertiary sediments, and may even represent a later formation.

The Hurwal formation was mapped by Ross (38) as "Younger Mesozoic Sedimentary rocks", and overlies the granodiorite in an overturned position along the ridge north of Hummingbird Mountain, between the main and east forks of Eagle Creek. On Main Eagle Creek it has been thoroughly metamorphosed to hornblende gneiss and schist. South of Bennetts Peak a large area of grey to greenish altered rock, apparently of volcanic origin, has been included in the Hurwal as the rock appears to overlie the limestones along the creek. The "Triassic (?) volcanic rocks" of Ross (38) are also mapped with the Hurwal formation.

Thickness. The formation varies in thickness within the area from nothing to 1500 feet on Hurricane Divide and in Sentinel Peak. Nowhere is the top exposed, although the upper limestone interbedded within it on Hurricane may represent the highest Mesozoic horizon within the area.

Lithology. Although perhaps the most conspicuous rock type is a very hard black hornfels, other types are slaty and shaly, but sandstone and quartzite beds are not uncommon. In the Imnaha area well-bedded sandstone has been folded and faulted on a minute scale so that miniature structural features such as grabens, overthrusts, and normal faults may be obtained in hand specimens. One specimen showing well-defined ripple marks was collected in this region. Disseminated pyrite cubes occasionally appear, and locally fossils have been replaced by pyrite.

Staples describes some of the hornfels types as follows:

"In $NW\frac{1}{4}$ of sec.36, T.2 S., R.43 E., there are numerous hornfels, many of them cut by basalt dikes. One of them (R 1361) shows carbonaceous spots which are slightly drawn out and aligned, and contains considerable biotite and quartz. A few highly corroded plagioclases are present and some magnetite and pyrite. This dense black rock is undoubtedly derived from a shale and is a good example of what is often termed an 'argillite'.

"On the Metzger property at an elevation of 6700 feet in sec.4, T.3 S., R.44 E., on the ridge north of Little Granite Creek is a hornfels (R 1426) which is a dense black massive rock with conchoidal fracture. It contains a dissemination of pyrite and there is faint evidence of bedding with alignment of pyrite in this direction. This hornfels which is probably derived from a shale, has a dense groundmass composed chiefly of quartz, with some feldspars, both twinned and untwinned, and with considerable fine pyriboles.

"A light colored hornfels (R 1380) is found in $SW\frac{1}{4}$ of sec.18, T.3 S., R.44 E., on the top of the ridge just west of Francis Lake. This hornfels is very fine-grained, highly siliceous, of a uniform color, and in addition to quartz and pyroxene in a fine mosaic, is veined with garnet".

Age and Correlation. The age of the Hurwal formation is uppermost Karnic and Noric; it is conformable with the underlying Martin Bridge formation. A good fossil collection within 50 vertical feet of the basal contact with limestone is of uppermost Karnic age. (See Appendix A, locality no.9). On the basis of lithology and stratigraphic position the Hurwal is correlated with the "Younger Mesozoic Sedimentary Rocks" mapped in the southern Wallowas by Ross (38:38-40). No unconformities or fossils to suggest Jurassic age, or even Rhaetic, were found.

The volcanics south of Bennett's Peak may be equivalent to Ross's (38:36) "Triassic (?) Volcanic rocks", as their stratigraphic position appears similar. This series is thus also tentatively correlated with the rocks mapped as Hurwal formation.

Fig.1. Ridge between east and west forks of Wallowa River from Lakes Basin. Crest of ridge is Hurwal; white band is Martin Bridge limestone; lower cliffs are granodiorite. Black band is a basalt dike. (Photo by John Eliot Allen).

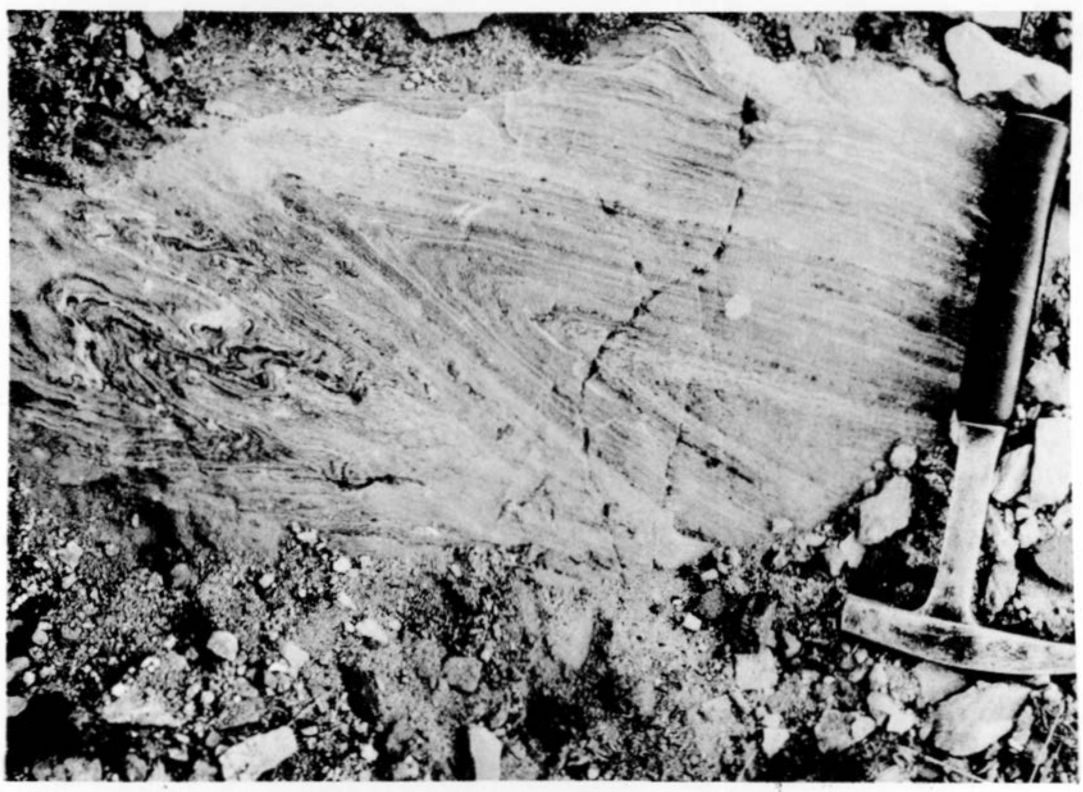


Fig.2. Contorted limestone on Adams Creek.

Granodiorite and Related Rocks

General Features. Granodiorite and quartz diorite occupy over 175 square miles in the Wallowa Lake quadrangle. The central and western portions of the area are occupied by the main mass of the Wallowa batholith, which is overlain only on a few of its highest peaks by small, more or less isolated patches of basalt. The McCully prong, an eastward extension of the batholith about three miles wide, crosses over both forks of the Wallowa River and into McCully Creek, where it disappears under the basalt on the east side of the creek. Two granitoid cupolas break through the metamorphics in the northern area to form the Sawtooth boss, which occupies most of the drainage of Lake Creek below Francis Lake, and the Adams Creek boss, which is separated from the main mass by a thin, irregular zone of metamorphics along the creek of that name. In the ridge west of B.C.Basin a small boss or wide dike of aplite cuts the limestone, and on Marble Mountain there are several large aplitic dikes.

Lithology. Staples refers to the petrography of the rocks of the batholith as follows:

> "Granitoid Rocks.- The large batholithic mass in the center of the area is composed predominantly of granodiorite and quartz diorite. Specimens taken from various points on the batholith show a variation in the mineralogic composition, especially in the amounts of quartz, alkali and plagioclase feldspars, and the types of pyriboles and micas."
>
> "On the Lostine River in sec.26, T.3 S., R.43 E., there is an exposure of a part of the batholith which permits study of a typical and but slightly altered phase. This rock (R 1346) is granitoid, hypidiomorphic, and has an average grain size of 2.4 mm. The principal feldspar is andesine, which composes about 35% of the rock and shows considerable zoning. Orthoclase is present to the extent of about 12% and there is 25% of quartz. Hornblende and biotite are present in about equal amounts and together make up 24% of the rock. Both of these minerals show considerable embayment of quartz and plagioclase. A small amount of perthitic intergrowths are present. Titanite along with magnetite are prominent as accessory minerals. A basalt dike is reported to cut through the granodiorite close to the place from which this specimen was taken.
>
> "The country rock in Bowman Creek, in sec.27, T.3 S., R.43 E., near the molybdenite prospect is very interesting. This quartz diorite (R 1304) is very poor in orthoclase, but contains considerable biotite. The andesines are large and show distinct zoning. Numerous aligned inclusions of hornblende, magnetite and black acicular crystals are present in the feldspar. The deuteric effects in this rock are very pronounced. Fine examples of uralitization are present. Both hypersthene and augite are found altering to hornblende. This rock has been affected by the close proximity of the hydrothermal activity shown in the nearby molybdenite deposit.
>
> "A specimen (R 1348) taken from near the west sall contact of a basalt dike in the N$\frac{1}{2}$ of the SE$\frac{1}{4}$ of sec.26, T.3 S., R.43 E., shows the effect of the contact action on the granodiorite. The groundmass is a mosaic of andesine, orthoclase, and quartz, with phenocrysts of zoned plagioclase. Biotite here occurs in orbs and elongated rods as well as strewn out through the rock. Some muscovite is developed in allotriomorphic

grains. The alteration in the zoned plagioclase is interesting in that the centers of the crystals are almost completely kaolinized while the outer zones are comparatively fresh. This may indicate later enlargement of the feldspar by accretion."

"A specimen (R 1468) from the NW$\frac{1}{4}$ of sec.7, T.4 S., R.44 E., on the west fork of the Lostine River (elevation 6000 feet) shows a massive granitoid hypidiomorphic phase with considerable quartz (18%) and only a few grains of orthoclase. The plagioclase is andesine (48%) and the rock is rich in hornblende (25%) with biotite present in small amounts. There is considerable alteration of the rock, especially of the andesine to sericite, with some kaolinite; and corrosion and embayment of the hornblende by both plagioclase and quartz. This rock is a good example of quartz diorite, or tonalite.

"Some important features resulting from this intrusion are to be noted. Solutions bearing certain metals emanated from this batholith and penetrated any existing fractures, in some cases far out into the adjacent formations, resulting in veins of quartz. For the most part these are apparently not large. Other material, largely quartz and feldspar with little or no metals produced acid dikes, aplite and pegmatite. Still a third feature of this intrusion of granodiorite into the enclosing rocks is a contact metamorphism characterized by formation of garnets, epidote and molybdenite.

"For some as yet unknown reason the quartz veins on the north side of the range are not as large and do not have the metal content of those on the south side. If future work should prove that this is general it will be a very important guide to the prospecting of the region as a whole."

At Hummingbird Peak there is a contact zone up to 500 feet thick in which a great textural variety of hornblende-gneisses, schists, and hornfels have been developed and no sharp line of definition can be drawn between the sedimentary and igneous rocks. On the north side the contact is much sharper.

Goodspeed (38) believes that replacements of the sediments by the granodiorite on the south side of the range is metasomatic rather than a result of stoping or assimilation. In the northern Wallowas it appears that the older sediments have been intruded and disturbed by a viscous magma, which came in largely along the contact between the greenstone and the Lower Sedimentary series and resulted in the accentuation of the folding of the pre-existing sediments.

"Acid Dikes. There are many dike rocks, both acidic and basic cutting the granodiorite batholith. Among the acid dikes might be mentioned a set of narrow, very typical granite-aplite dikes which are found in the center of the NE¼ of sec.33, T.3 S., R.43 E. One specimen (R 1306) is a light-gray, allotriomorphic rock containing about 40% quartz and an equal amount of orthoclase, with about 8% of albite. The principal alterations are from orthoclase to kaolinite, with some development of sericite, and a chloritization of the biotite. The grain size is less than 2 mm. (which size has been set as an upper limit for aplites by some writers). Like many aplites there is considerable perthitic intergrowth. It was formerly stated that panidiomorphic textures were characteristic of aplites but it is now generally believed that a panallotriomorphic texture such as is exhibited by this rock is more characteristic (Johannsen, A., A Descriptive Petrography of the Igneous Rocks: vol.1 p.39, vol.II, p.92).

"At the 'Contact' molybdenite prospect on the east side of the Lostine River above Lapover (sec.24, T.3 S., R.43 E.) there is a very typical aplite dike at the portal of the east tunnel. The rock (R 1388 - see Plate III-A, fig.1) is phanerocrystalline, massive, and practically devoid of ferromagnesium minerals. There is about 32% quartz and 63% feldspar, with predominate orthoclase, but microcline and albite are also present in large amounts. There are both micropegmatite and microperthite present and very small amounts of muscovite, diopside, zircon and apatite as accessories.

"A good example of some of the effects produced in the granodiorite by later intrusions of acid dikes is shown in a specimen (R 1332) taken from the SW¼ of sec.23, T.3 S., R.43 E. The dike material is sufficiently coarse-grained to be considered a pegmatite. The granodiorite next to the contact contains about 35% of hornblende and biotite in about equal amounts. Some of the most interesting alteration effects are the change from biotite to hornblende, the alteration of hornblende to chlorite, and the kaolinization and sericitization of the feldspars. The quartz shows considerable strain.

"The effects of assimilation along the edges of a siliceous dike in crystalline limstone exposed in a prospect hole at 6600 feet elevation in sec.24, T.3 S., R.43 E., is shown by a specimen (R 1379) taken at the contact. The contact rock is light gray, finely granular, and composed of calcite, muscovite, and diopside in about equal amounts with only small amounts of quartz and pyrite. The feldspars which make up about 10% of the rock are highly sericitized.

"Basic Dikes. Numerous aschistic and diaschistic dikes of both intermediate and basic composition cut through the granodiorite. In the SE corner of sec.22, T.3 S., R.43 E., a hornblende andesite porphyry (R 1313- see Plate III-B, fig.7) is found which contains about 35% hornblende. This felsitic rock has a grain size of 0.66 mm. and the feldspar laths are andesine. An interesting feature is the alteration of the phenocrysts present. The outer zone is almost completely kaolinized while the interior of the crystals is fresh.

PLATE III-A

Fig. 1. Micropegmatitic intergrowth (quartz in feldspar) in aplite. R 1388. X-nicols. X 110

Fig. 2. Hornfels composed of diopside (dark) with background of quartz and feldspar. R 1322. 1-nicol. X 54.

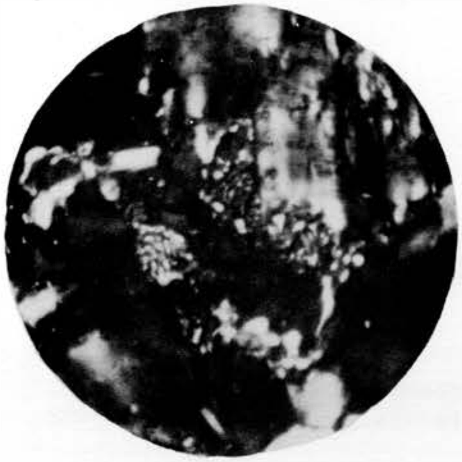
Fig. 3. Alteration of biotite (black) to chlorite (gray) in granodiorite. Quartz is penetrating the biotite along the cleavage. The inclusions in the biotite are apatite. R 1332. 1-nicol. X 75.

Fig. 4. Same as Fig. 3 except larger portion of the field. X 54.

Fig. 5. Twinning in tremolite in quartz tremolite schist. The schistosity is apparent in the groundmass. R 1473 X-nicols. X 28.

Fig. 6. Biotite orb in granodiorite. R 1348. 1-nicol. X 20.

PLATE III-A



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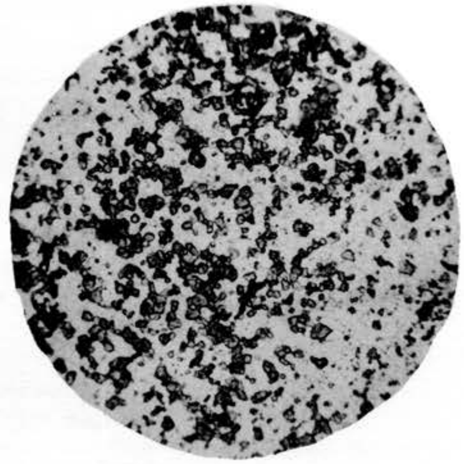

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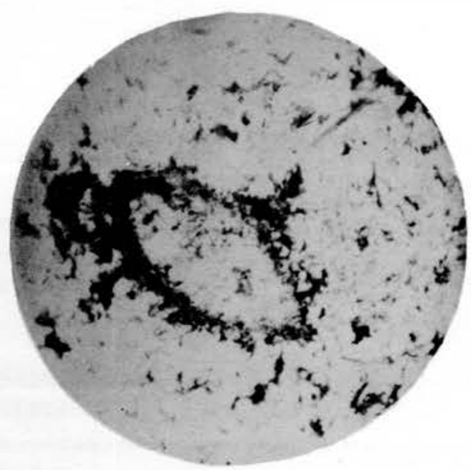

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PLATE III-B

Fig. 7. Andesine phenocryst in hornblende andesite showing alteration at edges of phenocryst with fresh interior. R 1313. X 20.

Fig. 8. Twinned hornblende crystal accompanied by orthoclase, andesine, and quartz in granodiorite. R 1346. X-nicols. X 20.

Fig. 9. Olivine diabase showing two generations of labradorite with olivine (dark) and augite in diabasic groundmass. R 1406. X-nicols. X 20.

Fig.10. Biotite lath in granodiorite. Orthoclase has cut through the biotite and worked along the cleavage. All of the orthoclase in the biotite is in optical continuity. Polysynthetic twinning is in andesine. Quartz also is present. R 1346. X 20.

Fig.11. Crystalline limestone showing banding by carbonaceous matter at right angles to elongation of calcite grains. A slight amount of schistosity has been induced. R 1386. X-nicols. X 20.

Fig.12. Schiller structure in augite (light) which is altering to hornblende. Mineral with strong cleavage and heavy outline is biotite. Quartzdiorite. R 1304. 1-nicol. X 54.

PLATE III - B

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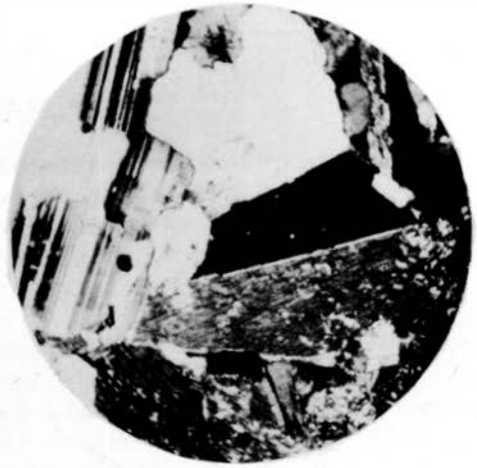

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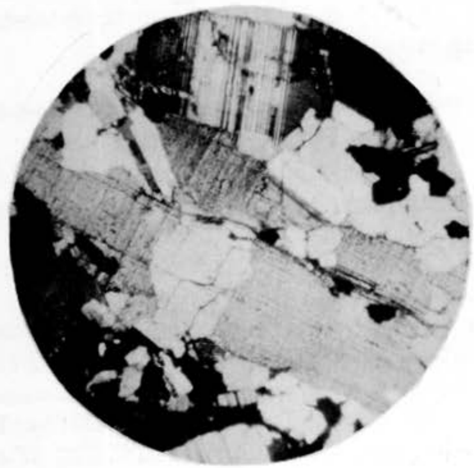

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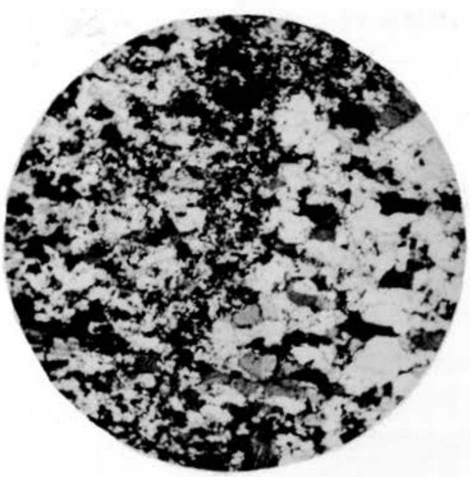

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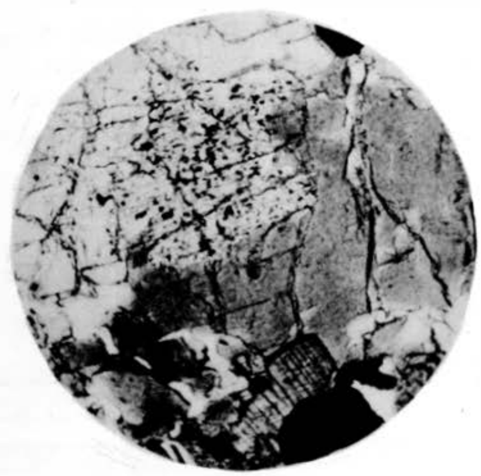

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Dark Colored Dikes (mainly Tertiary)

Among the more spectacular features of the central Wallowas are the great dikes which cut all the pre-Tertiary formations, but are more prominent within the granodiorite. Of many dikes that appeared from a distance to be basaltic, some on closer examination proved to be lamprophyric phases (complementary dikes) of the granodiorite intrusion. These dark-colored dikes are undifferentiated on the map. The dikes vary from a foot or less to over 50 feet in thickness, but seem to have an average thickness of about 20 feet. Within the area 82 such dikes, varying in length from a few hundred feet to over three miles have been mapped. Most of the dikes were mapped from a distance, but their contrast with the white granite on the bare rock faces made this mapping acceptably accurate. The trends are from 10° to 30° northwest in the Lostine River drainage and in the Lakes Basin; nearly north-south in the Hurricane and Wallowa drainage; but in the Main Eagle Creek drainage there were three sets of dikes with different trends. The dips are almost vertical wherever observed.

One dike cuts the granodiorite at the west side of Wood Lake, NW. corner of sec.15 T.3 S., R.43 E. Specimens from this dike (R 1311, 1312) according to Staples:

> "Are fine-grained with good diabasic texture. There is considerable granular augite but olivine is rare. At places the texture becomes hypo-crystalline with glass making up a large amount of the groundmass. Magnetite is present in large amounts, occasionally in euhedral crystals".

The only contact effect resulting from the intrusion of the late basaltic dikes is a slight baking at the contacts found in rare instances. The contacts are exceptionally sharp, as if the injected liquid was at low temperature and exerted little pressure during its intrusion.

In the Wallowa Lake quadrangle the north-south trending dikes cut across the structures of all pre-Tertiary formations, contradicting Gilluly's (37:64) suggestion that the emplacement of the basaltic dikes which have similar attitudes in the Baker quadrangle "presumably have been controlled by the older joint system in the pre-Tertiary basement". It is believed that the stresses resulting in the north-south fracture system were connected with the outflows of the Columbia River basalt.

Without much doubt these dikes supplied the vents for the flows of Columbia River basalt which flooded most of the region.

Columbia River Basalt Formation

General Features. The most widespread geologic formation in northeastern Oregon is the Columbia River basalt. It consists of a series of lava flows with minor amounts of interbedded sediments and pyroclastics, which once covered what is now the Wallowa Mountain area. In the northeastern part of Wallowa Lake quadrangle these flows underlie Wallowa Valley at an elevation of 4500 feet and have a very flat dip. South of the great Wallowa fault, they appear high on the crests of the ridges at elevations 6000 to 9000 feet. Toward the western, eastern, and southern edges of the quadrangle, the lavas overlie other formations at lower elevations. In the central portion of the area, only remnants of these flows occur, capping such peaks as Point Joseph (9300 feet), Lookout Mountain (8800 feet), Sturgill Peak (8900 feet), Brown Mountain (9000 feet), and Aneroid Point (9600 feet.) The thickness of the flows in Aneroid Peak is over 1500 feet, and the lavas may be thicker in the northeastern portion of the quadrangle.

Lithology. The lavas are usually dense, dark gray to black, and aphanitic with columnar jointing, locally well developed. Glassy, vesicular, scoriaceous or porphyritic textures are not uncommon. A highly magnetic, dense, black type was noted on Lookout Mountain. Staples described a specimen from Aneroid Peak as follows:

> "Aneroid Peak is composed of a dense, black, basalt rock that is characteristic of many of the highest points of the region. At an elevation of 9200 feet, in the NE corner of sec.22, T.4 S., R.45 E., a specimen (R 1406 - see Plate III-B, fig.9) contained a few large phenocrysts about 6 mm. in length in a groundmass consisting of laths averaging 0.6 mm. The rock has a diabasic texture and consists of about 63% labradorite with 12% olivine and 24% augite. The olivine is altered in part to iddingsite and antigorite. Although this specimen contains a few phenocrysts, they are not sufficiently numerous to justify one calling the rock a porphyry. This rock is very typical of the Columbia River basalts".

Relations with Underlying Rocks. The Columbia River basalt flowed out upon and covered a gently rolling, late mature surface, with a relief of from 500 to 1500 feet. A rather deeply weathered granitic soil mantled the old terrain, and this thick weathered zone occasionally remains, as on the slopes northeast of Aneroid Lake and around the Great Northern Mines west of Glacier Peak. Gravels are found at several places along the contact. Just east of Lookout Mountain, a bed of early Tertiary stream gravels up to 30 feet in thickness lies upon the granite and under the basalt. It is composed of round, waterworn boulders, up to 3 feet in diameter, of quartzite, aplite, and other metamorphic and igneous types of rock. The quartzite boulders are nearly all scarred with crescentic chatter marks, and make up over 20% of the bed.

Age and Correlation. The basalts have been correlated on the basis of lithology and stratigraphic position with the Columbia River basalts which are presumably of Miocene age. No fossils were found within this series in the Wallowa quadrangle, although a Miocene flora has been described from sedimentary interbeds in the basalt to the south and west by Gilluly (37:62) and Ross (38:55).

Quaternary Deposits

Most of the unconsolidated deposits in the Wallowa quadrangle are glacial in origin, or are derived from glacial deposits. The boulders are predominantly granitoid, with minor amounts of greenstones, limestones, and hornfels. There are very few basalt boulders. The deposits consist of material of all sizes.

The group of great, compound, lateral and terminal moraines which impound Wallowa Lake is undoubtedly one of the most spectacular and best preserved in the United States. The lateral moraine is over 800 feet high at its upper end, and its evenly sloping sides strongly suggest an artifical embankment. At least five stages of glacial advance and retreat or stand-still are indicated by ridges on its outer and terminal slopes. The moraines at the mouths of Lostine and Hurricane Creeks are less distinct but still are prominent features. Their small size in relation to the size of the canyon suggests that a portion of the uplift of the range along the fault scarp occurred after early glaciation. Moraines are well developed along the east side of Main Eagle Creek, and a small terminal moraine with two lobes impounds Two Color Lake, just south of Hummingbird Mountain. The tops of the lateral moraine ridges on Eagle Creek are 1000 feet above the valley floor. Granodiorite erratics are found 2500 feet above the valley floor in Lostine canyon.

Structure and Deformation
by
John Eliot Allen

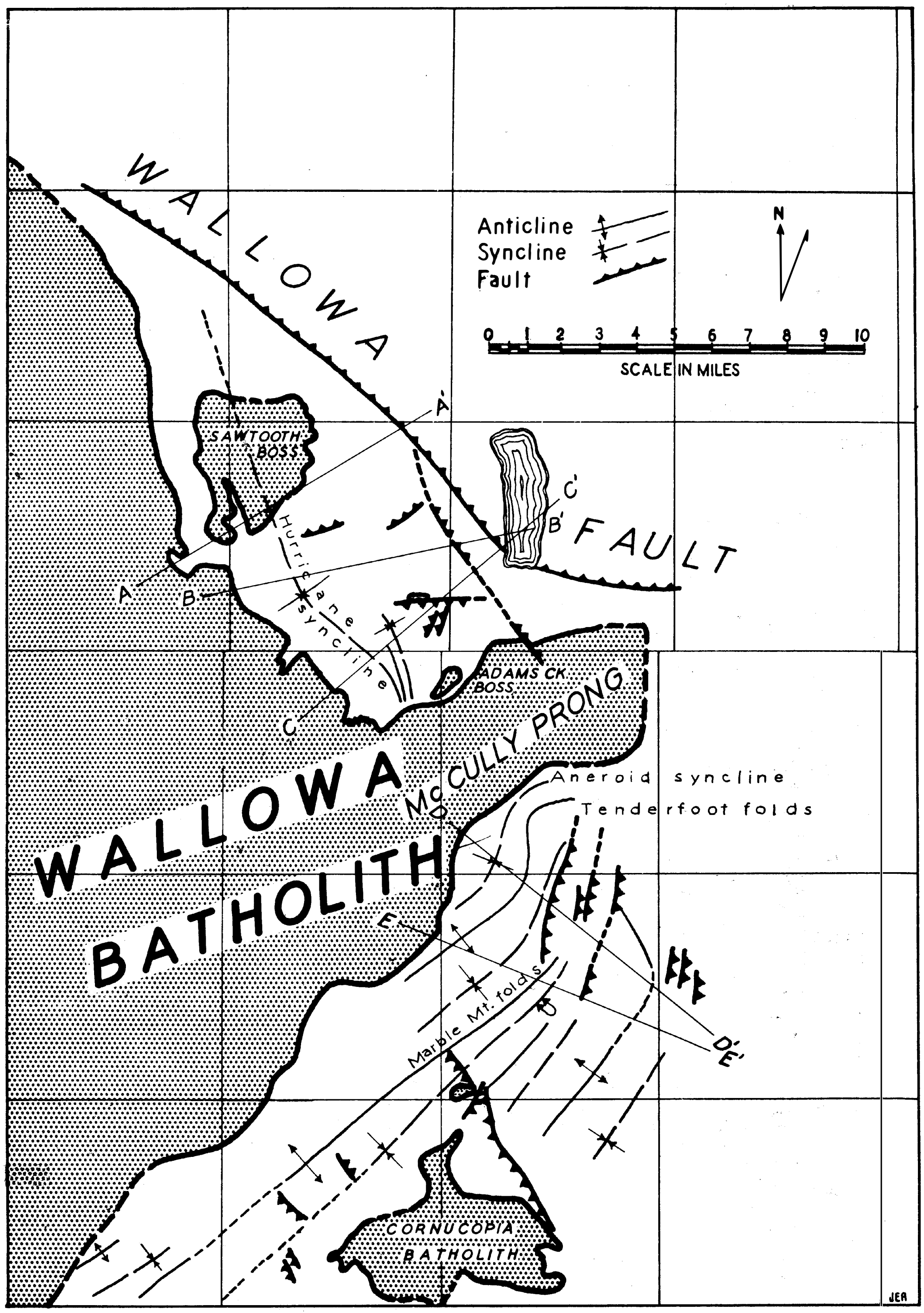
General Features. The pre-granodioritic sedimentary and metamorphic rocks of the Wallowas are conveniently divided by the McCully granodioritic prong into two areas: the northern, exposed south and west of Wallowa Lake and in the Hurricane and Lostine canyons; and the southern, exposed south of Aneroid Lake, in the headwaters of the Imnaha and the west fork of the Wallowa, and extending south into the Eagle Creek and Cornucopia areas mapped by Ross (38) (see Plate IV).

Earth movement due to stresses of varying origin has occurred repeatedly in the Wallowa Mountains. A list of these periods of folding and faulting suggests the complex structures resulting from them:

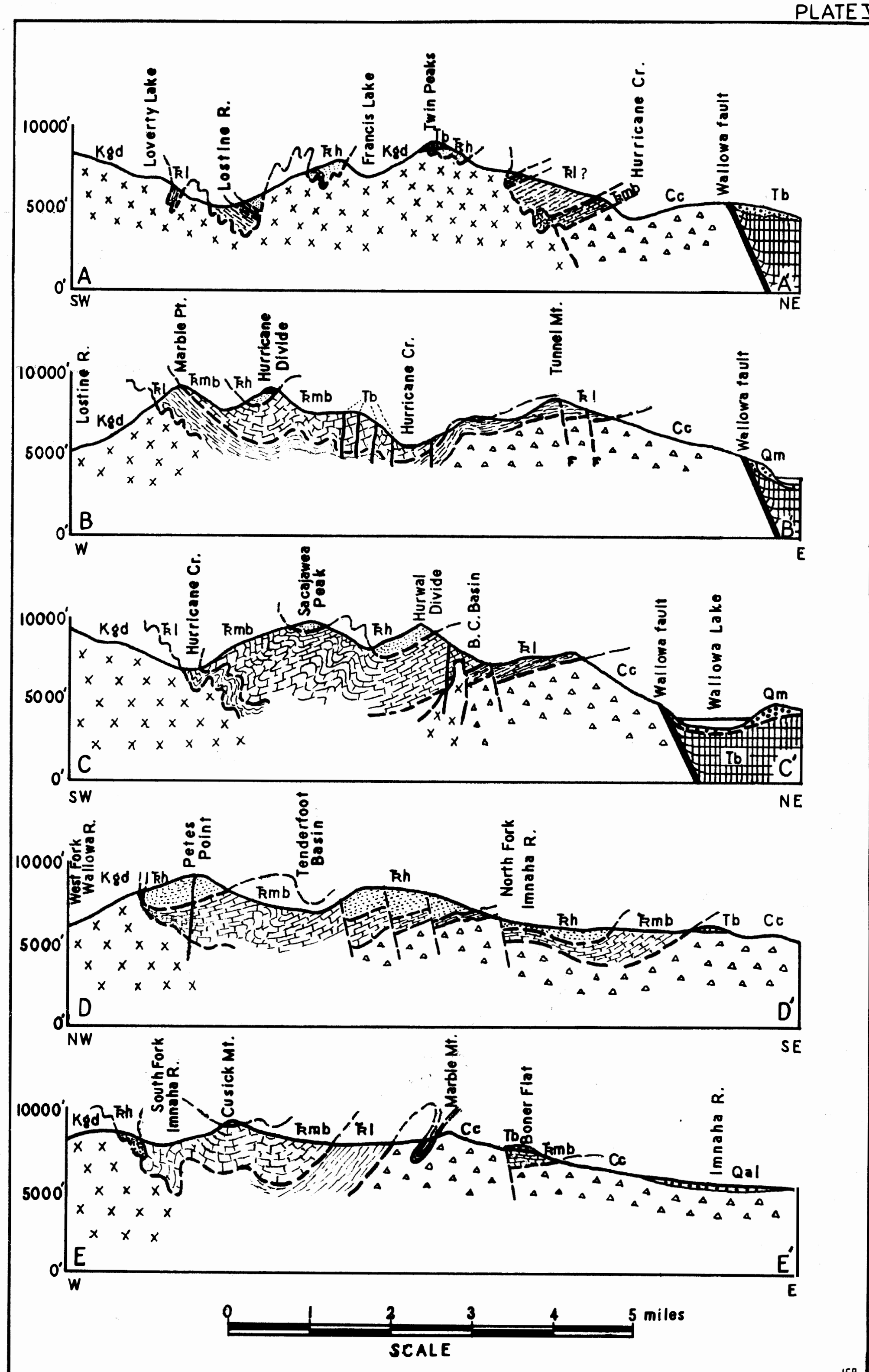
- Paleozoic intrusion (Ross 38:61)
- Permian or early Triassic folding (Ross 38:61)
- Late Mesozoic granitic intrusion, with extensive and complex folding and subordinate faulting and uplift.
- Middle Tertiary faulting, with basaltic intrusion of dikes and extrusion of lava flows.
- Late Tertiary or Quaternary faulting and uplift.

Paleozoic deformation, as suggested by Ross (38:61) has not been recognized in the northern Wallowas, but the unconformable relationships between the Lower Sedimentary series (which is in places missing entirely) and the Martin Bridge formation suggests that Permian or Triassic folding took place. The trends of the structures produced by this folding have not been definitely recognized.

Within this area, most of the major structural features were developed before or during the intrusion of the Wallowa batholith. The various lines of



MAJOR STRUCTURES IN THE WALLOWA LAKE QUADRANGLE



GEOLOGIC CROSS SECTIONS IN THE WALLOWAS

evidence for dating this Mesozoic folding will be discussed later.

The Tertiary deformation consisted of gentle arching and warping, with the main axis of folding striking northwest, as in the Baker quadrangle (Gilluly 37:71). There was also strong faulting along the north flank of the fold.

Structures in the Northern Area. The major structure within the northern area is a large northwest-plunging syncline, whose axis extends northwesterly from Ice Lake across the summit of Sacajawea Peak, across Hurricane Creek through Twin Peaks to Traverse ridge (sections A-A; B-B; C-C; Plate V). This fold is intruded in its central portion by the Sawtooth boss of granodiorite, and numerous minor folds complicate the structure, especially on the western flank. At Ice Lake this great syncline terminates abruptly against the granodiorite of McCully prong, and several minor folds occur. The limestone turns to the west and down over the face of the Matterhorn, as well as to the east and down Adams Creek, where it is split by the Adams Creek boss.

The Clover Creek greenstone series in the northern area lies entirely on the northeast flank of the major syncline, and dips to the southwest. The Lower Sedimentary series is in part absent and in part overlies the greenstone to the northeast. It is in direct contact with the granodiorite on the south and west, the thick greenstone series being absent. Along and near the western contact, the sediments are intruded by apophyses of granodiorite and themselves form outliers and xenoliths within the granodiorite (Section A-A', Plate V). On a large scale, the western contact is approximately parallel to the strike of the lower sediments of the west flank, but on the south it cuts abruptly northeastward across them, leaving only a narrow band to represent an original thickness of several thousand feet.

The Clover Creek greenstone and to a less extent the argillaceous Lower Sedimentary series and the Hurwal formation have reacted competently to the intrusive and folding stresses, in comparison to the Martin Bridge limestones which have been contorted, folded, squeezed up, and pinched out in an extraordinary manner.

The calcareous Martin Bridge formation is so highly folded that the structures could not worked out in detail. The limestones apparently flowed like a viscous liquid, creating irregular complex folds of all sorts - isoclinal, fan-shaped, and crenulate. Layers of more competent sediments interbedded within the limestone, or dikes and sills intruded into it, have been pulled apart, the flow bands in the limestone now passing smoothly around these isolated knobs of argillaceous or basaltic material. In the limestones on the east side of the Matterhorn a small dike paralleling the flow banding, about $1\frac{1}{2}$ inches wide, has been pulled apart by the movement. Its rectangular fragments, none of them over a few inches long, total about 10 feet in length, and are now spread out over a distance of 55 feet. The stretching in this locality has thus been over five-fold.

Along the north side of McCully prong south of Wallowa Lake, the granodiorite is separated from the greenstone only by a thin band of calcareous and argillaceous metamorphics. Apparently here the greenstone acted as a resistant buttress to the intrusive forces, squeezing the less competent materials until they were almost pinched out. The contact is nearly vertical for 2500 feet, and in places dips into the granite.

The west contact of the metamorphics with the granodiorite on the Lostine River, abruptly turns eastward at the Iron Dike Ranger Station, and crosses the ridge 2 miles south of Francis Lake basin into Hurricane Creek towards the Matterhorn, where it again makes a sharp turn to the northeast. These two bends seem to occur on two zones of weakness which affected and guided the intrusion of the batholith in these areas. The relative movement was eastward on the south side of each zone, or else the north side dropped down. The zones of weakness trend northeasterly, the northern zone lying just south of and parallel to structure section A-A' (from Bowman Creek basin through Marble Point and Twin Peaks - coinciding with the south edge of the Sawtooth Boss). The southern zone parallels the contact of McCully Prong from the Matterhorn down Adams Creek, across Middle Mountain and up Royal Purple Creek.

All mining prospects in the northern area seem to lie along these two zones. The mineralization at the Wilson Mines (John Henry Lake - Bowman Creek), and the Great Northern Mines (Copper Creek) is upon their southwestern extensions into the batholith; and the Marble Point, Falls Creek, Granite Creek, Matterhorn, Adams Creek, Royal Purple Creek and McCully Creek (Transvaal) prospects lie upon these same trends, usually at the granodiorite-marble contacts.

Structures in the Southern Area. The southern area of pre-granodiorite rocks occupies the headwaters of the Imnaha River and a small area south of Aneroid Lake. The granodiorite here apparently intruded from the west and north, crumpled up the Lower Sedimentary and the limestone series against the competent greenstones lying to the east. A number of northeasterly-trending folds resulted,whereas northwesterly-trending folds were developed in the northern area.

On the west flank of the Aneroid Lake syncline the limestones and Lower Sedimentary series were pinched out against the granodiorite to a very thin band (Section D-D', plate V), but in the Tenderfoot anticline one or two miles to the east there is an apparent thickness of limestone of more than 2000 feet. Both this latter structure and the Tenderfoot syncline a mile farther east curve sharply to the east as they pass up over the divide between the Imnaha and Wallowa drainage, a bend caused by the protruding McCully granodiorite prong lying to the north.

Three other structures south of the main Imnaha River have been tied in from Ross' map (38). Just west of Marble Mountain a tightly closed isoclinal syncline and anticline, overturned to the east, cause a nearly uniform westward dip of the strata along the ridge. These same structures have been mapped by Ross along the east fork of Eagle Creek and probably tie in with those mapped at the extreme southern edge of the map on main Eagle Creek.

Ross indicates a gentle anticline in the greenstones which would cross the Imnaha River near Polaris Ranger Station. If this turns to the northeast up the east valley wall of the middle and north forks of the Imnaha, it would join the anticlinal structure noted there in the limestones and argillites.

The structural details in many places within both areas are so complicated that the sections drawn only represent the most logical of several possible explanations of the features observed. For instance, some of the faults indicated (section in D-D', Plate V) are only inferred from the stratigraphic position of the beds. They may be sharp folds or thrusts from the west rather than normal faults as plotted. The face of Sacajawea Peak is so highly folded that only inference as to structure could be drawn.

Faulting. Separate periods of faulting in the Wallowa Mountains cannot always be distinguished with certainty. Faults with north-south and east-west trends (Tunnel Mountain and Big Creek faults) bound a horst about two miles wide, uplifted about 500 feet possibly by subjacent granodioritic intrusions which have reached the surface only in small areas at the head of B.C.basin and just below Hurricane rapids. Multiple north-south faulting on the south wall of B.C. basin has about 500 feet of total displacement, the west side having dropped.

The continuous westward dip in the Hurwal sediments along the ridge between the North and Middle forks of the Imnaha cannot be reconciled with the apparent almost horizontal contact between them and the underlying limestone and greenstone, unless a series of faults successively drop the eastern blocks down or thrust the western blocks up (Section D-D', Plate V). The westernmost of these faults was mapped in the field, others were in part inferred.

A summary of the most significant structural features of the region would include the following:

1. The trends of the axes of folding in the northern and southern areas, separated by the McCully Prong, are at right angles to each other.
2. The contacts between the granodiorite and the older rocks are steepest where the granodiorite cuts across the structures on the north side of the McCully Prong. Elsewhere the attitude of the bedding in the older rocks approximates the attitude of the contact.
3. The apparent thickness of the limestone is greatest near salients of older rocks into the batholith. Where the batholith nears the greenstone in the McCully Prong the intervening rocks - limestones and other sediments - are very thin.
4. Compound faulting, especially in the southern area, is associated with isoclinal and overturned folding, and both are best developed adjacent to the greenstones.
5. Large-scale mineralization (sulphide type and otherwise) within the Wallowas is restricted to the southern side of the range. Mineralization and metallization are predominantly of contact-metamorphic type. on the north side.
6. Most mineralization within the northern Wallowas is restricted to three zones that trend northeasterly and suggest displacement during the batholithic intrusion.

The hypothesis which seems best to explain all these features is one which suggests that most of the folding was developed by and during the intrusion of the batholith itself. The viscous magma apparently broke through the relatively competent and brittle greenstones and came up from the west along the contact between the greenstone and the overlying sediments. The latter were crumpled against the greenstones, and repeatedly faulted. The intrusion was also guided by northeast-southwest trending zones of weakness.

Tertiary structures. The dikes of basalt that contributed to the once overlying plateau lavas came up over the entire area along predominantly north-south fissures. In only a few places do they deviate from this trend more than 20 degrees (to the west). The accompanying Figure 4 indicates the strike of the dikes noted and mapped. Most of the dikes approach verticality. Many of them are over a mile in length, and several are over two miles long. Parallel faulting without intrusion appears occasionally (as at B.C.Basin, Hobo Lake, Wood Lake, Middle Mountain, and Point Joseph).

Cross faulting which has dislocated dikes in B.C.Basin and on Big Creek could be used as age criteria were it not for the fact that some of the dikes are known to be lamprophyric and contemporaneous with the last stages of the granodioritic intrusions, rather than basaltic and mid-Tertiary in age. Petrographic work has been done on only a few of these dikes, and the two types were seldom distinguished in the field.

The location of the main northwesterly-trending Wallowa fault zone which forms the great northern escarpment of the range is based mainly on physiographic evidence, although several parallel faults with small displacements have been observed. It was along this major zone of fracturing that a large part of the late Tertiary or early Quaternary uplift of the range took place. There is a surprising lack of glacial debris at the mouth of the great Lostine drainage system. None of the movements can have been postglacial, or the Wallowa Lake moraines would have been disturbed.

To the northwest of Lostine Canyon and probably to the southeast of Wallowa Lake as well, the Wallowa fault passes into a monocline. It seems probable that the flexures and faulting along this zone are due to compressive forces and upthrust, as has been suggested by Smith (27:421-440) in the case of the basin-range faulting of the Steens Mountain, rather than to the simple downdropping of the plateau side to the northeast. In the Baker quadrangle to the southwest, Gilluly (37:77) believes that the dominantly northwesterly trend of the Tertiary structures there

"... seems to indicate a regional control during the deformation. The broad folds suggest a slight compression normal to this trend, but the prevalence of parallel normal faults seems to indicate the compression was not great at levels

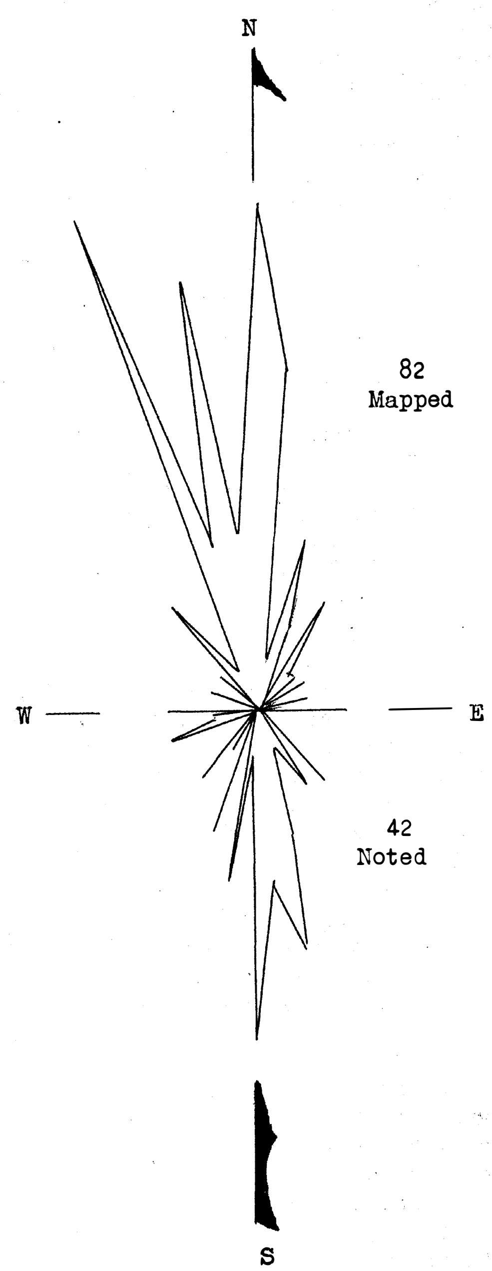


Fig.4. Trends of basaltic dikes in the Wallowas.

> now exposed. It may be that these features are best explained by vertical adjustments of the crust, consequent on the great extrusions of the Columbia River basalt, which must have upset the subcrustal equilibrium. Differential vertical movements, acting under compression sufficient only to control the trend of the resulting wrinkles and breaks, seem competent to have produced the existing Tertiary structural features. Their general independence of pre-Tertiary trend lines seems to suggest a deep-seated source of the movements."

This explanation suggests an attempt to adjust the field evidence with preconceived notions of the mechanics of normal faulting, rather than a logical correlation of the folding and the faulting as exhibited, into a harmonious hypothesis of upthrusting due to compression.

SUMMARY OF HISTORICAL GEOLOGY

Great lava flows and tuff beds were extruded some time prior to middle Triassic time (probably in Permian) in a manner similar to that of the Columbia River basalts and tuffs. After some erosion resulting from uplift, the land area sank and was covered by salt water in which were deposited limey and clayey sediments. These later became the metamorphosed sediments and limestones. Fluctuating conditions of depth of water and source of material account for the changes in types of sediments. The shallow sea bottom swarmed with invertebrate life such as corals and several types of shellfish.

No Jurassic sediments have been recognized in the area. If they once existed, they have been totally eroded. Perhaps in this region, the land had already begun to emerge from the sea during the Jurassic and the Triassic formations were being folded and eroded. As folding progressed and the earth's crust was weakened, underlying molten rock (magma) sought its way upward. Breaking through the greenstones it made more progress through the less competent rocks by forcing them aside and folding them intensely. Thus the limestones were squeezed and their enormous thickening around the head of Lake Creek and on Hurricane Creek was developed. The magma also advanced by stoping, as large blocks of the sediments are found completely isolated within the granitoid rock. Assimilation was better developed in the southern portion of the range where according to Goodspeed (39) much of the granite itself eventually came to be made up of more or less dissolved sediments.

As the granodiorite cooled and contracted, it fractured to permit dikes of granodiorite-porphyry, aplite and lamprophyre to penetrate its upper portions and the cover of older rocks. During the last stages of intrusion of the batholithic mass, the important metalliferous mineral ore bodies of the southern Wallowas were emplaced.

The next great chapter in the geological history of the Wallowa region is concerned largely with erosion. It is uncertain to what extent the area was baseleveled, but plainly the folds were extensively beveled off. Today as one looks over the whole range from some vantage point like the Hurwal Divide, he is struck by the accordant tops of the ridges. The erosion was so deep that large portions of the granitic batholith are now exposed. During this erosion interval streams whose courses were quite at variance with the present stream patterns were developed.

Evidence of these is offered by heavy conglomerate lying on the granodiorite and below the Miocene basalts.

Approximately 40 million years ago, in Miocene time, occurred the tremendous outpouring of basic lavas called the Columbia River basalts. These issued from long fissures, now occupied by the prominent basaltic dikes that extend for great distances, as much as two miles, across country. As erosion has removed much of this overlying basalt, its original thickness is unknown, but presumably it originally was three or four thousand feet thick. Sometime later, diastrophic movements in the form of gentle upwarping and profound faulting resulted in the upthrusting of the Wallowa region as a great block or horst. The most spectacular of the faults forms the precipitous northern slope of the range. Other faults probably account for the Grand Ronde Valley, a down-faulted block of the earth's crust, a few miles west of the quadrangle. Eagle Creek in part may flow along such a fracture. During this uplift of at least 5000 feet and following it (if indeed it has ever ceased) erosion by running water maintained the already well-developed radial drainage system and cut deep V-shaped valleys, which were present at the advent of the ice age.

The glacial history of the Wallowa Mountains is treated fully in the following chapter on physiography.

CHAPTER IV

PHYSIOGRAPHY
by
Warren D. Smith and Wayne R. Lowell

Introduction. In the preceding chapter a full discussion of the rocks and their structures was given. Igneous rocks and various kinds of sedimentaries, most of which have been profoundly metamorphosed, cover most of the area. The igneous rocks consist of deep-seated, coarse-grained types resembling granites, of lavas lying for the most part above the granitic rocks, and of still others in the form of dikes that cut the older formations. The metamorphosed sedimentary rocks include limestones, indurated sandstones, and shales which are greatly folded and contorted. The different rock types are in some cases harder than the neighboring formations, but in other cases they are somewhat less resistant.

In all of these different types of rocks there are certain definite structures such as schistosity, jointing, faulting, and folding which have left their impression upon the physiography of the region by producing certain details of topographic expression.

In older discussions of the physiography of a given terrain empirical terms were employed, but in the modern treatment of the subject, it is customary to consider the subject according to (1) material and structure, (2) process, and (3) stage.

Stated in terms of the above the distinctive characteristics of this region may be summarized as follows:

1. A complex terrain composed of harder and softer rocks has been profoundly folded, intruded, and metamorphosed.

2. Very considerable and probably recurrent elevation has been accompanied by faulting on a large scale and dissection by erosion by both water and ice.

3. Although the region has passed through several cycles of erosion and uplift in the past, only the last two cycles affect the present topography. It is now in a stage of late youth to early maturity.

Summary. The major physiographic features are:

1. A great irregular dome-shaped mass of rocks stands out as an island mass partially surrounded by a lava plateau of lower elevation.

2. This central mass has been dissected by streams with a general radial pattern, which nevertheless follows contacts and other structural features, and whose valleys were later modified by glaciation.

3. The fairly even skyline and accordant ridge tops of the central portion were developed by erosion of the area to maturity in an earlier cycle of erosion, before the outflow of basalts.

4. The remnants of the basalt flows represent a now almost completely eroded but once extensive sheet that covered the whole area.

5. The northern front of the older rocks of the area is bounded by a major fault scarp whose maximum displacement is approximately 5000 feet, and which passes into a monoclinal fold to the northwest and to the southeast.

6. The depositional features consist of landslides, glacial outwash, moraines, and recently reworked glacial material, which lie within the over-steepened valleys or near their mouths. Coalescing, alluvial, piedmont fans have been developed along the Wallowa fault front, with alluvium and outwash in the Wallowa Valley.

The major land forms are due to: (1) original structural trends in the pre-granitic terrain, (2) volcanism, (3) diastrophism - gentle upwarp and faulting, (4) erosion (by streams and glaciers) and deposition.

The minor (and some of the major) features are due to: (1) inequalities in the hardness, texture, and resistance to erosion of the rock formations, (2) joints, schistosity, fractures, and stratification within these formations, (3) glacial erosion (4) weathering, (5) the work of plants and animals including man.

Structure of and variations in resistance of the pre-basaltic rocks to erosion have resulted in the localization of some of the largest valleys and highest peaks. In the course of lowering the base-level some 4000 to 5000 feet, any initial stream pattern developed upon the surface of the basalts other than a general radial arrangement of the drainage, has been extensively altered by the structures in the sub-basaltic rocks upon which the streams were superposed.

The Lostine and Hurricane Valleys lie parallel to and on the flanks of a syncline in the older rocks, and their courses have been determined by the contact of the less resistant rocks in the syncline with more resistant formations (granodiorite and greenstone) on either side. Adams Creek, Royal Purple Creek, and Thorpe Creek all run along the contacts of less resistant limestone with more resistant rocks. The upper course of the West fork of the Wallowa River probably was determined by the granodiorite contact with older rocks. In the southern area, the Imnaha drainage cuts across the structures and is hence little guided by them.

The highest peaks in the range are composed in most cases of the more resistant Hurwal formation, generally in localities where its thickness has been retained in a synclinal structure, as on the ridges around Francis Lake and south of Aneroid Lake to Sentinel Peak. It also caps the Hurwal Divide.

Jointing in the granodiorite, best exhibited in the Lakes Basin, has done much to govern the process of erosion. The east-west strings of lakes, both along Lake Creek and to the north, are due mainly to this well-developed structure.

Volcanism accounts for the nearly horizontal lava flows in several parts of the area. Such peaks as Lookout, Aneroid, and Twin Peaks are capped by Columbia River basalt. In the case of Lookout Peak at least, its location is due to the extra thickness of basalt within a pre-basalt valley. There are numerous dikes of basalt that cut the older rocks and have withstood erosion better than the granite. As a result, they now stand up in great walls. In some cases, these dikes seem to have even guided the trend of adjacent valleys. This is especially evident in section 25, just south of Moccasin Lake.

Diastrophism accounts for the fact that this mountain mass stands up some 5000 feet above the surrounding plateau. This great upwarp occurred mainly before (but possibly in part during) glaciation, and may have contributed to the hanging position of such valleys as Bowman Creek, Wilson Basin, Lake Creek, and others. Positive evidence for this early rejuvenation has been in part destroyed by the glaciation. The north side of this upwarp was faulted to produce the most conspicuous single topographic feature of the range, namely the great northwest-southeast-trending escarpment of the Wallowa fault. The upper part of this escarpment is very steep, but below about the 7500-foot contour there is a prodigious mass of slump and fan material. The apparent lack of sufficient morainal material at the mouth of Hurricane and Lostine Rivers to account for the glacial erosion along their courses suggests that some movement on this fault occurred during glaciation. The lack of any dislocation of the Wallowa Lake moraines proves that no movement took place after this (Wisconsin?) glacial stage.

Erosion by running water and later - and most important - by moving ice, has carved out tremendous canyons several thousand feet deep, such as Lostine, east and west forks of the Wallowa, and others. Some of the most conspicuous features due to a combination of structure and erosion by ice are to be found in the center of the range. Eagle Cap is a typical half-dome of granodiorite on whose northeastern flank still cling remnants of ice surviving from a more extensive glacier that some time attained a maximum length of close to 15 miles. Surrounding this peak but principally in the basin to the north of it are many small cirque lakes.

Since the retreat of the ice, there has been considerable continued erosion within the main canyons, with the development of "gorges" cut into rock lips as in the west fork at the head of Wallowa Lake, in Hurricane Canyon at the "rapids", at the "falls" of the Imnaha, and in the Lostine near Pole Bridge. These gorges have been incised from 10 to 50 feet in solid rock. The tortuous courses of these gorges show that they could not have been formed by ice action, or before glaciation.

Landslides and snowslides due to the very steep slopes in the higher portions of the range are of frequent occurrence and they quite markedly alter the topography of the local terrain. The action of snow slides was particularly conspicuous along Hurricane Creek in the winters of '37 and '38. In several places these devastating slides swept across the valley and far up the opposite slopes cutting a wide (one-fourth to one-half mile) swath through the timber and also stripping the soil in places down to bed rock.

Physiographic history. The remnants of the earlier stages in the physiographic history of this region have been mentioned in the chapter on geologic history. Later events have mainly obliterated earlier surfaces. The physiographic story properly begins with the vents of the Miocene.

In the Miocene, repeated outpourings of rather liquid basaltic lava flows covered most of eastern Oregon and Washington. The flows attained a thickness of several thousand feet in this area, and covered pre-existing surfaces. This old surface was probably a matureland. A great deal of this lava cover has since been removed, but some of it still remains even in higher portions of the range as remnants several hundreds of feet in thickness of nearly horizontal basalt flows.

Upthrusting of the whole range as a block occurred in the post-Miocene, continuing perhaps through the remainder of the Tertiary and possibly even into the

Quaternary. On the north side of the range extensive faulting occurred, but in other portions, on the flanks particularly in the northwest, the flows were bent upward without great breaks. The major topographic features of the region can be attributed to this great horst-like elevation and the resultant erosion.

During this uplift and following it, erosion was at work. The drainage pattern probably was considerably altered. Previous to the lava eruptions and uplift, the streams had undergone adjustment in accordance with the previous folding of the sediments and derangements attendant upon the granodiorite intrusions. After the lava eruptions and dome-like uplift the drainage of the area as a whole became decidedly radial in pattern, and after the uplift of the north side, the streams cut down deeper there than elsewhere.

*Glaciation. Climatic conditions changed and brought on glaciation in this area. Winter snows persisted through the summers. When the temperature remained sufficiently low so that most of the precipitation fell in the form of snow, the snowfields rapidly expanded and thickened. The southwesterly winds rising to pass over the high central ridges and peaks (Sacajawea, Matterhorn, and Eagle Cap) dropped most of the suspended moisture as snow which accumulated in the Lake Basin area north of Eagle Cap and in another area east of the highest ridge extending southeastward from Eagle Cap. Snow lodged on the lee side of ridges and, protected from the prevailing winds, accumulated to great depths.

Topographic control by high peaks and ridges of precipitation in the névé collecting fields is suggested by the two areas, one north and the other southeast of Eagle Cap. These apparently have been subjected to greater glacial erosion than other parts of the mountains. There has been pronounced cirque development on the north and east sides of ridge crests. Lack of extensive glaciation in the west, southwest and northeast parts of the mountains is probably due to topographic factors which controlled precipitation.

From the growing névé fields, the direction of the outward spreading ice was controlled by the drainage channels radiating from Eagle Cap. Each of the large canyons (East Fork and West Fork of the Wallowa, Imnaha, Pine Creek, Eagle Creek, Minam, Hurricane and Lostine) of the drainage system contained a glacier which removed mantle rock, and scoured and polished the walls and rock floors in developing their present U-shapes.

Since the glacial features in the Wallowa Mountains are similar in the various areas, Lostine Canyon, Wallowa Lake moraines, and Aneroid Lake and Glacier Lake cirques have been chosen for description because of their accessibility and since they are places of interest most often visited.

Glacial features of the Lostine Canyon. Lostine River flows through Lostine Canyon from the north end of Minam Lake, (center sec. 30, T.4 S., R.44 E.) and leaves the mountains at the town of Lostine in the Wallowa Valley. The canyon trends slightly west of north, and is one of the canyons radiating outward from Eagle Cap Mountain near the center of the range.

The floor of Lostine Canyon has an average approximate gradient of 200 feet per mile for the 22 or 23 miles of its length. From Lostine to the forks of the

* The rest of this chapter is adapted from the Master's thesis of Wayne Russell Lowell, a member of the 1938 and 1939 summer field parties.

Fig. 1. Perched granodiorite erratics at 7300 feet elevation in Lostine Canyon. (Photo by Warren D. Smith)

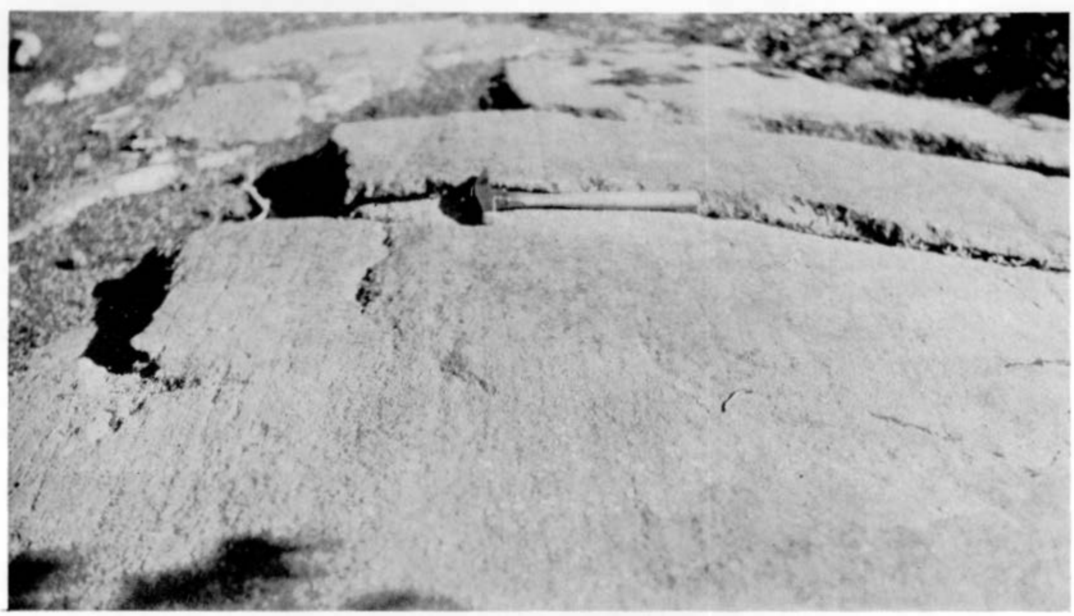


Fig. 2. Striated rock surface in Lostine Canyon. (Photo by Warren D. Smith)

river (SE. cor. sec.6, T.4 S., R.44 E.) the floor is covered with morainal material which for the most part has been reworked by the stream. The river is a series of cascades in this part of the canyon. Above the falls the canyon floor is a succession of park-like areas separated by steep gradients similar to the lower canyon.

Throughout the length of the canyon the valley has a wide U-shape, the floor rising away from the stream until the rock walls abruptly emerge from the fill and talus. The rock slopes steepen until they are almost vertical in places, and then level off toward the crests of the ridges.

Due to cirque development on the ridge west of Lostine River, nearly all of the large tributary streams enter from the west side. Most of the tributaries head in cirque lakes and cascade down the steep canyon walls to join the main river.

Upper Lostine Canyon is cut in granodiorite, the surface of which retains much evidence of the glacial erosion to which it has been subjected. North of Iron Dyke Ranger Station the canyon follows for a distance along the contact of sedimentary rocks with granodiorite. The surface of these rocks, which are easily weathered, retains little evidence of glacial erosion.

At the Pole Bridge (sec.15, T.2 S., R.43 E.) there is an abrupt drop of approximately a hundred feet in the canyon bottom. The stream cascades through a steep channel eroded in this rock bench, and flows into a widening valley of low gradient as it leaves the Wallowa Mountains. About here, also, the valley walls lose their steep slopes and the ridges decrease in elevation.

The lateral and terminal moraines of the Lostine ice tongue appear in the enlarged mouth of Lostine Canyon, located in sec.4, T.1 S., and sec.34, T.2 S., R.43 E.

The lateral moraines lie against the east and west walls respectively. The east moraine is distinct and continuous for more than a mile and averages 400 feet in height. The west moraine is neither extensive nor well defined.

From the upstream ends of these moraines, another set of smaller hummocky moraines diverges from the valley walls and approaches the center of the valley. These moraines are from one-half to three quarters of a mile long. The east moraine is 375 feet and the one on the west is 250 feet high (Stovall 29:81). Separating these is a short, low ridge that was once probably continuous with them, but is now separated by channels. Lostine Creek flows through the channel to the west at the present time. These moraines do not show any considerable amount of weathering on the higher portions.

The road traverses the large east moraine and crosses what is probably the terminal moraine. The area between the road and the river is in part cultivated. Cultivated fields upstream from the moraines indicate at least a thin covering of fine soil over part of the till. The thickness of this soil is not known, and the area is limited, as upstream (in sec.10, T.2 S., R.43 E.) gravel extends entirely across the valley floor.

If it is assumed that the converging moraines were originally joined at the center and had a fairly uniform elevation throughout their length, then a temporary lake might have occupied the area between the moraines and the glacier front.

The cultivated soil behind the moraines may be a remnant of fine sediment deposited in such a shallow "Lostine Lake".

Another lateral moraine 875 feet high just within the narrows of the canyon (probably in NW$\frac{1}{4}$ sec.15, T.2 S., R.43 E.), and on the west side of the river may belong to a later stage of glaciation. The moraine crosses a tributary gulch diverting the stream several hundred feet northward before it joins the main river (Stovall 29:81).

J. C. Stovall used the two sets of moraines as evidence for two stages, but found no evidence for two periods of glaciation. If by two stages of glaciation Stovall meant a stage of maximum advance represented by the higher lateral moraines and another stage, represented by the lower converging moraines upstream, where the glacier was stationary for a time in its retreat, then the writer is in accord with his conclusion.

No evidence has been found by the writer that suggests more than one period of glaciation in Lostine Canyon. If there was an earlier glaciation in the canyon, the last advance of the ice tongue destroyed the evidence. This was also the conclusion reached by Stovall. The ice was probably at least 400 feet thick at its terminus with increasing thickness up the canyon. The moraine, approximately located in sec.22, suggests a thickness of 900 feet of the ice about one mile above the terminus.

On the east side of the river, (in sec.35, T.2 S., R.43 E.), are three distinct low, lateral morainal ridges at elevations of 4850 to 5000 feet. These ridges are separated by shallow fossae. Dissected recessional moraines of this kind were also found upstream from French Camp below the base of the east ridge.

<u>Triangular facets</u>, which have resulted from truncation by glacial erosion of ridges extending into the canyon, are to be seen throughout the canyon. The best example noted is located at the mouth of Lake Creek (SW$\frac{1}{4}$ sec.1, T.3 S., R.43 E.).

<u>Erratics</u> are found on a limestone bench, 200 feet wide at an elevation of 5600 feet, (in SE$\frac{1}{4}$ sec.35, T.2 S., R.43 E.). Rounded granodiorite boulders up to two feet in diameter are scattered over this scoured surface. Boulders of this type were found up to the 6500-foot contour.

On a similar limestone bench on the south face of Marble Point (sec.24, T.3 S., R.44 E.) granodiorite erratics 8 by 10 feet were found at an elevation of 7300 feet. The closest granodiorite lies a half mile to the south. Erratics do not occur at higher elevations on this ridge.

The elevation of this bench corresponds to that of the nearly vertical wall in the granodiorite to the south, and marks in this part of the valley, the approximate upper limit of the glacier, which would here be about 2100 feet thick.

Roches moutonnées are prevalent in Lostine Canyon above the forks of the river. The best examples are found about one mile from the forks on the floor of the main canyon.

Prominent rock ridges parallel the valley and are quite long, with a height varying up to ten feet. The joint-block hollows are deeply eroded and rounded. The surfaces are polished and striated, with the striations parallel to the trend of the canyon. In places the polished and striated surface is spalling off. In all cases the up-canyon ends of the roches moutonnées are smooth and rounded and the opposite ends may or may not show plucking depending on the jointing in the rock. Roches moutonnées developed on granodiorite and greenstone have been well preserved, but were not preserved in this area when developed on metamorphosed limestone and shales.

Glacial striae and polished rock surfaces are abundant throughout the area in which granodiorite is the surface rock. Cirque basins show the best development of striae which in all cases parallel the drainage direction of the basins. Striae on the divide which separates the head of East Fork of Lostine Canyon from Lake Basin indicate that ice moved from the Basin into the canyon.

The nose of the ridge between the East Fork and Lostine rivers shows polished surfaces to an elevation of 7325 feet. Above this elevation the ridge is rugged with a serrate crest.

Tributary cirque glaciers in hanging valleys contributed ice and debris to the main glacier. Most cirques and hanging valleys were high enough to discharge onto the surface of the valley glacier. The west ridge of Lostine Canyon contains many well-developed cirques and hanging valleys. Bowman Creek heads nearly two miles south of Chimney Lake and flows northward to emerge from its hanging valley eighteen hundred feet above the river. Much of the steep slope below the valley is polished and contains glacial flutings.

Snowslides during the late spring and summer in Lostine Canyon cut wide swaths down slopes, carrying timber and talus into the valley bottoms. The most severe snowslides occurred just up-canyon from French Camp. Possibly there was only one slide; if so, it was very large. Trees two feet in diameter were snapped off at the base and, together with a large amount of rock talus, were carried a considerable distance across the canyon floor.

Occasional straight strips reaching far up the steep slopes appear to be the scenes of recurrent slides. The rock surface is bare and fairly smooth, with no encroaching brush or timber.

The Lostine Valley Glacier originated in the névé collecting field in the vicinity of Eagle Cap. The ice, which was derived from this area moved northward along the canyon, receiving additions from cirques and small collecting fields on and under the ridges. The glacier probably reached its maximum thickness below its junction with the East Fork glacier. The discharge of numerous cirque glaciers continued to add both ice and detritus to the surface of the valley glacier, but the greater size of the canyon below the forks allowed the ice to spread laterally with probably an initial decrease in thickness.

At the forks, the nose of the ridge between the two canyons is polished and smoothed up to an elevation of 7325 feet or 1600 feet above the canyon floor, while erratics were found at 7300 feet on Marble Point or 2100 feet above the floor. Below Lake Creek, erratics were found 1500 feet above the valley bottom. Near the Pole Bridge a lateral moraine 875 feet high indicates a thickness of approximately 900 feet, and some three miles below the bridge the moraines indicate a thickness of four hundred feet or more.

The surface of the glaciers had a fairly uniform gradient, though the thickness was not constant. The lack of large moraines is thought to be evidence that the glaciers eroded only slightly in modifying the shapes of the canyon.

Glacial features of the Wallowa River Canyons. South of Wallowa Lake are the canyons of the East and West Forks of the Wallowa River. A mile above the south end of the lake, these two rivers join. The combined stream (Wallowa River) discharges into the lake to issue again at the north end. These two forks of Wallowa River drain the largest and most extensively glaciated area of any single stream in the mountains.

Glacial striae in the Lake Basin indicate the westward movement of ice and névé into Hurricane and West Fork of the Lostine Canyons, although the topography suggests that the greatest movement of the ice and neve was eastward into the West Wallowa Canyon and thence northward. The profile of the upper canyon and the Lake Basin indicate a large amount of erosion and plucking from the eastern wall, while the east lateral moraine tells of extensive transportation and deposition of till on that side.

The Wallowa Lake moraines (see frontispiece) are the most impressive depositional features resulting from glaciation in the area, and furnish the best evidence as to the size of the glacier which extended five miles beyond the mouth of the canyon.

The height, extent, and topography of the moraines tell a great deal about the glacier which built them, and suggest factors which controlled the direction of the movement of the glacier and the source of the morainal material transported by the ice. There are two large compound lateral moraines, the east and west laterals, and a terminal moraine at the north end of the lake. Beyond the terminal moraine an outwash plain extends beyond the town of Joseph.

The Wallowa Lake moraines probably contain more till than all the other morainal deposits in the area. Both the east and west laterals are composite moraines recording two major stages of glaciation and possibly several minor advances and retreats of the glacier during each stage. The inner moraines are the highest and merge with a terminal moraine to form the enclosed basin containing Wallowa Lake.

The heights of the two lateral moraines are nearly the same, although there is much difference in their lengths. The heights and lengths of the individual moraines that make up the large laterals vary considerably. Each composite lateral moraine consists of ridges of till of two ages.

The east moraine has a maximum height of over 900 feet above the lake surface and to this can be added another 200 or more feet below the water level. A mile from the south end, the lake has a depth of 283 feet (Smith 28:178); and, though the character of the bottom is not definitely known, it is probably covered with at least a thin veneer of till. The maximum height of the moraines is then approximately 1200 feet measured from the lake bottom to the crest. Measured from the alluvial fan surface on the east side the height would probably not be as much as 900 feet.

The east moraine abuts against the north shoulder of Signal Point and extends northward for nearly a mile as a single narrow ridge to where the oldest moraine of the earlier glacial stage branches off to the east. From this point on, there is continual divergence to the west by the successively younger moraines. This composite lateral moraine might be better described as a large main ridge which is divided into five definite ridges or fingers on its northern end (to be designated A, B, C, D, and E), with the longest fingers extending nearly five miles northward beyond the mountain shoulder, or one and a half miles beyond the north end of Wallowa Lake. (Stovall: 29:95).

The easternmost moraine (A) trends slightly east of north in a line with the trend of the West Fork Canyon. Each successive moraine diverges slightly westward from the first moraine until the last one curves west of north to form a slight crescent. The individual moraines increase in altitude from the eastern (A) to the western (E) ridges, and are separated by shallow valleys that are features of the original deposition and are not erosional.

An early stage of glaciation is indicated by the appearance of the four smaller eastern moraines (Stovall 29:93). These moraines have less steep slopes than the younger western moraines, and boulders are almost absent as surface features. The slopes are fairly uniform with only slight evidence of gullying.

The oldest of these four moraines (A) has a height of 750 feet where it branches from the composite moraine and extends for three miles east of north in a line with the trend of the West Fork Canyon. The height decreases in this distance to about 400 feet. The other three moraines nearly parallel the one just described, but have a slight westward curve. The elevations are almost uniform, but each successively younger moraine (nearer the lake) is slightly higher. Hummocky topography occurs near the terminals, but a definite terminal moraine is lacking.

The moraine (E) associated with the younger stage of glaciation forms the even-crested ridge that resembles a huge railroad embankment. The crest appears level until seen from the summit, or above, and then the ridge shows a series of hummocks throughout its length. The elevation decreases slightly towards the foot of the lake where it drops rapidly as the lateral merges with the terminal moraine. This younger western moraine (E) is divided into two parallel ridges of uniform height separated by a valley 25 to 30 feet deep.

In sharp contrast to the boulder-free, subdued slopes of the older moraines is the boulder-strewn, steep slope of the younger. Boulders range from a few inches to several feet in diameter and all have fresh surfaces with occasional facets and striae. The majority of the boulders are rounded. The western slope (lake side) of the moraine varies from 30 to 35 degrees.

The older of the two ridges comprising "E" extends beyond the end of Wallowa Lake and terminates in a line of hummocks which curves westward to join the west moraine. The inside ridge (bordering the lake) curves westward at the north end to merge with the terminal moraine which is joined by the west lateral to form the Wallowa Lake basin. A recessional moraine which loses elevation towards the terminal moraine is separated from the latter by a gully-like fossa.

The terminal moraine is approximately three-quarters of a mile wide and varies in elevation from a few feet, south of Joseph, to 400 or 500 feet where it merges with the east and west laterals. The surface is hummocky and boulder-strewn. The lake drainage has cut a channel through the terminal moraine to divide it into two segments. On the north side ~~of~~ the terminal moraine passes into a series of scattered hummocks before merging with the outwash plain which extends for a considerable distance down the Wallowa Valley. On the south (the lake side) the moraine is made up of several steps or terraces, some of which are definitely ridge-like. These benches indicate a slight retreat of the glacier in its final stage.

The lateral moraine on the west side of Wallowa Lake has nearly the same height but not the length of the east lateral. It also is a composite moraine, branching about one mile north of the canyon mouth into ridges curving slightly westward; the easternmost segment swinging eastward to unite with the lower terminal moraine. The first moraine to curve away from the large lateral branches three quarters of a mile north of the canyon mouth is about 400 feet high and less than a mile in length. The large moraine has been deposited over the southern end of this small lateral which seems to correspond to the older moraines on the east side of the lake (Stovall 29: 99-100). The surface is free of large boulders.

The large lateral is composed of two parallel ridges separated by a shallow valley and corresponds to the youngest ridges on the east side, already described. These two morainal ridges merge with the terminal moraine, and with the two youngest morainal ridges on the east give the appearance of continuous arcs around the lake. The slopes are steep and covered with boulders similar to those on the east moraine.

The difference in extent of the east and west lateral moraines has already been mentioned. The east moraine has a greater areal extent, has more material and has more individual ridges in its makeup than the west lateral. The extent, the amount of debris, and the number of ridges can be accounted for by either or a combination of two hypotheses. First, that the east side of the glacier eroded, transported and deposited more material than its western side; or second, that the exposed east side of the glacier received many more hours of sunshine each day than the west side which was protected by the high mountains to the west, and resulted in a zone of more or less stagnant ice on the west and a zone of continual movement along and toward the east side.

The canyon of the east fork of the Wallowa River is typically U-shaped and is essentially a hanging valley. The floor rises 3000 feet in four miles; in the first two miles the gradient is 1000 feet. Above the steep gradient, the floor flattens and contains a large park area. Aneroid Lake is the largest of the four lakes occupying basins in the canyon floor or in cirques.

One crosses two fairly large recessional moraines in ascending the canyon. The first is about two miles and the other about a mile below Aneroid Lake. The moraines are normal to the canyon and in places have been deeply dissected. Large rounded granodiorite boulders with fresh surfaces are more prominent than other types of rock. A young growth of timber is rapidly gaining foothold on the till.

Glacier Lake Cirque (see Plate VII), on the east of Eagle Cap (in sec.2, T.5 S., R.44 E.), is the most imposing and the best developed cirque in the Wallowa Mountains. It is developed in granodiorite, and the vertical walls and the trend of the low rock ridges just above the lake surface point to extensive ice plucking of this jointed rock. Successive slightly concave benches above the vertical walls were filled with snow banks. The talus accumulation below the snow banks attests to recurring freezing and thawing along joints and fractures. From the position of the snow banks behind the talus it is evident that shallow depressions exist between the talus and the walls. Much of this talus collects by rolling down the steep snow surfaces, but its ridge-like appearance suggests downward movement of deep snow banks forcing the talus down slope; this action would preserve the fossa which under normal conditions would be filled and a uniform slope built against the wall.

The last small glacier existing in the Wallowa Mountains is located in a depression on the ridge at the head of Glacier Lake Cirque. The writer did not

GLACIER LAKE AND CIRQUE, WITH EAGLE CAP IN THE BACKGROUND
(Courtesy of the U. S. Forest Service)

PLATE VII

see this glacier as too much of the previous winter's snow was still lying in the cirque. Stovall in 1929 described the glacier as being some 800 feet long, 60 feet wide and 24 feet thick.

Glacial pavement is a prominent feature throughout the Lake Basin area. Only along the canyon floors has detritus accumulated in sufficient quantities to support a real growth of timber.

Roches moutonnées and striae are abundant in the canyons and the Lake Basin. The strike of the striae is predominantly in the direction of the drainage channels. Scoured and striated surfaces can be found on the highest elevation of the divide between the Lake Basin and the East Fork of the Lostine, and between the Lake Basin and the Hurricane Canyons.

Summary. Throughout the glaciated area mantle rock is almost entirely absent, while outside of the glaciated area alluvium and mantle rock occur in varying thicknesses. The glaciers were effective transporting agents in removing practically all of the mantle rock.

The glaciers eroded scores of rock basins in the canyon and cirque floors that are now occupied by lakes and developed numerous serrate ridges and pinnacle peaks. Aggraded basins have become beautiful park areas supporting a luxuriant growth of grasses, flowers, and timber.

The névé field surrounding Eagle Cap had its maximum depths, probably 2000 feet or more, in the Lake Basin, and in the vicinity of Granite Mountain northwest of Cornucopia. The névé covered all of the central area of the mountains with the exception of a few high ridges and peaks. Away from the central névé field, the north and east sides of ridges were also deeply buried.

The drainage channels contained valley glaciers that moved away from the central collecting field. The valley glaciers had a maximum thickness near their heads and diminished in thickness with decreasing altitudes.

The lengths of the individual glaciers seem to have been controlled by the distance to the 4500-foot contour in the direction of movement of each valley glacier. Between the 4000- and 4500-foot contours the rate of melting of the ice apparently was in equilibrium with the rate of ice advance.

The three large valley glaciers on the north side reached to or beyond the mountain front. The Wallowa and Hurricane glaciers descended to an elevation slightly below 4500 feet. The Lostine glacier reached its maximum extension about three miles south of Lostine at approximately the same elevation. On the south side the Main and East Eagle glaciers descended slightly below the 4500-foot elevation, and the Pine Creek glacier reached almost to Carson near the 4000-foot contour. The Imnaha glacier extended at least six miles beyond the Blue Holes to an elevation of about 4200 feet. Glacial striae and grooving on the greenstones of Imnaha Valley indicate that it probably contained the largest of all the valley glaciers. In the Fish Lake - Duck Lake region the ice seems to have reached slightly below the 5000-foot contour. Isolated cirque glaciers did not descend to such low elevations.

The moraines at Wallowa Lake and at the mouth of Hurricane Canyon contain till of two glacial stages. The younger moraines are strewn with fresh unweathered boulders, and the steep slopes have not been modified by erosion. Because of the unweathered morainic material and the comparatively unmodified glacial features within the mountains, the last glacial stage is referred to the late Pleistocene. Ross (38:60) refers the glacial deposits in the Pine Creek area to the Pleistocene.

The older moraines probably belong to an earlier glacial stage of the Pleistocene. Until a thorough study of the till has been undertaken and the results compared with till of known age in other regions, the writer prefers not to refer it to a definite glacial epoch. Possibly both glacial stages, certainly the last one, belong to the most recent glacial stage (the Wisconsin) of Pleistocene time. No attempted comparison of the Wallowa till with till from other areas has been undertaken.

During recent time much erosion has been accomplished by freezing and thawing and by snow movement and slides. In the spring and summer falling rocks from cliffs and steep slopes are common occurrences. Snowslides are also common, often carrying much debris down the slopes.

Snow banks, some of which are nearly large enough to be classed as snow fields, persist into the late summer, and after winters of excessive snowfall much remains unmelted through the summer and fall.

The average temperature at Baker, Wallowa, and Joseph, all situated in valleys bordering the mountains, is 43.1 degrees. The average for the mountains would be several degrees lower. Either a decrease of a few degrees in average temperature with the present average snowfall, or a slight increase in precipitation in the form of snow might be sufficient to cause the accumulation of snowfields again in the Wallowa Mountains.

After the waning of the ice, normal stream action became again the dominant agency at work, but this has been so recent that these streams have as yet modified the glacial sculpture only to a slight degree.

Plants and animals, including man, are at work now making slow changes in the topography which in their cumulative effects over long enough time will have marked results. We see these activities going on in the removal of forest cover, road building, and in mining operations.

PLATE IX

HURRICANE VALLEY AND THE MATTERHORN
(panorama by R. C. Treasher)

CHAPTER V

ECONOMIC GEOLOGY

by Warren D. Smith, John Eliot Allen, and Wayne Lowell.

History of Mining in the Area

Unfortunately the history of mining in the northern part of the Wallowa region is somewhat sketchy. There have been several enterprises dating from early days, but the details of these are rather obscure. Mr. Joe LeGore, a prospector now in his 80's and living at Enterprise, furnished most of the acceptable information on these early mining activities. According to him there was some mining interest and activity as early as 1862. The first recorded mining claim was about 1885.

At many places in the northern Wallowas one comes upon old prospects. For the most part prospecting has been carried out in a haphazard manner and not according to any well organized plan.

It is reported that in the middle 80's, a shipment of 1,350 pounds of silver ore was made from the Williams Mine with a return of about $65.00.

In the late 80's, Dr. J. T. Dean built a small smelter at the head of Wallowa Lake. After a period of experimenting, said to be unsuccessful, the plant burned down.

In 1904 or 1905 the famous (or infamous) Tenderfoot episode occurred. This was a mining promotion in the Tenderfoot Basin. Camps were built and rather elaborate preparations were made to extract ore, but according to the best information samples had been salted and the project was abandoned.

During the 20's there was a substantial development at the Black Marble Quarry. Kilns were built and limerock (actually crystalline limestone or marble) was burned for some years. It is said that the product produced when used in plaster for building houses was of very superior type because, as the plasterers term it, it "worked" particularly well. The dark colored or black marble of the quarry makes, when polished, a most beautiful stone for interior finishing or decorating. It has been classified by stone cutters as equal to any of the imported marbles and superior to many. The rock is quite massive and contains few streaks or imperfections. The jet black ground mass carries spots, blobs and streaks of white calcite, perhaps fossils originally, that give the polished stone a most beautiful and pleasing figure.

Summary of Types of Mineral Deposits

Gold:

Gold was discovered in the southern Wallowas on the "Two Granites" on Pine Creek in the late 1870's, and since that time probably $15,000,000 has been taken from the various claims of the property now known as Cornucopia Gold Mines. For the last three years, production has been at a rate of well over three-quarters of a million dollars a year. The granitoid formation from which the gold has its source appears also in the northern area and makes it possible but not probable (judging by prospecting to date) that gold deposits may yet be found there.

Copper:

Many occurrences of copper minerals, usually chalcopyrite, have been found in the northern Wallowas. Tunnels have been driven into a number of these deposits but so far no bodies of commercial importance have been opened up. In several localities in the eastern and southern portion of the Wallowas there is evidence of more substantial deposits of copper but none of these is producing at the present time. The ore of the Cornucopia Mine in the southern Wallowas contains enough copper to help pay the freight on the concentrates to the smelter.

Due to the small size and inconsistent nature of the copper showings in the northern Wallowa area it does not appear that prospecting for copper should be encouraged in this area.

Molybdenite:

This mineral, molybdenum sulfide, is found irregularly disseminated along granodiorite-limestone contacts at a half dozen localities in the northern Wallowas. It occurs as a contact metamorphic mineral in the contact zones known as tactites, along with epidote, garnet, and several of the other rock-forming minerals. At such points samples have given assays from 0 to 6 or 8 percent molybdenum. However, examination of the more likely deposits indicates that molybdenite is not present in commercial quantities.

When there is a greater demand for the mineral it is probable that further exploration will be justified. It is always possible under the conditions that exist in the northern Wallowa Mountains, (where great masses of granite lie in contact with limestone) that disseminated bodies of the contact ore minerals may be present.

Tungsten:

Tungsten in small amounts has been detected at several points in "tactite" zones between granodiorite and limestone, by means of ultra-violet lamp. A number of reasonably high-grade samples were obtained but continuity of the ore zones does not appear to be satisfactory. The habit of the tungsten mineral, scheelite in this case, is similar to that of molybdenite. Evidence at hand does not justify the statement that one would expect presence of tungsten only where molybdenite is in evidence.

Since it is very difficult or practically impossible for the ordinary prospector to identify scheelite in the field without laborious panning or without the use of the ultra-violet lamp, it is possible that commercial bodies of tungsten may have been overlooked in the northern Wallowa area. There are miles of limestone granodiorite contact in this very rough mountainous country where prospecting is difficult and which very likely have never been prospected at all. Presumably most of the contact zones that contain easily recognizable sulphides have been found, but it seems unfair to eliminate the entire area as unfavorable for the presence of tungsten in commercial amounts.

The same general statement applies to tungsten that was made with reference to molybdenite as regards future demand and the justification for additional prospecting.

Marble:

In this northern Wallowa area there are several large masses, doubtless square miles in extent, of limestone that has been largely metamorphosed to marble. Locally it is a compact mass of true marble ranging from fine-grained to quite coarse-grained and elsewhere it is a typical coarse-grained crystalline limestone or marble. The stone ranges from white through pink and gray to jet black in color. So far its only utilization has been for calcining; but its use as a building stone is justified on the basis of its beauty and fine quality.

Granodiorite, which in the trade is known as "granite", is excellent for building stone, but in the Wallowas no use has yet been made of it.

Basalt finds its chief use as road metal. Production in the Wallowa area is limited, since quarries must be located relatively close to road construction.

Abrasives:

The garnet developed in the "tactite" along the granodiorite-limestone contacts might be utilized as an abrasive, but here again the demand on the west coast is probably small, and transportation would be a major difficulty.

Description of some of the Mines and Prospects

Known prospects and mines are listed alphabetically at the end of this chapter. A few of the prospects in the northern portion of the quadrangle show molybdenite and tungsten. These and one non-metallic (marble) property were selected for especial study, and are described below in some detail. Prospects and mines in the southern portion of the quadrangle are discussed in the Oregon Metal Mines Handbooks (39).

Contact Group (9)* (also known as Iron Dyke, Peacock, White Eagle, and Dr. Scott claims). This group of 10 patented claims is situated at an elevation of about 7100 feet in the center of the $E\frac{1}{2}$ of sec. 24, T. 3 S., R. 43 E., on the east side of the Lostine Valley above Lapover. It was discovered in 1906 and 1907, and it is said that $30,000 was spent in development work, mostly during the years from 1909 to 1912. R. B. Bowman was the original locator.

Swartley (14) visited the property and reports that:

> ". . . . a nearly vertical pyroxenite dike 5 to 40 feet wide, diagonally cuts across the limestone in an E-W direction. A few hundred feet of the lower end of this dike was observed, and as far as one could see the dike continued to the very mountain top. . . . .
> "The dike rock is dark green in color with a texture nearly dense. In thin sections it is seen to consist of about 75 percent augite pyroxene, about 15 percent labradorite, 5 percent biotite, and 5 percent quartz. The quartz is probably a secondary mineral. Most of the labradorite feldspar crystals are badly altered.
> "The dike has been somewhat fractured and in the small fissures the pyrite and pyrrhotite have been deposited together with some chalcopyrite. Some of the contact-metamorphic minerals, garnet and epidote, are in evidence near the borders of the dike for the most part, but sometimes are seen in the adjacent limestone. The pyrite and pyrrhotite appear in greater percentages in the outer portions of the dike. This dike, a basic differentiate of the great intrusion injected in a molten condition into the fissure in the limestone, probably has sufficient heat

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* Numbers refer to location of properties on the geologic map (Plate I).

with the assistance of mineralizers to form the small amount of garnet and epidote present.
"Practically no mineralization is seen in the limestone adjoining the dike. In an examination of several open cuts scattered for a considerable distance along this dike the copper minerals appear to be too thinly scattered through the dike to call it ore. Without the presence of precious metals in fair amounts this primary deposit would not pay to work."

A vertical east-west aplite dike from 20 to 50 feet wide is intruded parallel to the contact between argillite and limestone on the north, and granite on the south. It is more probable that mineralization is due to the acidic than to the basic intrusions. Several crosscuts and drifts explore the various contact zones.

The main east crosscut tunnel at 7130 feet elevation runs 370 feet N. 25° E.; starting in granite, crossing an east-west fault contact which dips 80° N. at 150 feet and entering dense highly siliceous argillite or hornfels, bedding of which strikes N. 75° W. and dips 60° N. Near the end of the tunnel (probably close to the argillite-limestone contact) the dense massive pyroxenite dike mentioned in the quoted description above is penetrated. In a short side drift at a point 50 feet from the end of the crosscut a 5-foot lens or xenolith of highly contorted black limestone shows a contact aureole of garnet, epidote and crystalline calcite, with small stringers of pyrite and molybdenite.

About 600 feet to the northwest a drift near the contact of limestone and aplite has been driven S. 75° E. for 75 feet. The tunnel runs along an oxide zone through 20 feet of aplite, 20 feet of argillite (which appears to be almost surrounded by aplite) and 50 feet of aplite. The oxide zone consists largely of limonite, hematite, and some malachite. It dips 80° S. and varies in width from one to twelve feet.

Frazier Prospect (13). This deposit is located at an elevation of 8700 feet on the divide between the Imnaha and Wallowa River drainages in the center of the N½ of sec.12, T.5 S., R.44 E. Just west of the trail at Hawkins Pass, a limestone block or roof pendant about 400 feet in diameter caps the ridge. It is surrounded by granodiorite. The tunnels into the tactite zone at the base of the nearly horizontal contact of limestone above and granite below lie mainly on the north side of the ridge, not over 200 feet from the summit.

Hess and Larsen (21) visited the property and report that:

"At the prospect a thick series of alternating marbles, quartzites, and schists are intruded by a large body of quartz diorite striking about N.70° E. and dipping about 50° S. 20° W. Along much of the marble-diorite contact there is little tactite, but about a semicircular outcrop of marble a few hundred feet across that is nearly surrounded by diorite the tactite zone is from a few feet to 20 feet or more in width and the adjoining diorite has itself been considerably metamorphosed. The most abundant mineral of the tactite is a brown garnet with moderate iron content; green epidote, quartz, and calcite are less abundant; and green hornblende and chlorite are abundant locally. Titanite, apatite, scheelite, and the sulphides pyrite, chalcopyrite, and molybdenite occur in small amount. As usual, the minerals are irregularly distributed, and the sulphides which are later than the garnetization, are associated

with fractures in the tactite and the adjoining granite and are especially abundant on the granite side of the contact.
"The outcrop and geologic relations of the tactite indicate a body of moderate size. Along the borders of quartz lenses there are some bunches that are rich in scheelite. A picked sample from a bunch on the west side of the ridge panned 17 percent of WO_3, and about as good material was seen at another point on the east side a few hundred feet away. However, two grab samples from the tactite rock panned only a trace of WO_3. On the whole this deposit appears to be at least as promising for scheelite as for copper or molybdenum, and a little surface prospecting for scheelite by trenching and constant panning would seem advisable."

The limestone is grey and crystalline, with occasional dark bands, which strike east-west, with varying dips toward the south. White quartz and tactite dikes, veins and stringers from less than an inch to several feet in width run up into the limestone from its base, which has been completely altered to tactite. This altered zone (which is from 15 to 20 feet thick) is composed largely of citron-yellow grossularite garnet, often massive, but usually crystalline with zoned crystals of combined dodecahedral and hexoctahedral form, up to 2 centimeters in diameter. Epidote is less prominent, but becomes more abundant near the intrusives, while the garnet becomes darker, approaching dark red-brown and even black. Calcite and quartz are abundant. The granodiorite near the tactite is massive and glassy, with very little of the black biotite which characterizes it a few feet away from the contact. Metallization occurs next to the dikes and veins of quartz and tactite, and sometimes extends a few inches into the intrusive. Metallic minerals seen in the field were molybdenite, in flakes up to 15 mm. diameter; pyrite, frequently altered to limonite; and chalcopyrite, often altered to chrysocolla. Scheelite was later detected in hand specimens with an ultra-violet lamp.

Great Northern Prospects (14). Numerous prospects lie in the saddle between the Minam and Lostine River drainages at an elevation of 8400 to 8500 feet in sec.22 and 23, T.4 S., R.43 E. Because of snow on the ground when these deposits were visited the data is incomplete.

The country rock is granodiorite, although the ridge tops on either side of the saddle are capped with basalt. Aplite dikes are numerous, and several feeder dikes of the basalt were noted.

The main drift was caved, but is said to be 200 feet long. At its mouth, a two-foot vein of quartz contains sericite, talc, iron oxides, and chrysocolla. The last mineral impregnates the wall-rock for some distance from the vein. Ore from the property high in gold and silver is said to have been taken out by pack train many years ago.

Farther to the west on the northwest side of the saddle, small prospect holes reveal quartz veins from 1 to 14 inches wide carrying bornite, chalcopyrite and their alteration products, iron oxide, and chrysocolla. A very soft silvery metallic mineral, not molybdenite, was also noted. Another small prospect hole showed quartz with sericite and thin plates of specular hematite.

Green Group (15) (also known as Copper King, Copper Gem, Mountain Gem). This group of 9 claims is located at an elevation of about 5900 feet on Adams Creek, half a mile west of its junction with the west fork of the Wallowa River, in the SE¼ of sec.6 and the NW¼ of sec.7, T.4 S., R.45 E.

The deposit was first located in 1906. In 1907 or 1908, a corporation was formed and a 135-foot tunnel was driven in the bed of the creek diagonally towards a contact of granodiorite and limestone. Two other short crosscuts lie nearly half a mile to the northeast on the same contact. A caved tunnel near them is said to be 300 feet long. The claims lie along a narrow north-east trending band of limestone and calcareous schist which has been nearly pinched out or engulfed by granite lying both to the northwest and southeast. Pegmatite, aplite, and basalt dikes are present.

At an elevation of 5800 feet the south tunnel (Copper King) has been driven from the creek bed along a tactite zone consisting of reddish grossularite garnet. There are small amounts of pyrite, chalcopyrite, and epidote. Massive green epidote also occurs with patches and crystals of molybdenite. Magnetite is present in small amounts. Crystalline limestone float containing considerable fluorite is reported by Swartley (14).

A 25-foot crosscut at an elevation of 6000 feet lies a quarter of a mile to the northeast. It follows a pegmatite dike composed of quartz and large flakes of biotite. The quartz is barren and the face of the drift is in limestone. Above and to the east, an aplite dike cuts the limestone and a 5-foot vertical band of garnet is developed. A basalt dike which came up along the same fracture bounds the tactite on the east. The garnet zone is said to extend on up the hill to the west.

A caved tunnel is located 500 feet farther northeast (near the center of the SE$\frac{1}{4}$ of section 6). A considerable amount of fairly high-grade molybdenite appears on the dump, the gangue consisting of epidote, with minor amounts of garnet, pyrite, and chalcopyrite. At this locality the granodiorite-limestone contact is quite complicated, with intense folding of the limestone.

<u>LeGore Prospect</u> (18). (Red Cloud). The LeGore molybdenum prospect is located in LeGore's Basin at the head of Falls Creek (tributary to Hurricane Creek) in the E$\frac{1}{2}$ of the SW$\frac{1}{4}$ of sec. 8, T. 3 S., R. 4 W. A good road from either Joseph or Enterprise extends to within about a mile of the junction of Falls Creek and Hurricane Creek. At Falls Creek, a trail leads upward to LeGore's Basin at an elevation of 7900 feet.

Because of the deep snows the prospecting time is limited from late June to October. During these months the basin is accessible by a steep pack trail. The property is on or near the contact of granodiorite, which makes up the north wall of the basin at the head of Falls Creek, with a tongue of somewhat altered calcareous to silicious shale and massive limestone, which extends northward into the granodiorite. (See Plate X). Northwest-striking, vertical columnar basalt dikes cut other rocks without noticeable alteration of wall-rock.

The granodiorite has intruded the metamorphics. Small inliers of shale are found on the granodiorite and windows in the shale expose the underlying intrusive. In the area mapped the metamorphics consist of a thin blanket overlying the granodiorite. The "blanket" thickens to the north and south.

The metamorphics strike N. 5° E. and dip 40° W. The dips are nearly normal to the contact with the granodiorite. The mineralized limestone lens (see Plate X) is cut through in two places.

The intrusion of the granodiorite resulted in a more or less continuous alteration zone along the contact with the metamorphics, which is best developed in the limestones.

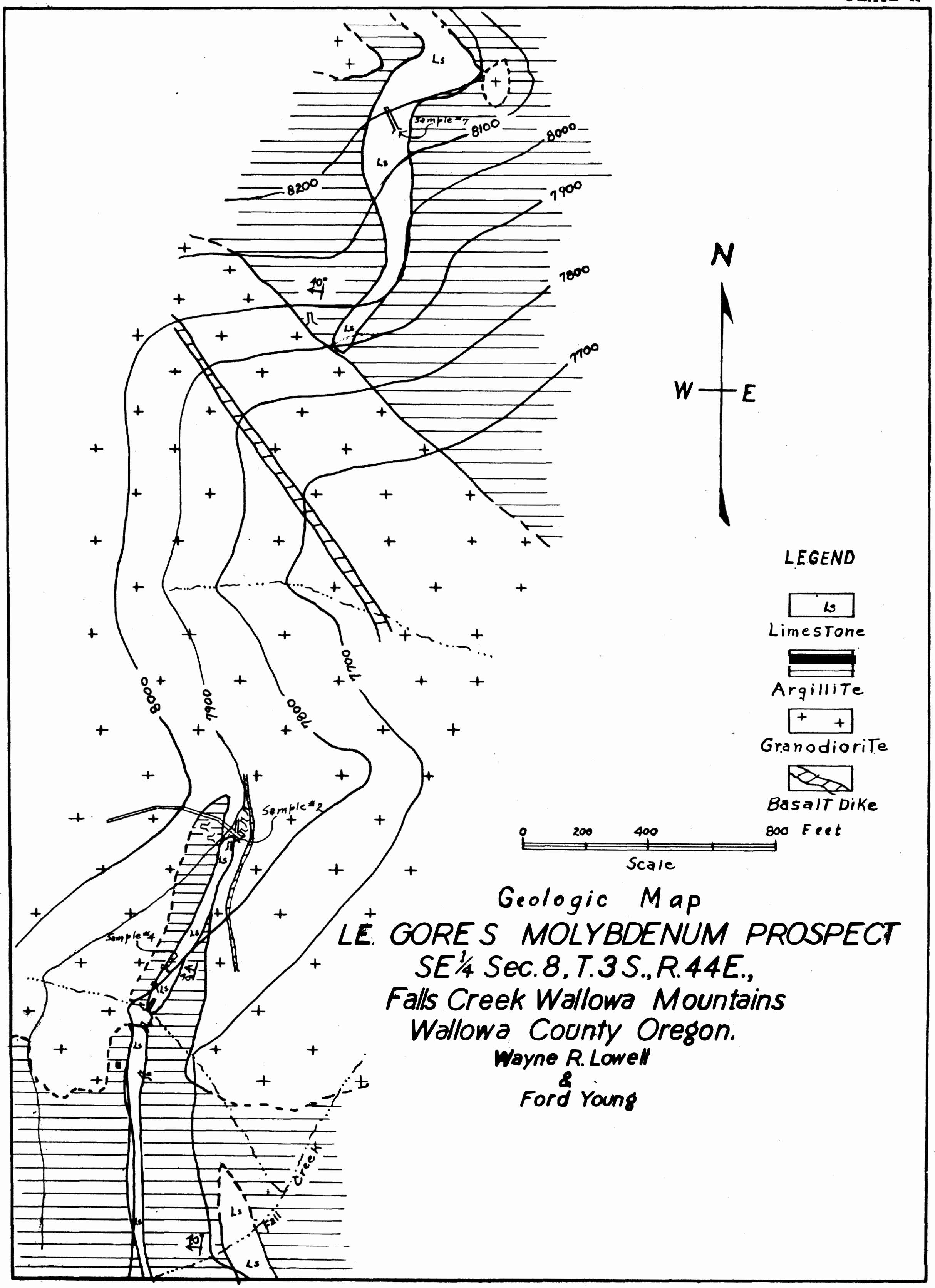
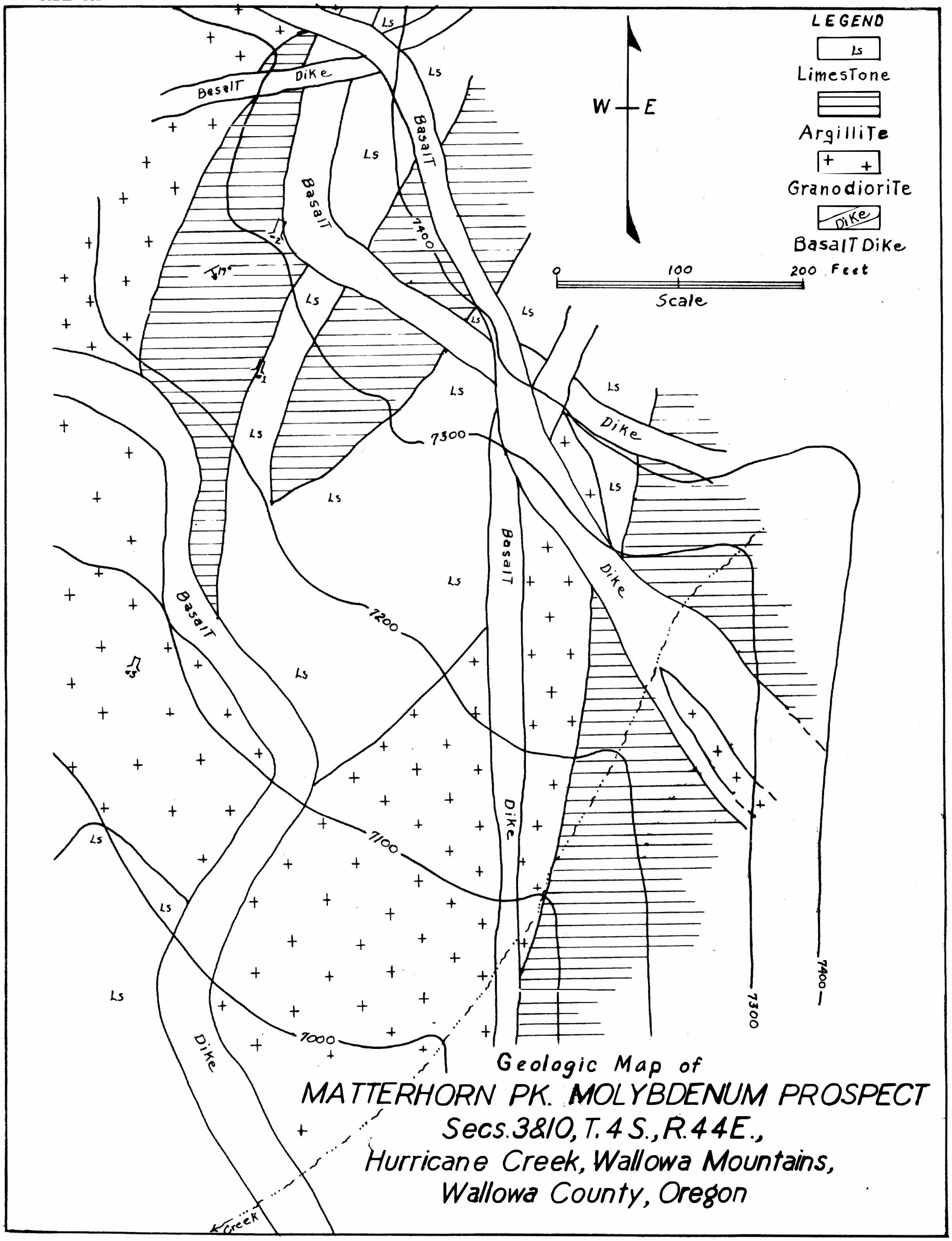

Ls
Sample #7
8100
8000
8200
7900
7800
7700
40°
N
W
E
8000
7900
7800
7700
Sample #2
Sample #4
Fall Creek
LEGEND
Limestone
Argillite
Granodiorite
Basalt Dike
0 200 400 800 Feet
Scale
Geologic Map
LE GORES MOLYBDENUM PROSPECT
SE¼ Sec. 8, T. 3 S., R. 44 E.,
Falls Creek Wallowa Mountains
Wallowa County Oregon.
Wayne R. Lowell
&
Ford Young

PLATE XI


LEGEND
Ls
Limestone
Argillite
Granodiorite
Dike
Basalt Dike
W
E
0
100
200 Feet
Scale
Basalt
Dike
Ls
7400
7300
7200
7100
7000
Creek
Geologic Map of
MATTERHORN PK. MOLYBDENUM PROSPECT
Secs. 3&10, T. 4 S., R. 44 E.,
Hurricane Creek, Wallowa Mountains,
Wallowa County, Oregon

The contact alteration zone consists mostly of grossularite with some metallic sulphides and varies in width from a few inches to several feet, as compared with zones consisting wholly of garnet in the metamorphics at some distance from the contact. The sulphides are disseminated in "tactite", an assemblage of metamorphic minerals consisting of grossularite, epidote, quartz, calcite and wollastonite, with traces of scheelite.

Primary metallic sulphides include molybdenite, pyrite, chalcopyrite, and very minor amounts of sphalerite. Secondary minerals are generally small fracture fillings or coatings on primary minerals and include molybdite (molybdenum oxide), limonite, azurite, chrysocolla, and calcite. One narrow ¼-inch vein of fluorite was found cutting the granodiorite.

Mineralized zones in most places do not stand out from the surrounding rock. The contacts can be closely located and when the few inches of talus is removed these zones may be seen. More than a dozen shallow open cuts expose the mineralized zones.

For the most part the mineralization parallels the limestone-granodiorite contact and the zone is of varying width, never more than 20 feet wide. Small stringers of tactite follow and cut across bedding planes but do not seem to have extended very far into the metamorphics. These stringers narrow rapidly giving an impression of shortness, although garnetization appears on the surface at considerable distance from known outcrops of intrusive. Of the minerals occurring, only scheelite and garnet are of restricted occurrence, being associated with high temperatures or pressures, or both; the others are "persistent minerals" found in deep to shallow environments. The contact relations and the mineral association suggest a contact-metamorphic paragenesis. Limonite, azurite, chrysocolla, and molybdite are oxidation products of the primary minerals.

No molybdenite or scheelite ore-bodies of economic importance have yet been discovered. The development work, with one exception, has been restricted to shallow open cuts along the limestone-argillite contact, which show spotty occurrences of metallic sulphides. No serious attempt has been made to drift along the limestone-granodiorite contact where it is exposed by downward cutting of the creek, or where the limestone pinches out against granodiorite at the entrance to the long tunnel. The long tunnel is entirely in granodiorite.

<u>Conclusions</u>:

1. Geologic conditions were such that sparse metallization and abundant garnetization took place.
2. The restricted size of metallized spots suggests a paucity of metalliferous solutions in the magma.
3. Molybdenite and other metallic sulphide occurrences in the immediate area are scattered, and apparently are not connected. Evidently each occurrence was due to magmatic solutions diffusing at scattered points and not concentrated before migration.
4. The limestone remnant is so small that a workable deposit is doubtful even though ore of commercial grade should be discovered along the contact.

Nine channel samples were taken for assay. The assay returns were as follows:

Sample	Length	Width	Molybdenum	Tungsten
1	6'	4"	Nil	Nil
1-A	15'	4"	Trace	Nil
1-B	1'	4"	Nil	Nil
2	9'	4"	0.18%	Trace
3	1'	4"	Nil	Trace
4	10'	6"	0.49%	Nil
5	6'	4"	Trace	Nil
6	12'	4"	Nil	Nil
7	5'	4"	0.03%	Nil

Northwest Lime Company (24). The only non-metallic mineral substance in this area that has been exploited to date and which may be of considerable future value is the black marble in the SE¼ of sec.19, T.2 S., R.44 E. Moore (37:128) describes it as follows:

"This quarry is in a dense forest high on the face of the Wallowa Mountains, at an altitude of nearly 7000 feet. It is reached by a steep, narrow road, over which limestone is hauled from the quarry to the mill. The limestone here forms no cliff, and the slope is the same as that of the face of the mountain. The quarry is in a narrow gulch above several old limekilns, used to burn lime from limestone boulders taken from the stream bed.

"The limestone is a dense sooty-black rock marked by scattered white splotches, possibly the remains of fossil algae. A few fossil shells were seen in it, but none of determinative value were found. The limestone is well bedded, and the strata range from 1 to 6 feet in thickness. No shaly partings were noted, the bedding being conspicuous only on weathered surfaces. The rocks strike N.35° W. and dip 10° SW. The heavy forest cover and the short time available prevented any attempt to trace out the beds. According to Parks, the outcropping bed is from 50 to 500 feet thick and may be traced nearly 1000 feet west of the quarry, where it grades into a gray marble.

"A sample of the limestone collected in the quarry was submitted to the chemical laboratory of the Geological Survey for analysis.

Analysis of limestone from quarry in sec.20, T.2 S., R.44 E.

SiO_2	1.17	P_2O_5	Trace	
Al_2O_3	.17	SO_3	None	
Fe_2O_3	.12	MnO	Trace	
FeO	None	SrO	.40	
MgO	1.23	Li_2O	Trace	
CaO	53.15	FeS_2	None	
Na_2O	.08	Organic matter	1.75	
K_2O	.08			
H_2O	.10	Total		100.54
TiO_2	Trace			
CO_2	42.05	Specific gravity		2.70

"Recomputing this analysis to a basis free of volatile constituents gives the following result:

SiO_2	2.07	Na_2O	0.14	
Al_2O_3	.30	K_2O	.14	
Fe_2O_3	.21	SrO	.71	
MgO	2.18			
CaO (lime)	94.25	Total		100.00

"This analysis shows that burning the limestone should yield a high-calcium lime. According to Dr. E. W. Lazell, Portland, this limestone burns to a superior grade of lime with a very desirable texture. The lime slacks easily and works smoothly.

"This deposit is worked by a local company known as the Black Marble & Lime Co., which was organized in February 1925 and is capitalized at $350,000. The cost of the present plant and of the development of the property up to the time of my visit in 1931 had been $325,000, according to the company's officers.

"At the present time the face of the quarry is about 40 feet high, and to avoid the necessity of removing large amounts of overburden a tunnel has been run into the face and a large chamber mined out. The limestone is shot down, loaded by hand into cars, and dumped into storage bins. The original plans called for the erection of an aerial tram about 4 miles long to carry the limestone to the mill, but insufficient money was raised and a caterpillar tractor and trailers were used as a temporary substitute. The trailers weighed 15 tons apiece and carried 10-ton loads. They were hauled over a long, narrow, steep road 7 miles to the mill. The limestone is now hauled by 5-ton trucks".

"The mill is near Enterprise and has a capacity of about 10,000 tons of quicklime a year. Its total production to June 1931 had been about 7000 tons. The plant consists of a weighing house where the limestone is dumped and loaded into tared cars, which carry it up an incline and dump it into any one of three vertical kilns. The warehouse is on the hillside below the kilns, and the finished product can be loaded directly into the cars.

"This deposit is the most promising of those in Wallowa County. Should the proposed aerial tramway be erected and markets for the products be found on the coast, operation of the deposit might well prove profitable."

In the summer of 1938 the quarry and plant were not in operation.

One of the finest individual exhibits at the 1915 Panama-Pacific Exposition in San Francisco was a beautiful table made of this polished black marble. It is as fine a grade of ornamental stone as the famous Belgian stone.

There are other deposits of crystalline limestone in this area some of which can be called true marble. On the trail to Cornucopia about 2 miles southeast of Tenderfoot, there is a fine grade of pink marble of statuary grade apparently of considerable extent.

Two economic factors, transportation and lack of a market, will probably prevent the commercializing of these deposits for some years. It is possible that much of this limestone may eventually be used in the making of cement, since there is an abundance of both limestone and argillaceous schists available. This will come about, however, only when other more accessible deposits have been exhausted.

Seeber Prospect (30). Development work has been done at two places close to Aneroid Lake, in the center of sec.21, T.4 S., R.45 E., at an elevation of about 7700 feet. A hundred foot tunnel running N.50° E. along the granodiorite-limestone contact, is located southwest of the cabins.

According to Swartley (14):

"The mineralized zone is about 20 feet wide, although the granodiorite is altered to a greater width. Typical contact-metamorphic minerals, such as garnet and epidote are found, and the recrystallized limestone contains some quartz. Sometimes the garnet and epidote crystals are very small, but frequently are as much as three-fourths of an inch in diameter. The altered granodiorite is impregnated with chalcopyrite in spots, and small indistinct veins of molybdenite occur also.

"A better place to observe this contact is on the abrupt walls above the lake, where it is exposed for several hundred feet with widths up to 50 feet.

"The mineralization is similar to the one just described, but considerable chalcocite is present. This high-grade copper mineral is disseminated along the contact zone for some 200 feet and for considerable widths. It is found both in the altered granodiorite and in the recrystallized limestone, although more of it is seen in the latter. The intergrowth of garnet, epidote, and quartz is usually fine-grained. Besides chalcocite, small amounts of molybdenite and chalcopyrite are present.. . . . This contact with its metamorphic zone has been developed but little, and much of this could have been done to greater advantage. The crosscut started some distance below the contact in the loose rock and has not yet reached it. The outcrop is so situated that it would not be very hard to develop it with open cuts. In the present state of development it is impossible to make any predictions as to what future development might bring forth".

Tenderfoot Mine (34). This so-called "mine" is located at the center of the basin near the headwaters of the north fork of the Imnaha River, in sec.33, T.4 S., R.45 E., at an elevation of about 7300 feet. It is on the main trail from Aneroid Lake to Cornucopia.

The Tenderfoot is mentioned only because it figured in one of the worst scandals in the mining history of the state. Several old prospect tunnels were driven in argillite and limestone, in which is disseminated liberal amounts of pyrite. One tunnel shows black limestone with a quartzite interbed.

Prior to 1914, considerable capital was raised on the basis of salted samples before the fraud was disclosed.

Wilmot Group (37) (Matterhorn Group). The Wilmot or Matterhorn molybdenum prospect is located near the base of the western slope of Matterhorn Peak on the east wall of Hurricane Canyon near the section line between sec.3 and 10, T.4 S., R.44 E. It is approximately 1100 feet east of the log cabin built at the lower end of the meadow which starts in the NW$\frac{1}{4}$ of sec.10. A forest service road extends approximately two miles up Hurricane Canyon and a pack trail follows the creek through the canyon and into the Lake Basin. The claim is about 10 miles from the road terminus.

The east wall of Hurricane Canyon, near the prospect, is steep to precipitous and three shallow gullies trending east of north produce irregularities in the slope. Because the deep snows remain unmelted until early summer, the area is generally not accessible until June.

Light-colored medium-grained granodiorite intrudes fine-grained gray to black shale or siliceous hornfels and crystalline limestone. Basaltic dikes formed by three successive intrusions criss-cross the other rocks. Dips and strikes in the metamorphics are variable. The strikes are northeasterly, and dips are northwesterly. Basalt dikes have been intruded along hornfels-marble and metamorphic-granodiorite contacts and have cut across these rocks as well as across earlier dikes. Displacement of intruded rocks by the dikes seems to be limited to off-sets normal to local dike trends. Flow lines in marble that may or may not be remnants of bedding planes are well developed and are indicative of the deformation to which the limestone was subjected.

Mineralization along the metamorphic granodiorite contact in this area is not well developed and is more or less spotty. Garnetization occurs to some extent along shale-marble contacts, but is well developed in two places where stringers of granodiorite penetrate thin interbedded shale and marble as at cuts 1 and 2 (see plate XI). Sparse metallization has taken place in many isolated spots.

Primary metallic sulphides include molybdenite, pyrite and chalcopyrite. Primary non-metallics present are garnet, epidote, quartz, calcite, and some scheelite. Secondary minerals are fracture fillings of calcite and occasional coatings of molybdite on molybdenite, and malachite around chalcopyrite. Graphite is present along flow lines or bedding in marble for as much as 10 feet from the mineralized zone (at pit 2). Mineralized zones (at cuts 1 and 2) stand out as cliffs 15 to 20 feet high. In other places, mineralization has not been as extensive and must be searched for by exploratory cuts. Numerous small exposures of garnet are to be found along the contact where it is not covered by talus. The zones either parallel the vertical dip of marbles and shales (cut 1); or the vertical contact of dike-shale-marble (cut 2); or the granodiorite-metamorphic contact (cut 3). In one or two places garnetization occurs along granodiorite stringers that cut across the bedding planes in shales.

Mineralized zones are closely associated with the granodiorite-metamorphic contact, generally fading out with increasing distance from the intrusive. Mineralization was not seen above the 7400-foot contour. The two tactite bodies examined (cuts 1 and 2) were formed in a thin marble lens (2 to 3 feet thick) interbedded with shales. The vertical attitude suggests replacement of marble by solutions ascending parallel to the dip from the underlying intrusive.

Of the primary minerals present, only scheelite and garnet are of restricted occurrence being associated with high temperatures or pressures, or both; the others are "persistent minerals" found in deep to shallow environments. Limonite, malachite and molybdite are oxidation products of the primary minerals.

No molybdenite or scheelite ore-bodies of economic importance have yet been discovered. The development work has been restricted to three shallow cuts which show thin tactite zones with a paucity of metallics. At cuts 1 and 2, the tactite may contain more metallics at depth, but the limited size of the zones is not sufficiently encouraging to warrant deeper exploration. Of the two mineralized zones, the one at cut 2 is the larger. It is a thin vertical lens having dimensions of 10 ft. wide x 3 ft. thick x 15 ft. high. It is unlikely that the metamorphics extend to any great depth in the granodiorite; so a deeper continuation of mineralization would not be expected.

Conclusions:

1. Geologic conditions were such that sparse metallization and abundant garnetization took place.
2. The restricted size of metallized spots suggests a paucity of metalliferous solutions in the magma.
3. Molybdenite and other metallic sulphide occurrences in the immediate area are scattered, are of small extent, and apparently are not connected. Evidently each occurrence was due to magmatic solutions diffused by the magma and not concentrated before migration. Channel samples assayed for molybdenum gave the following results:

Sample No.	Location	Molybdenum
S-1	Cut 1 (tactite)	Trace
S-1	" (shale)	Nil
S-1	" 2 (tactite)	0.09%
S-2	" (shale)	Nil
2	" 3 (shale and granite)	Trace
3	" 2 (shale and granite)	1.33%
4	Outcrop (tactite on ridge)	Nil
5	Outcrop (tactite) in gulch west of stream	Nil
6	Outcrop (tactite) on ridge	Trace
7	Outcrop (tactite) on ridge	Nil

APPENDIX

List of Mines and Prospects

(*Described in text)

(Numbers refer to localities on Plate I)

1.	Andy Heaverne's Prospect			Sec.6 (or 31) T.5 S., R.45 E.
	Apex	(see Summit Mining Co.)		
2.	Basin Mine		El. 5100'	W½ sec.29, T.6 S., R.43 E.
3.	B.C.Basin Prospect		El. 8400'	NW¼ sec.36, T.3 S., R.44 E.
4.	Black Marble & Lime Co.	(see Northwest Lime Co.)		
	Blue Lake Mine	(see Donnelly Prospect)		
5.	Boner Flat Prospect		El. 8100'	Center south line of SE¼ sec.15, T.5 S., R.45 E.
6.	Bowman Creek Prospect		El. 8100'	Just N. of center of sec.27 T.3 S., R.43 E.
7.	Carnahan Mine		El. 7500'	SE¼ sec.4, T.6 S., R.45 E.
8.	Cotton Claims			SE¼ sec.22, T.5 S., R.43 E.
	Companion	(see Cornucopia)		
9.	*Contact Group (also known as Iron Dyke, Peacock, White Eagle, Dr.Scott claims)		El. 7000'	Center of E.½ sec.24, T.3 S., R.43 E.
	Copper Gem	(see Green Group)		
10.	Copper Creek (Dotson) Prospects			Sec.27, T.5 S., R.43 E.
	Copper King	(see Green Group)		

11. Cornucopia Mountain Claims
The following claims are mostly in sec.21, 27, and 28 T.6 S., R. 45 E.

Companion	Queen of the West
Corundum Group	Red Boy
Forest Queen	Red Cross
Geo.W.Smith Claims	Red Jacket
Jackley	Robert Emmett
Jim Fisk	Union
Last Chance	Valley View (Wild Irishman)
Mayflower	White Elephant
Mountain Chief	

Corundum Group (see Cornucopia)
12. Donnelly Prospect (Blue Lake Mine) El.8600' SE cor.sec.36, T.4S., R.43 E.
Dunham Miles Group (see Summit Mining Co.)
Dr.Scott Claims (see Contact Group)
East Eagle Mining & Milling Co. (see Summit Mining Co.)
Forest Queen (see Cornucopia)
13. *Frazier Prospect (Golden Cat, Sunset, etc.) El. 8800' Center $N\frac{1}{2}$ sec.12, T.5 S., R.44 E.
Gem Group (see Green Group)
Geo. W. Smith Claims (see Cornucopia)
Golden Cat (see Frazier Prospect)
14. *Great Northern Prospects (3 prospects) El.8400-8500' $W\frac{1}{2}$ sec.23 and $E\frac{1}{2}$ sec.22, T.4 S., R.43 E.
15. *Green Group (formerly known as Gem Group, Copper Gem, Mountain Gem, & Copper King) El.6000' $SE\frac{1}{4}$ sec.6 and $N\frac{1}{2}$ sec.7, T.4 S., R.45 E.
16. Gyllenberg's Prospect (Hecla Consolidated) El. 8000' $NW\frac{1}{4}$ sec.21, T.3 S., R.44 E.
Heaverne's Prospect (see Andy Heaverne's Prospect)
17. Hummingbird Mountain (Veatch) Prospects El. 8000' NE corner sec.6 T.6 S., R.44 E.
Hecla Consolidated (see Gyllenberg's Prospect)
Iron Dyke (see Contact Group)
Jackley (see Cornucopia)
Jim Fisk (see Cornucopia)
Last Chance (see Cornucopia)
18. *LeGore Prospect El. 7900' $SW\frac{1}{4}$ sec.8, T.3 S., R.44 E.
Sec.18 or 19? T.4 S., R.45 E.
19. Love and Kelly Prospect $NE\frac{1}{4}$ sec.5, T.6 S., R.44 E.
20. Manuel Lopez Prospect
Matterhorn Group (see Wilmot Group)
Mayflower (see Cornucopia)
21. McCully Basin Prospect El.8400' $NW\frac{1}{4}$ sec.23, T.4 S., R.45 E.
22. Metzger Property El.7200' ? Sec.5, T.3 S., R.44 E.
Midway (see Summit Mining Co.)
Mountain Chief (see Cornucopia)
Mountain Gem (see Green Group)
24. *Northwest Lime Co. (formerly Black Marble & Lime Co.) El.7000' $SE\frac{1}{4}$ sec.19, T.2 S., R.44 E.
25. Norway El.6600' $SE\frac{1}{4}$ sec. 9, T.6 S., R.45 E.
Peacock Group (see Contact Group)
Queen of the West (see Cornucopia)

	Red Boy	(see Cornucopia)	
	Red Cross	(see Cornucopia)	
	Red Jacket	(see Cornucopia)	
26.	Red Mountain	El. 6400'	$E\frac{1}{2}$ sec.17, T.6 S., R.45 E.
	Robert Emmett	(see Cornucopia)	
28.	Royal Purple Prospect	El.7700 '	Center of $W\frac{1}{2}$ sec.34, T.3 S.,R.45 E.
29.	Schirmer and Landis Prospect		$NW\frac{1}{4}$ sec.6, T.6 S., R.44 E.
	Scott Claims (see Dr.Scott)		
30.	*Seeber Prospect (Walla Walla Group)	El. 7700'	Center sec.21, T.4 S., R.45 E.
31.	Sheep Rock Mine (also known as McGee property)	El. 6000'	$SW\frac{1}{4}$ sec.29, T.6 S., R.44 E.
32.	Simmons Mine	El. 6800'	$E\frac{1}{2}$ sec.8, T.6 S., R.45 E.
33.	Summit Mining Co. (includes Woodard and Dunham Miles Groups and Apex, Midway, Woodrow and Zenith Claims	El. 5500'	$N\frac{1}{2}$ sec.29, $E\frac{1}{2}$ 20, and $SE\frac{1}{4}$ 17, T.6 S., R.45 E.
	Sunset Prospect	(see Frazier Prospect)	
34.	*Tenderfoot "Mine"	El. 7300'	Near center sec.33, T.4 S.,R.45 E.
35.	Transvaal Prospect	El. 7400'	SW cor.sec.35, T.3 S., R.45 E.
	Union	(see Cornucopia)	
	Valley View	(see Cornucopia)	
	Walla Walla Group	(see Seeber Prospect)	
36.	Wallowa County Mining and Development Co. (Williams "Mine")	El. 6300'	$NE\frac{1}{4}$ sec.15, T.5 S., R.46 E.
	White Eagle Group	(see Contact Group)	
	White Elephant	(see Cornucopia)	
	Williams "Mine"	(see Wallowa Co.Mining & Development Co.)	
37.	*Wilmot Group (Matterhorn Group)	El.8000'	$S\frac{1}{2}$ sec.10, T.4 S., R.44 E.
38.	Wilson"Mine"	El.7100'	$NE\frac{1}{4}$ sec.33, T.3 S., R.43 E.
	Woodard Group	(see Summit Mining Co.)	
	Woodrow	(see Summit Mining Co.)	
	Zenith	(see Summit Mining Co.)	

Mines in the southern portion of the quadrangle are mostly described in the Oregon Metal Mines Handbook, Bull. 14-A, 1939.

CHAPTER VI

SCENIC RESOURCES
by
Warren D. Smith.

Although time may bring to light greater mineral resources in the northern half of the Wallowa Range, at present the principal resources of this area are scenic and recreational and may be for many years to come. For this reason we shall stress this subject and try to show that these are of major economic importance.

What constitutes scenery? Nothing more nor less than rocks, water, vegetation and light, all blended into scenes in thousands of patterns. The therapeutic importance of scenery in the life of a busy, restless, and over-tired people is not clearly appreciated by the average man, but its value is well understood by physicians and psychiatrists.

As we look over the scenic offerings of this area, we note very considerable differences depending upon the geological setting, elevation, and physiographic stage. For instance, we may begin low on the plateau in front of the range itself. Here we have wide open spaces, vast stretches of lava-covered surfaces which at first look monotonous, but which with the reddish-brown coloring relieved by the yellow of golden grain in summer have a peculiar charm of their own. Here the great distances enchant one and beckon the traveller onward toward the far-off horizon. Through this in a broad green belt sweeps the Wallowa River, one of Oregon's most beautiful streams, the broad quiet reaches of which are broken by stretches of canyon with great piles of lava sheets on either side.

If we go up into the stream valleys that dissect the masses of tumbled mountain formations, we find totally different pictures. The abrupt change from the plateau to the mountain valleys is sudden and startling. Due to the great fault on the north part of the Wallowa Mountain block the mountain streams plunge abruptly from their deeply incised valleys onto the plateau. What with the great depth of these canyons, two and three thousand feet, and the heavy vegetation (quite lacking on the plateau) the change is from the sunny and open vistas to obscurity and at times deep gloom. These canyons were originally sharply V-shaped but due to glaciation are now U-shaped. The streams that occupy these valleys are, due to the steep gradient, tumbling torrents, difficult to cross in the spring and early summer.

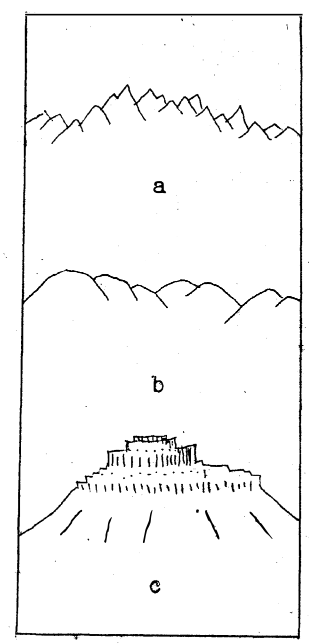


Fig.5. Skyline types in the Wallowa Mountains.

At the heads of the valleys are the great central peaks of the range. These are all between 9500 and 10,000 feet elevation. Some are of granodiorite whose jointing and weathering have produced a sharply serrated skyline or half domes. Others of marble are more rounded. One of these peaks, the Matterhorn, is almost pure blue-white marble throughout its entire mass and in the moonlight is an entrancing sight.

Other peaks like Aneroid are made up of nearly horizontal flows of basalt surmounting a base of granodiorite and are roughly conical or flat-topped. So we find three quite different skylines in the mountainous portion of this area (fig.5).

The lakes probably have greater appeal to the tourist and vacationist since they have always appealed to man and provided him with sport. As already indicated in a previous chapter, we have two distinct kinds of lakes represented here, both of glacial origin, the morainal lake, of which Lake Wallowa is the only example, and the cirque lakes high up near the heads of the glaciated valleys. Aneroid Lake will serve as an excellent example of this class.

To give the dimensions and depth of Wallowa Lake would tell relatively little about it. It is not just another lake, so wide, so long, and so deep. It is a symphony in form, light and shade, and deep, brooding mystery, and next to Crater Lake, Oregon's most unique natural feature. Forgetting for the time being the poetry and romance of this body of water, it is geologically one of the finest, if not the finest, examples of this type of lake in America. Its stupendous lateral retaining walls, actually lateral moraines, are gargantuan piles of loose stones thrown up as by some colossal steam shovel. In fact, a live glacier, which here did this work of heaping up millions of cubic yards of gravel and boulders is a modern "bulldozer" magnified thousands of times.

If you take a saddle horse (just in case you cannot "take it" on foot) and go up into the "lakes basin", you can find a whole flock of lakes of all shapes and varying depths hollowed out of the granodiorite floor of the valleys. They occupy amphitheater-like basins with their lower (downstream) sides marked by a hard rock lip over which water spills ofttimes in beautiful cascades, as at Ice Lake. Mirror, Moccasin, and Douglas Lakes are just a few of these many rock-floored and rock-walled gems in the mountain hinterland of the Wallowas. While these lakes are beautiful, they are not unique, being quite common in the high Cascades, Sierra Nevadas, Rockies, and many other mountain ranges of the world. They differ, however, in several respects from the lakes at the same elevation in the Cascades. Instead of granodiorite, there is a dark backwall of basalt or andesite lava in the Cascades and the trees and other vegetation are different from those in the Wallowas.

Surrounding these upland lakes, or in some cases having taken their places, are many high mountain meadows. It is these same little meadows that lend so much charm to the country of the Swiss.

A few suggestions are offered here for improving this area for the delectation of the lowland dweller. One suggestion is that a few rustic rest-houses about ten miles apart be erected where the traveller can put over over-night. Another is the cutting of an east-west trail across the various radiating ridges and valleys. At present most of the trails follow the north-south valleys and the traveller rarely gets up onto some of the most picturesque vantage points. Some of the few trails that do lead up onto the ridge tops are exceedingly hazardous.

Some especial trips, which we believe would be of great interest to the vacationist who is physically active, are the following:

1. The Lostine-Minam Trail - the first 18 miles can be made by car, the remainder of the way (8) miles to Eagle Cap by horse trail.

2. Wallowa Lake via East Fork of the Wallowa River to Aneroid Lake (good cabins) and on to Tenderfoot Basin and thence to Cornucopia via Boner Flats. This can be made in one long day with a horse, though pretty strenuous. It is much better to take a light pack and camp out one night. The Tenderfoot mining camp, long abandoned, with not even one shack standing, was the scene of one of the worst mining swindles ever perpetrated in this state. Very interesting and complicated geological formations are to be seen on this trip.

3. Hurricane Creek to the Matterhorn and Sacajawea Peaks - very striking scenery - good horse or foot trail. One can continue on to the Basin and to Eagle Cap and return down the West Fork of the Wallowa River to Lake Wallowa.

4. Wallowa Lake to B. C. Basin and to Hurwal Divide. This is a very strenuous trip, and it can be done on horseback. However, we recommend travelling on foot as this trail is very steep and poor in spots. The trip along the Hurwal Divide offers one of the finest panoramas in the state of Oregon. This part of the trip is exceedingly rough in places, absolutely unfit for a horse, and is at an elevation of over 9000 feet.

5. Trip by horse or on foot along the top of the east moraine of Wallowa Lake, easy going after one has climbed to the top.

6. Up the West Fork of the Wallowa to Ice Lake and the Matterhorn, about 6 miles. One should take a horse for this trip unless he is a good hiker.

APPENDIX A

LOCATION OF TRIASSIC FOSSIL COLLECTIONS FROM THE WALLOWA LAKE QUADRANGLE.

1. On Eagle Creek, 1/3 mile below mouth of East Eagle Creek. (NW$\frac{1}{4}$ of NE$\frac{1}{4}$ sec.7, T.7 S., R.44 E.W.M.) Lindgren (02.581).

2. On Eagle Creek, 1$\frac{1}{2}$ mile below mouth of East Eagle Creek. (Center of S$\frac{1}{2}$ sec.8, T.7 S., R.44 E.W.M.) Lindgren (02.581).

3. On Eagle Creek, 2$\frac{1}{2}$ miles above mouth of East Eagle Creek. (Center of W$\frac{1}{2}$ sec.35, T.6 S., R.43 E.W.M.) Lindgren (02.581).

4. At Martins Bridge on Eagle Creek (Center of N$\frac{1}{2}$ of NW$\frac{1}{4}$ sec.21, T.7 S., R.44 E.W.M.) Smith, J.P. (12:94)

5. Below Martins Bridge, on Eagle Creek (Sec.21 or 28, T.7 S.,R.44 E.W.M.) Ross (38:35).

6. On the south side of the Imnaha,near the base of the Martin Bridge Formation (SW$\frac{1}{4}$ sec.19 and NW$\frac{1}{4}$ sec.30, T.5 S., R.45 E.W.M.) Ross (38:35).

7. Near the head of Twin Bridge Creek (SE$\frac{1}{4}$ sec.6 and NE$\frac{1}{4}$ sec.7, T.7 S., R. 44 E.W.M.) Ross (38:35).

8.(AA) Black Marble Quarry, Martin Bridge Formation (?) El.7000', SE$\frac{1}{4}$ sec.19, T.2 S., R.44 E.

9 (AB) Hurwal Divide, top of MartinBridge, 50' below base of Hurwal, el.9300', line between SW$\frac{1}{4}$ sec.25, T.3 S., R.44 E. and the NW$\frac{1}{4}$ sec.36,T.3 S.,R.44 E.

10 (AC)North escarpment, Point Joseph, near center of Lower Sedimentary Series, el. 7500', NE$\frac{1}{4}$ sec.24, T.3 S., R.44 E.

11(AD) South side of Point Joseph from (pink limestone) at base of Martin Bridge formation, el.9000', N.edge sec.25,T.3 S., R.44 E.

12(AE) Hurricane Divide, Hurwal Formation, el.8000',plus, NW$\frac{1}{4}$ sec.20, T.3 S.,R.44 E.

13(AF) West of Petes Point, Lower Hurwal Formation, el.8500', center of W$\frac{1}{2}$ sec.29, T.4 S., R.45 E.

14(AG) Francis Lake and vicinity, Hurwal Formation, el.7800' plus, NW$\frac{1}{4}$ sec.20, T.3 S., R.44 E.

15(AH) Dollar Lake and vicinity, Lower Hurwal Formation, el.7800', NW cor.sec.22, T.4 S., R.45 E.

16(AI) Between N. & middle Forks of Imnaha R., Lower Hurwal Formation, el.8500', NE$\frac{1}{4}$ sec.4, T.5 S., R.45 E.

17 (F1270A) Dollar Lake near base of Hurwal Formation, el.7900', NW$\frac{1}{4}$ sec.22, T.4 S., R.45 E.

18 (F1270C) ditto

19 "Near Black Marble Quarry"

APPENDIX B
FOSSIL CHECK LIST FROM THE TRIASSIC of the WALLOWA MOUNTAINS

	Lindgren (02:581)			Smith (12;94)	Ross (38:35)			W.D.Smith & Allen 1941		
Locality Numbers:	1	2	3	4	5	6	7	8	9	19
Sponges										
Steinmannia sp.								x		
Corals							x			
Astrocoenia sp.								x		
Confusastrea sp.								x		
Heptastylis sp.								x		
Heterastridium conglabatum Reuss				x						
Montlivaultia norica Frech				x						
Spongiomorpha cf. acyclica Frech				x						
Thecosmilia sp.								x		
Thecosmilia norica				x						
Brachiopods										
Terebratula ? sp.					x					
Pelecypods										
Daonella ?					x					
Halobia sp.				x						
H.cf.superba Mojs.				x						
H.sp.rel.superba Majsisovics					x					
H.cf.austriaca				x						
H.cf.salinarium				x						
Pectinoids						x				
Gastropods								x		
Coelostylina sp.								x		
Purpuroidea sp.								x		
Turritella or Pseudomelania		x								
Cephalopods:										
Nautiloids									x	
Ammonoids	x				x		?		x	
Arcestes sp.						?				
Arcestes carpenteri Smith										x
Arcestes cf. A. traski Smith										x
Clionites sp.					x					
Clionites tornquisti Smith										x
Clionites fairbanksi H. & S.										x
Discotropites cf.D.sandlingensis Hauer										x
Dittmarites sp. ?				x						
Hannaoceras nodifer H. & S.										x
Juvavites sp.								x		
Leconteiceras californicum H. & S.										x

APPENDIX B (continued)

	Lindgren (02.581)			Smith (12:94)	Ross (38:35)			W.D. Smith & Allen 1941		
	1	2	3	4	5	6	7	8	9	19
Paratropites (Gymnotropites) sp.										x
Paratropites sellai Mojs.										x
Paratropites antiselli Smith										x
Sagenites herbicho Mojs.								x		
Tropites cf. T. subbullatus Mojs.										x
Tropiceltites caducus (Dittmar)										x
Echinoids			x							
<u>Crinoids</u>										
Pentacrinus			x							

APPENDIX C.

PRELIMINARY REPORT ON FOSSILS FROM THE WALLOWA MOUNTAINS

by Seimon W. Muller

STANFORD UNIVERSITY

April 20, 1939.

"The lot AA (no.8) is of upper Triassic age. It represents the upper Karnic stage. In this lot I have so far identified the following forms:

Sagenites herbichi Mojs.
Juvavites sp.
Halobia sp.
Steinmannia sp. (a sponge)
Astrocoenia sp. (a coral)
Confusastrea sp. (a coral)
Thecosmilia sp. (a coral)
Heptastylis sp. (a coral)
Coelostylina sp. (a gastropod)
Purpuroidea sp. (a gastropod)

"The lot AB (no.9) contains poorly preserved nautiloids and ammonoids, the general nature of which permit me to state that it is also of upper Triassic age (top of the Karnic stage).

"The lot AC (no.10) is also of upper Triassic age but suggests a horizon slightly lower than either the AA or the AB. The lots AE, AG, AH, F1270A and F1270C, likewise represent the upper Triassic. I have not yet been able to determine whether they belong to the Karnic or Noric stage. The most interesting lot in the collection is that from "near the black marble quarry". This lot contains many species of ammonites which are conspecific with those from the Trachyceras sub-zone of the Tropites subbullatus zone of California.

The following species have been so far recognized from the black marble quarry (no.19) lot:

Clionites tornquisti Smith
Clionites fairbanksi H S
Discotropites cf. D. sandlingensis (Hauer)
Paratropites sellai mojs.
Paratropites antiselli Smith
Tropites cf. T. subbullatus Mojs.
Paratropites (Gymnotropites) sp.
Leconteiceras californicum H S
Hannaoceras nodifer (H&S)
Arcestes cf. A. traski Smith
Arcestes carpenteri Smith
Tropiceltites caducus (Dittmar)
Sagenites herbichi Mojs.
Halobis cf. H. superba Mojs.

"If it weren't for the fact that this lot bore the label of Wallowa Mountains I would have taken it for a typical collection from the Shasta region. On the enclosed sheet I indicate the positions of these collections in the standard Triassic column".

APPENDIX D

GLOSSARY OF TECHNICAL TERMS USED IN THE BULLETIN

Mineral descriptive terms used in the detailed petrographic descriptions are not included, since they are of interest only to the petrographer. Definitions are mostly from C. M. Rice, "Dictionary of Geological Terms", 1940.

andesite:	a volcanic rock composed essentially of plagioclase (andesine or oligoclase) and one or more of biotite, hornblende and pyroxenes.
anticline:	an arch or upfold in rock beds.
aphanitic:	having a texture so fine that the individual grains or crystals cannot be distinguished with the naked eye.
aplite:	a finely crystalline muscovite granite occurring in dikes.
apophyses:	veins, tongues, or dikes that can be directly traced to larger intrusions, from which they are offshoots.
argillaceous:	clayey.
basalt:	a dark colored igneous lava, composed essentially of plagioclase and pyroxene.
batholith:	a large mass of intrusive rock without visible or inferable floor of solid rock.
breccia:	a rock composed of angular fragments cemented together.
calcareous:	limey.
cirque:	a steep-walled amphitheatral recess in a mountain side, resulting from glacial erosion.
competent:	combining sufficient firmness and flexibility to transmit pressure, and by flexure under thrust, to lift an overlying load.
conglomerate:	a rock made of worn and rounded pebbles of other rocks, cemented together.
crenulate:	minutely wrinkled or folded.
cupola:	a dome- or boss-like protrusion from the body of a batholith.
deuteric:	alterations in an igneous rock produced during the later stages, and as a direct consequence of, the consolidation of the magma of the rock.
diaschistic:	dikes of dark and light color, both derived from same source.
diastrophic:	pertaining to processes by which the crust of the earth is deformed.
drachenfels:	similar to the scenery on the "Dragon rock" mountain, one of the Siebengebirge, on the Rhine river in Prussia, south of Bonn.
fossa:	ditch, moat, or trench.
gabbroid:	similar to a gabbro; an igneous rock of granitic texture, composed of plagioclase and monoclinic pyroxene.
gneiss:	a banded crystalline rock composed of granular and schistose minerals.
graben:	a depressed tract of land caused by faults.
granite:	a coarse-grained igneous rock composed essentially of quartz, alkali feldspar and any of: biotite, muscovite, amphibole, pyroxene.
granitization:	assimilation of country rock by gases and vapours to form a granitic rock.
granodiorite:	a rock intermediate between granite and quartz-diorite, composed essentially of quartz, feldspar, and hornblende.
greenstone:	igneous rocks that have altered sufficiently to develop enough chlorite to give them a green cast.
hornfels:	a dense compact rock produced from slate by the contact action of granitic intrusion.
horst:	a tract of the earth's crust separated by faults from the surrounding tracts which have been relatively depressed.

intercalated: interlaminated, interbedded.
isoclinal fold: a fold whose walls are parallel to each other.
lamprophyric: dark colored porphyritic dike rocks differentiated from a granitic magma.
lithology: that branch of geology that deals with the origin and properties of rocks.
magma: liquid molten rock, from which igneous rocks are formed by solidification.
metamorphism: rock alteration of deep-seated origin.
metasomatic: pertaining to the process of replacement of one set of minerals by another set, through chemical action.
monocline: beds dipping in only one direction.
moraine: an accumulation of earth, stones, etc., carried and finally deposited by a glacier.
neve: granular snow, characteristic of the upper parts of valley glaciers.
outlier: an area of younger rock entirely surrounded in area by older rock.
overturned fold: a fold in which one side has passed the vertical, so that the beds in that limb are no longer right side up.
pegmatite: a very coarse-grained granite often occurring in dikes, characterized by segregation of minerals.
phenocryst: isolated or individual crystals of mineral imbedded in a finer grained groundmass of an igneous rock.
physiography: description of the natural features of the surface of the earth.
pyroclastic: fragmental volcanic rock.
quartz diorite: a coarse-grained igneous rock composed essentially of quartz, plagioclase, hornblende and biotite.
quartzite: a quartz sandstone, recrystallized or recemented by silica.
roof pendant: a residual portion of the country rock which originally overlaid the batholith but is all but eroded away.
schist: finely foliated metamorphic rocks, the foliation being due to the presence of mica, chlorite, or other platy minerals whose orientation is parallel.
stratigraphy: the study of the rock strata, their conditions of deposition, their character, age, distribution and the like.
syncline: a trough or structural basin in rock beds.
unconformity: an erosional break in the continuity of sedimentation. Where one formation rests on the eroded surface of another.
vesicular: containing gas bubbles.
xenolith: a fragment of other rock or of an earlier solidified portion of the same mass enclosed in an igneous rock.

APPENDIX E

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APPENDIX F

VEGETATION IN THE WALLOWA MOUNTAINS

The following is a list of some of the typical trees, shrubs and herbs found in the Wallowa region. This list is based upon collections made by Mabel S. Miller and amended by Dr. L. E. Detling, curator of the University of Oregon Herbarium.

TREES

Lowland white fir (Abies grandis Lindl.)
Rocky Mountain red cedar (Juniperus scopulorum Sarg.)
Engelmann spruce (Picea Engelmannii Engelm.)
Mountain hemlock (Tsuga Mertensiana (Bong.) Sarg.)
Western white pine (Pinus monticola Dougl.)
Western yew (Taxus brevifolia Nutt.)
Aspen (Populus tremuloides Michx.)
Black cottonwood (Populus trichocarpa T. & G.)
Almond-leaved willow (Salix amygdaloides Anderss.)
Black willow (Salix lasiandra caudata (Nutt.) Sudw.)
Mountain birch (Betula fontinalis Sarg.)
Lodgepole pine (Pinus contorta Loud.)

SHRUBS

Alpine willow (Salix commutata Bebb)
Bee willow (Salix sitchensis Sanson)
Lemmon's willow (Salix Lemmonii Bebb)
Glandular bush birch (Betula glandulosa Michx.)
Lake or deep woods gooseberry (Ribes lacustre Poir.)
Thorny gooseberry (Ribes irriguum Dougl.)
Sticky black currant (Ribes viscosissimum Pursh)
White-barked currant (Ribes petiolare Dougl.)
Lewis' mock-orange (Philadelphus Lewisii Pursh)
Pear-fruited rose (Rosa pisocarpa Gray)
Bush mountain ash (Sorbus sitchensis Roem.)
Mountain balm (Ceanothus velutinus Dougl.)
Sagebrush (Artemisia tridentata Nutt.)

HERBS

Two-edged pink onion (Allium anceps Kell.)
Bog onion (Allium Geyeri Wats.)
Yellow bells (Fritillaria pudica (Pursh) Spreng.)
Spotted cat's ear or mariposa lily (Calochortus nitidus Dougl.)
White wild hellebore (Veratrum californicum Durand)
Death camas (Zygadenus venenosus Wats.)
Elegant zygadene (Zygadenus elegans Pursh)
Purple bells, grass widow (Sisyrinchium grandiflorum Dougl.)
Calypso, lady slipper (Calypso bulbosa (L.) Salisb.)
White lady slipper (Cypripedium montanum Dougl.)
Crimson monkey flower (Mimulus Lewisii Pursh)
Indian paint brush (Castilleja miniata Dougl.)
Jacob's ladder (Polemonium humile R. & S.)

STATE DEPARTMENT OF GEOLOGY & MINERAL INDUSTRIES
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Publications

BULLETIN		Price
1	Mining Laws of Oregon, 1937, with 1939 Addenda	$0.10
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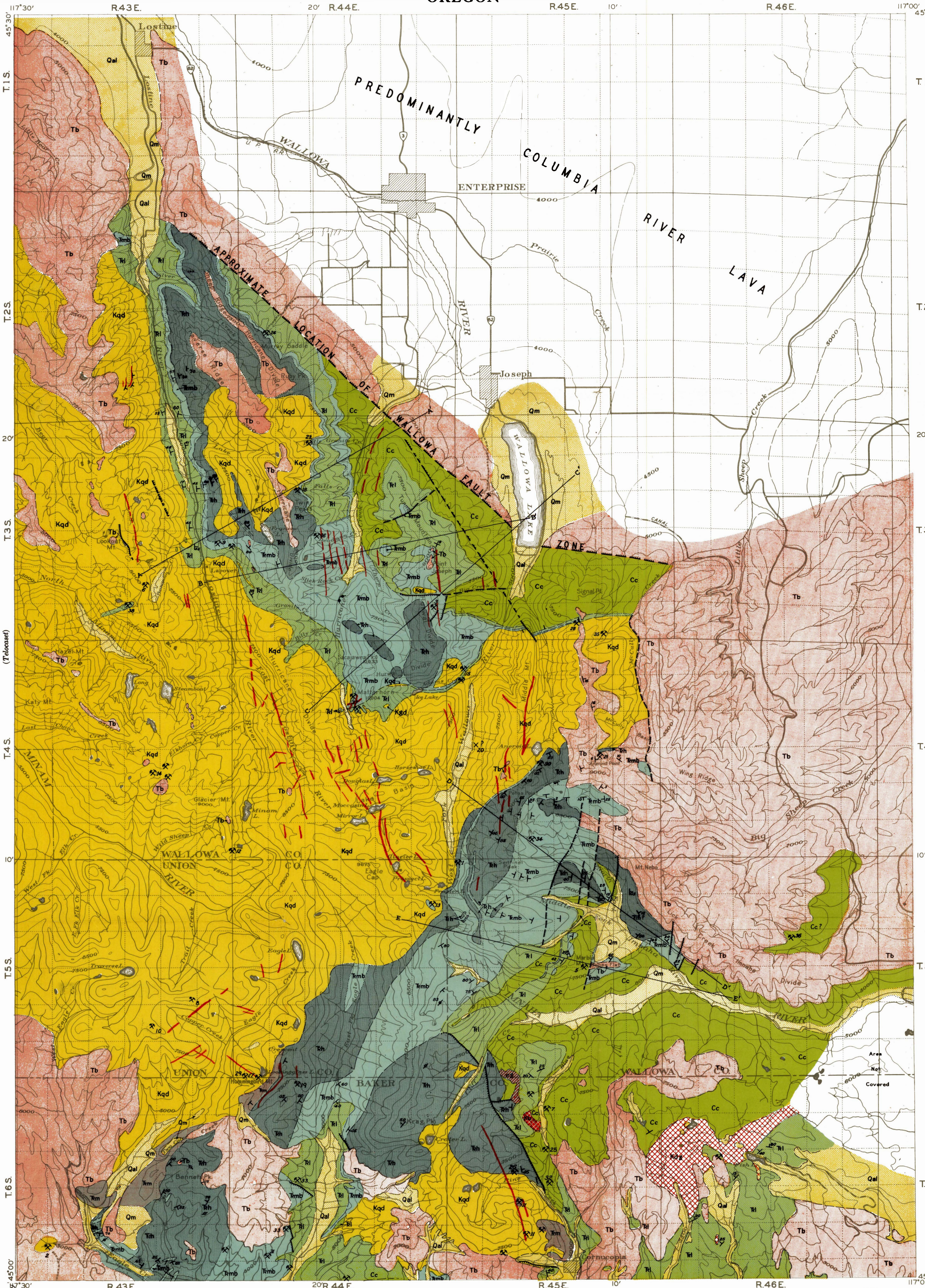
PLATE I

ISSUED BY THE
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND
MINERAL INDUSTRIES
EARL K. NIXON, DIRECTOR
PORTLAND, OREGON

RECONNAISSANCE GEOLOGIC MAP OF THE WALLOWA LAKE QUADRANGLE OREGON

TO ACCOMPANY BULLETIN No. 12
"GEOLOGY AND PHYSIOGRAPHY OF THE
NORTHERN WALLOWA MOUNTAINS" By
WARREN D. SMITH, JOHN ELIOT ALLEN
AND OTHERS.



EXPLANATION

(in part after Ross, 1938)

CENOZOIC — QUATERNARY — Pleistocene and Recent

Qal Qm Alluvial and glacial deposits
(Unconsolidated gravel and sand, and morainal material)

UNCONFORMITY

CENOZOIC — TERTIARY — Miocene

Tb Columbia River basalt
(Principally basalt flows and feeder dikes. May also include a few lamprophyric dikes)

UNCONFORMITY

MESOZOIC — CRETACEOUS (?) — Intrusives

Kgd Quartz diorite and granodiorite
(Batholithic masses of quartz diorite and granodiorite with numerous variations in composition)

Kb Oligoclase bostonite
(Dark bluish-gray aphanitic rock with small feldspar phenocrysts)

Kdg Diorite-gabbro complex

MESOZOIC — UPPER TRIASSIC — Upper Karnic

Trh Hurwal formation

Trm Metamorphic facies

(Includes "Younger Mesozoic sedimentary rocks" and "Triassic (?) volcanic rocks" of Ross, 1938. Mostly shales, black and gray slates, and micaceous and quartzitic sandstone; altered in places to hornfels, schists, quartzites and gneiss. Fossiliferous)

Trmb Martin Bridge formation
(Crystalline limestone, minor amounts of calcareous shale, and some conglomerate. Fossiliferous)

UNCONFORMITY

MESOZOIC — UPPER TRIASSIC — Middle Karnic (in part at least)

Trl Lower sedimentary series

eg Epidote-garnet rock

(Includes "Carboniferous (?) sedimentary series" of Ross, 1938, south of the Imnaha River. Shales, sandstones, with minor amounts of limestone and conglomerate; mostly altered to slate, hornfels, schist, and crystalline limestone. Fossiliferous on Point Joseph. Epidote-garnet rock probably a contact-altered phase)

UNCONFORMITY DOUBTFUL

PALEOZOIC — CARBONIFEROUS — Permian

Cc Clover Creek greenstone
(Green, gray, and purple metamorphosed lavas and pyroclastic rocks, principally andesite, with some interbedded sediments and limestone lenses)

Contact

Contact inferred

Attitude of beds
vertical
horizontal

Fault (showing downthrow side)

Fault inferred or approximately located

Mines and Prospects
(Numbers refer to alphabetical list of mines and numbers given in text.)

MINES AND PROSPECTS

(*Described in text)

1. Andy Heaverne's Prospect .... Sec. 6, T. 5 S., R. 45 E.
2. Basin Mine .... W½ sec. 29, T. 6 S., R. 43 E.
3. B. C. Basin Prospect .... NW¼ sec. 36, T. 3 S., R. 44 E.
5. Boner Flat Prospect .... Center south line of SE¼ sec. 15, T. 5 S., R. 45 E.
6. Bowman Creek Prospect .... Just N. of Center of sec. 27, T. 3 S., R. 43 E.
7. Carnahan Mine .... SE¼ sec. 4, T. 6 S., R. 45 E.
8. Colton Claims .... SE¼ sec. 22, T. 5 S., R. 43 E.
9. *Contact Group (also known as Iron Dyke, Peacock, White Eagle, Dr. Scott Claims) Center of E. ½ sec. 24, T. 3 S., R. 43 E.
10. Copper Creek (Dotson) Prospects .... Sec. 27, T. 5 S., R. 43 E.
11. Cornucopia Mountain Claims .... Mostly in secs. 21, 27 and 28, T. 6 S., R. 45 E.

Companion	Jim Fisk	Red Cross
Corundum Group	Last Chance	Red Jacket
Forest Queen	Mayflower	Robert Emmett
Geo. W. Smith Claims	Mountain Chief	Union
Jackley	Queen of the West	Valley View (Wild Irishman)
	Red Boy	White Elephant

12. Donnelly Prospect (Blue Lake Mine) ... SE cor. sec. 36, T. 4 S., R. 43 E.
13. *Frazier Prospect (Golden Cat, Sunset, etc.) Center N½ sec. 12, T. 5 S., R. 44 E.
14. Great Northern Prospects (Three prospects). E½ sec. 22 and W½ of sec. 23, T. 4 S., R. 43 E.
15. *Green Group (formerly known as Gem Group: Copper Gem, Mountain Gem, etc.; and Copper King). SE¼ sec. 6 and N½ sec. 7, T. 4 S., R. 45 E.
16. Gyllenberg's Prospect (Hecla Consolidated). NW¼ sec. 21, T. 3 S., R. 44 E.
17. Hummingbird Mountain (Veatch) Prospect. NE corner sec. 6, T. 6 S., R. 44 E.
18. *LeGore Prospect .... SE¼ sec. 8, T. 3 S., R. 44 E.
19. Love and Kelly Prospect .... NE¼ sec. 5, T. 6 S., R. 44 E.
20. Manuel Lopez Prospect .... Sec. 18 or 19, T. 4 S., R. 45 E.
21. McCully Basin Prospect .... NW¼ sec. 23, T. 4 S., R. 45 E.
22. Metzger Property .... Sec. 5, T. 3 S., R. 44 E.
24. *Northwest Lime Co. (formerly Black Marble & Lime Co.) SE¼ sec. 19, T. 2 S., R. 44 E.
25. Norway .... SE¼ sec. 9, T. 6 S., R. 45 E.
26. Red Mountain .... E½ sec. 17, T. 6 S., R. 45 E.
28. Royal Purple Prospect .... Center of W½ sec. 34, T. 3 S., R. 45 E.
29. Schirmer and Landis Prospect .... NW¼ sec. 6, T. 6 S., R. 44 E.
30. *Seeber Prospect (Walla Walla Group). Center sec. 21, T. 4 S., R. 45 E.
31. Sheep Rock Mine (also known as McGee property). SE¼ sec. 30, T. 6 S., R. 44 E.
32. Simmons Mine .... SE¼ sec. 16, T. 6 S., R. 45 E.
33. Summit Mining Co. (includes Woodard and Dunham Miles Groups and Apex, Midway, Woodrow and Zenith claims). Sec. 17, 20, and N½ sec. 29, T. 6 S., R. 44 E.
34. *Tenderfoot "Mine" .... Near center sec. 33, T. 4 S., R. 45 E.
35. Transvaal Prospect .... SW corner sec. 35, T. 3 S., R. 45 E.
36. Wallowa County Mining & Development Co. (Williams "Mine"). NE¼ sec. 15, T. 5 S., R. 46 E.
37. *Wilmot Group (Matterhorn Group) ... SW¼ sec. 10, T. 4 S., R. 44 E.
38. Wilson "Mine" .... NW¼ sec. 33, T. 3 S., R. 43 E.

Base after United States Forest Service
Forest Atlas, Wallowa and Minam Folio Sheets,
Surveyed 1912-1917.

TRUE NORTH — MAGNETIC NORTH 21°
APPROXIMATE MEAN DECLINATION 1937

1 0 1 2 3 4 5 Miles

Contour interval 500 feet
Datum is mean sea level

1941

I Geology by Warren D. Smith, John Eliot Allen, Ray C. Treasher, Wayne Lowell, Lloyd L. Ruff. 1938-1939
II Geology by Clyde P. Ross, 1938.
III Geology by E. T. Hodge, 1938.
IV Geology inferred or incomplete.