FRONTISPIECE

The northern Ruby Mountains as seen looking south from the southwestern portion of the East Humboldt Range

THE GEOLOGY OF THE NORTHERN RUBY MOUNTAINS AND THE EAST HUMBOLDT RANGE
ELKO COUNTY, NORTHEASTERN NEVADA

by

SIGMUND SNELSON

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Department Geology

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ABSTRACT

The northern Ruby Mountains and the East Humboldt Range constitute the northern part of a major north-northeast-trending mountain mass in the Basin and Range province of western United States. The range is situated in northeastern Nevada, approximately midway between the Wasatch Range of central Utah and the Sierra Nevada of eastern California.

The main mass of the range is composed of a rather high grade, regionally metamorphosed, and internally thrusted succession which is tentatively subdivided into two units. These units are at least in part in thrust contact with one another. The lower unit is designated the Angel Lake unit and includes over 3000 feet of metamorphic rocks which include granitic to dioritic gneisses, sillimanite-bearing biotite schists, quartzitic schists, quartzites, lime-silicate rocks, and marble. The rocks in the upper portion of this unit are polymetamorphic, exhibiting all degrees of superimposed cataclasis ranging from mild cataclasis to ultramylonitization. The upper metamorphic unit is designated the Snow Water unit. It contains 1000? feet of marble, lime-silicate rock, white quartzite, schists, and pegmatite. Regional and local data support a Precambrian age for these two units.

Two low-angle thrusts have been recognized within the metamorphic succession. Available evidence suggests that the age of thrusting was Precambrian, and that the movement along at least one of the thrust planes was from east to west.

In thrust contact with the metamorphic basement are Paleozoic and lower Mesozoic strata. The following units are recognized: upper Pogonip? group and Eureka quartzite (Ord.); undifferentiated carbonates (Sil?-Dev.); Guilmette formation (Dev.); Pilot shale?? (Dev.-Miss?); Diamond Peak formation (Miss.); Ely limestone (Penn.); Arcturus formation and "Park City formation" (Permian); undifferentiated limestones and shales (Early Triassic).

The major thrust plane which brings the Paleozoic and lower Mesozoic strata over the metamorphic basement is called the Secret Creek thrust. This thrust truncates layers in both the upper and lower plate successions, and nearly all the Paleozoic-Mesozoic formations are variously in contact with it. A series of faults subordinate to the underlying sole thrust tectonically eliminate, truncate, and repeat many of the units in the upper plate. The age of this thrusting is post-lower Triassic and is earlier than all of the Tertiary deposits in this area, which include possibly early and almost certainly middle Tertiary rocks. Evidence indicates that the direction of thrusting was from west to east.

Remnants of the thrust plane in the East Humboldt Range indicate that it is broadly folded into a huge northerly trending and doubly plunging anticline nearly 30 miles long. In the northern Ruby Mountains the thrust plane forms a broad northerly plunging anticline. The trend and magnitude of this major folding rather closely parallels the basic topography of the range. Evidence indicates that the episode of anticlinal folding, associated with subordinate faulting, essentially created the basic outline, shape, and trend of the northern Ruby-East Humboldt Range and occurred in late Cenozoic time. Some flanking Tertiary continental sediments and volcanics----tentatively subdivided into the Clover Valley, Starr Valley, and Willow Creek units (oldest to youngest)----were deformed during this range-forming episode. Late Pleistocene to Recent faults of relatively minor displacement locally form scarplets along and adjacent to the range front, and represent the latest known episode of Cenozoic deformation.

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INTRODUCTION

General Statement

The northern Ruby Mountains and the East Humboldt Range* constitute the northern part of a major north-northeast trending mountain mass in the Basin and Range province of western United States. The range is situated in northeastern Nevada, approximately midway between the Sierra Nevada of eastern California and the Wasatch Range of central Utah.

The purpose of this investigation was to study and map the internal rocks and structure of the range. The external (boundary) structure, glaciation, and geomorphology of the range were previously studied by Sharp (1938a, 1938b, 1939a, 1939b, and 1940) and as a result of his work, the Ruby-East Humboldt Range has become a common textbook example of a typical Basin-Range mountain (Eardley, 1951; Billings, 1954; Thornbury, 1955).

Location and Accessibility

The northern Ruby-East Humboldt Range is located in Elko County, northeastern Nevada. It lies 190 miles due west of Salt Lake City, Utah, and 250 miles east-northeast of Reno, Nevada. More closely adjacent towns are Elko, Nevada, 30 miles to the east, and Wells, Nevada, 6 miles to the northeast. The area mapped lies within latitudes 41°08' and 40°40', and longitudes 115°20' and 115°00'. It embraces approximately 300 square miles.

U. S. Highway 40, extending from Salt Lake City to San Francisco, passes by the northern end of the range. U. S. Highway 93, which extends from Twin Falls, Idaho to Las Vegas, parallels the east flank of the East Humboldt Range for 30 miles. State Highway 11 traverses the range at Secret Pass, a low divide between the northern Ruby Mountains and the East Humboldt Range.

* Not to be confused with the Humboldt Range of west-central Nevada.

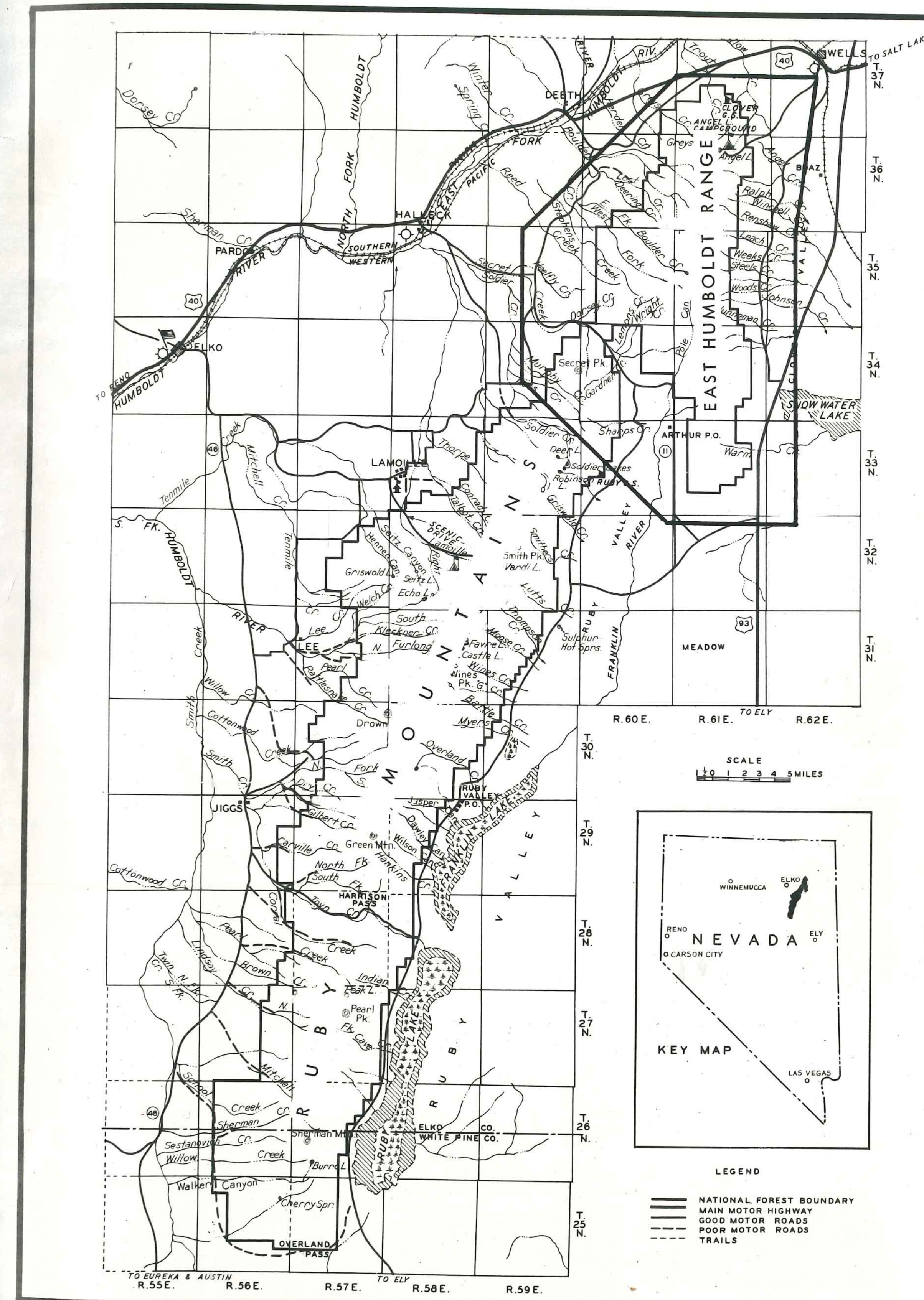

Figure 1. Geographic setting of the northern Ruby-East Humboldt Range

The base of the mountains is usually accessible by dirt roads, but most of the interior of the range is reached only by trail. There are two gravel roads entering canyons of the range itself. One road leads from the town of Wells to Angel Lake, which is located on the east slope of the northern portion of the East Humboldt Range. Another road, south of the mapped area, leads into the central Ruby Mountains and up Lamoille Canyon from the town of Lamoille on the west flank of the range.

Geography

Topography and Description

Both the high relief and the distinctive glacial topography contrast the Ruby-East Humboldt Range from its neighbors. King (1878, p. 62) called it "...the most prominent mountain mass in eastern Nevada".

The range is asymmetric and trends south-southwesterly for 78 miles from its northern end near the town of Wells. The eastern face is much steeper than the western slope.

The range maintains an overall elevation of around 10,000 feet with local peaks reaching 11,400 feet. Patches of snow can be found at these higher elevations even in mid-summer. The range is flanked by wide desert basins 5600 to 6100 feet above sea level.

Three relatively low passes cross the range. From north to south these are: Secret Pass, Harrison Pass, and Overland Pass. The hills extending south of Overland Pass are not considered as part of the Ruby Mountains.

Just south of Wells, several miles east of the northern part of the East Humboldt Range, lie three relatively low north-south-trending hills. The northernmost hill is the largest, and for convenience will be referred to hereafter as "Clover Hill."

A subsidiary ridge projects southerly for 12 miles from the southeast corner of the main mountain mass of the East Humboldt Range. This ridge separates the northern end of Ruby Valley, which extends up the east flank of the Ruby Mountains, from Clover Valley, the lowland which parallels the eastern front of the East Humboldt Range. This ridge will be hereafter referred to as the southern East Humboldt Range.

Just across a low divide at the northern end of Ruby Valley is a 5 square mile lowland known as Secret Valley. It is 100 to 400 feet higher than Ruby Valley. Secret Valley is well hidden from Ruby Valley to the south, and reportedly was a favorite early-day hideout for robbers and stock rustlers.

The range was originally called the Humboldt Mountains (King, 1878; Hague, 1877), but later maps have given it two names. The mass north and northeast of Secret Pass is now known as the East Humboldt Range, and the mass to the south is called the Ruby Mountains.

Drainage

Many streams flow from the Ruby-East Humboldt Range throughout the year, which is somewhat unusual for ranges in this region. At the head of many of these streams are small glacial lakes.

Most of the streams on the east side of the range crest empty into the wide, flat intermountain basins of Clover and Ruby valleys. Ruby, Franklin, and Snow Water lakes lie in the lower parts of these closed playa basins.

In contrast, the streams of the west side have open drainage, and are important tributaries to the well-known Humboldt River. This is the largest river in the state of Nevada. It is about 250 miles long and disappears north of the Carson Sink in the western part of the state.

Climate

According to Eakin <u>et al</u> (1951):

> The climate of (Ruby and Clover valleys) is arid to semi-arid and is characterized by low precipitation on the valley

floor, low humidity, high rate of evaporation, and a wide range in temperature, both seasonal and daily.

Precipitation increases generally with altitude in the adjacent mountains. The higher parts of the East Humboldt Range and the Ruby Mountains rank closely with other areas of precipitation in Nevada and locally the precipitation may exceed 35 inches.

Precipitation on the floor of Clover Valley probably ranges from 5 to 12 inches a year... .

Vegetation

On the range flanks vegetation includes sagebrush (Artemisia tridentata), big greasewood (Sarcobatus vermiculatus), black sage (Artemisia nova), and various grasses. Within the range are various types of aspen, pine, and juniper.

Investigation

The author first became interested in the geology of the northern Ruby Mountains and the East Humboldt Range while he was in northeastern Nevada doing field work on his master's thesis in the southern Pequop Mountains. When the writer decided to continue on for the Ph.D. degree, Dr. Peter Misch, who had previously done some reconnaissance in the area in 1953, suggested that the stratigraphy, petrography, and internal structure of the range would be an excellent problem, and would be a significant addition to the geologic mapping program by the University of Washington Geology Department in various parts of the Eastern Great Basin. Sharp (1938a, 1938b, 1939a, 1939b, and 1940) had previously reported on the Cenozoic geology of the area, and the present investigation was to deal with the pre-Tertiary rocks and internal structure of the range which had not been mapped by Sharp.

During the course of the present study, some structural relations were found in the range which appeared to shed new light on the Cenozoic history and boundary ("basin-range") structure of the range. This led the author to study the Tertiary deposits and their relation to the range front in more detail than was originally intended.

The present dissertation is the result of 26 months of research from April, 1955 to June, 1957. The six summer months of 1955 and 1956 were spent in the field.

Aerial photographs (1:20,000) were used in geologic mapping. Subsequently the geologic data was transferred to a topographic map. An enlarged copy of the Halleck quadrangle was used as a base map for the southern three-quarters of the area; and an enlarged and modified Forest Service map (1953), Grazing Service map and an uncontrolled Jack Ammann photo index (No. 22SE) were used for the northern quarter.

During the course of the investigation, approximately 350 rock thin-sections were prepared and studied by the author. In addition, 70 fusulinid sections were prepared; they were studied by Gerald Marrall of the Union Oil Company in Compton, California and H. J. Bissell of Brigham Young University. The fossil material is deposited in the Paleontology Museum, Department of Geology, University of Washington as Lot No. 35. Representative rock specimens and thin-sections are deposited in the Petrography Collection, Department of Geology, University of Washington as Lot SN.

Acknowledgements

The writer gratefully acknowledges the guidance, encouragement, and helpful criticism from Dr. Peter Misch, who supervised the investigation, paid a field visit, and read the manuscript. The assistance and helpful suggestions provided by Dr. Howard A. Coombs and Dr. V. Standish Mallory is sincerely appreciated.

The author wished to acknowledge the assistance in the field by Grover Akre during the first six weeks of the summer of 1956; and also wishes to thank Dale Kremer, undergraduate in geology at the University, whose able geological assistance in the latter part of the 1956 field season was equally matched by his mechanical abilities.

Mention must be made of the writer's constant and devoted companion for both field seasons, his faithful dog "Geiger". With tale-telling wounds received from snapping coyote traps and an irate sheep rancher's bullets, "Geiger", who never missed a day in the field, will probably never forget his Nevada adventure.

The Union Oil Company of California very generously provided financial support through the courtesy of John Hazzard, and for this assistance the author is very grateful. Appreciation is also extended to William H. Easton of the University of Southern California who kindly provided determinations of the mega-fossil collections. The author is likewise indebted to Gerald Marrall and H. J. Bissell for their identifications of the fusulinid material.

Lastly, thanks are also extended for their courtesy to Dan Flynn of the General Petroleum Corporation, Ed Johnson of the Continental Oil Company, and Bill Martin of the El Paso Natural Gas Company, who were in Elko during parts of the present study.

METAMORPHIC SUCCESSION

General Statement

The main mass of the northern Ruby Mountains and the East Humboldt Range is composed of a rather high grade, regionally metamorphosed, and internally thrusted succession consisting essentially of granitic to dioritic gneisses, schists, quartzites, lime-silicate rock, and marbles which are occasionally cut by pegmatitic, granitic, diabasic, and aplitic dikes and sills.

Subdivision into Units

The metamorphic series is tentatively subdivided into two units. The lower unit is designated as the Angel Lake unit, and the upper as the Snow Water unit.

The two units differ in their overall lithology, and are, at least in part, in thrust contact with one another. The lower or Angel Lake unit includes granitic to dioritic gneisses, biotite schists, quartzitic schists and schistose quartzites, pegmatite, lime-silicate granulites, lime-silicate marbles, and pure marbles. In the upper portion of the Angel Lake unit, and as the overlying thrust plane is approached, these rock types exhibit all degrees of cataclasis ranging from mild cataclasis to ultramylonitization.

The upper or Snow Water unit consists predominantly of marble, lime-silicate marble, banded lime-silicate granulite, schist, pegmatite, and white quartzite. This succession, which is, at least in part, in thrust contact with the underlying Angel Lake unit, contains both cataclastic and non-cataclastic rocks, with mylonites at and near the thrust plane.

The thickness of the two units cannot be accurately estimated inasmuch as the base of the lower or Angel Lake unit is not exposed, and the top of the

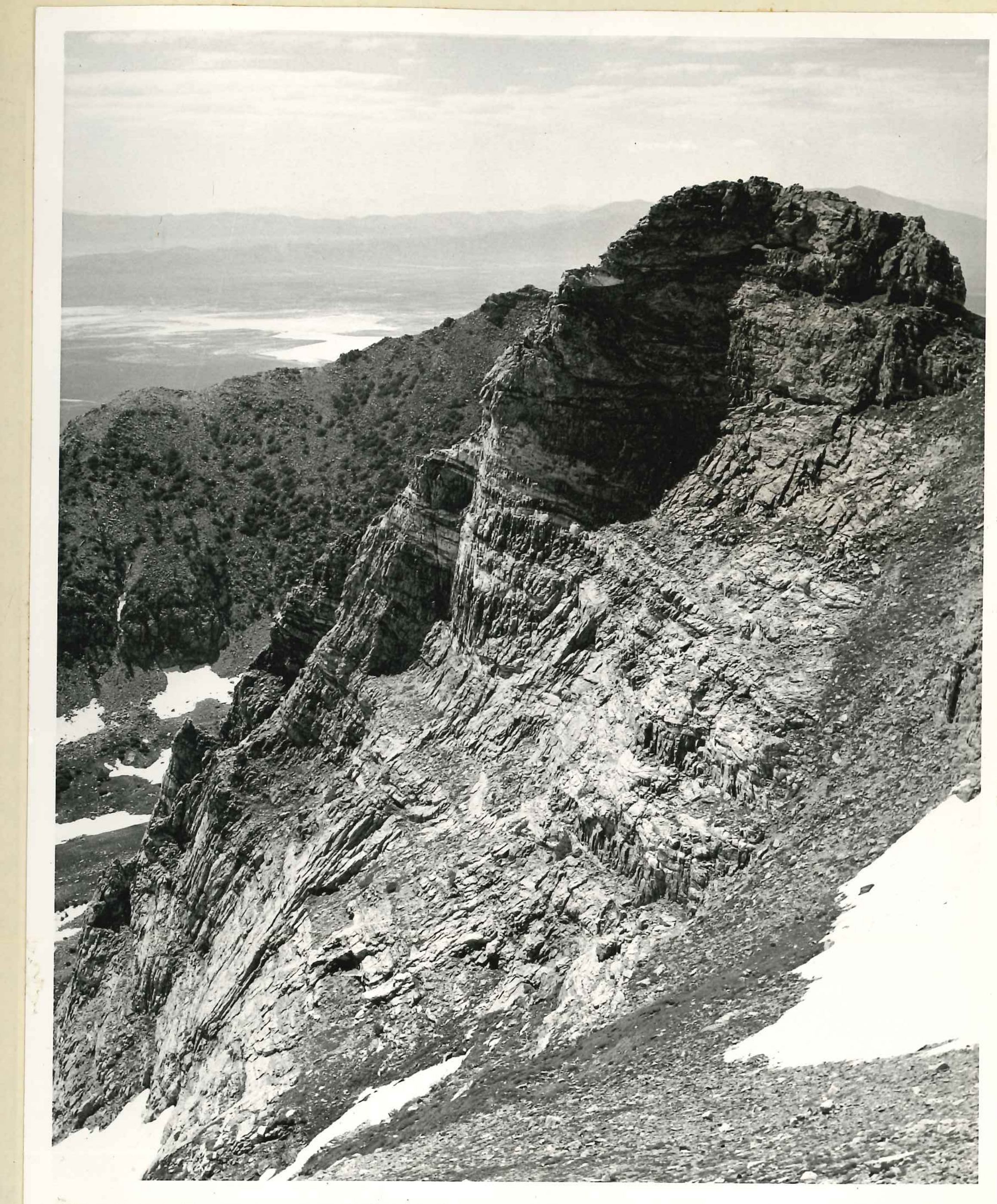

Fig. 3a. Layers of higher-grade gneisses, schists, quartzites, and lime-silicate rocks in the Angel Lake unit as seen near the head of the south fork of Steels Creek looking to the southeast. Snow Water Lake is seen in the background.

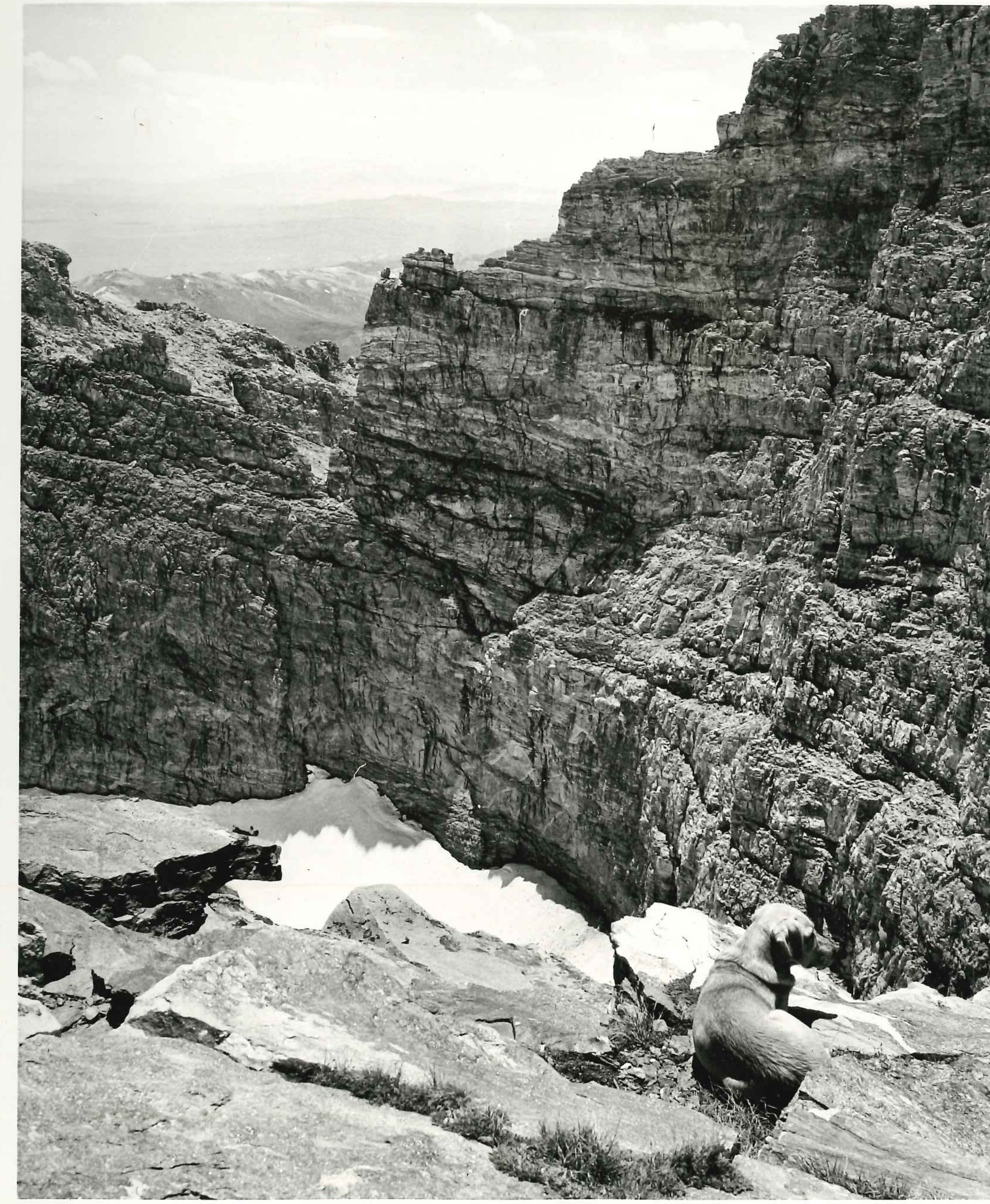

Fig. 3b. High-grade metamorphic rocks in the Angel Lake unit magnificantly exposed on the east-facing precipice below Humboldt Peak in the East Humboldt Range. View is looking southward.

Snow Water unit is truncated by a thrust mass of Paleozoic strata.

The maximum exposed thickness of the Angel Lake unit is roughly 3000 feet, and of the Snow Water Unit, 1000? feet. Far greater thicknesses of these units may occur in the Ruby Mountains south of the presently mapped area, and a detailed study in the Ruby Mountains would be necessary before formal nomenclature is proposed.

Age of the Rocks and the Type of Metamorphism

Two views have been expressed regarding the age of the metamorphic rocks in the Ruby-East Humboldt Range. One view is that the original rocks were Paleozoic and that metamorphism occurred in late Jurassic to early Tertiary time. The divergent view is that the age of both the parent rock and the subsequent metamorphism is Precambrian.

The metamorphic rocks in the range were first discussed by King (1878, p. 12, 62) and Hague (1877, p. 528, 537), who considered them to be Archaen. Hill (1916) in an early mining district reconnaissance mapped the rocks in the range core intrusive biotite granite of possible late Cretaceous or early Tertiary age. Blackwelder (1935, p. 157) in a regional Precambrian summary implied that the rocks are Precambrian. Sharp (1939b, p. 886) originally thought that the entire metamorphic succession was a Paleozoic sequence which was metamorphosed in the late Mesozoic or early Tertiary, but later (1942, p. 675-676) concluded that some of these rocks may possibly be Precambrian.

Sharp was the only author to attempt a systematic subdivision of the metamorphic succession, and the only author to present a reason for his particular age designation. He divided all the internal rocks of the range, metamorphic and non-metamorphic, into four formations. They were: a lower dolomite unit (lowermost), a quartzite formation, a middle limestone unit, and an upper limestone formation (uppermost).

According to the stratigraphic column in Sharp's earlier paper (1939b), all of these above formations were regarded as Paleozoic rocks contact-metamorphosed by early Tertiary or late Mesozoic binary granite (two-mica granite), porphyritic granite, and pegmatite intrusions (See Appendix).

Supporting his original view that the parent rock of the lower dolomite unit was Paleozoic, he stated that this "dolomite" (consisting of "sillimanite-garnet schist, quartz-biotite schist, quartzite, marble, and diopside granulite") is "believed to be Paleozoic as it is part of a conformable series in which overlying beds are Carboniferous... ." In support of his belief that the quartzite formation (consisting of "brown quartzite and smaller amounts of quartz-biotite schist, marble, granulite, and biotite gneiss") is Paleozoic, he states, "It is conformable with overlying beds which contain Carboniferous fossils and is, therefore, thought to be Paleozoic."*

The conformably overlying beds that Sharp refers to are his middle and upper limestone formations of reportedly Permo-Carboniferous age. Although Sharp mapped none of the four formations areally, his several cross-sections enabled the present writer to observe what rocks were considered to constitute these formations. On the basis of these observations, it appears that Sharp's lower dolomite unit and quartzite formation constitute a high-grade regionally metamorphosed layered rock succession; and that, in the northern Ruby Mountains and the East Humboldt Range at least, Sharp's middle and upper limestone are actually thrust slices of rocks that range in age from Ordovician to Early Triassic, and which are not conformable with the underlying metamorphic basement but on the contrary lie on a basal thrust plane that truncates rock

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* In his later paper, Sharp (1942, p. 675) revised some of the earlier views regarding the age of the lower "dolomite" unit and the overlying "quartzite" formation. He stated, "The previously named quartzite formation (Sharp, 1939b, p.887) is undoubtedly the Lower Cambrian Prospect Mountain quartzite... High-grade metamorphic rocks, originally impure dolomite, limestone, shale, and sandstone, are exposed (Sharp, 1939b, p. 886-887) below the Lower Cambrian quartzite. These rocks are seemingly conformable with the quartzite... and may be Lower Cambrian... or... they might correspond in part to the Proterozoic... ."

layers of both upper and lower plates.*

Since the type of metamorphism in this area has a decided bearing upon its age interpretation, this question will be discussed first. Arguments will subsequently be presented which concern the probable age of the metamorphic terrane.

On the basis of the following seven points, the writer has concluded that the main body of metamorphic rocks in the northern Ruby Mountains and the East Humboldt Range is the product of regional metamorphism and not contact metamorphism:

1) The metamorphism is regional, in the descriptive sense. That is, metamorphic terrane occurs over a large area, well over 150 square miles in the mapped area, and several hundred more square miles in the central Ruby Mountains.

2) The greater portion of the metamorphic rocks studied in the area are synkinematic, i.e., deformation and recrystallization interpreted to have occurred essentially contemporaneously during metamorphism.

3) The rocks in many instances are polymetamorphic. Earlier gneisses, schists, quartzites, and lime-silicates were mylonitized by later dynamic (mechanical) metamorphism, which in some localities show a later stage of mild feldspathization.

4) The metamorphic rocks are of a rather high grade over the entire area, generally the warmer mesozone and cooler katazone.

5) Metamorphic rocks with all degrees of feldspathization are present. These range from feldspar-porphyroblast schists, augen-gneisses, and lit-par-lit replacement gneisses, to relatively homogeneous gneisses.

* It is to be noted, however, that on the basis of reconnaissance by this writer, the middle limestone of the central Ruby Mountains indicated by Sharp in his cross-sections EE', FF', and the west half of DD', (see Appendix) is apparently not part of the upper plate, but part of the metamorphic basement. It appears distinctly different from the rocks shown in Sharp's middle limestone of the East Humboldt Range (cross-section AA' and the east half of DD') which are definitely Paleozoic rocks of the upper plate.

6) Intrusive bodies within the metamorphic succession are limited to dikes and sills which appear not only too small to account for the widespread higher-grade metamorphism, but which even lack apparent contact metamorphic effects upon immediately adjacent rocks.

7) In a nearby area where Paleozoic rocks are intruded by a large igneous body, metamorphic effects are local and rarely occur more than 30 feet from the intrusive contact. This intrusive body is exposed in Harrison Pass in the southern Ruby Mountains. It is a large mass of granite and quartz monzonite over 7 miles wide and apparently extending northward from the pass up the east flank of the range for at least 10 miles. The narrow aureole of marble, hornfels, and tactite (lime-silicate hornfels) in the Paleozoic rocks, as described by Klepper, _et al_ (1944), are in striking contrast with the regional, schistose, higher-grade, feldspathized, and in part polymetamorphic rocks of the northern Ruby-East Humboldt Range.

If the metamorphic terrane in question is not a product of contact metamorphism but is rather a regional metamorphic succession in the broader sense (Harker, 1939), the problem of its age still remains. The following points strongly suggest that both the original succession and its metamorphism was Precambrian:

1) The regionally metamorphosed terrane is neither conformable with nor gradational into Carboniferous rocks, but on the contrary it is in thrust contact with variously aged rocks as old as Ordovician. Thus, the only argument previously used in support of a Paleozoic age for the metamorphics is not valid, and the view that the metamorphic lower plate succession is a Precambrian basement would seem less unlikely than before.

2) On the basis of field work in the East Humboldt Range and northernmost Ruby Mountains, the author found that rocks of carbonate derivation (now marble, lime-silicate marble, and lime-silicate granulite) appeared to be less

abundant than rocks of sandstone and shale derivation (now gneisses, schists, and quartzites). Known Paleozoic successions within the general area, significantly, are predominantly carbonate rocks, and the same holds true for surrounding areas.*

3) The regional setting argues against higher-grade regional metamorphism and feldspathization in post-Paleozoic time. Northeastern Nevada is regarded by most geologists to have been a part of the Paleozoic miogeosyncline or Millard Belt (Kay, 1947) which lay to the east of the "Manhattan geanticline" (Nolan, 1928; Eardley, 1951). The latter is a north-northeast trending line through central Nevada that is said to separate typical eugeosynclinal from typical miogeosynclinal deposits (Krumbein, 1950) to the east.

During deep-seated orogenic upheavals, it is reportedly the mobile eugeosynclinal belts that become subjected to regional higher-grade metamorphism (King, 1951; Misch, 1949; Read, 1954 and others). A hypothesis suggesting such metamorphism in post-Paleozoic time in this miogeosyncline would, at best, seem to warrant serious skepticism. Such skepticism would appear to be well founded in view of the next argument.

4) The widespread occurrence of unmetamorphosed Paleozoic rocks in eastern Nevada strongly suggests that no higher-grade regional metamorphism of the Paleozoic succession has occurred anywhere in this region, otherwise these sequences now so widely exposed might be expected at least in some places to grade into such higher-grade metamorphics.**

* This second point applies to the main bulk of metamorphic rocks exposed in the range, namely, the rocks comprising the Angel Lake unit. It does not apply to the Snow Water unit which containsmany carbonate-derived rocks. Additional evidence which supports a Precambrian age for this unit is discussed in the section on the Snow Water unit (Southern East Humboldt Range --- Quartzites).

** What may be regarded as apparent minor exceptions to the above statement is local dynamic metamorphism of Paleozoic rocks at or near major thrust planes in east-central Nevada. Misch and Easton (1954), for example, found that the Pilot shale at a major basal thrust plane in the southern Schell Creek Range is altered to phyllite and slate. Grant Steel and H. J. Bissell have called the writer's attention to exposures of Ordovician rocks in the Wood Hills just southeast of Wells which show a mild degree of metamorphism. The meta-

Angel Lake Unit

Introduction

The Angel Lake unit is a higher-grade metamorphic succession which constitutes the main bulk of the northern Ruby Mountains and the East Humboldt Range. The base of this unit is not exposed, as previously stated, but of the approximately 3000 feet of strata exposed in the East Humboldt Range, roughly the upper 1000 feet consists of rocks showing superimposed cataclastic structures. The percentage of cataclastic rocks and the intensity of cataclasis increases upwards in this 1000 feet, with the more highly cataclastic rocks occuring beneath the overlying thrust mass of the metamorphic Snow Water unit.

The lower, essentially non-cataclastic 2000 feet of Angel Lake strata are exposed most prominently on the east side of the East Humboldt Range between Wiseman Creek and Angel Lake. The higher, cataclastic strata occur near and at the crest of the range and are widely exposed along its western flank. The most readily accessible exposures of the cataclastic rocks are in the area of the Secret Creek gorge along Nevada Highway 11.

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morphism is reported to be essentially limited to the Ordovician Pogonip formation, whose base is not exposed; and the metamorphism does not significantly affect rocks above the Eureka quartzite which overlies the Pogonip (H.J. Bissell, personal communication).

Some of the shales in the Pogonip formation have reportedly become slates possessing slaty cleavage and inconspicuous recrystallization, but lacking the general lustrous appearance and well-formed sericite or chlorite characteristic of low grade phyllites. Carbonate rocks in the succession have developed a marble-like sheen, but generally lack coarse recrystallization.

In the northern Pequop Range directly southeast of the Wood Hills similar incipient low-grade metamorphism of the Pogonip occurs (Bissell, personal communication). The presence of limestone mylonites in the northern Pequop area (Hazzard and Turner, 1957) which are reportedly similar to those which occur along a major basal thrust zone in the Snake Range (Misch and Hazzard, et al, 1953), together with other occurrences of dynamic metamorphism along major thrust planes (Misch and Easton, 1954), suggests a possible cause of the incipient metamorphism in the Pogonip rocks of the Wood Hills and northern Pequop Mountains. That is, a basal thrust plane could be lying beneath the Wood Hills and the northern Pequop Range, and movement along this plane could

Non-cataclastic Succession

Lower portion

Light grey granitic to trondhjemitic biotite gneisses appear to be the most distinctive rock type in the more poorly exposed lower parts of the non-cataclastic portion of the Angel Lake unit. Granitic biotite gneiss (B70) was found in the bottom of the Leach Creek cirque; gneissose biotite quartz monzonite (L40) occurs near the upper end of the north fork of East Fork Boulder Creek; weakly gneissose biotite granite (E49a) and trondhjemitic biotite gneiss (E49b) was collected from the valley bottom at the head of Pole Canyon; and granitic biotite gneiss (A33a) is exposed at the base of the Ruby Mountains one mile south of Sharps Creek.

The amount of potassium feldspar in the gneisses ranges from 65 percent in the granitic varieties to 15 percent in the trondhjemitic gneisses. The plagioclase is invariably oligoclase, and its abundance varies from 6 percent in some of the granitic gneisses to 55 percent in the trondhjemitic varieties. The amount of quartz varies between 20 and 30 percent. Brown biotite is sometimes concentrated in schistose layers, but elsewhere it is generally evenly distributed and constitutes less than 6 percent of the rock. It is the biotite which gives the gneisses their weak to moderate foliation. Horn-

have caused the mild dynamic (mechanical) metamorphism of some of the lower units of an upper plate. The presence in these localities of slates rather than hornfels or massive argillites would support weak dynamic metamorphism in preference to static thermal metamorphism of a hypothetical subjacent intrusion.

Further, a basal thrust plane exposed at "Clover Hill", where Paleozoic rocks are thrust over a part of the rather high grade metamorphic series, lies only 3 miles west of the Wood Hills. It would not seem unlikely that the thrust passes underneath the intervening valley to the east and continues at depth under the Wood Hills. Thrust sheets which could be related a a large-scale basal thrust plane, are known to be present in at least the northwest and southeast portions of the Wood Hills (Bissell, personal communication).

In summary, the reportedly incipient dynamic metamorphism of rocks of the Ordovician Pogonip formation in the northern Pequops and in the Wood Hills is quite probably not related to the higher-grade regionally metamorphosed Ruby-East Humboldt succession, but perhaps is the result of weak dynamic metamorphism induced along an underlying basal thrust plane.

Fig. 4. Regionally metamorphosed higher-grade gneisses, schists, quartzites, lime-silicate rocks, and marbles of the Angel Lake unit as seen looking west-southwest toward the head of the south fork of Angel Creek in the northern East Humboldt Range.

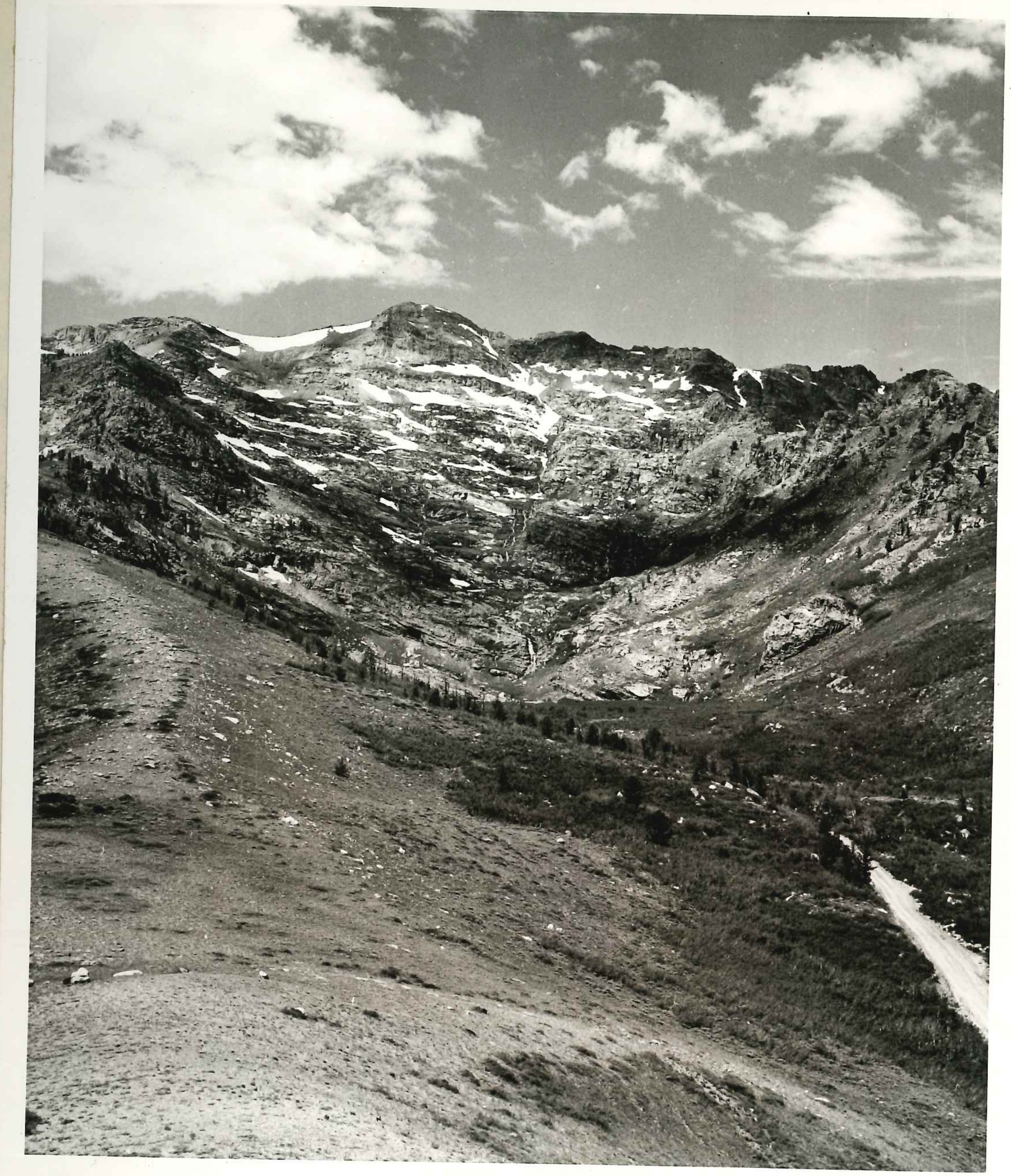


Fig. 5. View of the Angel Lake unit looking west toward the Angel Lake cirque in the northern part of the East Humboldt Range.

blende was not encountered in any of the specimens studied. Muscovite is sometimes present in amounts of less than 1 percent. Garnet is an occasional minor constituent. There are traces of secondary sericite and chlorite. Accessory apatite, zircon, magnetite, and tourmaline are sometimes present in varying amounts.

The gneisses are fine-grained to finely medium-grained and textures are crystalloblastic. Individual grains are invariably anhedral. Myrmekitic intergrowths are common, and appear to be the result of microcline replacing oligoclase. Albitic rims obscure the twinning on the margin of some oligoclase grains and suggest local albitization.

Middle portion

The majority of the rocks in this portion of the Angel Lake unit fall into one of the following catagories: gneisses, quartzitic schists and schistose quartzites, lime-silicate rocks and marbles, and amphibolites. In addition, there are pegmatitic areas in irregular patches, dikes, and lenses. Aplites are present, but are much less common than pegmatites. Diabase dikes have intruded the succession, and are clearly later than the main episode of regional metamorphism. Prominent fissure-like openings extending rather deep into the more resistant host rock are frequently caused by the weathering of the less resistant diabases of the dike conduits (Fig. 8).

Small scale folds are often seen in various members of the Angel Lake unit. A series of overfolds in biotite gneisses is exposed at the crest of the Ruby Mountains about a mile south of Sharps Creek. Overfolding is to the southwest (Fig. 6). On the lower flank of the East Humboldt Range just north of Chase Creek, near recumbent folds in an orange-weathered biotite gneiss are overturned to the east (Fig. 7).

The gneisses in this portion of the Angel Lake unit are very heterogeneous in composition even in a single outcrop. All degrees of feldspathiza-

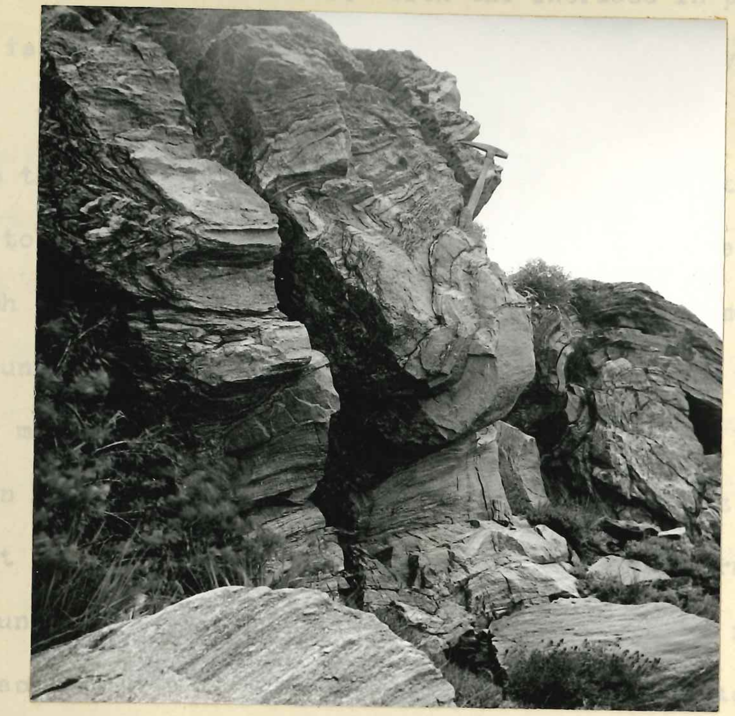


Fig. 6. Biotite gneiss overfolded to the southwest. Crest of the Ruby Mountains about one mile south of Sharps Creek, looking northwest.

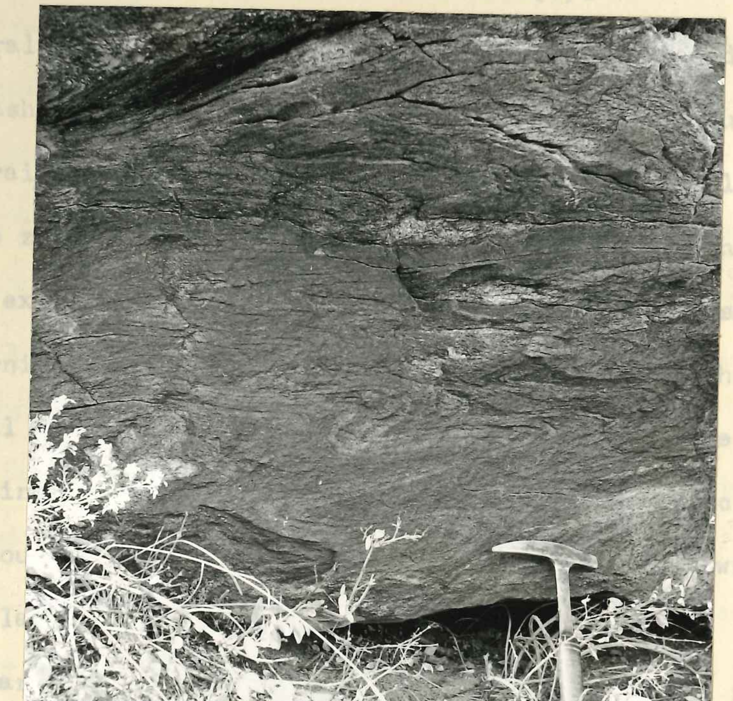


Fig. 7. Near-recumbent folds in biotite gneiss near Chase Creek in the East Humboldt Range, looking north. Note attenuation of the lower limbs, indicating that overturning was to the east.

tion are present, and the quartz dioritic gneisses pass vertically and laterally into more pegmatitic varieties. With the increase in potash feldspar content there is a corresponding decrease in the schistosity and the percentage of mafics.

In the thin-sections of gneisses studied, the amount of plagioclase ranges from 8 to 75 percent of the rock. Oligoclase is more common than andesine. Potash feldspar is completely absent in some specimens, but occurs in most in amounts up to 55 percent. Quartz ranges from 15 to 55 percent. Biotite is the most common mafic contituent, varying mostly between 1 and 10 percent. Green hornblende is limited to a few of the quartz dioritic gneisses, and in these it comprises up to 15 percent of the rock. Garnet is occasionally present in amounts up to 2 percent. A trace of orthite was found in two specimens, and a trace of epidote in two others. Muscovite and accessory zircon, apatite, sphene, opaques, and tourmaline are likewise present in traces, as is retrogressive chlorite, sericite, and kaolinite(?).

Texturally, the gneisses are fine- to medium-grained and crystalloblastic. Potash feldspar is often seen to embay and even surround twinned plagioclase grains which show myrmekitic textures. Plagioclase is sometimes zoned, but the zoning is not uniform even within the same thin-section. One specimen, for example, shows an anhedral grain with fairly sharp euhedral oscillatory zoning (one recurrence), and several grains with gradational anhedral normal zoning. Quartz varies greatly in grain size and shape, and undulatory extinction is almost ubiquitous in non-myrmekitic quartz. Biotite occurs in various shades of brown, pale brown, greenish brown, reddish brown, and brownish black.

The quartzitic schists and schistose quartzites are foliated rocks which nearly always have over 90 percent quartz and varying amounts of mica, feldspar, and in some cases, sillimanite. These quartzitic rocks pass both vertically and laterally into quartzitic gneisses. In a quartzitic two-mica schist (L35) near the upper part of this portion of the Angel Lake unit, sillimanite occurs as thin prisms in well-developed muscovite. Sillimanite was also found associated with biotite and oligoclase in a quartzitic gneiss (A34c). This latter specimen consists of 15 percent sillimanite, 40 percent calcic oligoclase, 40 percent quartz, and 4 percent biotite. Also present are traces of muscovite, sericite, chlorite, and kaolinite(?). In some schistose quartzites, the quartz is quite fine-grained, anhedral, and fairly equi-dimensional. A typical specimen (A34d) contains 92 percent quartz, 3 percent biotite, and 5 percent oligoclase. The biotite is sometimes altered to muscovite and magnetite, and in other places it is shredded. The oligoclase occurs as porphyroblasts. Some twinned grains show gradational, anhedral, normal zoning; and similar zoning of undetermined trend occurs in some untwinned grains.

Medium-grained cream-colored marble from the Angel Lake area contains some minor tremolite and phlogopite(?). A quartz-rich lime-silicate gneiss in the same area contains 55 percent quartz, 20 percent andesine, 15 percent scapolite, 5 percent diopside-hedenbergite, and lesser amounts of biotite, hornblende, clinozoisite, zircon, sphene, and apatite.

Dark green medium-grained amphibolites contain 50 percent or more green hornblende, up to 50 percent sodic-andesine to calcic-labradorite, about 5 percent quartz, and minor biotite. Plagioclase shows gradational, anhedral, normal and reverse zoning, as well as anhedral to subhedral oscillatory zoning. Secondary chlorite occurs locally after biotite. Accessory apatite is common.

The intrusive diabase rocks are finely medium-grained in the central portions of the dikes, and aphanitic at the outer margins. The rocks have typical ophitic texture (Fig. 9), with well-formed labradorite laths constituting 65 percent of the rock. There is about 25 percent of a non-pleochroic pale rose-brown clino-pyroxene, about 5 percent olivine which is partially

Fig. 8. Diabase conduits on the south side of the Angel Lake cirque in the northern East Humboldt Range.

Fig. 9. Ophitic-textured diabase from middle conduit.
O = olivine, P = clinopyroxene. (57 X magnification, crossed nicols).

altered to antigorite(?) and uralitic amphibole, about 3 percent magnetite, and very minor secondary biotite. The labradorite laths have gradational, anhedral, normal zoning, and show considerable sericitization.

Upper gneiss

In the Hole-In-The-Mountain Peak area, the upper gradational boundary of the dominantly non-cataclastic portion of the Angel Lake unit very roughly approximates the upper surface of a dark marker layer of essentially dark grey to black hornblende-bearing quartz dioritic biotite gneiss (Fig.10).

The dark gneiss of the marker layer is not truly homogeneous. Within it are numerous narrow layers which show variable proportions of biotite, hornblende, quartz, and feldspar. Especially typical of the marker gneiss is the abundance of criss-crossing feldspathic dikelets and lit-par-lit type feldspathic layers. King (1877, p. 68) was quite evidently referring to these feldspathic bodies in the gneiss when he noted that the rocks "seem to be clouded in peculiar irregular shadings across the stratification, like an irregular map in different shades of grey". And further, in perhaps one of the first descriptions of replacement dikes in this country, King accurately and descriptively recorded that this "irregular clouding ... looks upon the surface of the precipice almost like the presence of irregular intruded masses. Through these, however, the general lines and shades of the gneiss bed are seen to run; but the gneiss itself, within the limits of these vertical cloudings, has lost much of its schistose character, and is more granitic" (Hague, 1877, p. 536).

This dark "irregularly clouded" gneiss layer can be traced northward from Leach Creek along the range crest. At the head of the north fork of Leach Creek, the gneiss is riven by prominent vertical joints, and a distinctive series of pinnacles has developed as a result of erosion along some of these cracks. The dark gneiss layer is essentially the only well exposed

Fig. 10. The dark "marker layer" of hornblende-bearing quartz dioritic biotite gneiss of the Angel Lake unit as seen looking south near Hole-In-The-Mountain Peak in the central East Humboldt Range. Note the criss-crossing feldspathic dikelets which were first observed by King (1877).

metamorphic unit in this area of the north fork of Leach Creek and in fact, it is the only clearly discernable unit along the eastern range front for about two miles northward (Fig. 11). This is partly because the lower slopes of the range front are blanketed by vegetation and morainal debris, partly because of a northeasterly component of dip, and partly because of a possible northward thickening of the dark gneiss layer. The dark gneiss layer loses its prominence one-quarter mile south of Leach Creek.

As the dark gneiss marker lenses out southward, two layers of dark gneiss which are stratigraphically above the marker gneiss lense into the succession from the south. These two layers are seen as two prominent horizontal bands across the precipice just west and northwest of Weeks Creek. They intersect the range crest about one-half mile to the south, and are not seen again.

Allochthonous outliers of the upper gneiss

Thrust masses of hornblende-bearing quartz dioritic biotite gneiss are exposed in the general vicinity of Hole-In-The-Mountain Peak. These rocks are thrust over and truncate layers of the normally overlying "transition" sequence of the Angel Lake unit to be described. The allochthonous masses bear striking lithologic resemblance to the previously described dark gneiss marker layer in the uppermost non-cataclastic portion of the Angel Lake unit, and are regarded as probable outliers of it. The characteristic lit-par-lit type gneisses, the scattered criss-crossing feldspathic dikelets, and the narrow beds which have compositional variations in their amounts of quartz, biotite, hornblende, and feldspar, are all typically present.

The rocks are predominantly dark grey to black hornblende-bearing andesine-porphyroblast biotite gneisses of quartz dioritic composition. The ratio of hornblende to biotite is variable, but biotite is usually more common. The andesine porphyroblasts which are abundant and evenly scattered often give the rock a distinctive spotted appearance. These andesine porphyro-

Fig. 11. The east front of the central East Humboldt Range. The dark gneiss member of the Angel Lake unit is exposed at the skyline in the central portion of the photograph, and can be traced northward for several miles.

blasts are earlier than later feldspathization, which in some areas introduced potash feldspar and oligoclase.

The gneiss show various stages of development which have a transitional relationship to each other. A first stage is a finely medium-grained feldspar-porphyroblast gneiss, a second is a medium-grained to coarsely medium-grained augen gneiss, and a final stage is a coarser-grained banded lit-par-lit gneiss. The transition within this sequence is first accomplished by the development of oligoclase porphyroblasts along certain beds. Some porphyroblasts coallesce in one spot and form somewhat larger pods or augen. Where increase in porphyroblasts occur in adjacent or nearly adjacent layers, these feldspathized layers coallesce into a band, and an incipient "lit-par-lit" type layer is produced. At this stage considerable development of potash feldspar becomes evident. With further increase in oligoclase and potash feldspar growth, the "lit-par-lit" pattern becomes fully developed. The feldspar porphyroblasts within the layer are coarser-grained, and show augen shapes in many sizes and in varying degrees of coalescence.

The "lit-par-lit" pattern thus developed is not necessarily, in every detail, exactly parallel to the foliation of the adjacent gneiss (Fig. 12). In fact, on a small scale some layers are oblique to the overall schistosity. Significantly, planes of foliation in the adjacent gneiss are often observed to continue as delicate mafic stringers for varying distances into the slightly oblique feldspathic layer. Clearly, these layers are the result of replacement and cannot be accounted for by magmatic injection.

Some of the feldspathic layers show incipient ptygmatic folding, suggesting some post-"lit-par-lit" deformation and recrystallization.

In the dark hornblende-bearing quartz dioritic biotite gneiss which has not been later feldspathized, the plagioclase porphyroblasts are sodic andesine and constitute 50 to 60 percent of the non-feldspathized rock. Some grains show gradational, anhedral, normal zoning, and others show euhedral

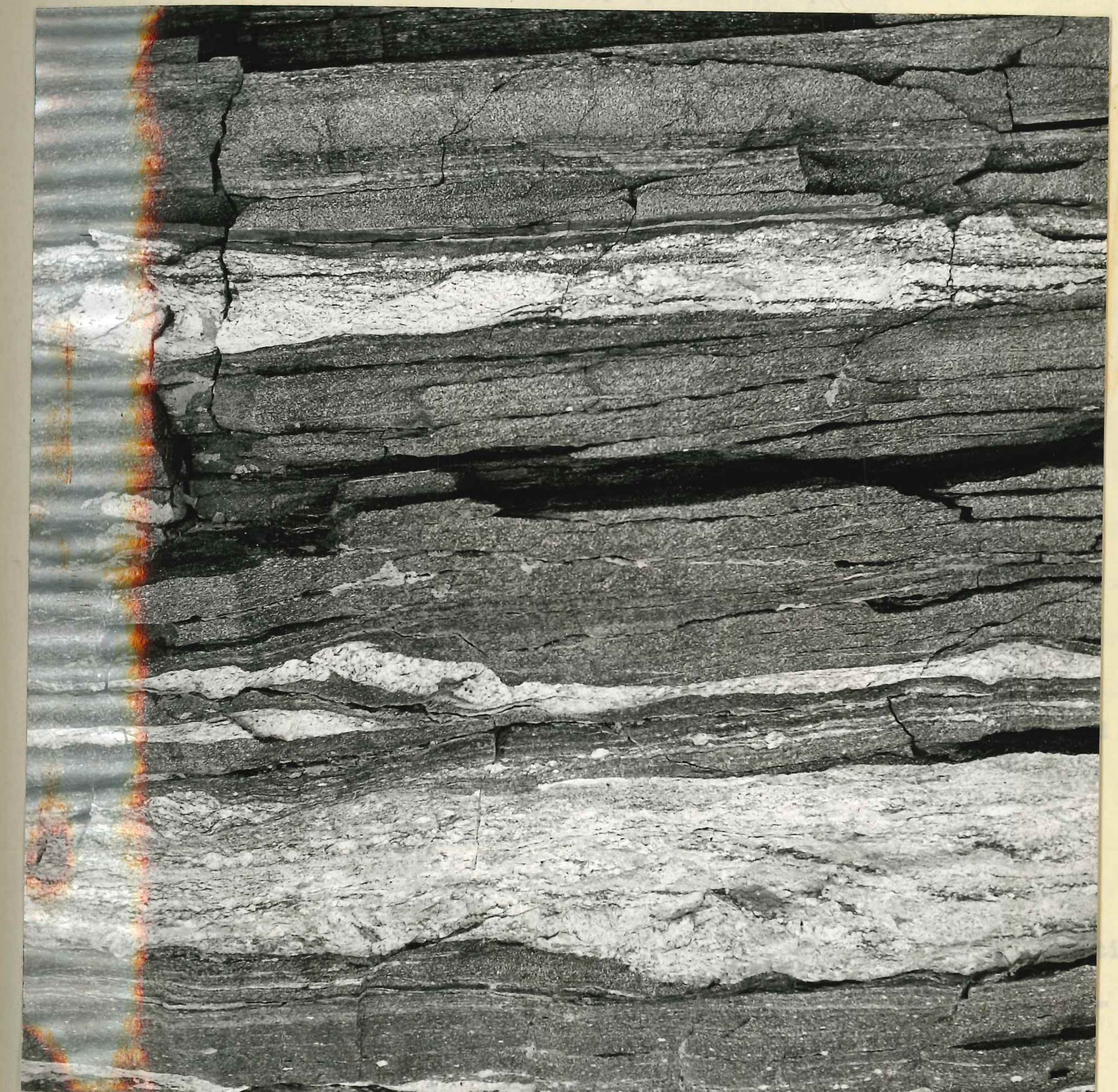


Fig. 12. Augen and lit-par-lit replacement structure in the allochthonous layer of hornblende-bearing quartz dioritic biotite gneiss at the peak (elev. 11,111) northwest of Gibbs Lake in the central East Humboldt Range. Vertical length of outcrop is about 2½ feet.

oscillatory zoning. The plagioclase grains are surrounded by finer grained area of quartz (20 to 30 percent), biotite (7 to 10 percent), hornblende (3 to 5 percent), and traces of accessory apatite and sphene. It is to be noted that potash feldspar, significantly, is almost entirely absent in these non-feldspathized areas. Rather, it is within the "augen", the "lit-par-lit" and replacement dikelet areas that the potash feldspar, together with the oligoclase, becomes prominent. In these the gneiss becomes leucocratic and more granitic.

Conclusions

The non-cataclastic portion of the Angel Lake unit is a synkinematically metamorphosed and feldspathized succession of originally sedimentary Precambrian rocks. The heterogeneity and layered nature of the rocks, together with the presence of marbles, lime-silicate rocks, and quartzites, testify to the sedimentary origin. The fact that the metamorphism was of rather high grade is indicated by the presence of sillimanite in various schists and gneisses, and also by the association of diopside, scapolite, and andesine in certain lime-silicate rocks.

The overall schistosity of the rocks in this portion of the Angel Lake unit, which is shown in thin-section to be crystallization foliation in contrast to cataclastic foliation, testifies to an early period of synkinematic metamorphism where penetrative deformation and recrystallization were presumably occurring contemporaneously. The subsequent folding of the planes of schistosity in certain areas indicated superimposed later deformation.

The evidence for feldspathization is abundant both in the field and in the thin-section, and there is some evidence that a minor amount of deformation and recrystallization occurred after feldspathization i.e., incipient ptygmatic folding.

The diabase dikes which intrude both the Angel Lake unit and the

Secret Pass unit are clearly later than the regional synkinematic metamorphism. Their exact age is unknown.

"Transition" Succession and Portions of The Non-cataclastic Succession

A succession of metamorphic rocks which is composed of both cataclastic and non-cataclastic members, overlies the dominantly non-cataclastic portion of the Angel Lake unit in the area between Hole-In-The-Mountain Peak and Humboldt Peak. This "transition" succession is roughly 600 to 800 feet thick, and lies between the dominantly non-cataclastic rocks in the lower two-thirds of the Angel Lake unit, and the dominantly cataclastic rocks in the uppermost 100 to 300(?) feet of the Angel Lake unit.

In the vicinity of Hole-In-The-Mountain Peak, the base of the "transition" succession very roughly approximates the upper surface of the previously described dark marker layer of hornblende-bearing biotite gneiss. The succession passes gradationally into the overlying, dominantly cataclastic sequence, which is widely exposed on the western flank of the range, in the Secret Creek gorge, and in the northern portion of the "Secret Hills" between Ruby and Secret valleys.

The "transition" succession was studied in the area between Humboldt Peak (VABM 11,000) and Hole-In-The-Mountain Peak (elev. 11,276). Specimens were collected along the northeastern slope of Humboldt Peak; on the cirque wall southwest of Boulder Lake; on the peak (elev.11,111) northwest of Gibbs Lake; and along the first west-facing slope south of Hole-In-The-Mountain Peak.

Hole-In-The-Mountain Peak Section

Hole-In-The-Mountain Peak itself is made up of a hornblende-bearing biotite gneiss which is a thrust remnant of possibly the dark marker gneiss layer which forms uppermost part of the lower, non-cataclastic portion of the

Angel Lake unit. Beneath this dark allochthonous gneiss the presently described "transition" succession of the Angel Lake unit is exposed. The succession is here a light-colored, cataclastic and non-cataclastic sequence of mostly gneiss, banded lime-silicate granulite and marble, schistose quartzite, and pegmatite. These rocks appear as a prominent light-colored horizontal band which can be seen from both Starr and Clover valleys.

The succession is distinctly layered. Within it are some large streamlined lenses and pods of darker gneisses, and some cross-cutting dikes (Figs. 10, 13 and 42). These streamlined megascopic features, together with the associated microscopic cataclasis, emphasize the horizontal shearing and deformation which must have affected this unit at one time.

<u>Gneisses</u>.-- The following representative gneisses from this area were collected and microscopically studied: dioritic hornblende gneiss, quartz dioritic augite gneiss, partially feldspathized quartz dioritic biotite paragneiss, cataclastic quartz dioritic hornblende-biotite gneiss.

The quartz dioritic pyroxene gneiss (L 46) is light green and cream-colored, and fine-grained. The texture is crystalloblastic. Plagioclase constitutes about 85 percent of the rock. It is mostly sodic andesine and has normal, anhedral, gradational zoning. Cores are about An_{35} and rims are about An_{28}. Quartz constitutes 8 percent of the rock. Augite (5 percent of the rock) is anhedral to subhedral, microscopically colorless, and has an extinction angle (Z:c) of 47 degrees. Potash feldspar is present but is less than 2 percent.

Medium-grained dioritic hornblende gneiss (L 5 and L 9) contains 60 to 76 percent sodic andesine (about An_{31}), 22 to 35 percent hornblende, 3 percent late chlorite, 2 percent late carbonate, 1 percent quartz, 1 percent sphene, and traces of potash feldspar, orthite, and apatite. This specimen is characterized by late fractures variously filled with carbonate and/or radiating growths of chlorite. Carbonate has replaced much of the hornblende. Chlorite is pale brown to grass green, and has anomalous "Berlin blue" interference colors.

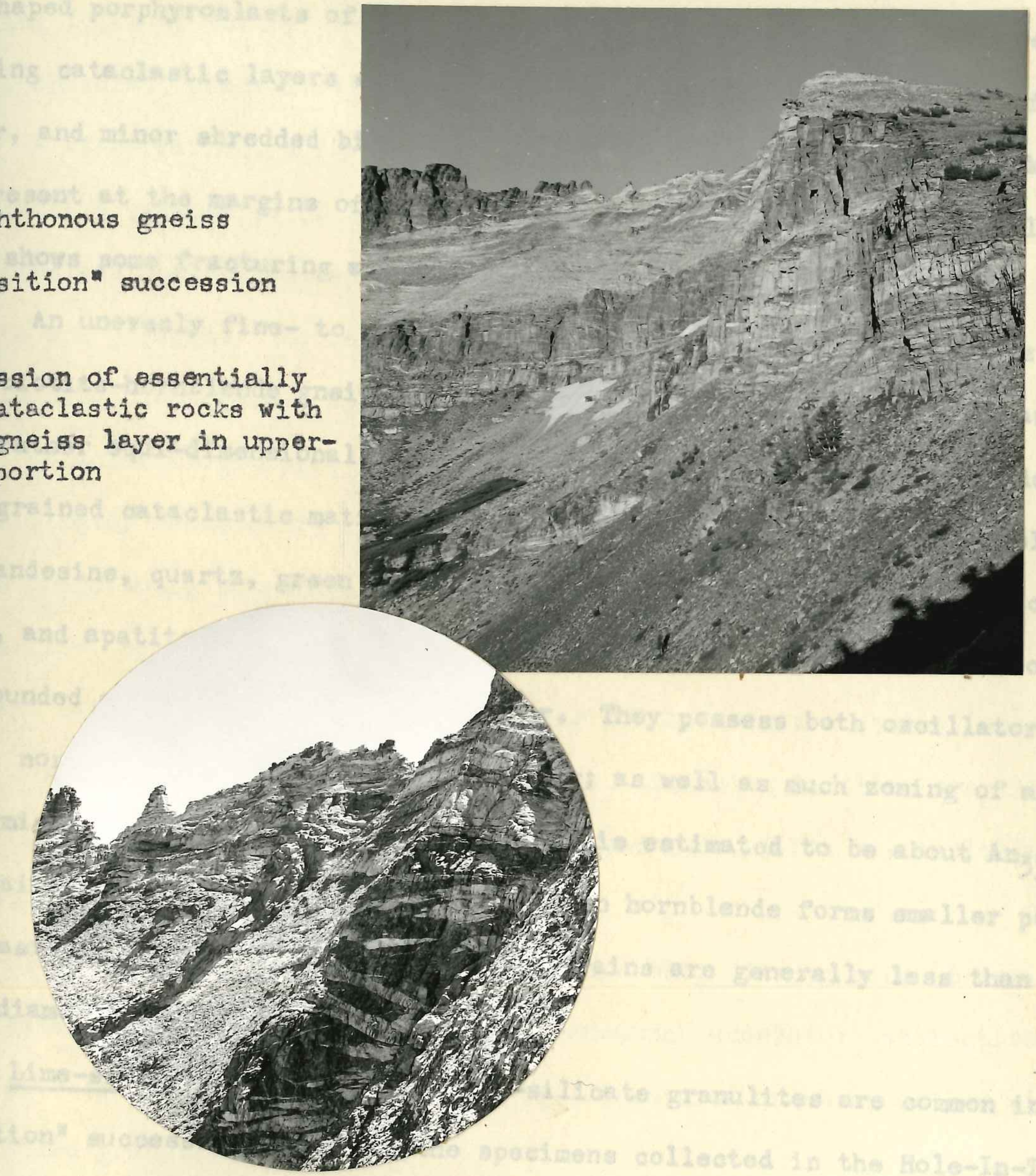


Fig. 13. The "transition" succession as seen on the west side of Hole-In-The-Mountain Peak. The peak (elev. 11,276 feet) lies to the left of the circled area. It is composed of an allochthonous mass of hornblende-bearing quartz dioritic biotite gneiss.

An unevenly fine- to medium-grained, strongly cataclastic leucogranitic gneiss (L 12) consists of microcline (55 percent), quartz (30 percent), calcic oligoclase, about An_{24} (14 percent), biotite and chlorite (1 percent). Pod-shaped porphyroclasts of microcline (1 to 2 mm. in length) lie between undulating cataclastic layers consisting of fine-grained sutured quartz, feldspar mortar, and minor shredded biotite and chlorite. Pre-cataclastic myrmekites are present at the margins of some microcline porphyroclasts. Calcic oligoclase shows some fracturing and healing by quartz.

An unevenly fine- to medium-grained, strongly cataclastic quartz dioritic biotite-hornblende gneiss (L 1) collected near the crest of the range contains rather equi-dimensional porphyroclasts of sodic andesine, surrounded by a finer-grained cataclastic matrix containing varying amounts of potash feldspar, sodic andesine, quartz, green hornblende, and brown biotite. Traces of orthite, sphene, and apatite are also present. The andesine porphyroclasts are somewhat rounded and average 1 mm. in diameter. They possess both oscillatory and simple, normal, anhedral, gradational zoning; as well as much zoning of an undetermined trend. The average composition is estimated to be about An_{35}. Some grains are slightly fractured. The green hornblende forms smaller porphyroclasts in the cataclastic matrix, and grains are generally less than .33 mm. in diameter.

Lime-silicate granulites.-- Lime-silicate granulites are common in the "transition" succession. Most of the specimens collected in the Hole-In-The-Mountain Peak area are non-cataclastic. These rocks vary in color; they are mostly buff, cream-colored, light green, or both red and green. The rocks are fine- to medium-grained, and microscopic textures are typically crystalloblastic except in the specimens with superimposed cataclasis. Minerals present in the non-cataclastic lime-silicate granulites are: diopside, hornblende, garnet, calcic scapolite, phlogopite, brucite, calcite, potash feldspar, labradorite, The hornblende in one dioritic gneiss has brownish cores and green to bluish-green rims, and has a uniform extinction angle (Z:c) of 20 degrees. The sodic andesine is usually zoned and averages about An_{31}. In the same specimen the following types of zoning were noted: (1) normal, euhedral, gradational; (2) normal, anhedral, gradational; and (3) oscillatory, anhedral, gradational.

A fine-grained, dark grey, partially feldspathized, banded quartz dioritic biotite paragneiss (L 11) dominantly consists of quartz, a sodic untwinned plagioclase, potash feldspar, and biotite. Traces of chlorite, apatite, and hematite are present. The feldspathized areas are coarser grained and consist of sodic oligoclase (about An_{17}), quartz, and potash feldspar.

Cataclastic gneisses studied are incipiently to strongly cataclastic. One incipiently cataclastic dioritic hornblende gneiss (L 32) passes laterally into an incipiently cataclastic banded lime silicate granulite within the same thin-section, apparently reflecting original compositional differences. The incipient cataclasis is noted at the margins of the calcic andesine (about An_{43}) grains which show minor development of mortar. Twinning lamellae are slightly bent in the plagioclase. The rock has preserved most of its crystalloblastic texture.

In a moderately cataclastic quartz-rich oligoclase gneiss (L 18), quartz is elongate, slightly sutured, and shows pronounced undulatory extinction. Calcic oligoclase (about An_{28}) has locally been fractured and been healed with recrystallized granoblastic quartz.

A fine-grained, moderately cataclastic garnet-bearing leucogranitic gneiss (L 34a) consists of about 80 percent microcline and 19 percent quartz, and traces of garnet and greenish-brown to greenish-black biotite. The quartz has highly sutured, fuzzy boundaries, and the grains posses a rather uniform optic orientation. Some recrystallization appears to have occurred during and possibly after cataclasis.

sphene, quartz, biotite and chlorite.

Plagioclase occurs in anhedral grains and, where determinable (L 13, B 72a), it is sodic labradorite (about An_{55}). Zoning of undetermined trend is invariably present. Potash feldspar was noted in only one specimen (L 10). Diopside is a common constituent and is present in all of the specimens studied. It is green in the hand specimen and is usually colorless in thin-section. Grains are mostly anhedral and have an extinction angle (Z:c) of about 39 degrees. Garnet is pale brownish-red in hand specimen and is colorless in thin-section. It is often poikiloblastic, and in one specimen (L 10) it has inclusions of diopside and calcite. Euhedral green hornblende occurs in only one of the specimens studied (B 72a). It is associated with diopside, scapolite, sphene, biotite, garnet, calcite and sodic labradorite. Biotite and chlorite are present only in this one specimen of lime-silicate granulite (B 72a). Scapolite is present in three specimens (L 10, L 32, and B 72a). It is colorless, and has high second-order interference colors. The relatively high birefringence would indicate a significant calcium content and therefore the mineral is probably approaching meionite. Phlogopite occurs in one specimen (L 6) and is associated with brucite. Phlogopite and brucite outwardly resemble one another in the thin-section because both are colorless and micaceous-appearing. Optic sign and birefringence distinguish the two. Phlogopite is biaxial negative and has high second to middle third order colors. Brucite is uniaxial positive, and in this specimen has grey and yellow first-order colors. In the hand specimen phlogopite occurs as pale brown flakes. Brucite is green and has a waxy luster; it resembles talc but is harder (H. = 2.5). Both primary and secondary calcite is present in all specimens, and in B 72a some calcite has replaced scapolite. Sphene occurs as subhedral to euhedral grains in two specimens (L 13 and B 72a).

The grade of metamorphism, based upon the widespread presence of diopside, sodic labradorite and scapolite, is probably warmest mesozone to coolest katazone.

One specimen of cataclastic lime-silicate granulite passes vertically into a previously described, strongly cataclastic quartz dioritic biotite-hornblende gneiss (L 1). The following minerals are present: diopside, sodic andesine (An_{35}), hornblende, quartz, potash feldspar, epidote, orthite, sphene, apatite, and hematite. Diopside is colorless, and has an extinction angle (Z:c) of about 41 degrees, which suggests a slight hedenbergite component. Cleavage planes are sometimes bent. Some grains appear shattered, and smaller particles are sometimes carried into the groundmass along shear planes. Grass-green to blue-green hornblende occurs in subordinate amounts and is often somewhat fibrous. It is found along undulating shear planes and some secondary transverse shear planes; it is often retrogressive along the margins of diopside. Quartz has been mostly reduced to a fine-grained mortar. Sodic andesine (An_{35}) is anhedral with irregular boundaries, occurring in both the groundmass and as fractured porphyroclasts. Twinning lamellae are commonly bent. Microcline occurs both in the cataclastic matrix and as porphyroclasts. Epidote occurs only in trace amounts along shear planes. One brown orthite core in an epidote grain was noted.

Quartzite.-- A single specimen (L 8) of white massive quartzite (Fig. 31) was collected from this area. The quartz forms an unevenly-grained, interlocking mosaic of unoriented, highly irregular-shaped grains. Individual grains show only mild undulatory extinction. The grain size varies from a fraction of a millimeter to about 3 mm. There is no cataclasis.

Peak 11,111

This peak is located northwest of Gibbs Lake and has no name. It is the second highest peak in the East Humboldt Range and has an elevation of 11,111 feet (Fig. 43). The peak itself is made up of an allochthonous outlier of dark quartz dioritic gneiss which is in thrust contact with the "transition" succession here, and is similar to the allochthonous mass at Hole-In-The-Mountain Peak, 2 miles due north. Specimens were collected on the ridge crest immediately southeast of the peak, and from rocks which were at one time beneath and within 30 feet of the overlying thrust plane. Most of the specimens collected are cataclastic.

Gneisses.-- The following cataclastic gneisses were collected: orthoclase-rich quartzitic gneiss (E 10d), garnetiferous leucogranodioritic gneiss (E 10f), orthoclase-rich quartzitic two-mica gneiss (E 10g), banded orthoclase-bearing quartzite and leucogranitic gneiss (10i), and quartz monzonitic gneiss (E 10k).

The moderately cataclastic orthoclase-rich quartzitic gneiss (E 10d) is unevenly fine- to medium-grained, and contains approximately 45 percent quartz, 35 percent orthoclase, 14 percent sodic oligoclase (An_{15}), 5 percent biotite, and minor garnet, muscovite and sericite. Distinctive are the porphyroclasts and porphyroclastic clusters of orthoclase which occur in layers of fine-grained cataclastic quartz, orthoclase, and oligoclase.

Accumulations of finer-grained orthoclase form streaked "tails" behind the porphyroclasts. The grains in these "tails" become smaller and smaller and eventually merge into the mortar of the matrix. The orthoclase is in part kaolinized.

Garnetiferous leucogranodioritic gneiss (E 10f) is unevenly fine- to medium-grained and moderately cataclastic. It contains approximately: 40 percent orthoclase, 35 percent sodic andesine (about An_{31}), 25 percent quartz, and 2 percent garnet, with minor muscovite and zircon. Pre-cataclastic porphyroblasts of orthoclase embay quartz and plagioclase and some myrmekites are developed. Sodic andesine shows zoning of an undetermined trend. Quartz mortar occurs only in narrow streams.

Unevenly fine- to medium-grained, moderately cataclastic, orthoclase-rich two-mica gneiss contains about: 43 percent quartz, 35 percent microcline, 15 percent sodic oligoclase about (An_{12}), 5 percent muscovite, 2 percent biotite, and traces of chlorite and zircon. Quartz-rich layers show moderately elongate quartz grains, the largest of which are .32 mm. wide and about 1.6 mm. long. In these quartz-rich layers are muscovite, biotite, and egg-shaped grains of sodic oligoclase. Finer-grained cataclastic layers contain potash feldspar, oligoclase, and quartz. Grains in these layers are highly irregular in shape, and most range between .016 and .2 mm. in maximum dimension. This matrix is rich in replacement features; potash feldspar generally seems to have replaced oligoclase, with the formation of myrmekite. Some potash feldspar porphyroblasts appear to project outward locally, embaying a small portion of the surrounding cataclastic groundmass. Biotite and muscovite are locally shredded along shear planes.

An unevenly fine- to medium-grained, strongly cataclastic, banded orthoclase-bearing quartzite and leucogranitic gneiss (E 10i) show two different types of response of quartz to cataclastic deformation. Quartzose layers are composed of sutured, elongate quartz grains which average .4 mm. in width and range in length up to 7 mm. Occasional anhedral microcline up to .5 mm. in diameter occurs in these quartz layers. Layers of cataclastic mortar up to one-half inch wide separate these quartzose layers. The bordering layers of mortar consist of granulated quartz, potash feldspar, oligoclase, occasional garnet, and larger porphyroclasts of microcline. Some of the porphyroclasts are as much as one-quarter to one-half inch in size, and the mortar streams flow around them. The porphyroclasts are locally tranversed by fissures which are variously filled with recrystallized quartz and some fine-grained muscovite.

An unevenly fine- to medium-grained, strongly cataclastic quartz monzonitic gneiss (E 10k) consists of about 35 percent microcline, 36 percent calcic oligoclase (about An_{28}), 20 percent quartz, 4 percent muscovite, and 4 percent garnet, kaolin, sericite, chlorite and limonite. Microcline and oligoclase porphyroclasts (up to .14 mm.) are surrounded by streams of highly granulated quartz, oligoclase, and potash feldspar. Porphyroclasts of microcline have been locally fractured, and the narrow fissures perpendicular to the foliation are sometimes filled with radiating muscovite growths.

Lime-silicate marble.-- A single specimen of grey lime-silicate bearing carbonate ultramylonite contains pods and grains of brownish weathering lime-silicate minerals which stand out in relief. The groundmass is composed of a very fine-grained calcite mortar which locally grades into a brownish, fuzzy, cloudy calcite fabric. The lime-silicate minerals occur as individual sub-rounded porphyroclasts, and in sub-rounded porphyroclastic clusters of lime-silicate rock. The following minerals are present in addition to calcite: diopside, scapolite, calcic labradorite (about An_{64}), phlogopite, quartz, and minor potash feldspar.

Quartzite.-- A fine-grained feldspar-bearing gneissose quartzite (E 10L) shows no cataclasis. It contains: 85 percent quartz, 8 percent albite-oligoclase (about An_{10}), 4 percent orthoclase, 2 percent biotite, and 1 percent muscovite. Quartz show preferred crystallographic orientation. Its boundaries are irregular but not sutured. Grains tend to have their longest dimension along the foliation, but they are not lenticular or strongly elongate.

Boulder Lake

On the rather steep cirque wall southwest of Boulder Lake, excellent exposures of the Angel Lake unit are present. Most of the specimens were collected from the lower third of the exposed sequence here, and most rocks are non-cataclastic. Therefore, the rocks mentioned here are only part of the "transition" succession and include rocks of the non-cataclastic portion of the Angel Lake unit.

Most of the rocks in this area appear to be gneisses, with subordinate amounts of marble, banded lime-silicate granulite, and quartzite, and pegmatite. The localities from which specimens were collected are shown on the accompanying photograph (Fig. 14).

At locality E 3, pegmatite and leucogranitic gneiss are associated with marble and lime-silicate granulite. The lime-silicate granulite is medium-grained, red-and-green, and weathers a rusty red-brown. The following minerals are present: hedenbergite, grossularite?, calcic labradorite (An_{64}), quartz, hornblende, scapolite, epidote and clinozoisite, calcite and sphene.

At locality E 4 is a buff weathering orthoclase-bearing quartzitic oligoclase gneiss, containing local lenses of pegmatite. It is overlain by a layer of greenish-black, fine-grained hornblende-bearing quartz dioritic biotite gneiss.

At locality E 6 is a medium- to coarse-grained phlogopite-bearing marble associated with lenses and pods of pegmatite (Fig. 15). These rocks are overlain by alternating layers of light and dark gneiss (E 9 and E 10). The dark gneisses are fine-grained amphibolitic biotite-bearing oligoclase gneiss (E 10) and orthoclase-bearing oligoclase-porphyroblast biotite gneiss (E 9). Specimen E 10 consists of: 60 percent calcic oligoclase (An_{27}), 20 percent hornblende, 15 percent biotite, 4 percent quartz, and 1 percent sphene, zircon, orthite, and apatite. Specimen E 9 contains: 50 percent calcic oligoclase (about An_{29}), 25 percent biotite, 15 percent orthoclase, and 10 percent quartz.

At locality E 7, a rusty-brown weathering biotite-bearing, gneissose quartzite is underlain by granodioritic biotite gneiss. At locality E 8 is a diopside-tremolite-andesine (An_{42}) lime-silicate gneiss (E 8c). It is associated with a moderately cataclastic quartz dioritic biotite gneiss (E 8b) and a gneissose, phlogopite-bearing lime-silicate granulite (E 8c).

Humboldt Peak* (elev. 11,000)

Along the northeastern slope of Humboldt Peak over forty specimens of gneiss, schist, lime-silicate rock, and quartzite were collected and studied. The writer made a collection of representative rock types between the 9800-foot contour and the 11,000-foot contour at the peak. These rocks comprise the upper portion of a thick layered metamorphic succession that is magnificently exposed upon an east-facing precipice which descends nearly vertically for 2,000 feet below Humboldt Peak (Fig. 3b). In the lower half of the succession studied, no cataclastic rocks were found, and hence the succession described here includes rocks of the non-cataclastic portion of the Angel Lake unit. Seven mildly to moderately cataclastic specimens were collected in the upper portion of the succession; they are associated with many non-cataclastic varieties.

Gneisses.-- The following types of gneiss were collected: gneissose granite (E 12, E 16, and E 20), gneissose carbonate-bearing biotite diorite (E 15), weakly gneissose trondhjemite (E 22), tremolite-bearing quartzitic andesine gneiss (E 23), biotite-bearing quartz-dioritic hornblende gneiss (E 24), garnet-bearing leucogranitic gneiss (E 31), and leucogranitic gneiss (E 32).

Gneissose granites are fine- to medium-grained and contain 48 to 60 percent microcline, 15 to 21 percent calcic oligoclase (averaging about An_{26}), 20 to 30 percent quartz, 4 to 5 percent brown biotite, and trace of zircon. Textures are crystalloblastic, and myrmekitic and microgranophyric intergrowths are common.

Gneissose carbonate-bearing biotite diorite is fine-grained, and contains about 67 percent sodic andesine (about An_{37}), 17 percent green biotite, 15 percent calcite, and traces of zircon, sphene, apatite, and chlorite. An-

*Peak is not named on Halleck Quadrangle, but elevation is given.

hedral andesine grains comprise most of the rock, and the interstitial areas contain mostly green biotite and calcite. Calcite locally forms delicate projections into andesine grains and appears to have replaced the latter. Biotite is pleochroic from pale green to dark green. Green biotite was not observed in non-carbonate-bearing granitic to dioritic rocks; and the reason for green biotite in this specimen may be due to the presence of some lime in the parent rock.

Weakly gneissose trondhjemite is medium-grained, and consists of a granoblastic mosaic containing about 70 percent calcic oligoclase (about An_{28}), 22 percent quartz, 5 percent orthoclase, and 3 percent brown biotite, and a trace of chlorite.

Biotite-bearing quartz dioritic hornblende gneiss is fine-grained, greenish-black, and resembles a biotite amphibolite in hand specimen. The thin-section shows, however, that there is only 23 percent hornblende. Other mineral percentages are: calcic andesine (about An_{42}) 55 percent, 17 percent brown biotite, 5 percent quartz, and traces of sphene, orthite, and apatite.

Fine-grained, pale green-and-white, tremolite-bearing quartzitic andesine gneiss contains 45 percent quartz, 38 percent sodic andesine (about An_{38}), and 17 percent tremolite. Tremolite is subhedral to euhedral and shows preferred orientation. Quartz and andesine form a granoblastic mosaic.

Fine-grained garnet-bearing leucogranitic gneiss contains: 60 percent microcline, 28 percent quartz, 10 percent calcic oligoclase (An_{29}), 2 percent garnet, biotite, muscovite, and a trace of chlorite.

Unevenly fine- to medium-grained leucogranitic gneiss contains: 48 percent microcline, 28 percent quartz, 21 percent calcic oligoclase (An_{25}), 3 percent biotite, and less than 1 percent muscovite. Myrmekitic intergrowths are common, and where microcline porphyroblasts are adjacent to the finer-grained groundmass, a pseudo-cataclastic replacement texture has developed.

Quartzites and quartzitic schists.-- Four representative quartzitic rocks were collected from this succession. They are: feldspar-bearing quartzitic biotite schist (E 30), orthoclase-bearing quartzitic schist (E 34), andesine-bearing gneissose quartzite (E 39), and gneissose biotite quartzite (E 41).

Quartz comprises between 80 to 90 percent of these specimens. The quartz grains vary greatly in size, from a fraction of a millimeter to 3 mm. Boundaries are sharply irregular but lack the sutures characteristic of cataclastic quartz. The majority of the grains have a longer dimension along the plane of foliation, but there is no pronounced lenticular structure. The quartz grains in specimens E 30 and E 41 show a rather uniform optic orientation.

Biotite is always present in amounts up to 11 percent (E 30). It is a light to very dark brown variety, and gives some of these rocks their megascopic schistose character.

Plagioclase ranges from sodic oligoclase -- An_{10} (E 41) to calcic andesine -- An_{47} (E 39), and is present in amounts up to 10 percent.

Microcline is present in specimens E 30, E 34, and E 41, in amounts less than 2 percent. Muscovite occurs locally in very minor amounts.

Lime-silicate gneiss.-- A dark green, fine-grained lime-silicate gneiss (E 19) consists of a crystalloblastic mosaic of about 33 percent diopside, 27 percent tremolite, 25 percent sodic labradorite, 14 percent quartz, and minor sphene. Diopside is anhedral and colorless in thin-section, and has an extinction angle (Z:c) of 40 degrees. Tremolite is anhedral to euhedral, is colorless, and has an extinction angle (Z:c) of 19 degrees. The plagioclase is locally zoned. One grain has oscillatory, gradational, anhedral zoning with (1) a sodic labradorite core (An_{55}), (2) an intermediate zone of calcic oligoclase (An_{25}), and (3) a sodic andesine rim (An_{35}).

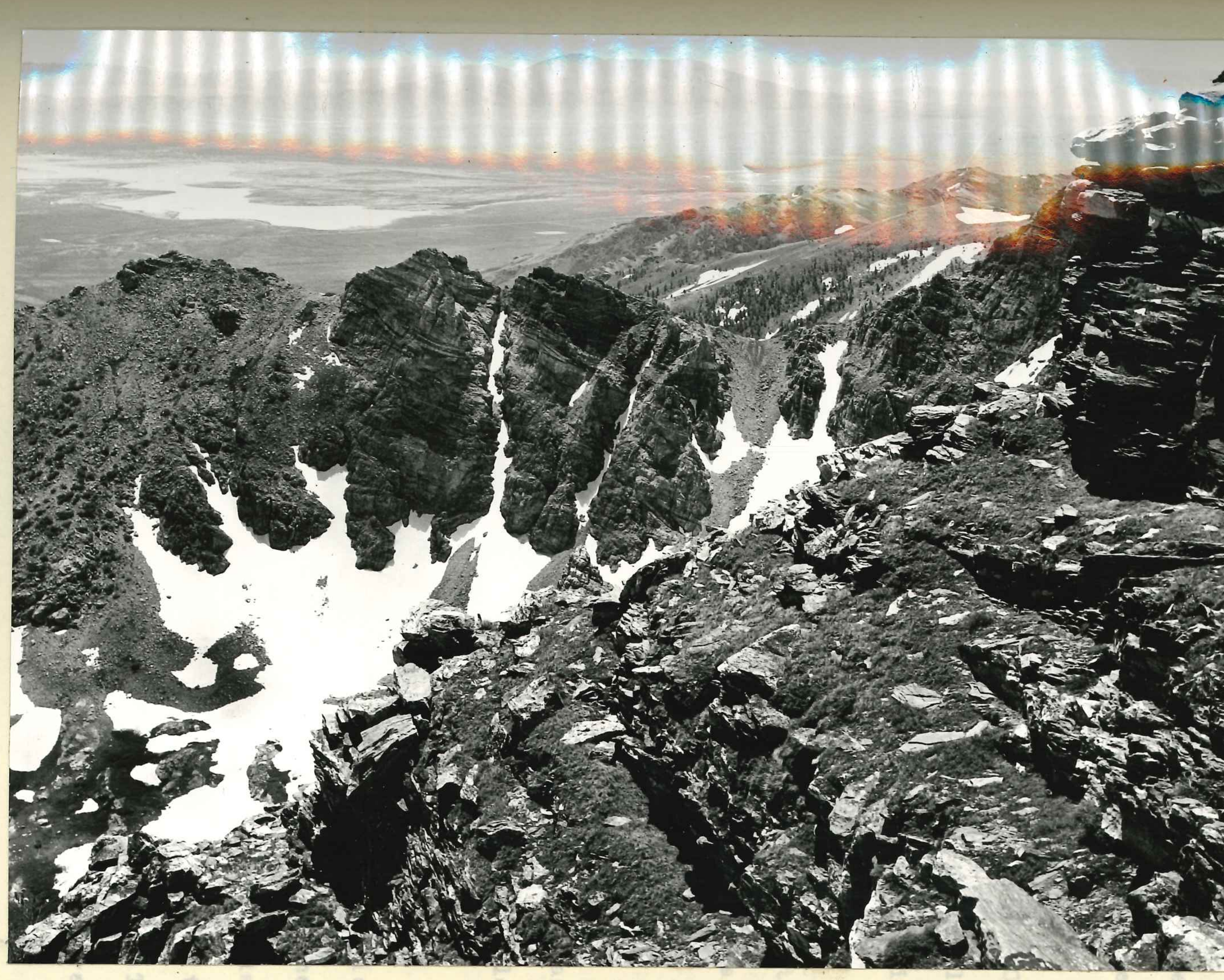


Fig. 16. West-dipping gneisses, schists, quartzites, and lime-silicate rocks in the Angel Lake unit east of Humboldt Peak. View is looking to the south, and Spruce Mountain can be seen in the central background. The precipice seen in Figure 3b is to the upper right, outside the picture.

Mylonitic Succession

The uppermost portion of the Angel Lake unit is composed primarily of mylonitic rock. The base of this upper succession is not sharply defined since these beds and the underlying "transitional" succession grade imperceptibly into one another. The mylonite succession is tectonically overlain, with local truncation, by the Snow Water unit.

The upper mylonitic succession is estimated to be 100 to 300? feet thick. The rocks in it differ from the lower portions of the Angel Lake unit only in their degree of superimposed cataclasis; they are compositionally quite similar to the less cataclastic, underlying rocks. Included in this upper mylonitic succession are: granitic to quartz dioritic mylonite, pegmatitic mylonite, lime-silicate mylonite, mylonitic quartzite and quartzite schist, thinly banded chert-like mylonite, as well as some non-cataclastic pegmatite.

The beds in this mylonitic sequence are best exposed along the west flank of the East Humboldt Range; in the Secret Creek gorge area; and in the northern portion of the "Secret Hills" between Secret and Ruby valleys.

Mylonites derived from granitic to quartz dioritic gneisses

The mylonitic gneisses can often be distinguished megascopically from their non-cataclastic counterparts. The mafic-bearing mylonitic gneisses generally have a more pronounced foliation , and are often platy or slabby. They commonly contain lenticular pods of feldspar which resemble augen; the foliation in the rocks is often streaky and "flows" around these pods. The mafic-bearing mylonitic gneisses commonly weather orange-brown, black, grey, or yellowish grey.

In the field, pegmatitic pods and lenses are locally seen wedging apart the laminated structures of the mylonites. The contacts of these pegmatitic bodies are often concordant to the cataclastic foliation of the overlying and underlying mylonites, and some of these concordant pegmatites show cataclasis;

but some of the pegmatite contacts are discordant to, and cut across the cataclastic foliation of the adjacent mylonite (Fig. 17). These latter pegmatite bodies show no cataclasis and are clearly later than the main episode of mylonitization. Thin-sections reveal similar relations between individual feldspar grains and the cataclastic groundmass. On the basis of these and other features, it appears that prior to, probably during, and definitely after mylonitization, feldspathization was occuring.

The leucocratic mylonitic gneisses, and the less cataclastic mafic-bearing gneisses, can rarely, with certainty, be identified as mylonites in the field.

Quartz, potash feldspar, and plagioclase are the most common constituent of these gneiss-derived mylonites. Brown biotite is frequently found in the mafic-bearing varieties. Muscovite is present in leucocratic mylonites. Epidote and orthite are occasionally present in small amounts. Apatite, sphene, and zircon are common accessories. Chlorite, sericite, kaolin, and carbonates, are variously present in very minor amounts.

Textures.-- Basically, the texture of most of the gneiss-derived mylonitic rocks is the same. Porphyroclasts of feldspar are embedded in a "flowing" cataclastic matrix of fine-grained quartz and feldspar and, generally, biotite. The size and amount of the porphyroclasts vary, as do the grain sizes in the cataclastic matrix. The rocks possess distinct flow structure marked by shredded biotite and streams of fine-grained quartz-feldspar mortar. These streams flow around porphyroclasts and, as a result, the flow structure is rather wavy. The grains in the mortar vary in size. Most of the grains are between .003 and .3 mm. in diameter. Porphyroclasts are most often feldspar and are generally less than one-quarter inch in diameter.

Mineralogy.-- Potash feldspar is a common constituent in these mylonites. It occurs as large porphyroclasts (usually less than 4 mm.), and in the fine-grained mortar of the cataclastic groundmass. Microcline twinning and streaky

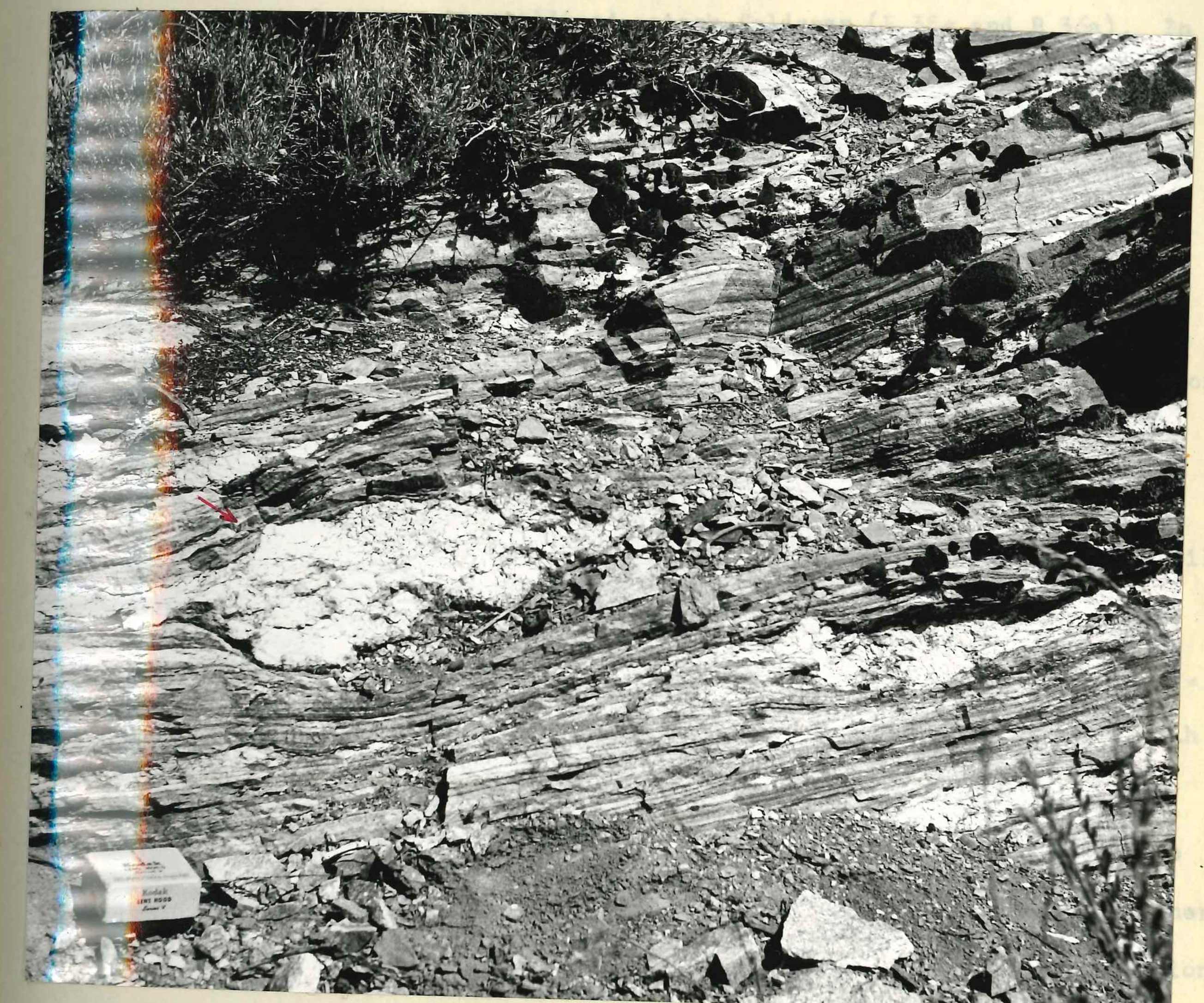


Fig. 17. Post-cataclastic pegmatite pod in a laminated biotite-feldspar-quartz mylonite in the Secret Creek gorge area. The pegmatite is essentially concordant to the cataclastic foliation of the mylonite, but note the local discordance at the arrow.

perthitic lamellae are occasionally present. Many grains are partially kaolinized. Larger grains of potash feldspar are seen to replace plagioclase locally forming myrmekitic intergrowths. These intergrowths occur within, but are more commonly at the margins of the potash feldspar grains (Figs. 18 and 19). Porphyroclasts of potash feldspar are crushed in places, and the fractures are partially healed by recrystallized potash feldspar (B 35c and B 36a). In some cases, the porphyroclasts have been split and the resulting fissures are filled mostly with recrystallized quartz (A 9, A 46, A 53, and A46-7d).

Plagioclase occurs as porphyroclasts or in myrmekite within and marginal to potash feldspar grains, or as part of the fine-grained cataclastic mortar. Both oligoclase and andesine are present, and their respective presence generally coincides with a granitic or a more quartz dioritic composition of the specimen. Porphyroclasts are sub-angular to sub-rounded, and usually are less than 2 mm. in diameter. Twinned, zoned crystals are quite common. Some grains have normal, gradational, anhedral zoning (A 49), others have oscillatory, gradational, anhedral zoning (DE 3), or oscillatory, sharp euhedral zoning (F 44). Twinning lamellae may be straight (Fig. 21) or bent (Fig. 22). In many specimens, the plagioclase porphyroclasts are fissured and filled with quartz and/or potash feldspar (M 11 and A 53). Myrmekitic intergrowths of plagioclase and quartz occur within potash feldspar grains (A 46-7d), but are more common at the margins of the grains. It is difficult to ascertain whether some of the marginal myrmekites formed during and slightly after mylonitization, or whether they are entirely pre-mylonitization (Fig. 18 and 19).

Quartz basically occurs in three textural types in the gneiss-derived mylonites. These are: (1) elongate, sutured, strained, cataclastic quartz. (2) very fine-grained cataclastic mortar quartz; and (3) late, non-cataclastic granoblastic quartz. Many specimens contain all three textural types. The elongate, sutured quartz often occurs as lenticles between very fine-grained quartz mortar, and also is commonly seen flowing around feldspar porphyroclasts.

Fig. 18. Myrmekite at the margin of potash feldspar in mylonitic granitic gneiss in the Angel Lake unit. Spec. B 35a (20 X magnification crossed nicols).

Fig. 19. Myrmekite at the margin of potash feldspar in a mylonitic granitic gneiss in the Angel Lake unit. Spec. B 42 (20 X magnification, crossed nicols).

Two factors are suggested to account for the first two types of cataclastic quartz: (1) The intensity of cataclasis; and (2), the original ratio of quartz to feldspar. It was noted that layers which are almost entirely made up of quartz tend to form the elongate, sutured, strained and often uniformly oriented quartz grains. In immediately adjacent areas which contain both quartz and feldspar, a fine-grained quartz-feldspar cataclastic mortar is commonly seen (Fig. 23). Hence, with the same intensity of deformation, quartz mortar and elongate, sutured quartz can apparently occur simultaneously, the type of deformation apparently depending upon the ratio of quartz to feldspar. With increasing deformation, however, the quartz-flow can break down into mortar, as has been noted in a group of quartzite mylonites at the base of the Snow Water unit (Fig. 40).

Late granoblastic quartz is most commonly seen filling fractures in feldspar grains.

Biotite occurs in all of the mafic-bearing mylonites. The biotite is usually highly shredded along shear planes. In some specimens it forms a continuous hair-thin streak along these planes; elsewhere, it occurs as minute discontinuous flakes along shear planes. When mylonitization is extreme (A 9), the biotite forms a pulverized brownish "dust" along the shear planes. Biotite varies in color; it is most often pleochroic from pale brown to brownish black. Reddish-brown varieties are also common. Chloritization is very rare.

Muscovite is only locally present in the mafic-bearing mylonites. When present, it is associated with minor magnetite streaks and appears to be an alteration product of biotite along shear planes. It is usually larger than the adjacent biotite and is not shredded.

Epidote and orthite often occur in these gneiss-derived mylonites.

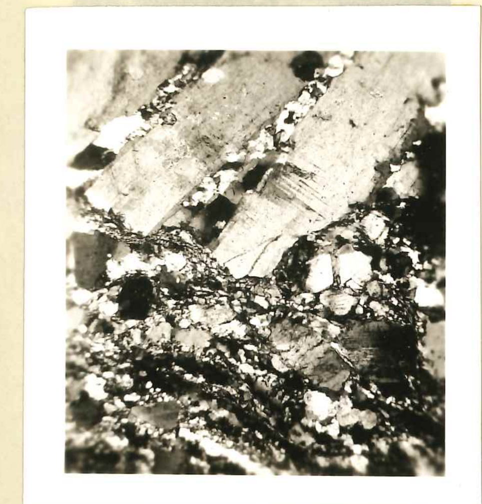


Fig. 20. Fractured microcline porphyroclast healed by granoblastic quartz in a granitic gneiss mylonite. Microcline twinning is not prominent in this position of the microscope stage. Spec. A 53 (20 X magnification, crossed nicols).

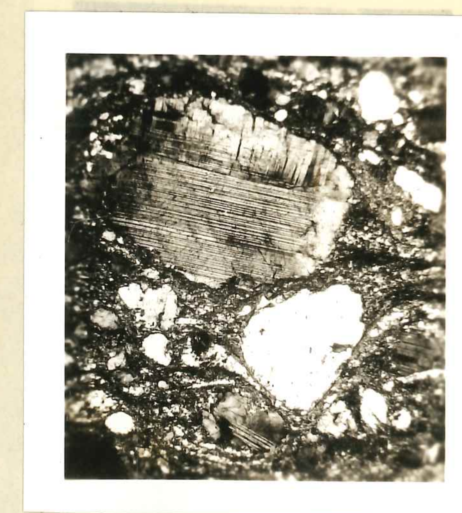


Fig. 21. Relatively straight twinning lamellae in a sub-rounded porphyroclast in granodioritic gneiss mylonite. Spec. F 44 (20 X magnification, crossed nicols).

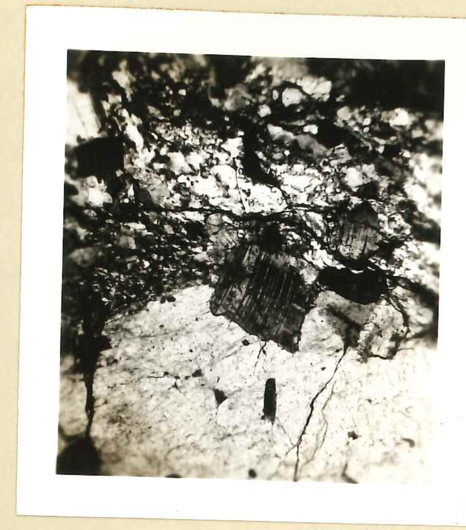


Fig. 22. Bent plagioclase twinning lamellae in pegmatite-derived mylonite. Plagioclase is partially enclosed by potash feldspar. Spec. A 46-7a (20 X magnification, crossed nicols).

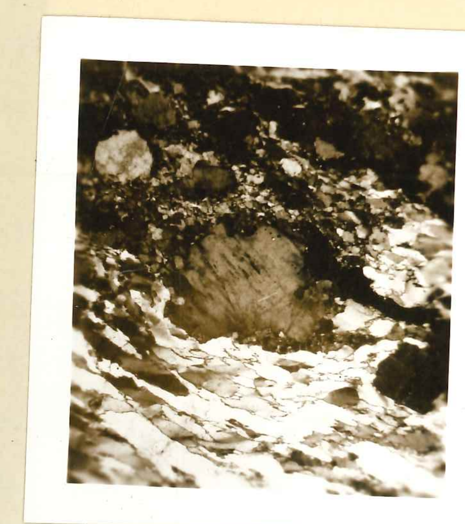


Fig. 23. Mylonitic pegmatitic gneiss showing two types of cataclastic quartz: 1) elongate, strained, sutured quartz, and 2) cataclastic mortar of quartz and feldspar. (20 X magnification, crossed nicols).

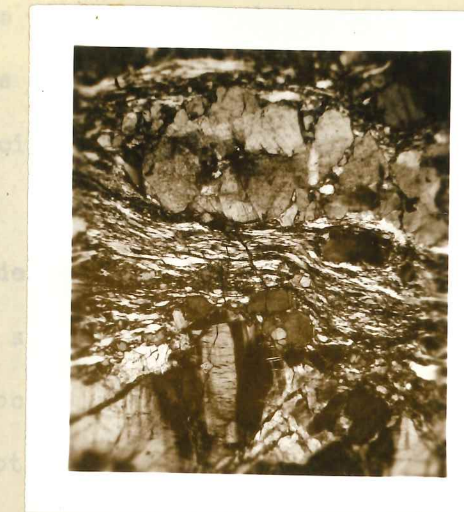


Fig. 24. Elongate, strained, sutured quartz flowing between feldspar porphyroclasts in a granitic mylonite. Spec. A 9 (20 X magnification, crossed nicols).

Fig. 25. Quartz in a very fine-grained quartz-feldspar mortar flowing between feldspar porphyroclasts. Spec. A 9x (20 X magnification, crossed nicols).

In a less cataclastic specimen, epidote is intergranular and associated with biotite (DE 3). In one specimen (N-A 49) epidote with an orthite core is intergranular, and some epidote in this specimen has partially replaced plagioclase. In another specimen (B 84b) orthite occurs as tiny euhedral crystals along shear planes.

Green hornblende is present in some medium-grained mylonitic amphibolitic rocks, a typical specimen of which contains about 35 percent hornblende, 34 percent calcic oligoclase (about An_{27}), 15 percent quartz, 10 percent potash feldspar, and minor biotite, zircon, apatite, sphene, calcite and chlorite. The hornblende occurs as large porphyroclasts in a cataclastic matrix of quartz and feldspar, and also as lenticular slivers along shear planes.

<u>Quartzitic Mylonites</u>

Most of the quartzitic mylonites in this portion of the Angel Lake unit have a distinctively laminated appearance; however, mica is only occasionally megascopically visible. The quartzite mylonites are platy to slabby and are white to orange-brown or blackish. They are vitreous to sub-vitreous, and slightly translucent to completely opaque on the thin edges. Some unusual varieties resemble grey and black banded cherts, and these are invariably extremely fine-grained ultramylonites. Tiny pods of feldspar are commonly present in all the quartzitic mylonites. The quartz groundmass in these rocks is aphanitic-appearing; for no individual grains can be distinguished megascopically. Under the microscope, the longest dimension of the individual grains is seen to vary greatly, from less than .004 mm. in the ultramylonites, to up to 4 mm. in the mylonites.

Thin-sections cut parallel to the lineation and perpendicular to the platiness of the quartzite mylonites often show sutured, strained, uniformly oriented quartz grains, which are elongate in the direction of lineation. Hair-thin dark shredded mica layers often are parallel or sub-parallel to the quartz

Fig. 26. Epidote-bearing biotite gneiss before mylonitization. Note oriented, well-formed biotite laths. Spec. A 39 (57X magnification, plane light).

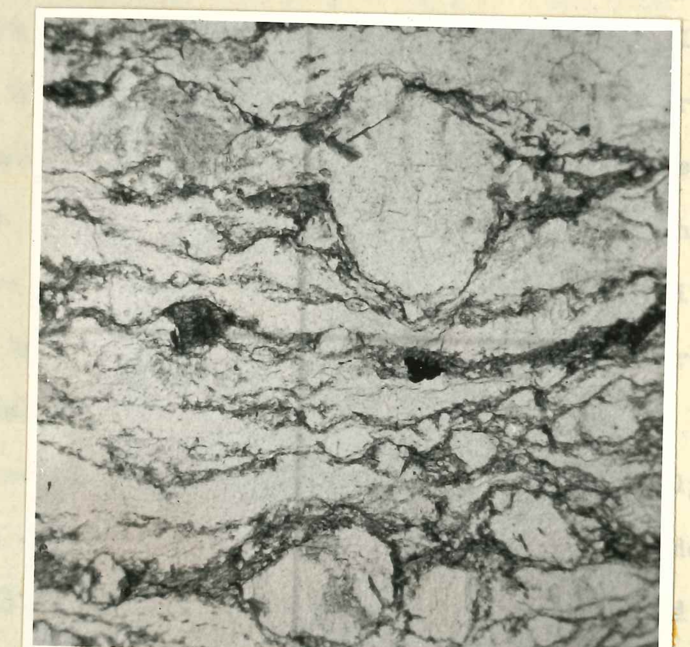


Fig. 27. Epidote-bearing biotite gneiss after mylonitization. Note highly shredded biotite along wavy shear planes. Spec. B 84a (57 X magnification, plane light).

elongation. These hair-thin layers locally widen where small bulging non-shredded muscovite lenses occur. A systematic study of the optic orientation of quartz in relation to its elongation was not made in most of the specimens; however, in two rocks (A 19 and M 1) the c-axes of quartz were found to be perpendicular to the lineation and parallel to the platiness of the rock.

The lack of mortar development in most of the purer quartzitic mylonites is believed to be due, to a certain extent, to the apparent plastic response of bulk quartz when subjected to a certain degree of mylonitization. This apparent plastic response is interpreted as being actually due to the combined operation of deformation and recrystallization. Quartz is commonly seen as elongate, strained, and highly sutured grains in these specimens. The quartz grains flow around the feldspar porphyroclasts; apparently similar structures have been called by Scottish Highland geologists "quartz-flow". In discussing microstructures in mylonites Peach _et al_ (1897, p. 597) stated: "Quartz appears to yield without fracture to stresses tending to produce fluxion more readily than feldspar, and what may be termed quartz-flow round angular grains or crystals of feldspar may sometimes be observed. In such cases the appearance under the microscope suggests that an original grain of quartz of approximately equal dimension in different directions has been converted into a curved lenticle, and that in the process of deformation the crystalline individuality of the grain has been lost. In place of the original individual an aggregate has been produced, the constituents of which are more or less lenticular in form."

The sutured, strained, elongate, often preferentially oriented quartz grains are almost certainly a product of active mechanical deformation in this area, for (1) they are interbedded with mortar-textured gneiss-derived mylonites; and (2) quartzites deep in the non-cataclastic succession of the Angel Lake unit show no sutured or highly strained grains, and often lack the uniform optic orientation so commonly found in the presently described quart-

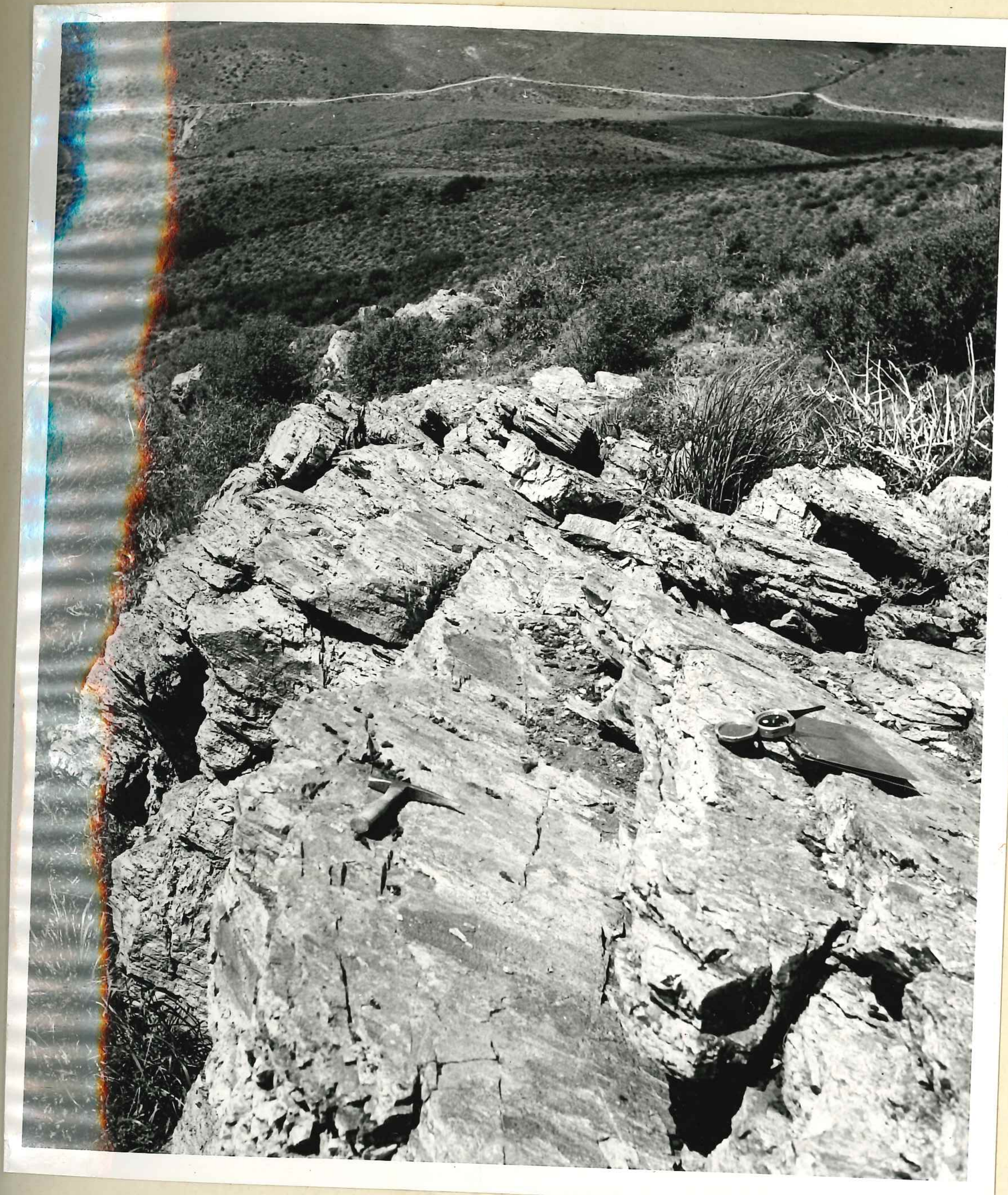


Fig. 28. A slabby east-dipping quartzite in the mylonitic succession of the Angel Lake unit, as seen looking north toward the Secret Creek gorge.

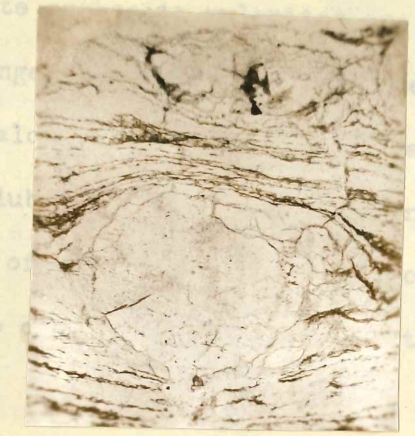


Fig. 29. Feldspar—bearing quartzitic mylonite. Note highly shredded biotite along wavy shear planes, the prominent feldspar porphyroclasts, and the thin layers of sheared quartz. Spec. B 40 (20 X magnification)

Fig. 30. As above under crossed nicols

zites of the mylonitic succession (Fig. 31).

Lime-silicate carbonate mylonites

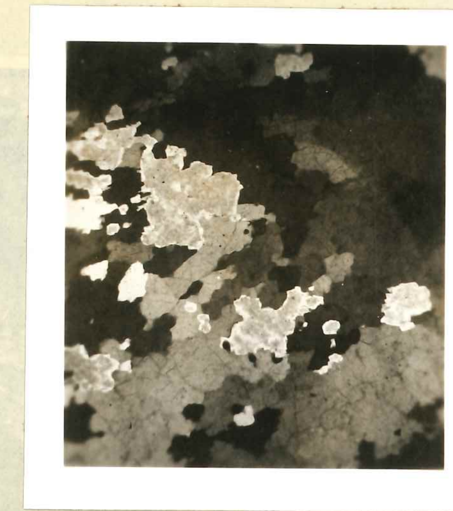
Banded lime-silicate carbonate mylonites are commonly found interbedded in this uppermost Angel Lake succession. Some of these beds evidently were tectonically dragged along the top of the truncated Angel Lake succession and apparently provided a lubricant during what is interpreted to be Precambrian thrusting. These beds are often overfolded and contorted, and are commonly seen sandwiched between the overlying Snow Water unit and the tectonically underlying Angel Lake unit.

The lime-silicate carbonate mylonites often weather grey, buff, or orange-brown. They are predominantly composed of a fine-grained to aphanitic calcite matrix which includes small porphyroclasts of individual silicate minerals, as well as larger cataclastic fragments of hornblende gneisses, lime-silicate granulites, quartzites, and other rocks. These inclusions range in size from a fraction of a millimeter to several feet. They occur as pods, layers, and lenses, and generally weather out in relief. The calcite often forms a very fine-grained mortar, and the nearly equi-dimensional individual grains generally are less than .02 mm. in diameter. The grain sizes are substantially finer in more intensely mylonitic varieties, and in some, the calcite cannot be resolved into individual grains even under high-power (280 X). In these ultramylonitic specimens, the calcite appears as a streaked, blurry brown clouded mass. In many hand specimens, the matrix of these carbonate mylonites superficially resembles a fine-grained to aphanitic limestone, often lacking any outward signs of the intense deformation it has undergone.

The mineral inclusions in the mylonites are sub-angular to sub-rounded and include: diopside, plagioclase (calcic oligoclase to calcic labradorite), potash feldspar, hornblende, epidote, quartz, scapolite, biotite and sphene.

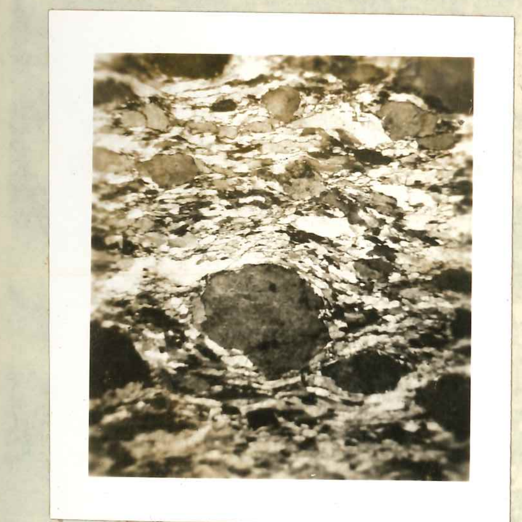
NON-CATACLASTIC QUARTZITE

Tremolite-bearing quartzite from Robinson Lake area in the Ruby Mountains (Q 11).

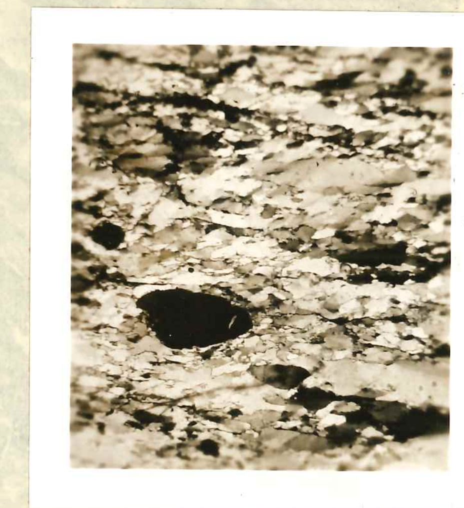


Pure quartzite from the Hole-In-The-Mountain Peak area (L 8).

CATACLASTIC QUARTZITE



Feldspar-porphyroclast quartzite mylonite from the Secret Creek gorge area (B 36b).



Feldspar-bearing quartzite mylonite (B 35). Feldspar grains occupied the now-void black spots in the photograph.

Fig. 31. Comparison of the textures of quartzites in the lower portions of the Angel Lake unit with the quartzites in the mylonitic succession of the Angel Lake unit. All above are 20 X and under crossed nicols.

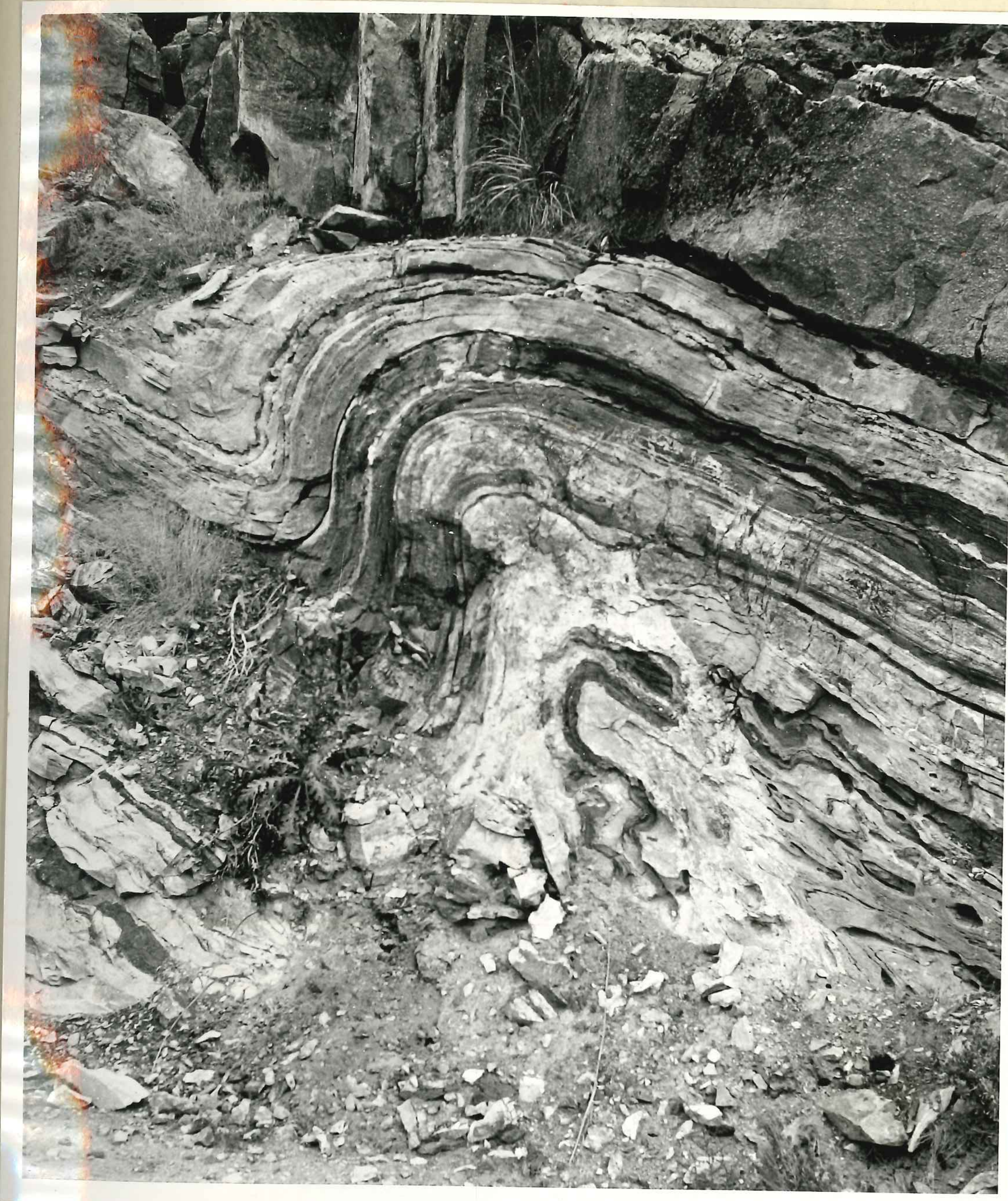


Fig. 32. Looking north at west-overturned fold in lime-silicate bearing carbonate mylonite in the mylonitic portion of the Angel Lake unit at locality in the Secret Creek gorge area. More resistant dark massive layer above is a porphyroclastic biotite-feldspar-quartz mylonite. Outcrop here is about 7 feet high.

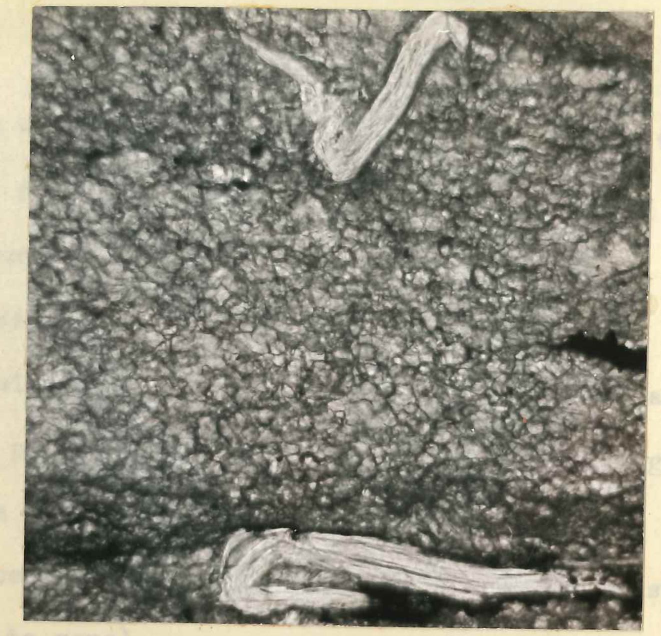


Fig. 33. Lime-silicate-bearing carbonate mylonite in the Angel Lake unit showing contorted mica in a very fine-grained calcite mortar. Spec. E 71 (plane light, 150 X magnification).

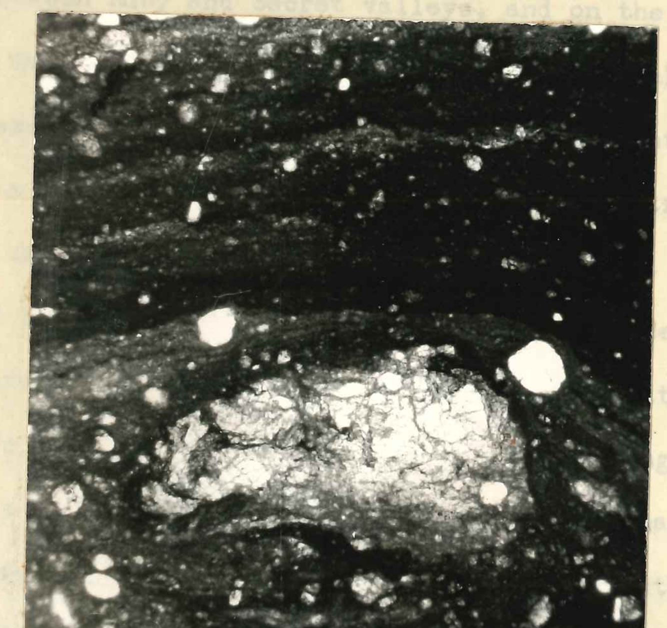


Fig. 34. Lime-silicate bearing carbonate ultramylonite in the Angel Lake unit showing a streaked, fuzzy, clouded calcite groundmass. Porphyroclasts here are mostly quartz and feldspar. Spec. A 48 (plane light, 57 X magnification).

Snow Water Unit

Introduction

The Snow Water unit is about 1000? feet thick in the mapped area and is distinguished from the Angel Lake unit on the basis of its distinctive lithology. The unit is characterized by white quartzite; cream-colored and light grey to medium dark grey carbonates; greyish orange to yellowish brown weathering lime-silicate marbles; banded lime-silicate granulites, and white to cream-colored pegmatite. It typically lacks the many granitic to quartz dioritic gneisses commonly found in the Angel Lake unit. The metamorphic grade of this succession may vary but much of it is warmest mesozone (upper part of the kyanite zone).

The unit is less widely exposed than the Angel Lake unit. Good exposures occur on "Clover Hill" in the northeastern portion of the area, in the "Secret Hills" between Ruby and Secret valleys, and on the southward projecting ridge of the East Humboldt Range east of Snow Water Lake.

The succession is, at least in part, in thrust contact with the Angel Lake unit, and its base is often a white mylonitized quartzite. The underlying Angel Lake unit is in places truncated at the thrust plane. The Snow Water unit itself is truncated at the overlying Mesozoic Secret Creek thrust plane which has brought Paleozoic and lower Triassic formations over the rocks of the metamorphic basement. As a result of this overlying truncation, the Snow Water unit is quite probably not complete in this area. Much greater thicknesses are probably present in the Ruby Mountains south of the mapped area, and therefore a more complete description of the Snow Water unit must await future study.

Southern East Humboldt Range

Lime-silicate granulites

Lime-silicate granulites are common in the Snow Water unit along the southern East Humboldt ridge. Most of these granulites are thinly to thickly layered, and more resistant individual layers often weather as protruding plates. The rocks generally weather in shades of buff, green, and orange-brown. The layers are not uncommonly wedged apart by large and small pegmatite pods and lenses (Fig. 35).

The mineralogy of the lime-silicate rocks varies greatly. One of the most interesting specimens contains the following minerals: quartz, potash feldspar, calcic labradorite (about An_{65}) phlogopite, actinolite (Z:c = 14 degrees), diopside, (Z:c = 39 degrees), zoisite, grossularite?, carbonate, zircon, sphene, apatite, and tourmaline. This rock is a fine-grained banded lime-silicate gneiss predominantly composed of a xenoblastic mosaic of quartz and potash feldspar. The banded nature of the rock is due to layers rich in oriented phlogopite and actinolite and appreciable accessory sphene. Zoisite, grossularite?, and diopside are mostly poikiloblastic, enclosing quartz and feldspar grains of the groundmass. Some actinolite is unoriented and replaces diopside.

Massive lime-silicate granulites are occasionally present in this area. One unevenly fine- to medium-grained variety is pale green and predominantly composed of diopside and tremolite. Other minerals present are microcline, calcic andesine (about An_{45}), calcite, and accessory sphene and apatite. Mutual intergrowths of diopside and tremolite comprise over 90 percent of the rock, and diopside itself makes up about 60 percent. The diopside is colorless in thin-section and pale green in hand specimen. It is occasionally twinned and has an extinction angle (Z:c) of 38 degrees. Locally diopside is

Fig. 35. Platy lime-silicate layers and pegmatite pod in the Snow Water unit exposed on the crest of the southern East Humboldt Range.

variously enclosed in calcic andesine and also in carbonate. The tremolite occurs as laths which occur at random throughout the specimen. Individual laths often cut across one another. The tremolite is colorless to very faintly green in thin-section and is pale green in hand specimen. It has an extinction angle (Z:c) of 17 degrees. Although called tremolite on the basis of its often colorless nature in thin-section, its occasional faint greenish colors suggest that some iron is locally present. About 3 percent of the rock is grid-twinned microcline, 3 percent is calcic andesine, and 3 percent is calcite. The andesine locally contains small diopside inclusions, and is occasionally sericitized. Some calcite appears to be replacing diopside and andesine.

Another variety of lime-silicate granulite is particularly rich in epidote. The rock is medium-grained, containing megascopically visible olive-yellow epidote, dark green pyroxene, and dark red garnet. Microscopic study shows the following minerals and their approximate percentages: epidote (50 percent), hedenbergite? (27 percent), grossularite?-andradite? (8 percent), sodic andesine--about An_{35} (5 percent), uralite (4 percent), calcite (2 percent), quartz (2 percent), scapolite (2 percent), phlogopite, sphene, apatite, chlorite (together 1 percent). The granulite is medium-grained and granoblastic. The epidote has anomolous first order interference colors in yellowish greens and blues, and normal second order colors. It has a 2V of about 90 degrees, and is probably an iron-bearing clinozoisite. The hedenbergite? is pale green in thin-section and has a maximum observed extinction angle (Z:c) of about 46 degrees. The grossularite-andradite? is poikiloblastic. The sodic andesine (about An_{35}) locally shows gradational, anhedral zoning of undetermined trend. The shape of the zoning pattern is often parallel to the anhedral, irregular outline of the crystal. Uralite replaces hedenbergite?, is green to bluish green and has an extinction angle (Z:c) of 17 degrees.

Another lime-silicate granulite is almost entirely composed of epidote, grossularite?-andradite?, calcite, and quartz. The rock is medium- to coarse-grained and is both light green and pinkish red. Epidote is anhedral to subhedral and has anomalous interference colors of the first order and normal colors of the second order. It has a 2V of approximately 90 degrees. The garnet is very pale red-orange in thin-section and is poikiloblastic with inclusions of epidote and calcite. Calcite is both primary and secondary, occasionally replacing garnet and epidote. Quartz has undulatory extinction and is concentrated in certain areas.

<u>Carbonate rocks</u>

Marbles within the Snow Water unit are quite common in the southern East Humboldt ridge. They are white to buff, light to dark grey, fine- to medium-grained, both pure and impure, cataclastic and non-cataclastic. Some layers show banding and others are massive.

Most of the marbles to be described are interbedded in the Snow Water unit, but one prominent layer of rather pure grey marble occurs directly beneath the Secret Creek thrust plane in the southern East Humboldt Range. Its relation to underlying members of the Snow Water unit is not fully known, though it is clearly truncated by the overlying thrust plane, and does appear to be a part of the Snow Water unit. Nevertheless, it is conceivable that this layer could be a tectonic sliver of Paleozoic marble sandwiched in the thrust zone, and for this reason it is only tentatively mapped with the Snow Water unit.

Some other rather pure marbles near the Secret Creek thrust plane, and which the writer has only tentatively mapped as Precambrian occur in scattered outcrops in the "Secret Hills", in the Secret Creek-Dorsey Creek area, on the west flank of the northern Ruby Mountains and the East Humboldt Range, and at "Clover Hill".

The pure non-cataclastic marbles are often dolomitic, giving no effervescence on the weathered surfaces and only slight effervescence on the fresh surfaces. The weathered surfaces are slightly rough or gritty. In thin-section the grains are of rather uniform size averaging about 1 mm. in diameter. They form an interlocking granoblastic mosaic, but individual grains often have irregular rather than linear borders.

A slightly impure banded marble is banded because of tiny scattered graphitic? particles localized along linear trends. The carbonate grains form a non-cataclastic interlocking granoblastic mosaic, and individual grains have both irregular and linear boundaries. Phlogopite? and quartz are present in trace amounts.

One interesting dark grey, fine-grained, xenoblastic dolomitic marble has large radiating tremolite "suns" along isolated schistosity planes. These suns are up to 3 inches in diameter. The dark grey color of the rock is due to tiny scattered graphite? particles which appear throughout the non-tremolitic portion of the rock. Thin-sections cut perpendicular to the tremolite layers show that recrystallization of carbonate accompanied the development of tremolite. Tremolite occurs as well-developed colorless laths, and has an extinction angle (Z:c) of 19 degrees.

Other impure marbles contain varying amounts of phlogopite?, quartz, potash feldspar, and zoned, untwinned plagioclase. Carbonate grains in some of these specimens occasionally show weakly folded cleavage planes and slight cataclasis at their margins. All gradations exist between these weakly cataclastic impure marbles and mylonitic varieties (Figs. 36 to 38).

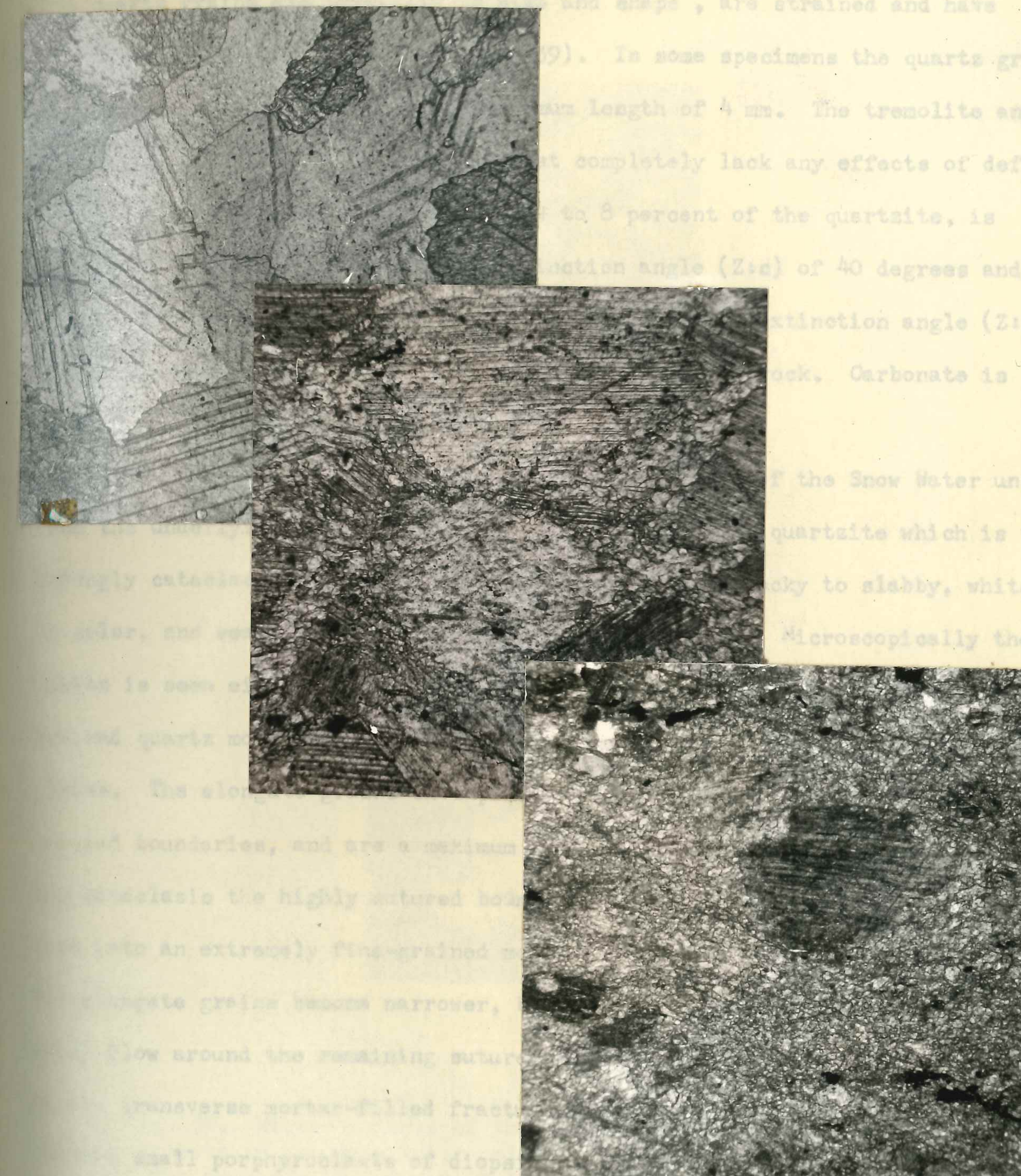
Impure carbonate mylonites are often medium dark grey, thinly banded, and very fine-grained to aphanitic. They sometimes resemble platy argillaceous limestones, for they often lack any outward evidence of deformation. In detail, however, some locally show small scale recumbent folds. Thin-sections show that these rocks are composed mostly of calcite (95 percent) with subordinate amounts of quartz, potash feldspar, plagioclase, phlogopite?, sphene, and apatite. The calcite in the aphanitic specimens is seen microscopically to form a very fine-grained granulated mortar which flows around porphyroclasts of quartz and feldspar. The individual calcite grains average .012 mm. in diameter. Phlogopite? is often folded. In a slightly coarser-grained variety the calcite grains in the granulated matrix average .02 mm. in diameter. Porphyroclasts of quartz, plagioclase, potash feldspar, phlogopite, muscovite, and calcite range in size from .12 to .8 mm. The larger feldspar grains are seen megascopically in the specimens as small white "knots." Scattered graphite? and other opaque impurities are localized along some shear zones. Some carbonate mylonites show two shear directions, one transverse to the other.

Quartzites

Quartzites are quite common in the Snow Water unit and several such bodies occur in this southern East Humboldt area. Some quartzites are quite pure, some contain muscovite, others contain tremolite and white diopside, and still others contain sodic plagioclase. The quartzites are white to light grey, cataclastic and non-cataclastic, and slabby to massive. Generally the mylonitic quartzites are slabby. The quartzites are usually white in the field, but locally weather to a pale yellow-orange. Some of the massive quartzites are probably vein quartz, perhaps associated with the widespread pegmatite bodies. In these particular quartzites, the quartz shows no uniform optic orientation, has highly irregular boundaries, and undulatory extinction. Invariably, scattered grains of sodic plagioclase and muscovite are present. The plagioclase lacks cataclasis, is generally highly sericitized, and often occurs in clusters of subhedral grains which transect the highly sutured quartz grains of the matrix. The plagioclase lacks twinning, but has positive sign and rather low relief. It is probably either sodic oligoclase or albite.

The tremolite and diopside bearing quartzite is unevenly fine- to medium-grained, but locally contains large white diopside crystals up to 4 inches in length. Thin-sections of these large diopside crystals show local-

NON-CATACLASTIC AND CATACLASTIC CARBONATE ROCKS IN THE SNOW WATER UNIT



Figs. 36 to 38. Upper left: granoblastic non-cataclastic marble. Center: moderately cataclastic carbonate rock showing an early stage in the development of calcite porporphyroclasts and mortar. Lower right: carbonate mylonite consisting predominantly of a very fine-grained calcite mortar with a calcite porphyroclast in center. All above are under plane light and magnification is 57 X.

lized replacement by tremolite and occasional inclusions of quartz, potash feldspar, and carbonate. This white diopside is probably completely iron-free. The quartz grains are irregular in size and shape , are strained and have irregular to sutured boundaries (Fig. 39). In some specimens the quartz grains are somewhat elongate, reaching a maximum length of 4 mm. The tremolite and diopside are sub- to euhedral and almost completely lack any effects of deformation (Fig. 38). Diopside comprises 4 to 8 percent of the quartzite, is colorless, locally twinned, has an extinction angle (Z:c) of 40 degrees and a 2V between 80 and 88 degrees. Tremolite laths have an extinction angle (Z:c) of 20 degrees and comprise about 1 to 2 percent of the rock. Carbonate is present in trace amounts, locally replacing diopside.

Near the thrust plane which separates portions of the Snow Water unit from the underlying Angel Lake unit, is a mass of white quartzite which is strongly cataclastic to mylonitic. The quartzite is blocky to slabby, white in color, and weathers locally to a pale yellow-orange. Microscopically the quartz is seen either as highly elongate grains, or as an extremely fine-grained quartz mortar. The mortar has developed at the expense of the elongate grains. The elongate grains show pronounced undulatory extinction, highly sutured bounderies, and are a maximum of 5 mm. in length. With the increasing cataclasis the highly sutured boundaries between the elongate grains break down into an extremely fine-grained mortar (Fig. 40). With further cataclasis the elongate grains become narrower, breaking down into streams of mortar which flow around the remaining sutured quartz slivers. Locally occur very narrow transverse mortar-filled fractures. Some of these quartzite specimens contain small porphyroclasts of diopside and some minor muscovite. The cataclasis has split some of the diopside grains, and the tiny fractures created are filled with recrystallized quartz. The muscovite is shredded along its margins.

Fig. 39. Micro-textures of the diopside and tremolite bearing white quartzite in the Snow Water unit. Specimen K 15 collected at the crest of the southern East Humboldt Range (crossed nicols, 20X magnification).

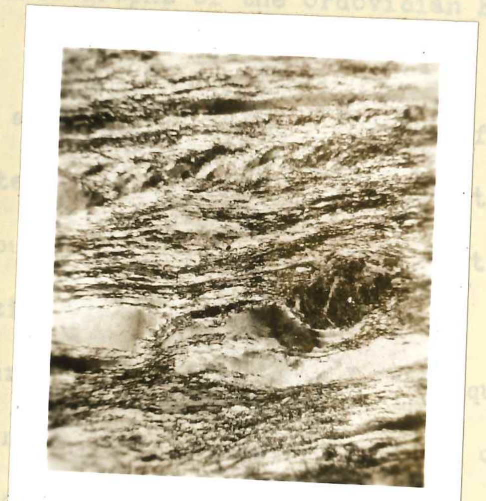


Fig. 40. White cataclastic quartzite near the Horse Creek thrust plane at the base of the Snow Water unit at the head of Horse Creek. Note the development of quartz mortar at the expense of the elongate, sutured quartz grains. Spec. K 20 (crossed nicols, 20 X magnification).

These white quartzites provide data additional to the points earlier mentioned regarding the age of the Snow Water unit. The basic question is whether these quartzites are Precambrian or whether they are metamorphosed Paleozoic quartzites. If Paleozoic, they would almost need to be a metamorphosed equivalent of the Ordovician Eureka quartzite because of their distinctive white color and relatively small thickness. (The Eureka quartzite is the only relatively thin white quartzite in the Paleozoic succession of this region).

Since apparently no direct method to tell the age of a quartzite is known, textural and compositional comparisons were made. The writer compared hand specimens and thin-sections of Eureka quartzite from both "Clover Hill" and the northern Egan Range with the Snow Water quartzites.

The textural differences are noticable in hand specimen (see section on Eureka quartzite), but are best seen in thin-section. The reader may observe these differences by comparing photomicrographs of the Snow Water unit shown in Figs. 39 and 40 with photomicrographs of the Ordovician Eureka quartzites in Fig. 50.

The Snow Water quartzite is also compositionally quite different from the specimens of the Eureka quartzite. As previously mentioned, the Snow Water quartzite often contains varying amounts of muscovite, diopside, tremolite, and sodic oligoclase. The Eureka quartzite contains only quartz.

The differences in the textures and composition of these quartzites suggest to the writer that they are not the same unit. Since one of the units is definitely the Ordovician Eureka quartzite, it would seem likely that the other is Precambrian, since these seem to be the two logical alternatives.

Schists

Some very interesting phyllitic-appearing two-mica schists occur on the southern East Humboldt ridge but were not seen elsewhere in the area. These rocks are quite striking in the field because of the brilliant silvery, silky-like luster on foliation planes. One specimen studied contains about 55 percent muscovite, 20 percent quartz, 20 percent potash feldspar, 3 percent biotite, and minor plagioclase, garnet, orthite, apatite, and tourmaline. The rock shows little ripples in hand specimen and these are seen as small-scale asymmetric folds in the thin-section. The length of the mica grains does not exceed .8 mm. and the width is .032 mm. or less. The quartz and feldspar grains are about .25 mm. in their maximum dimensions. In another specimen the mica is much finer-grained, with a maximum length of .28 mm., and the quartz and feldspar rarely exceed .04 mm.

Pegmatites

The exposures on the southern ridge of the East Humboldt Range show most of the distinctive lithologies of the Snow Water unit. The abundance of large pegmatitic masses is a particularly impressive feature in this area. These masses vary greatly in size, but where relations are clear, they are seen to be essentially concordant masses, such as sills, pods, and lenses that appear to wedge apart layers of banded lime-silicate marbles and granulites. Locally, the pegmatite cuts across the foliation of the lime-silicate rocks. The pegmatite is mostly white to cream-colored and is medium- to coarse-grained. Larger masses of the pegmatite often show intersecting shear planes and fractures whose surfaces are often iron-stained and weather rusty orange, dark brown, or black. Movement, if any, along most of these shears and fractures is negligible. On the west side of the southern East Humboldt ridge, northwest of the Warm Springs Ranch, the pegmatite weathers into large rounded knobs which rise above the surrounding grass-covered slopes.

Microscopic study shows that the pegmatite varies greatly in its plagioclase-potash feldspar ratio. The plagioclase in the specimens studied is generally sodic oligoclase (approximately An_{12}, optically negative, est. $2V = 85^{o}$), and sometimes makes up as much as 90 percent of the rock. These particular varieties are trondhjemitic pegmatites and contain about 6 percent quartz, 3 percent muscovite, and 1 percent potash feldspar. Other varieties are variously richer in potash feldspar quartz, and muscovite. However, in all the specimens studied in this area, sodic oligoclase exceeds potash feldspar.

The individual grain sizes of the pegmatites vary greatly from a fraction of a millimeter to over 2 inches. Textures are crystalloblastic and grains are all anhedral and have irregular boundaries. Perthitic intergrowths of albite in microcline are not uncommon. Quartz always has undulatory extinction. The crystalloblastic textures in some specimens show superimposed cataclasis affecting the quartz and feldspar. One unusual specimen has narrow chlorite veins locally filling small fractures and elsewhere appearing to replace feldspars. The chlorite is pale green and occurs as radiating growths. It has normal first order grey interference colors.

Miscellaneous

A fine-grained porphyroclastic granitic mylonite was collected along the ridge crest in this area but it probably represents an allochthonous thrust mass and not part of the Snow Water unit.

Other relationships suggesting thrusting within this unit were noted at several localities, but detailed mapping and additional petrographic study will be necessary before definite conclusions can be made.

"Secret Hills" Area

In the "Secret Hills" between Secret Valley and Ruby Valley, the Snow Water unit is composed of several hundred feet of white, cream-colored, light grey to bluish-grey cataclastic marble; white, cataclastic quartzite; and white to cream-colored pegmatites. In the area of the Secret Creek gorge the unit is composed mostly of marble and white quartzite.

In the "Secret Hills", the Snow Water unit is characterized by its

Fig. 41a. Large rounded pegmatite knobs in the Snow Water unit as seen looking west at the east flank of the southern East Humboldt Range.

Fig. 41b. Pegmatite sill in banded lime-silicate rock in the Snow Water unit exposed on the crest of the southern East Humboldt Range.

overall whitish color. The unit is here thrust over the Angel Lake unit and is overlain by Paleozoic rocks which are remnants of the Secret Creek thrust of Mesozoic age. As a result of the thrusting at its base and top, the unit as preserved in this area is mostly cataclastic, and lacking in the many non-cataclastic lithologic types which occur in the southern East Humboldt Range.

Quartzites

The quartzites in this area are mostly white to bluish-grey and often closely resemble some of the white quartzites in the southern East Humboldt ridge. Some varieties contain oriented muscovite, and others contain diopside, tremolite, and sodic oligoclase. When these minerals are present, they are oriented along distinct foliation planes.

The quartzites in this area show three types of cataclasis. The earlier cataclasis is interpreted to be related to Precambrian thrusting, and has resulted in elongate grains with sutured boundaries and strong undulatory extinction. A second type of cataclasis has been superimposed upon these earlier features, probably during the much later, Mesozoic thrusting. This episode of cataclasis has microbrecciated and locally slickensided the earlier sheared elongate quartz. Angular fragments showing these earlier sheared quartz textures are now dislocated and scattered throughout a very fine-grained cataclastic quartz mortar;hence the rock has lost all directional tendencies. This brecciation is not apparent in the hand specimen. The third type of cataclasis is a megascopically visible brecciation, which is localized along a north-northwesterly trending high-angle fault in Pole Canyon. These megabreccias are occasionally iron-stained.

Carbonates

The carbonates in this area are mostly white, buff, light grey to bluish-grey, unevenly fine- to medium-grained cataclastic marbles. All of the specimens collected are cataclastic, showing moderately cataclastic to mylonitic textures. The carbonate grains have responded to deformation by twin-gliding, by bending of cleavage planes and twinning lamellae; and also by granulation of grains into a fine-grained mortar. Porphyroclasts of carbonate surrounded by very fine-grained carbonate mortar are commonly observed. All grains in these cataclastic marbles have highly irregular boundaries and are completely anhedral. Some specimens contain traces of such minerals as quartz, diopside, tremolite, plagioclase and epidote. Some of the cataclastic carbonates described could possibly be slivers of Paleozoic marble along the Secret Creek thrust zone (see p. 72).

Pegmatites

Pegmatite is not as widely exposed in the "Secret Hills" as on the southern East Humboldt ridge. Nevertheless, many scattered outcrops of it do occur. Both non-cataclastic and cataclastic varieties are present. The pegmatites studies are medium- to coarse-grained and some contain more potash feldspar than those previously described. One non-cataclastic specimen, lacking mica, contains microcline (70 percent); quartz (20 percent); calcic oligoclase, about An_{25} (10 percent). The microcline is perthitic, has excellent grid and carlsbad twinning, and contains inclusions of both quartz and oligoclase. Muscovite is present in some pegmatites in amounts up to 2 percent.

Secret Creek Gorge Area and Elsewhere

Members of the Snow Water unit are poorly exposed in the Secret Creek gorge. Only occasional exposures of white quartzite and banded buff and grey marble are seen. The unit in this area is not differentiated from the Angel Lake unit on the accompanying geologic map of the range.

On the west flank of the East Humboldt Range, scattered patches of marbles and quartzites of what are probably portions of the Snow Water unit are present. These patches were not individually mapped and are included with the Angel Lake unit on the accompanying geologic map.

At "Clover Hill" members of the Snow Water unit are also exposed.

STRUCTURAL FEATURES OF THE METAMORPHIC SUCCESSION

General Statement

The structural features of the metamorphic succession in the East Humboldt Range and the northern Ruby Mountains record at least five phases of deformation presumably from Precambrian to late Cenozoic time. The four earlier phases described here affected the internal structure of the rocks themselves. Later phases of deformation broadly folded the earlier deformed beds, and in the area of the East Humboldt Range, these rocks now form a huge northerly trending, doubly plunging anticline. The metamorphic succession in the northern Ruby Mountains forms essentially an east-dipping homocline.

The four earlier phases of deformation, which are mostly recorded as small scale features in the rocks, are now summarized in their historical setting:

1) The overall schistose character of the many metamorphic rocks which have not undergone later mechanical deformation and cataclasis, is interpreted to represent an earlier phase of regional synkinematic metamorphism, where penetrative deformation and recrystallization were occurring contemporaneously.

2) Small scale internal structures in some of the schistose rocks in the non-cataclastic portion of the Angel Lake unit indicate that perhaps in the later stages of the first phase, folding occurred while the rocks were still in a state in which deformation and recrystallization could occur contemporaneously.

3) The third phase of deformation probably in Precambrian time was widespread low-angle thrusting. This thrusting mylonitized and folded a large portion of the previously metamorphosed rocks. The microscopic evidence for this episode of thrusting has been described above. The first part of the pre-

sent chapter will deal with the megascopic features of the thrusts within the metamorphic succession.

4) A fourth phase of deformation brecciated and sheared some of the mylonitic rocks which were previously formed in the third phase of deformation. This fourth phase of deformation evidently occurred during a major episode of much later, Mesozoic thrusting when Paleozoic and Early Triassic strata were thrust over the truncated layers of the metamorphic basement. The features of this fourth phase of deformation are discussed under Mesozoic Structure.

5) Broad, large scale folding in late Cenozoic time (see Cenozoic Structure and History) represents another phase of deformation which affected the metamorphic succession. In the East Humboldt Range the metamorphic rocks now form a huge northerly trending elongate dome, whose gently inclined western limb strikingly conforms to the present topography, and whose 25 mile-long axis closely parallels the crest of the range. Slightly modifying this overall north-south-trending anticlinal structure are some rather broad transverse folds.

In the northernmost Ruby Mountains, the truncated metamorphic beds beneath the anticlinally folded Mesozoic thrust plane form essentially an eastward-dipping homocline.

This section deals with a) the field evidence for thrusting within the metamorphic succession (third phase of deformation), and b) the broad folding in the succession.

Thrusting

Introduction

Two major low-angle thrusts occur within the metamorphic succession in the East Humboldt Range. The lower thrust was mapped within the Angel Lake unit, and apparently brings stratigraphically lower members of this unit over stratigraphically higher members. The thrust is exposed at the highest peak in the range, and is appropriately named the Hole-In-The-Mountain Peak thrust. The second thrust occurs higher in the succession and brings portions of the Snow Water unit into thrust contact with the underlying Angel Lake unit. This thrust is best exposed in the "Secret Hills"-Horse Creek area and is appropriately named the Horse Creek thrust.

The structural relation, if any, between these two thrusts is not known Both, however, are believed to be Precambrian in age, and unrelated to the much later period of Mesozoic thrusting which has affected this area.

Presumably minor thrusts within the succession have not been mapped individually. Relationships suggesting such minor thrusting are present in the southern East Humboldt Range, from Hunneman Creek southward. These possible thrusts, however, have been recognized mostly by the petrographic study of specimens collected rather than on field relations which are often obscure. More detailed mapping combined with petrographic study would be helpful in understanding the subordinate structures within the metamorphic succession in the southern East Humboldt Range.

Hole-In-The-Mountain Peak Thrust

Thrusting within the Angel Lake unit is convincingly displayed at and near Hole-In-The-Mountain Peak*. This area is particularly well exposed, and contacts are conspicuous.

Several allochthonous masses of the Angel Lake unit occur in this area, the largest at Hole-In-The-Mountain Peak. A klippe occurs at Peak 11111', and apparently another klippe occurs along the west-northwesterly trending ridge between the two East Fork Boulder Creeks.

* This peak is the highest point in the range, 11,276 feet above sea level. It is probably the same peak that previously King (1878) called Mount Bonpland. It was later called Hole-In-The-Mountain Peak because of a very prominent hole that occurs in a triangular shaped rock spire along the range crest just south of the peak itself. The opening is roughly 10 feet in diameter, and was possibly formed by the differential weathering of a carbonate-rich pod surrounded by more resistant gneisses and quartzitic rocks.

The allochthonous mass at Hole-In-The-Mountain Peak is the most prominent of the three. It is roughly estimated to reach a thickness of 300 to 500 feet and can be traced northward for about a mile. It is a dark grey to black hornblende-bearing quartz dioritic biotite gneiss that truncates the near horizontal layers and lenses of the underlying leucocratic-appearing "transition" succession of the Angel Lake unit. This truncation is so distinct, that it can be observed from Starr Valley, 7 miles to the west. The thrust plane, which strikes roughly east-westerly and dips 5 to 20 degrees northward, truncates not only near-horizontal units in the lower plate but likewise cuts diagonally across near-horizontal beds in the upper plate (Fig. 42).

The dark biotite gneiss layer in the upper plate bears a striking resemblance to the marker of biotite gneiss in the upper part of the non-cataclastic succession of the Angel Lake unit, and they are possibly the same lithologic unit.

The Peak 11,111' klippe lies 2 miles south of Hole-In-The-Mountain Peak and forms the second highest peak in the range. A klippe of hornblende-bearing quartz dioritic biotite gneiss in here in thrust contact with the underlying "transition" succession of the Angel Lake unit. The klippe has a triangular outline and is not over 60 feet thick. The thrust plane has a gentle northwesterly component of dip, and truncates near-horizontal layers and stringers in both upper and lower plates (Fig. 43).

A probable klippe forms another peak about a mile west of Peak 11,111'. This klippe was observed from a short distance but was not visited; therefore the lithology of the upper plate is not definitely known here. The klippe has a pear-shaped outline, is nearly a mile long and has an estimated maximum thickness of 600 feet. It appears to sit as an isolated mass upon a ridge which descends northwestward from Peak 11,111 to Starr Valley. In contrast to the east-westerly striking and southerly dipping layers of the ridge itself, the layers of the klippe are horizontal.

PEAK 11,111'

Fig. 43. Klippe of hornblende-bearing quartz dioritic biotite gneiss at Peak 11,111' as seen looking to the northwest. Note truncation of near-horizontal layers in both the allochthonous gneiss and the underlying "transition" succession of the Angel Lake unit. Cataclastic gneisses and quartzites are seen in the foreground. Lime-silicate carbonate ultramylonite occurs near the thrust plane.

Horse Creek Thrust

The Horse Creek thrust is a major low-angle thrust which brings portions of the Snow Water unit into tectonic contact with the underlying, lithologically dissimilar, Angel Lake unit. The thrust sheet is exposed in the southern East Humboldt Range, in the "Secret Hills" between Ruby and Secret valleys, locally on the west flank of the East Humboldt Range, and at "Clover Hill" in the northeastern corner the mapped area.

In the "Secret Hills" a discordance is present between the attitudes of the Snow Water unit and the tectonically underlying Angel Lake unit. Both lower plate and upper plate successions in this area are predominantly cataclastic, and an intensely mylonitic lime-silicate bearing carbonate unit is present along the thrust zone. Previously described white quartzite mylonite is commonly at the base of the Snow Water unit in this area.

In the southern East Humboldt Range, white quartzite mylonite is exposed at the crest of the range near the head of Horse Creek. The thrust plane was not traced south of Wolverton Creek and more detailed work needs to be done in this area.

In the area of the Secret Creek gorge, the presence of the Horse Creek thrust is largely obscured by the much later, Mesozoic Secret Creek thrust. The Secret Creek thrust locally utilizes the older thrust plane, and in places truncates it. Only a few exposures of white mylonitic quartzite and mylonitic marble of the Snow Water unit are seen between the Mesozoic thrust plane and the underlying Horse Creek thrust plane. In this area, as in the "Secret Hills", the intensely mylonitic lime-silicate bearing carbonate unit is exposed along the thrust plane. This mylonitic unit is often highly contorted and in several localities is overfolded to the west, indicating that the thrusting of the Snow Water unit over the Angel Lake unit may have been from east to west. The unit is seemingly discordant to the eastward-dipping mylonite layers in the underlying Angel Lake unit and apparently was dragged, folded, and severely mylonitized along the Horse Creek thrust zone.

Megascopically the lime-silicate bearing carbonate mylonite can be described as a banded, fine-grained to aphanitic carbonate rock with numerous inclusions, pods, and lenses of other metamorphic rocks and minerals. These inclusions often weather green or dirty orange brown. The carbonate matrix often weathers a light to dark medium grey, and might be mistaken for a limestone. The streamlined pods of impurities, and the large and small scale contortions and overfolds, clearly shows the tectonic and metamorphic nature of the rocks. Microscopic study reveals their mylonitic to ultramylonitic character (Fig. 44). The mylonitic portions consist of a granulated calcite mortar that occurs in streams which flow around the numerous rock and mineral porphyroclasts. The calcite grains in the mortar roughly average .016 mm. in diameter. With increasing granulation the grains in the mortar become smaller, and in the ultramylonites no individual grains can be distinguished under high power (280 X). In these ultramylonites the calcite appears as a brownish, clouded, fuzzy mass with some narrow dark streaks marking certain shear zones. The minerals of the porphyroclasts found in these carbonate mylonites include diopside, epidote, hornblende, plagioclase, scapolite, quartz, and potash feldspar.

The Horse Creek thrust and the overlying Snow Water unit in the Secret Creek gorge area, on the west flank of the Ruby-East Humboldt Range, and at "Clover Hill", is not shown on the accompanying geologic maps. This is partly because of the lack of continous exposures of the often thin to absent upper plate unit in these areas, and partly because time did not permit more detailed mapping.

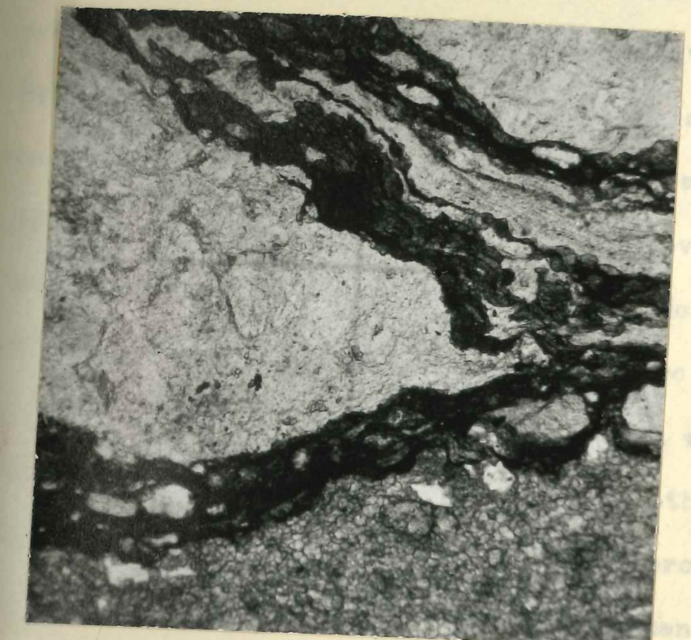


Fig. 44. Photomicrographs (plane light and crossed nicols) of impure carbonate mylonite in the Angel Lake unit near the Horse Creek thrust plane. Very fine-grained calcite is seen in the lower one-fourth of the photos. A portion of a large pod of a highly cataclastic quartz-feldspar-hornblende rock is seen in the upper three-fourths of the photos. Specimen B 85 (57 X magnification).

Age of the Thrusting within the Metamorphic Succession

The two previously described thrusts within the metamorphic basement presumably are related to mylonites found within both the Angel Lake and Snow Water units. The age of the mylonitization, then, would logically be the same as the age of thrusting. If this is true and if all mylonites belong to the same general episode of deformation, the evidence at hand suggests that the Hole-In-The-Mountain Peak thrust and the Horse Creek thrust are Precambrian in age. Another hypothesis is that the two thrusts are possibly Mesozoic in age and related to the Secret Creek thrust which brought numerous Paleozoic formations into direct tectonic contact with the metamorphic basement. The following evidence suggests but does not prove a Precambrian age for the mylonites and the thrusting within the basement succession:

(1) If thrusting within the metamorphic sequence occurred during the episode of Mesozoic thrusting, one might expect tectonic slices of the metamorphic succession up in the overlying thrust Paleozoic succession. No such slices were observed anywhere.

(2) Two ages and two types of cataclasis have been noted in rocks immediately beneath the Mesozoic thrust plane. One type of cataclasis is mylonitization; the other type is a superimposed later stage of shearing, brecciation, and occasional slickensiding. Details of these two stages of cataclasis are discussed elsewhere. The suggestion is that the Precambrian? thrusting was a penetrative type of deformation, affecting a considerable thickness of metamorphic strata; and that the Mesozoic thrusting mainly sheared and brecciated the earlier mylonites, whose beds are often truncated at the Mesozoic thrust plane.

(3) The episode of mylonitization was locally accompanied by mild feldspathization (Fig. 17). In some places essentially concordant pegmatite pods associated with feldspathization locally cut across mylonite foliation,

indicating that the pegmatite is locally post-mylonitization. Paleozoic rocks in the upper plate of the Mesozoic Secret Creek thrust lack any signs of feldspathization, which might be expected if Mesozoic thrusting, mylonitization, and feldspathization were essentially contemporaneous.

(4) The Secret Creek thrust mass rests upon and truncates members of both the Snow Water unit and the underlying Angel Lake unit. Probably more than 2000 feet of mylonitic and non-mylonitic members of the basement succession are truncated at the thrust plane, which further suggests that the mylonites in the basement succession were not the result of Mesozoic thrusting. (The nature of the upper surface of the metamorphic basement prior to Mesozoic thrusting is discussed in the next section).

Folding

The metamorphic succession in the East Humboldt Range forms an elongate anticline which is doubly plunging and which trends essentially north-south. The anticline reaches its culmination in the Hole-In-The-Mountain Peak area where attitudes are very nearly horizontal (Fig. 45). The range significantly attains its highest elevations in this area. North of here the rocks have an overall northerly component of dip with local reversals. These reversals are visible west-southwest of Winchell Lake and also just south of Greys Peak, and reflect broad east-westerly trending transverse folds which are superimposed upon the overall anticlinal structure. To the south, along the crest of the ridge which projects southerly from the southeast corner of the East Humboldt mass, reversals of dip are also present.

In the main East Humboldt mass, metamorphic layers comprising the western limb of the anticlinal dome are in places slightly undulating, generally maintaining a 10- to 30-degree dip westward. The long westward-sloping ridge crests north of the west fork of Boulder Creek nearly parallel the dip of the metamorphic layers (Fig. 46). Dip slopes occurring at the range front are

Fig. 45. Near-horizontal metamorphic layers in the Angel Lake unit at the crest of the East Humboldt Range anticline, as seen looking to the northwest from Clover Valley.

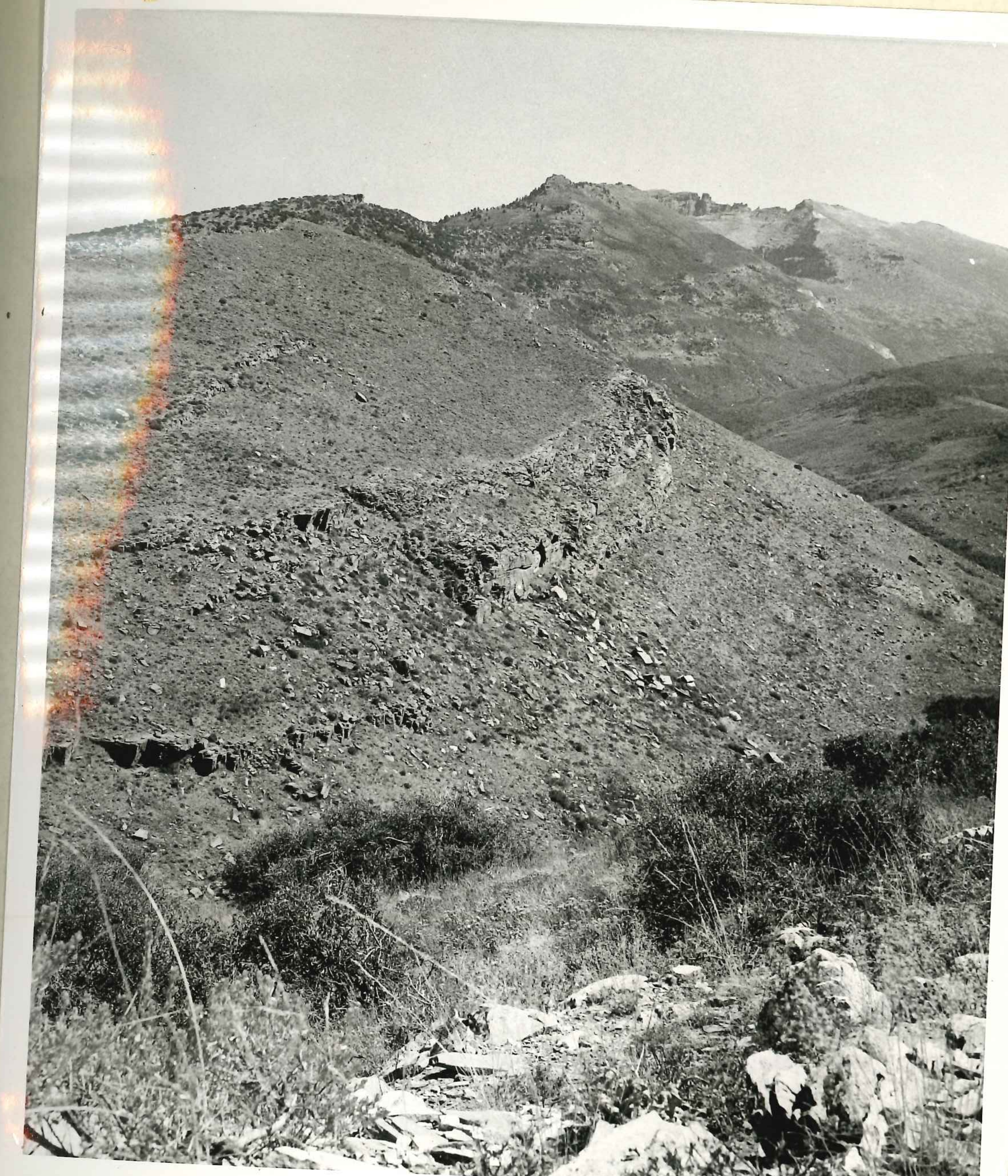


Fig. 46. Looking to the east and up dip at the metamorphic layers on the west limb of the East Humboldt Range anticline. Photo was taken just south of East Fork Boulder Creek. Hole-In-The-Mountain Peak is in the background.

Fig. 47. Looking east-southeast at northwesterly dipping metamorphic strata near the northern end of the plunging East Humboldt Range anticline. Note the conformity between the internal structure and the topography.

particularly well displayed north of Greys Creek in the northwest portion of the range (Fig. 47).

The east-westerly trending folds which modify the major anticlinal structure significantly have a distinct relation to the topographic outline of the western front of the range. Between East Fork Boulder and Herder creeks a pronounced embayment interrupts the normal northerly to northwesterly trend of the range front. The embayment is about 4 miles long and 2 miles deep. It consists essentially of Tertiary sedimentary and volcanic rocks overlain by a gravel-mantled pediment surface.

The outline of the embayment parallels the strike of the metamorphic beds; and these strikes in the bedrock reflect a broad westerly plunging syncline. The embayment is significantly deepest in the area of the synclinal axis. These features will be discussed further in the later section on Cenozoic Structure and History.

The eastern limb of the anticline is truncated at the Mesozoic Secret Creek thrust plane in the northern East Humboldt Range, and where the limb is somewhat better developed, it is not well exposed. For these reasons, the eastern limb of the anticline is not as obvious as the western limb. Extensive glaciation and pedimentation have eroded much of it in the central East Humboldt Range, and widespread vegetation on the lower portions of the steep east flank tend to conceal the easterly dipping units that do remain.

The erosion has encroached to and in places slightly beyond the anticlinal axis, and the most impressive rock exposures are at high elevations, occurring along the steep faces just below the range crest. Looking west from Clover Valley the most prominent rocks form broad horizontal bands across the sheer cirque walls present at the heads of Leach and Weeks creeks. Although not as obvious as the western limb, the eastern limb is apparent by the attitudes at a number of localities. Northeasterly dipping metamorphic rocks east of the range crest occur on the west bank of Trout Creek; the north bank of Clover Creek; and the northwest side of Angel Lake. Examples of easterly dipping rocks to the south include those along the north bank of Steels Creek just east of the range front, and further south above the head of Hunneman Creek.

The Angel Lake unit in the mapped portion of the northern Ruby Mountains forms essentially an easterly dipping homocline. Between this northern Ruby Mountain homocline and the East Humboldt Range anticline is an obscurely defined northwesterly trending syncline, and a northerly-trending high-angle fault which cuts both the basement rocks and the overlying Permo-Carboniferous formations. The homocline is best exposed in the Secret Creek gorge and in the northerly trending canyons entering into the gorge from the northern Ruby Mountains. Easterly dips here vary from 70 to 0 degrees. However, there are local reversals of dip in addition to some prominent overfolded structures to the west. Many of the rocks exposed in this Secret Creek gorge area, including those which are overfolded, are strongly cataclastic and mylonitic, and are members of the upper mylonitic portion of the Angel Lake unit.

The upper surface of the metamorphic succession, prior to Cenozoic doming, was apparently not underlain by a continuous single metamorphic horizon or layer which simply became bowed up. Evidence indicates that the succession was in part truncated prior to doming. In the Angel Lake area, for example, an overlying thrust plane that has brought Permo-Carboniferous rocks into contact with the metamorphic basement, truncates rocks of the eastern limb of the now anticlinally folded metamorphic sequence. And as mentioned, in the western portion of Secret Creek gorge area, a gently westerly dipping thrust sheet of Permo-Carboniferous rocks truncates the predominantly easterly-dipping metamorphic layers.

It is not definitely known whether the upper surface of the truncated metamorphic succession represents essentially 1) an ancient Precambrian erosion surface, which originally lay beneath an unconformably overlying Paleozoic

STRATIGRAPHY OF PALEOZOIC AND MESOZOIC ROCKS

General Statement

The Paleozoic and lower Mesozoic rocks in the northern Ruby Mountains and the East Humboldt Range are in thrust contact with a regionally metamorphosed higher-grade metamorphic basement regarded to be Precambrian in age; and nowhere in the mapped area is there a depositional contact present between the metamorphic basement and the Paleozoic rocks. The Paleozoic and Mesozoic rocks are internally complicated by a series of thrusts which are subordinate to the underlying sole thrust. As a result of this subordinate thrusting, units are tectonically eliminated and truncated, and others are repeated. The basal thrust plane cuts across stratigraphic units of both the underlying metamorphic terrane and the overlying Paleozoic formations. In tectonic contact with this basal thrust plane are rocks ranging in age from Ordovician to Lower Triassic.

The Paleozoic and Mesozoic strata in the range are not as widely distributed as the regionally metamorphosed succession which constitutesthe main bulk of the mountain mass. Exposures of Paleozoic units are essentially limited to: the northeastern flank of the East Humboldt Range near Wells; the southwestern portion of "Clover Hill", and the two smaller hills immediately to its south; the Polar Star Mine area at the southeastern end of the East Humboldt Range; the eastern flank of the northern Ruby Mountains; the Secret Creek gorge area in the northern Ruby Mountains and the southwestern portion of the East Humboldt Range.

Tertiary and Quaternary deposits occur mostly in the broad valleys adjacent to the mountain mass. Pleistocene morainal deposits are found within the range in many glaciated valleys. In several localities moraines extend slightly beyond the range flanks and into the broad neighboring basins.

PALEOZOIC-MESOZOIC

STRATIGRAPHIC NOMENCLATURE

AGE	NAME
Lower Triassic	undifferentiated limestone and shale

Permian	"Park City formation": upper limestone member carbonate and chert member phosphatic member lower limestone member
	Arcturus formation

Pennsylvanian	Ely limestone

Mississippian	Diamond Peak formation

Devono-Mississippian?	Pilot "shale" ??

Devonian	Guilmette formation

Silurian?-Devonian	undifferentiated carbonates

Ordovician	Eureka quartzite
	Upper Pogonip group?

Ordovician through Devonian Systems

Lower and Middle Paleozoic strata occur south of Wells, in the southwestern portion of "Clover Hill" and on the two smaller hills south of "Clover Hill". These three southerly trending hills are 2 to 3 miles east of the northeastern flank of the East Humboldt Range. Merriam (1940, p. 43) previously reported Devonian fossils from two of these hills. Lower? and Middle Paleozoic units are also present in the Polar Star Mine area in the southern East Humboldt Range.

Upper Portion of The Pogonip? Group

The lowest Paleozoic formation which can be definitely identified in the area is the distinctive white Eureka quartzite of Ordovician age. It is exposed at "Clover Hill". It is underlain by a silicified, fractured, and in part brecciated, fine-grained unfossiliferous sandstone and quartzite which is locally dolomitic; and which may be a correlative of the uppermost Pogonip "limestone" (named by King, 1878, p. 187-195). This underlying quartzitic unit is about 25 feet thick. It is a very light grey to yellowish grey on a fresh surface, but generally weathers a moderate reddish orange to brown, or light olive grey. It is best exposed on the west side of the southermost portion of "Clover Hill" where the unit shows bedding planes which often weather orange brown, and contrast against a yellowish grey-weathered background. The unit has been fractured, and not uncommonly very fine networks of orange-weathered siliceous veining are seen standing out slightly in relief. Isolated knobs of the unit are present farther north. One prominent knob occurs on the western flank, about midway between the northern and southern ends of the hill. Here the unit is coarsely brecciated, presumably due to thrusting at its base, and most fragments are over an inch in size (Fig. 49). Voids are present between fragments, but the fragments are firmly held together by secondary silica.

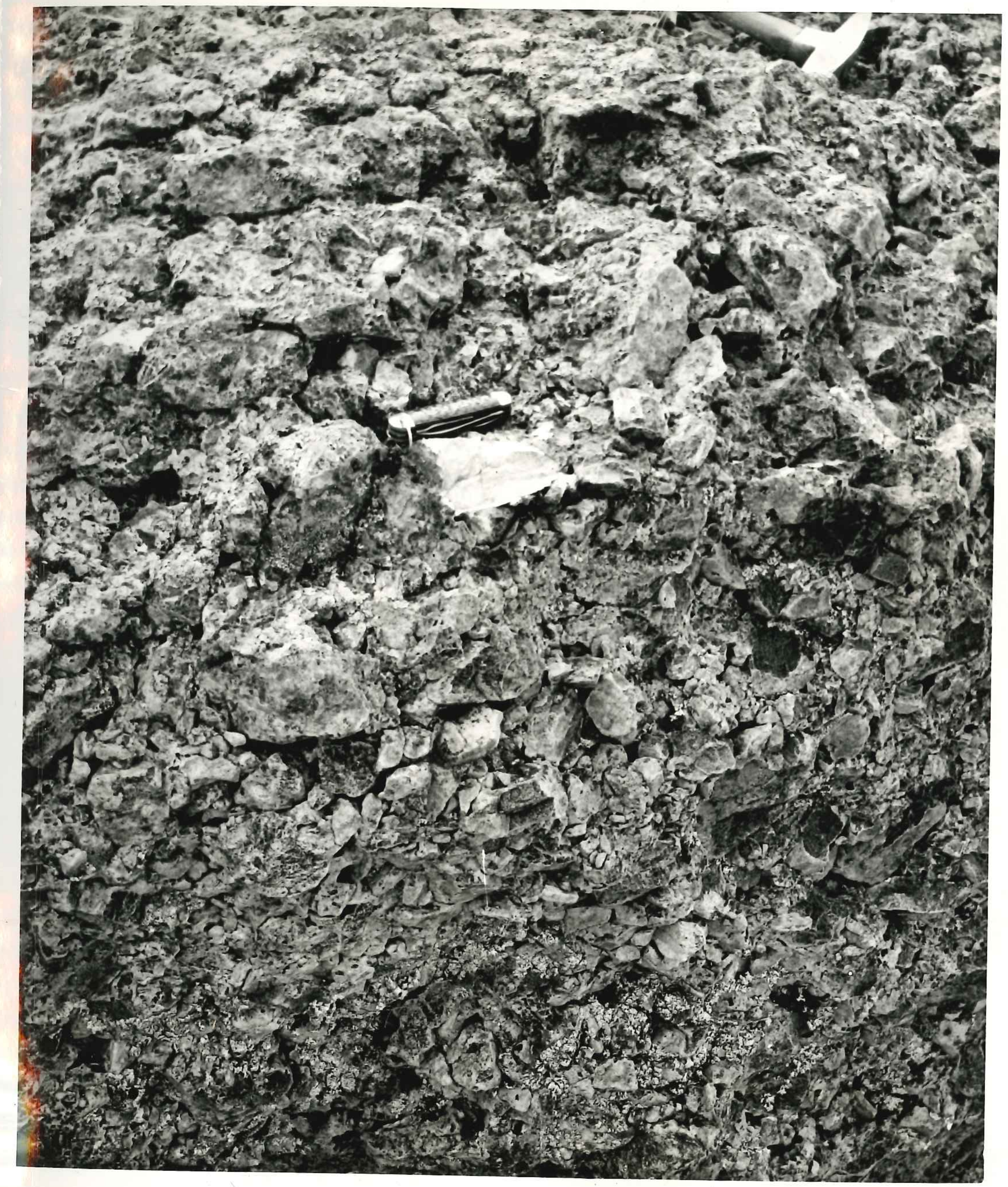


Fig. 49. Brecciated Ordovician? quartzite on the west flank of "Clover Hill".

Tiny quartz crystals often coat the orangish-weathered quartzite fragments. The knob is about 25 feet high and rests upon a fine-grained, thinly laminated, medium-dark bluish grey carbonate breccia.

The unit may be a sandy member of the uppermost portion of the Ordovician Pogonip group, or perhaps a lower division of the Eureka quartzite. Sharp (1942, p. 658) reported that near the top of the Pogonip in the southern Ruby Mountains there is 250 to 300 feet of fine-grained limy sandstone and quartzite. Kirk (1933, p. 30) reported cross-bedded sandstone and brownish-weathering sandy dolomite between the typical uppermost Pogonip limestone and the typical cliff-forming vitreous white Eureka quartzite at Lone Mountain (18 miles northwest of Eureka).

Other lower Paleozoic units which may possibly be Pogonip equivalents occur at the northeast corner of "Clover Hill", and southeast of the Polar Star Mine in the southern East Humboldt Range.

In the "Clover Hill" locality is a small outcrop of an essentially flaggy, dark grey, fine-grained limestone with dusky yellow to greenish shaly partings. No identifiable fossils were collected in it and its correlation is based upon lithology and is tentative. Another outcrop of a grey, more massive unfossiliferous limestone possibly belonging in the Pogonip group occurs southeast of the first outcrop and immediately east of a cement-encased spring.

In a structurally complex area southwest of the Polar Star Mine, Paleozoic units of possible Ordovician, possible Silurian, and rather definite Devonian ages are present. They underlie a thrust slice of fusulinid-bearing lower Permian strata. The possible Ordovician Pogonip rocks occur on the south side of a prominent southwesterly trending canyon that lies about one mile southeast of the main dump of the Polar Star Mine. The unit is composed of a thinly to thickly bedded, platy, medium dark grey to dark grey limestone, which shows greyish yellow to pale yellowish-brown shaly partings. These partings are occasionally hummocky and show tiny gastropod cross-sections. The unit lithologically resembles members in the upper Pogonip group in the Cherry Creek Mountains and in the northern Egan Range (Peter Misch and Bill Fritz, personal communication), although this correlation is tentative.

Eureka Quartzite

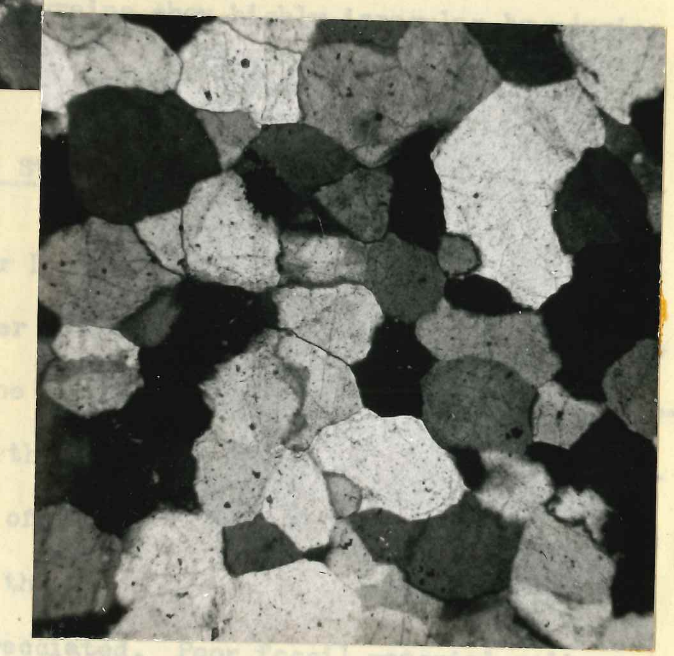
The Eureka quartzite (named by Hague, 1883, p. 262; 1892, p. 54-7) is exposed on the west side of the southernmost portion of "Clover Hill". The unit is not over 15 feet thick and is discontinuously exposed. It is white, vitreous, and fine-grained. Thin-sections of the rock show that the smallest grains are about .08 mm. in diameter and the largest about .5 mm. The average grain size is estimated to be .35 mm. There is no interstitial cement; rather, the quartz grains form a nearly equigranular mosaic (Fig. 50). The shapes of the original grains have evidently been obscured by secondary quartz which has grown in optical continuity with them. The grains show an absence of, or very mild undulatory extinction.

White quartzite regarded to be Precambrian in age, and which is scattered over the low hills east of Secret Pass is easily confused with the Ordovician Eureka quartzite upon cursory examination. Similarly, a vitreous quartzite in the Snow Water unit, located about a mile northwest of the Polar Star Mine in the southern East Humboldt Range, bears a superficial resemblance to the Eureka quartzite. These two quartzites, however, actually are quite different from the Eureka quartzite in both hand specimen and thin-section.

The Snow Water quartzite in the Secret Pass area is milky white and has a dense, more opaque appearance than the Eureka quartzite. Even on fresh fracture there are none of the tiny vitreous grains that are seen on the fresh Eureka quartzite surface. In thin-section many of the massive Snow Water quartzites show several stages of cataclastis as evidenced by earlier strained, and sutured, and sometimes elongate quartz grains which have been severely microbrecciated (Fig. 64). Sometimes some of the sheared elongate

EUREKA QUARTZITE

"Clover Hill"



Northern Egan Range

Fig. 50. Similarity in the texture of the Ordovician Eureka quartzite exposed at "Clover Hill" and the Eureka quartzite in the northern Egan Range, south of the town of Cherry Creek (collected by Bill Fritz). Crossed nicols, 57 X magnification.

quartz grains are faintly visible in the hand specimen as fine milky streaks. Other specimens of Snow Water quartzite east of Secret Pass are not massive, but are schistose and platy. They are invariably mylonitic and cannot be confused with the non-schistose Eureka quartzite.

The massive quartz rock which is about a mile northwest of the Polar Star Mine is white to medium grey, relatively translucent, and highly vitreous. It weathers into whitish smooth-surfaced boulders with rounded edges. The rock is unevenly fine-grained to rather coarse-grained, with some grains exceeding 7 mm. It is interpreted to be a large body of vein quartz, only superficially resembling the Eureka quartzite. In thin-section, scattered tiny non-oriented muscovite inclusions are seen in many individual quartz grains, and upon close examination in the field, very coarse-grained crystals of microcline are locally encountered. Texturally, the grains show highly irregular boundaries and pronounced undulatory extinction and micro-fracturing.

Silurian(?) and Lower Devonian Strata, and the Guilmette Formation

"Clover Hill" Area

At the southern end of "Clover Hill", fossiliferous strata of probable Devonian age, tectonically overlie the Ordovician Eureka quartzite. The Paleozoic rocks in this area are in basal thrust contact with the metamorphic basement succession which forms the core of the hill. Probably as a result of the thrusting, the attitudes of units in the upper plate are not consistant, and some limestones have been severely brecciated. Poor fossil material collected suggests a probable Devonian age for most of the limestones here. Lithologically, the rocks are massive to flaggy, medium dark to dark grey, fine-grained limestones. The massive limestones weather a light to medium light grey. The flaggy beds show mottled argillaceous partings which weather greyish yellow to dark yellowish orange. Fossil hash is occasionally exposed on these shaly partings. Thinly laminated, pale yellowish brown weathering, dark grey to greyish black, fine-grained dolomite is also present.

Most of the fossil material was collected at two localities, N 7 near the southern tip of the hill, and G 30 near the base of the hill about a quarter mile northwest. These localities are shown on Map No. 1. William H. Easton of the University of Southern California identified the collections. He reported trepostome bryozoans or Cladopora? sp., and stromatoporoids? from G 30, and at N 7 an assemblage of trepostome bryozoans?, stromatoporoids? or calcareous alga, crinoid ossicles, calcareous algae, conetid and strophomenoid brachiopods. A conularid resembling Styliolina of Devonian age (identified by the writer) was collected about three-quarters of a mile north of N 7.

Definite middle or upper Devonian* strata occurs about one-half mile south of locality N 7, and very near the northern tip of a second isolated hill that lies between Schoer and Ralph creeks. This Devonian locality has been previously reported by Merriam (1940, p. 43). He states that a collection made by Siemon Muller of Stanford University at this locality "north of the northeast corner of the Halleck quadrangle contains Spirifer cf. argentarius, possible Spirifer engelmanni, and abundant Atrypas. It probably represents the Spirifer argentarius zone of the Devils Gate formation". Collections made here by this writer (locality D 30) included Atrypa cf. A. missouriensis and Spirifer argentarius (identified by Easton), and Atrypa cf. nevadana (identified by writer).

Some of the limestone at this locality is a massive dark grey, fine-grained variety, whereas other specimens have a clayey feel, and are colored by thin pale red to pale purple-red, and light medium grey alternating bands. The soil in this area is often reddish in color, and the coloration in the rocks may be the result of hydrothermal action along a high angle fault plane on the west side of the hill.

Recent regional studies (Brooks, 1954; Osmond, 1954; Roberts, 1956)

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* depending upon the age of the Spirifer argentarius fauna -- see Nolan, 1956, p.51.

have extended the western Utah Devonian terminology (Sevy, Simonson, and Guilmette) into eastern Nevada. This writer accepts this terminology and correlates the Devonian strata at locality D 30 with the Guilmette formation (named by Nolan, 1930, pp. 421-432).

The rocks south of locality D 30 are unfossiliferous and form the main relief of the hill. There are several faults in the succession, and a suspected fault trends east-westerly, between the fossiliferous subsidiary knoll at D 30 and the main mass of the hill to the south. On the southern flank of the hill, light grey to very light grey weathering, relatively smooth-surfaced, fine-grained dolomite occurs, in addition to darker grey varieties. The dolomitic character of the rocks suggest correlation with part of the Silurian Laketown dolomite, and/or earlier Devonian dolomites of the Sevy or Simonson formations.

Upper Devonian strata are exposed on a small isolated third hill that lies between Winchell and Renshaw creeks, about 2 miles south-southwest of locality D 30. The succession has been locally faulted but maintains a southeasterly dip. The writer collected Amphipora? sp. (of Middle to Upper Devonian age) from medium grey weathering, fine-grained dark grey limestone. In a dark grey weathering, greyish black aphanitic limestone, some rhynchonellid and spiriferoid brachiopods and a tiny coiled gastropod were found. This hill is the "Humboldt School" locality (Merriam, 1940, p. 43) where Muller collected Cyrtospirifer portae and productellas, which Merriam reports to be of Upper Devils Gate (Upper Devonian) age. This writer correlates these rocks with the Guilmette formation.

Polar Star Mine Area

Probable Devonian strata occurs in the structurally complex Polar Star Mine area in the southern portion of the East Humboldt Range. Some of the probable Devonian rocks here are finer-grained apparently recrystallized or "marbleized" limestones, which in places are contorted. These rocks are associated with other strata, some of which may be Ordovician and Silurian in age, but because of structural complications and lack of diagnostic fossils, the presence of these two lower systems is yet to be proved. The succession is mapped as an Ordovician (?) to Devonian unit.

Structurally, the section is sandwiched between two thrust planes, which probably explains its structural complexity and partially recrystallized texture. It is tectonically overlain by the Permian Arcturus formation and is tectonically underlain by marble tentatively mapped with the Snow Water unit.

Most of the fossiliferous material from this vicinity is badly altered; however, at two localities a few better preserved fossils were collected. Locality G 27 (Map No. 4) lies south-southwest of the main dump of the Polar Star Mine, and on the same hill as the mine. Amphipora? sp. (identified by Easton) occurs here in a medium grey weathering, medium dark grey, fine-grained limestone. The hill is covered by prospect pits; and scattered small intrusions of a greyish yellow-green, fine-grained dike rock are also present.

Locality O-13 lies about $1\frac{1}{2}$ miles south-southeast of the Polar Star Mine, and on the east side of a ridge which projects in this direction from the mine area. From a somewhat mottled yellowish grey weathered, dark grey, fine-grained limestone, Easton has identified Cladopora? sp., trepostome bryozoans, stromatoporoids?, and a brachiopod cross-section.

Lithologically, the Lower? to Middle Paleozoic section in this area is composed of both limestone and dolomite, some of which is recrystallized and banded. Most of the rocks are light to medium dark grey. Some dolomitic varieties, however, weather a dark yellowish brown, and others a yellowish grey. Specimens are aphanitic to coarse-grained, but most are fine-grained.

On the ridge south-southeast of the Polar Star Mine, the Lower? and

Middle Paleozoic rocks are structurally complicated, and small sills and dikes of dark greenish igneous rock locally intrude the succession. In the first large transverse saddle area (near locality O-13), lying about one-half mile north of the southern end of the ridge, an unusual grey limestone occurs which has a lustrous "marbleized" appearance. Scattered throughout its medium dark grey, fine-grained calcite matrix are both elongate and rounded irregular-shaped areas of fine-grained white calcite. These white blobs are almost certainly recrystallized fossils, although all internal organic structure has been lost. The blobs vary in size, the elongate varieties being generally less than one-tenth inch wide and less than three-quarters inch long. Easton regarded these elongate forms as badly altered trepostomes. The rounded irregular-shaped blobs are larger in size, generally not exceeding 3 inches in length and an inch in width. Easton thought some of these may be altered stromatoporoids. From a less altered, previously described limestone in this general area, Easton identified Cladopora? sp.

The "marbleized" limestone of this saddle area strikes transversely to the south-southeasterly trend of the ridge, and dips are steep. Locally occur internal small-scale folds. In contrast, north-northwesterly along the ridge crest are light grey to dark yellowish brown, unfossiliferous dolomites and limestones whose strike is roughly perpendicular to the "marbleized" limestones.

The combined thickness of the Ordovician through Devonian sequence in the East Humboldt Range is unknown. At present it is not known how much, if any, of the lower Paleozoic rocks in the "Clover Hill" area succession to the north is duplicated in the Polar Star succession. A rough estimate of the combined thickness of the Lower and Middle Paleozoic rocks preserved in the northern area is 400 to 800 feet. In the Polar Star area is an estimated 300 to 500 feet. This is far less than known normal thicknesses of Ordovician through Devonian strata in adjacent areas, and almost certainly does not represent the original thickness deposited in the area of the East Humboldt Range.

Highest Devonian and Basal? Mississippian

Pilot "Shale"??

Overlying the Guilmette limestone at the previously mentioned "Humboldt School" locality on the east side of Clover Valley, are gentle talus slopes bearing evidence of a dominantly clastic succession consisting of a moderate reddish brown weathering, fine- to very coarse-grained sandstone; platy yellowish grey and olive grey siltstone; and light brown weathering, yellowish grey, argillaceous dolomite. Dusky brown, greyish black, greyish red, and dusky red chert fragments are also scattered over the gentle talus-covered slopes. The very coarse-grained sandstone is composed of a variegated mosaic of chert and quartz fragments. Most of the fragments are dark grey to greyish black. In lesser amounts, are dusky red and pale yellowish green chert grains. The unit may possibly be equivalent to the lower portion of the Pilot shale (named by Spencer, 1917, p. 26). The upper Devils Gate formation as described in the southern Ruby Mountains (Sharp, 1940, p. 666) is also a probable correlative of the Pilot shale.

Mississippian System

Diamond Peak Formation

The section which underlies the Pennsylvanian Ely limestone in the East Humboldt Range and is composed of quartzite and conglomerate is tentatively correlated with the Mississippian Diamond Peak quartzite (named by Hague, 1883, p. 253, 268). It is, also, probably in part equivalent to the Tonka formation, a name recently given to section of chert-pebble conglomerate and quartzite with calcareous interbeds in the Elko region (Dott, Jr., 1956, p. 2232). Dott proposed the Tonka as a local name and, also, tentatively correlated it with the Diamond Peak quartzite (p. 2233).

The age of the Diamond Peak formation* at Eureka, as most recently reported by Nolan (1956, p. 60-61), is upper Mississippian, with the possibility that the uppermost part of the formation may in some places be early Pennsylvanian. Dott likewise suggested that his Diamond Peak-equivalent Tonka formation includes both Mississippian and early Pennsylvanian strata. In the East Humboldt Range, fossils were not found in the Diamond Peak formation. Therefore, although the overlying Ely limestone contains a rich lower Pennsylvanian assemblage, no conclusions can be drawn as to the exact position of the Mississippian-Pennsylvanian boundary in this area.

The formation is often weathered a dark to moderate reddish brown. The colors of the individual chert and quartzite pebbles and granules in the conglomerates are highly variable. They range from white to black, moderate to dusky red, greyish to pale red-purple, moderate to pale blue green, and still other shades. They are sub-angular to sub-rounded. In addition to the conglomeratic portions there are quartzite, siltstone, and limestone members. The limestones are grey and fine-grained, and are interbedded with conglomerate and quartzite near the upper boundary of the formation. The quartzites vary in hue but are generally brownish. They are fine-grained, moderately vitreous, and well indurated. The siltstones observed were silicic, massive, and light greyish olive-brown.

The formation outcrops on the northeastern flank of the East Humboldt Range, north of Angel Lake; in the northwest Secret Valley area at the head of the unnamed southerly flowing creek between Dry Creek and Dorsey Creek; on

* The term formation is more appropriate than quartzite. See Nolan , 1956, p. 60.

the northwest side of Dorsey Creek; and on the steep slopes rising above the south fork of Reed Creek in the southwest portion of the East Humboldt Range. A distinctive pale red-purple colored variety of the conglomerate occurs in the southwest portion of the East Humboldt Range, south of Reed Creek.

In all of these localities the formation is in thrust contact with the high-grade metamorphic basement. The stratigraphic relations therefore, between the Diamond Peak formation and the previously discussed older Paleozoic formations in the East Humboldt Range area are not known.

The maximum thickness of Diamond Peak strata in the area is a roughly estimated 500 feet. This, of course, does not represent the original thickness presumably deposited here in view of the tectonic truncation of the formation at its base. The formation is stratigraphically overlain in some areas by the Ely limestone. In other localities it is tectonically overlain by thrust slices of the fusulinid-bearing Permian Arcturus formation.

Pennsylvanian System

Ely Limestone

Introduction

The Ely limestone outcrops in the northeast portion of the East Humboldt Range, on the west flank of the southern East Humboldt Range, on the east flank of the northern Ruby Mountains, and in the southwestern portion of the East Humboldt Range north of the Secret Creek gorge.

Lithologically, the rocks are mostly light olive grey to dark grey, fine- to medium-grained limestones which weather light to medium grey. Some varieties weather yellowish grey to greyish yellow. The limestones are typically massive and are ridge-forming. Olive grey to greyish black chert lenses and nodules are particularly common in the lower part of the succession. Some beds containing both chert and limestone pebbles and cobbles in a limestone matrix occur in the lower portion of the succession, and some 25 to 50 foot thicknesses of orange-brown weathering chert granule and pebble conglomerates occur relatively higher in the section.

Lower portion

The lower portion of the Pennsylvanian succession contains massive light grey-weathering cliff-forming limestone which yields a fauna which W. H. Easton identified as "probably lower Pennsylvanian, (equivalent to) the lower third of the Ely limestone". On this basis and on apparent lithologic similarity the succession is correlated with the Ely limestone (defined by Spencer, 1917, pp. 26, 27).

The contact of the Ely limestone with the underlying Diamond Peak formation is transitional. Beneath the massive Ely limestone is roughly 50 feet of interbedded limestone, quartzite, and conglomerate before the more uniform quartzite and conglomerate of the Diamond Peak formation is encountered.

Fairly good fossil collections in the lower Ely limestone were made in the southwestern East Humboldt Range north of the Secret Creek gorge. Near the peak of the hill (elevation 7908) between the gorge and Dorsey Creek (localities A 27, K 51, K 52, and K 53 on Map No. 2), the following fossils were collected:

Cleiothyridina orbicularis, Composita sp., Dictyoclostus sp., D. hermosanus, D. cf. D. hermosanus, Echinoconchus sp., Linoproductus sp., Marginifera cf. M. missouriensis, Marginifera aff. M. wabashensis, Neospirifer cf. N. triplicatus, and Schizophoria cf. S. resupinoides. Corals include Triplophyllites sp., and Lophophyllidium? sp. Bryzoans found are Tabulipora cf. T. carbonaria and Rhombopora sp. Also present are crinoid ossicles.

Additional collections from Lower Pennsylvanian strata were made on the ridge north of Dorsey Creek. From localities F 54 and F 55 came the following fauna: Cleiothyridina orbicularis, Composita sp., Dictyoclostus americanus, Dictyoclostus cf. D. hermosanus, D. hermosanus, Dictyoclostus cf. inflatus, Dictyoclostus portlockianus, Echinochonchus, Marginifera cf. M. muricatina, Neospirifer sp.; Chaetetes sp. (Fig. 51), Syringopora sp., Triplophyllites sp.; and trepostome bryozoans.

On the west end of the same ridge, at locality R 5, were: Cleiothyridina orbicularis, Composita sp., Hustedia cf. miseri, Marginifera missouriensis, Orbiculoidea sp., Punctospirifer campestris, Rhipidomella sp.; Caninia sp., Triplophyllites sp.; and trepostome bryozoans.

In the northeastern East Humboldt Range, one-half mile north-northeast of Angel Lake (locality A 56 on Map. No, 1), an isolated ledge of steeply dipping Ely limestone yielded: Cleiothyridina orbicularis, Dictyoclostus sp., Hustedia mormoni, Linoproductus sp., Marginifera cf. M. haydenesis, Marginifera wabashensis, Neospirifer n. sp., Neospirifer triplicatus, and Triplophyllites sp. At another good lower Pennsylvanian locality (N 16) in this area was: Cleiothyridina orbicularis, Composita sp., Derbya sp., Dictyoclostus? sp., Marginifera cf. M. muricatina, Neospirifer sp.; a pectinoid; Triplophyllites? sp.; and trepostome bryozoans.

South of the Secret Creek gorge on the east flank of the northern Ruby Mountains, are numerous outcrops of Pennsylvanian and Permian strata. The Pennsylvanian rocks override the metamorphic basement along an easterly dipping basal thrust plane. Lower Permian strata in turn are thrust over the Pennsylvanian rocks. This thrust Pennsylvanian-Permian section forms a series of prominent, though subsidiary, southerly trending hills for about 5 miles down the east flank of the Ruby Mountains. The hills rise about 1200 feet above the neighboring valleys, and are topographically separated from the metamorphic succession by a series of pronounced saddles. Permian strata form most of the east-facing slopes of these hills, and the Pennsylvanian units outcrop essent-

Fig. 51. Chaetetes sp. in a chert and limestone pebble conglomerate in the Ely limestone at locality F 55 on the ridge north of Dorsey Creek.

ially in a belt between the Permian and the metamorphic basement.

Pennsylvanian strata here vary in age from Lower Pennsylvanian to middle Virgilian. A wide range of Pennsylvanian strata is thus present; but thrusting within, beneath, and above the sequence made it impossible to arrive at an original thickness. The fossiliferous Lower Pennsylvanian strata occurs on the northernmost peak of these southerly trending hills (locality S 27 on Map No. 3). The following Lower Pennsylvanian species were collected: Dictyoclostus sp., Dictyoclostus cf. D. americanus, Dictyoclostus hermosanus, D. cf. D. hermosanus, Linoproductus? sp., Punctospirifer cf. P. kentuckiensis, Spirifer opimus; and trepostome bryozoans.

Upper portion

Relatively younger Pennsylvanian strata occur north-northeast of Angel Lake, stratigraphically above the previously mentioned lower Ely limestone at locality A 56. The interval between the two localities is partially covered by morainal material. The relatively younger rocks occur at locality N 11 (Map No. 1) and lie on the north side and near the end of a northeast-trending ridge. The locality lies roughly 2200 feet northeast of A 56. Confusingly, at the crest near the northeastern end of the ridge is an overlying thrust remnant of Leonardian limestone. Hence, walking from the ridge crest down the northwest side to locality N 11 one passes abruptly from fusulinid-bearing Leonardian strata to Pennsylvanian limestone. The fauna collected at N 11 includes: Composita sp., Dictyoclostus sp., Dictyoclostus cf. D. portlockianus, Orbiculoidea sp., Punctospirifer cf. P. campestris, Schizophoria sp., Wellerella cf. osagensis; a gastropod; and crinoid ossicles.

Younger Pennsylvanian rocks were also found on the west flank of the southern East Humboldt Range. In this area are ridge-forming, sometimes cherty medium dark grey limestones interbedded with occasional layers of orange brown chert pebble and granule conglomerates. At localities F 31 and F 32 (Map No. 4) along a westerly trending ridge, the following fossils were found: Dictyoclostus portlockianus, Composita sp., large unidentified productids, pectinoids, Fenestella sp., and trepostome bryozoans. W. H. Easton designated both this collection and the aforementioned N 11 assemblage as Pennsylvanian. Easton stated, presumably in partial reference to these localities, that the large productids were not familiar to him, and that "we did not find (any of these productids) in the Pennsylvanian strata around Ely. Moreover, Dictyoclostus portlockianus ... is a long-ranging productid that is more characteristic of Middle and Upper Pennsylvanian than it is of Lower Pennsylvanian strata such as occur around Ely. In view of these things, I have a suspicion that some of the Pennsylvanian in your area may be higher than we have encountered heretofore in Nevada".

Although fusulinids were not encountered at localities N 11 , F 31 and F 33 which would give a precise Pennsylvanian age for these particular rocks, some fusulinids were found in Pennsylvanian strata in the earlier mentioned hills that extend down the east flank of the northern Ruby Mountains. In these areas the presence of Middle and Late Pennsylvanian strata is firmly established about 1½ miles southwest of Secret Pass (BM 6465), at locality S 19 (Map No. 3). Gerald Marrall of the Union Oil Company of California identified Fusulina sp. and Bartramella sp. He dated these as Desmoinesian (good*).

About 1¼ miles south of S 19 in the same belt of probably internally thrusted Pennsylvanian strata, Triticites sp. of the lower Virgilian Series (fair) and Triticites sp. of the middle Virgilian Series (good) were found at locality S 7a.

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* Mr. Marrall graded all of his fusulinid datings variously as "good, fair or poor". These ratings will be mentioned along with his determinations for the benefit of the reader. Marrall stated that the determinations "marked good I like very much, the ones marked fair are fairly definite, and the ones marked poor resemble forms from the age given more than any other age".

Mega-fossils were collected at A 40, S 6, and S 9. From A 40 came Rhombopora cf. R. lepidodendroides; from S 6, Dictyoclostus cf. D. americanus and Fenestella sp.; from S 9, Fenestella sp., a rhychonellid brachiopod and a coral. Easton designated all of these collections as probably Pennsylvanian.

Correlation of the Virgilian strata in this area with established east-central Nevada nomenclature is not possible, for no Late Pennsylvanian strata--to the knowledge of this writer--has been found in the general Ely-Eureka region. In the Ely district, Spencer, (1917, p. 27-8) reported Fusulina cylindrica and Fusulina elongata? in the Ely limestone, indicating an upper Middle Pennsylvanian (Desmoinesian) age. In the Eureka district, Nolan (1956, p. 63) stated that "No fusulinids or larger invertebrate fossils characteristic of a Pennsylvanian faunal zone younger than the Atoka have as yet been found in the Ely limestone ... . There appear to be no beds definitely of Late Pennsylvanian age in the area; if any were originally present they presumably were removed by pre-Carbon Ridge (pre-Wolfcamp) erosion".

Douglass (1952, p. 24-25) in the Cherry Creek Range, north of Ely, found Pennsylvanian strata no younger than Desmoinesian. Douglass reported that Fusulina-bearing Desmoinesian strata are directly overlain by Wolfcampian rocks.

Nearer the Elko-Wells-Wendover area there is the reported presence of Late Pennsylvanian, in addition to Middle Pennsylvanian strata. Hence, the occurrence of Late Pennsylvanian rocks in the northern Ruby Mountains is not to be considered unusual for this region. For example, Dott (1955) reported Late Pennsylvanian fusulinids in his Strathern formation of the Elko region to the west; and Douglass (1952) reported Late Pennsylvanian fusulinids from the Toana Range to the east. In the Spruce Mountain area, south of Wells, both Middle and Upper Pennsylvanian rocks have been reported. Middle Pennsylvanian rocks were reported by Hague (1877, p. 511) who collected Productus Nebrascensis and Fusulina cylindrica "from the ridge north of Spruce Mountain, and from a number of other localities." Harlow (1956, p. 22) collected Wedekindellina from Pennsylvanian Ely? limestone, which reportedly (Thompson, 1948, p. 22) is limited to the "Zone of Fusulina" of upper Middle Pennsylvanian age. Upper Pennsylvanian beds occur in Harlow's "limestone-siltstone unit" which was tentatively dated as "Missouri-Virgil, Virgil-Wolfcamp, and Leonard" (Harlow, 1956, p. 25). Further, Dott (1955, p. 2281) reported "probably Upper Pennsylvanian, Triticites-bearing limestones east of Spruce Mountain (T. 25N., R. 70E.) succeeded by thick Wolfcampian siltstones and limestones ... ."

Unfortunately, in the present area the stratigraphic relations between the Late Pennsylvanian and the earlier Pennsylvanian strata are not definitely known due to structural complications and incomplete sections in often widely separated areas. Whether these strata represent an upper part of the Ely limestone which was here preserved, but was removed in the Ely district by pre-Wolfcamp erosion is not known. Age-wise, the rocks would correlate with parts of the Oquirrh formation of Utah, the Wells and Wood River formations of Idaho, and the Strathern formation of the Elko region, but it would seem premature to make a specific nomenclatural correlation at this time.

For the present, all Pennsylvanian rocks in the mapped area, including those of Virgilian age, are mapped together as Ely limestone. The fossil localities denoting older and younger Pennsylvanian strata have, of course, been shown on the accompanying geologic maps and will facilitate later work.

The minimum thickness of Pennsylvanian strata preserved in the northern Ruby Mountains and East Humboldt Range is tentatively estimated to be 2500 to 3000 feet.

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The minimum thickness of Pennsylvanian strata preserved in the northern Ruby Mountains and East Humboldt Range is tentatively estimated to be 2500 to 3000 feet.

Permian System

Introduction

A minimum of 4000 feet of Permian strata ranging in age from Wolfcampian to Guadalupian* is present in the northern Ruby-East Humboldt Range. The lower 2600 feet or so of Permian strata are correlated with the Arcturus formation of east-central Nevada. This unit consists of limestone, arenaceous and argillaceous limestone, siltstone, sandstone, chert pebble conglomerate, and chert and limestone pebble conglomerate.

The upper 1400 feet of Permian rocks includes elements characteristic of the Gerster formation of west-central Utah, the Phosphoria formation of southeastern Idaho and western Wyoming, and the Kaibab formation of northwestern Arizona; but the succession appears to most nearly resemble the Park City formation of north-central Utah, both in lithologic character and in the stratigraphic position and relative thickness of its members; and therefore, rather than introduce new nomenclature, it is tentatively correlated with the Park City formation. The type locality of the Park City formation, in turn, reportedly contains elements characteristic of: 1) the Gerster formation (T. M. Cheney, written communication, 1957); 2) the Phosphoria formation (Baker and Williams, 1940; McKelvey et al, 1956 and others); and the Kaibab formation (Baker and Williams, 1940).

The "Park City formation" in the present area can be subdivided into four mappable members. The lower member consists of about 200 feet of grey ridge-forming limestone, and probably correlates with at least part of the lower member of the type Park City formation, and may correlate with part of the more distant Kaibab formation. This lower member of the "Park City formation" is overlain by a phosphatic chert member, 150 feet thick, which probably is in part equivalent to the Rex Chert and possibly the Meade Peak member of

* or possibly younger (see J. S. Williams' discussion in McKelvey et al,1956,P.2858)

the Phosphoria formation (most recently discussed by McKelvey et al, 1956, p. 2845-48). This phosphatic member is overlain by a unit consisting of limestone, dolomite, and tan chert; which is in turn overlain by 80 to 100 feet of a richly fossiliferous limestone containing a *Punctospirifer pulcher* fauna. These two upper mappable units probably correlate with the upper member of the "Park City formation" in the north-central Utah area, which was recently designated the Franson member of the Park City formation (McKelvey et al, 1956, p. 2842). The uppermost of these two mappable units probably also correlates with the upper part of the Gerster formation in northwestern Utah (Nolan, 1930). T. M. Cheney has mentioned (written communication, 1957) that this same unit is present at the type locality of the Park City formation.

Arcturus Formation

Introduction

The Arcturus "limestone" was defined by Spencer in the Ely district (1917, p. 28) as a Pennsylvanian formation. Later studies have shown that the unit is Permian. The Eastern Nevada Geological Society Stratigraphic Committee (1953, p. 146-7) placed the Arcturus formation entirely within the Permian. Knight, (1956, p. 773-74) found *Parafusulina*, *Schwagerina*, and *Pseudofusulina* in a stratigraphic interval within the Arcturus formation, and demonstrated that this interval he studied is "equivalent to a zone bracketing the upper Leonard and lower Word formations of Texas".

The Arcturus formation outcrops in widely separated areas in the northern Ruby-East Humboldt Range. The unit is exposed on the east flank of the northern East Humboldt Range, along the ridge crest of the southernmost East Humboldt Range, and on both the east flank and the northern end of the northern Ruby Mountains.

The Arcturus formation in the mapped area is rich in fusulinid-bearing rocks of both Wolfcampian and Leonardian age. Because of structural complexities, however, the base of the formation has not been established, and the stratigraphic relations between the Arcturus formation and the upper Pennsylvanian strata are not known at present. Both older and younger units within the Arcturus formation are variously in thrust contact with underlying Devonian, Mississippian or Pennsylvanian rocks, and members within the Arcturus are clearly truncated by the underlying thrust plane.

Southern East Humboldt Range

The upper boundary of the Arcturus formation was established at the southern end of the East Humboldt Range where the overlying "Park City formation" is exposed. This upper contact is lithologically well defined and mappable, and is placed at the base of the resistant grey limestone member of the lowermost "Park City formation". The stratigraphic relationships of the Arcturus formation had to be established from the top down and not from the bottom up, and hence the writer will first proceed to describe the formation in reference to the overlying "Park City formation".

An estimated minimum of 1500 feet of the upper Arcturus strata underlie the "Park City formation" in the southern East Humboldt Range, but lower Arcturus strata is found in other areas. The upper Arcturus rocks outcrop for three-quarters of a mile along the ridge crest northwest of the Polar Star mine. The beds strike northeast and have an average dip of approximately 30 degrees to the southeast. The entire succession dips into an underlying low-angle thrust plane and is truncated by it. Fusulinids found in the lower portion of this upper Arcturus section are Leonardian in age. The apparent absence of fusulinids in approximately the upper 1475 feet of the 1500 feet of section to be described prevents giving any precise age for the upper portion of the sequence exposed in the East Humboldt Range.

Lithologically, the upper Arcturus succession contains rocks showing all gradations between limestones and siltstones. In addition, there are several beds of chert pebble conglomerate. The section is predominantly grass-covered. The slopes are subdued and are essentially devoid of prominent ridge-forming limestones.

The rocks in the upper Arcturus formation immediately below the "Park City formation" are charactericaIly rusty-orange weathering silty limestones. These prevail for several hundred feet, and are underlain by medium grey weathering, dark grey, fine-grained limestones and some chert pebble conglomerate layers. In one of the massive grey limestones roughly 800 feet below the "Park City formation" (locality J 9 on Map No. 4) a large Dictyoclostus sp. was found. At J 11 (approximately 1500 feet N73° W. of J 9) Omphalotrochus sp. was collected very close to a fault. The beds in this area show a variety of attitudes, and talus of igneous dike rock is present. For these reasons the precise stratigraphic position of Omphalotrochus sp. is not known, but it is roughly estimated to be 1050 feet below the "Park City formation". Omphalotrochus is a widespread index fossil of the Permian. It is found in Wolfcampian rocks in the southwestern U. S. and in the Phosphoria formation in Idaho (Mansfield, 1927, p. 76). In the Moorman Ranch Arcturus section west of Ely, Nevada, Knight (1956, p. 774) reports that W. H. Easton identified both Omphalotrochus and Dictyoclostus ivesi in various horizons in the "Zone of Parafusulina" as definied by Thompson (1948). Easton designated the Omphalotrochus collected by this writer as Wolfcamp or Leonard. Its stratigraphic position, however, would indicate a Leonardian age at this locality.

Some dark grey limestones in the Omphalotrochus interval show cross-sections of numerous small thin-shelled organisms (brachiopod fragments?) and some limestones contain bryozoans. One large unidentified gastropod cross-section measuring 2 inches in diameter was also collected. These particular fossil-bearing rocks were found on the east side of the ridge crest in the NE¼ of NW¼, Sec. 16, T. 33N., R.61E.

Stratigraphically below the interval described above, occurs yellowish to light olive grey weathering, thin-bedded, medium grey to yellowish-brownish fine-grained argillaceous limestone. Both platy and massive, reddish to dark yellowish orange argillaceous limestones and calcareous siltstones are also present. Leonardian fusulinids occur in a highly calcareous, light yellowish brown, and light greyish red to pale red siltstone that occurs about 1475 feet below the "Park City formation". At locality F 35 Gerald Marrall identified: Schwagerina sp. and Parafusulina sp. res. P. visseri var. lata Reichel 1935, Leonardian (good).

Numerous scattered patches of yellow-orange porphyritic intrusives and structural complications made it impractical to continue measurements much below the fusulinid-bearing rocks. In this underlying, unmeasured interval, there are present many orange-weathering, platy argillaceous limestones, in addition to some light grey to greyish black limestones. Light yellowish brown siltstones, and yellowish orange-brown chert grits also were observed. There is quite possibly an additional 500-1000 feet of Arcturus strata in this unmeasured interval.

An anomolous mass of reddish-tinted, dark grey limestone of Pennsylvanian age in this interval, containing Dictyoclostus portlockianus (specimens identified and dated by W. H. Easton), is apparently an outlier from the large thrust mass of Pennsylvanian strata which overrides Permian strata on the west flank of the southern East Humboldt Range.

On the basis of the foregoing data, much, if not all of the upper portion of the Arcturus formation in the southern East Humboldt Range is Leonardian. However, inasmuch as no diagnostic fossils were found in the upper 800 feet of the Arcturus formation or in the lower member of the "Park City formation" it is presently impossible to establish a Leonard-Guadalupian boundary within the Permian sequence.

A large isolated mass of Arcturus strata lies about one-half mile south of the Polar Star Mine. (The mine symbol shown on the Halleck quadrangle for the Polar Star Mine, incidentally, is apparently misplaced. Its proper location is shown on the accompanying geologic map of the area.) The following fusulinids were identified (localities are shown on Map No. 4): B 61:*Parafusulina sp.---Leonardian*. R 13:* Parafusulina sp.---Leonardian (fair)*. B 63:* Parafusulina shaksgamensis var. crassimarginata---Leonardian.* R 17: * Parafusulina sp. res. P. schucherti Dunbar and Skinner 1937?, *Parafusulina sp. res. P. visseri var. lata Reichel 1935?, *Schwagerina sp. res. S. wellensis Thompson and Hansen 1954, **Pseudofusulinella utahensis?, and **Oketaella sp.---Leonardian (fair)*; likely middle to upper Wolfcampian.**

Northeastern East Humboldt Range

The Arcturus formation occurs on the northeastern flank of the East Humboldt Range--east and northward from Angel Lake. The Arcturus formation in this area is in thrust contact with both lower and upper portions of the Pennsylvanian Ely limestone. The succession is internally faulted and its complete thickness is not known. All fusulinids collected from the section are Leonardian in age.

The section is best exposed on the long northerly trending ridge east of Trout Creek. Here the units strike north to northwesterly for about three miles, all the way to the northern end of the range. The rocks generally dip to the east, but there are exceptions. The slopes are quite subdued, but a few ridge-forming members do occur. Trees are virtually absent from all but the easternmost spurs which extend outward toward Clover Valley from the main

* In October, 1956, H. J. Bissell kindly furnished preliminary determinations for much of the author's Ruby-East Humboldt fusulinid collection, prior to a later more thorough study by Gerald Marrall in Compton, California. Bissell studied a series of 70 randomly oriented thin-sections, and from them provided the author with tentative identifications and ages. This allowed the author to work on several stratigraphic and structural problems while the material was in California being studied by Marrall. Marrall and Bissell thus worked independently and neither were aware of relative stratigraphic positions of the samples. Nor were either aware of the other's findings. Their individual identifications and age determinations are therefore as objective as possible. Understandably, sometimes each found some genera or species not observed by the other, and in some instances, they differed on whether the sample was Wolfcampian or Leonard.
Published information on the Wolfcamp-Leonard boundary in Nevada is non-

north-northwest trending ridge.

The Arcturus succession here predominantly consists of platy to massive limestones, calcareous siltstones and sandstones. The platy limestones are often greyish black, thinly bedded and fine-grained. They weather light brownish grey, pale brown, pale yellowish brown, and light olive grey. In one rare vertical exposure of these platy limestones (roughly 1½ miles due north of Angel Lake) some small scale intraformational folding and even overfolding was observed; these features probably represent local gravity sliding. The calcareous siltstones and fine-grained calcareous sandstones are generally seen as talus fragments which weather light orange-brown to pale reddish brown.

The massive resistant layers of variously argillaceous limestones can be seen protruding from talus covered slopes on the east side of Trout Creek, and on the tree-covered spurs on the easternmost flank of the range. Some of these limestones contain fusulinids, and some contain strophomenoid brachiopods and trepostome bryozoans. These massive limestones are light olive grey to dark grey and are generally fine-grained. They weather yellowish grey to pale yellowish brown, and locally light orange-brown.

Six fusulinid localities were found. However, because there are no topographic maps available for the northern East Humboldt Range, these localities cannot be located on a land grid with great accuracy. The locations given are therefore only approximate.

The most accessible fusulinid locality lies about two-thirds of a mile east of Angel Lake. The McCarran Way gravel road makes a horseshoe turn around the locality and then heads westerly toward Angel Lake. The locality

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existant and its position and correlation with the Texas Permian is still a problem. Marrall stated in a letter to this author dated February 12, 1957, that "Usually it is a matter of the Wolfcamp-Leonard boundary which causes the questions. At the present time I haven't enough control across it to be extremely accurate." Bissell (personal communication) is in agreement with Marrall in this regard.

Marrall's designations will be indicated by a *; Bissell's designations will be indicated by **.

(A 54 on Map 1) is on the peak of a spur composed of massive argillaceous limestone and calcareous siltstone which overlies a sequence of platy dark grey limestones. Fusulinids are also present in the roadcuts below the peak. Gerald Marrall identified Parafusulina res. P. skinneri and Schwagerina sp., of Leonardian age from this locality.

North-northwest of locality A 54, near the peak at the eastern end of the prominent ridge spur that lies between Angel and Clover creeks, are localities N 8 and N 12. The following fusulinids of Leonardian age were identified: (N 8) *Parafusulina sp. and *Schwagerina sp.---Leonardian (poor)*; (N 12) *Parafusulina sp., Pseudofusulina sp. res. P. juresanensis Rauser-Cernoussova 1940, and *Schwagerina sp. --- Leonardian (good).* Marrall stated that the "Pseudofusulina resembles forms from the upper Leonardian Series in Russia."

At locality D 17, which lies northeast of N 12, the following fusulinids were identified: *Parafusulina sp. res. P. apiculata Knight 1956, **Schwagerina sp., **Pseudofusulinella utahensis?, and **Oketaella sp. --- Leonardian (good)*; likely middle to upper Wolfcampian.**

A silty light olive grey limestone at locality N 17 contains:*Boultonia? sp., *Parafusulina sp. res. Parafusulina schucherti Dunbar and Skinner 1937, and Parafusulina sp. --- Leonardian (fair).*

Southwestern East Humboldt Range

Both Wolfcampian and Leonardian strata of the Arcturus formation are present in this area, and one locality was discovered which may be an excellent place for future study of the Wolfcamp-Leonard boundary.

Lower Permian strata rest in thrust contact on lower Ely limestone and also on members of the metamorphic basement. The rocks here do not particularly differ in lithology from the Arcturus strata previously described, containing platy to massive greyish limestone, yellowish grey to yellowish orange argillaceous limestones and siltstones, and in addition, some chert and limestone pebble conglomerates.

Both Wolfcampian and Leonardian fusulinids were collected in an approximate 100-foot interval at locality K 4 (Map No. 2). Within this interval is a narrow zone of yellowish grey to moderate olive grey weathering, fine- to medium-grained, brownish grey coralline limestone which is made up of a colony of Corwenia sp. (identified by W. H. Easton). Rather remarkably and accurately, Easton dated this coral as "at about the Wolfcamp-Leonard boundary", although he was not aware of its stratigraphic position with respect to both the Wolfcampian and Leonardian fusulinids collected in this interval.

The Wolfcampian fusulinids identified by *Marrall and **Bissell in this interval are shown on Table 1. (The lower case letters beside K 4 simply designate individual rock specimens and do not imply relative stratigraphic positions.) Both Bissell and Marrall were in agreement as to the Wolfcampian age for the specimens. Marrall dated K 4k, K 4e, K 4m, and K 4i as Wolfcampian (good), and K 4r and K 4j as upper Wolfcampian (fair). Bissell dated K 4k, K 4r and K 4e as likely middle Wolfcampian, and K 4i and K 4j as upper to middle Wolfcampian.

The following two specimens (K 4f and K 4v) may possibly have been collected at or near the Wolfcampian-Leonard boundary: (K 4f) *Parafusulina sp. res. P. schucherti Dunbar and Skinner 1937, *P. sp. res. P. skaksgamensis Reichel var. crassimarginata Knight 1956, *Schwagerina sp., **Pseudofusulinella sp., and **Schwagerina elkoensis?; (K 4v) *Parafusulina sp. res. P. schucherti Dunbar and Skinner 1937, *Parafusulina sp. res. P. visseri var. lata Reichel 1935, and Schwagerina sp. Specimen K 4f was dated by Marrall as Leonardian (good) and by Bissell as likely middle Wolfcampian. Specimen K 4v was dated by Marrall as Leonardian (fair); it was not examined by Bissell.

Fusulinids which were found at other localities (Map No. 2) in the southwestern portion of the East Humboldt Range are shown on Table 2. The ages of these assemblages and their approximate land grid locations are given in the

TABLE 1

	K4c	K4i	K4j	K4k	K4m	K4r
Oketaella sp.	**					
Parafusulina sublinearis						*
Paraschwagerina sp.		?**				
Pseudofusulinella sp.				**		
Pseudofusulinella utahensis?			?**			**
Pseudoschwagerina sp.	**	**				
P. sp. res. P. convexa		*				
Schwagerina sp.			?**	*		?**
Schwagerina elkoensis	**	?**		?**		
Schwagerina wellsensis	?**				res. *	
Schwagerina aculeata		res.*		res.*	res.*	
S. res. S. aculeata var. plena				*		
Schwagerina linearis	*		*			
Triticites sp.				*	*	
T. sp. aff. T. californicus				*		
T. sp. res. T. secalicus var. oryziformis		*				

* Identification by G. Marrall
** Identification by H. J. Bissell

Appendix.

Northern Ruby Mountains

Units of the Arcturus formation outcrop on the east flank and northern end of the Northern Ruby Mountains. Both Wolfcampian and Leonardian strata are present, and the lithologies are essentially the same as the previously described areas. Different portions of the Arcturus succession are variously in thrust contact with underlying Pennsylvanian and metamorphic rocks.

The fusulinids collected in this area (Map No. 3) are shown on Table 3. The ages of these assemblages and their approximate land grid locations are given in the Appendix.

TABLE 2

	A25	A26	B7	G33	G43	K1-2	K5	K6	K27	K29	K45	R1b	G32
<u>Oketaella</u> sp.			?*	**				**			**	**	
<u>Parafusulina</u> <u>bosei</u>?										**			
<u>Parafusulina</u> <u>gracillis</u>		?*			res*								
<u>P</u>. sp. res. <u>P</u>. <u>schucherti</u>							*		*				
<u>P</u>. <u>shaksgamensis</u> var. <u>crass-imarginata</u>			*				*		res*				res*
<u>Parafusulina</u> <u>sublinearis</u>												*	
<u>Parafusulina</u> <u>sublinearis</u> type						*							
<u>P</u>. res. <u>P</u>. <u>visseri</u> var. <u>lata</u>	*												
<u>Parafusulina</u> sp.			*	?**				*	*	*	?* **		
<u>Pseudofusulinella</u> <u>utahensis</u>?												**	
<u>Pseudofusulinella</u>? sp.							**	**					
<u>Pseudofusulina</u> <u>lativentra</u>?													*
<u>Schwagerina</u> sp.		*		* ?**			* **	* **	*	**	*		*
<u>S</u>. cf. <u>S</u>. <u>guembeli</u>			*										
<u>S</u>. res. <u>S</u>. <u>wellsensis</u>					*								
<u>S</u>. sp. res. <u>S</u>. <u>crassitectoria</u>											*		
<u>Triticites</u> sp. res. <u>T</u>. <u>secalicus</u> var. <u>oryziformis</u>				*									

* Identification by G. Marrall
** Identification by H.J. Bissell

	A17	A20	A21	P 3	P 5	S 1	S 2	S7c	S 8	S11a	S11b	S12	S13	S14	S15	S22	S23	S24	S25	S26	S33
Dunbarinella sp.																			*		
Oketaella? sp.														*							
Ozawainella? sp.																*					
Parafusulina sp.	*		*		**	?*	*		?**			?* **	* **		*	?**	*	*	**		
P. shaksgamensis var. crassimarginata								* res.				*	cf*		* res.						
Parafusulina sublinearis		*								*										*	
Parafusulina rothi?							**											**			
Parafusulina visseri	cf*										* res.										
Pseudofusulina sp.					?*			*	?*		?*			?*	?*	?*					
Pseudofusulinella utahensis?												** cf.									
Pseudofusulinella? sp.										**	**										
Schwagerina sp.			*	*	**	*					*			* **		*				*	*
Schwagerina elkoensis?											**										
Schwagerina wellsensis										?**				* res.							
S. sp. res. S. mucronata												*									
Schwagerina sp. res. S. turki																			*		
Stafella sp.																*					
Triticites sp.		*		?*																	?*

* Identification by G. Marrall
** Identification by H. J. Bissell

TABLE 3

"Park City Formation"

The name Park City formation was given by Boutwell (1907, p. 443-446) to beds underlying the red shales of the Triassic Woodside formation and overlying the Pennsylvanian Weber quartzite in Big Cottonwood Canyon near Salt Lake City, Utah. In its type area, the Park City formation has been reported to consist of three members, an upper and lower member both composed mainly of carbonate rocks, and a middle member composed of phosphatic shale and chert. The lower carbonate member is reportedly a lateral equivalent of at least part of the Kaibab formation (A. A. Baker and J. S. Williams, 1940, p. 631-634). The middle member is reported to be continous with the phosphatic shale member of the Phosphoria formation (Richards and Mansfield, 1912, p. 684-689). The upper carbonate member has recently designated the Franson member of the Park City formation(McKelvey _et al_, 1956).

Lower limestone

Overlying the Arcturus formation in the southern East Humboldt Range is 200 feet of massive, ridge-forming, yellowish to medium light grey, fine- to coarse-grained limestone which is locally dolomitic. The unit contains irregular pods and layers of milky, light tan, and dark grey chert, particularly in the lower portions. The formation is locally fossiliferous, containing brachiopod and crinoidal hash, but no forms were good enough for specific identifications beyond the recognition of some productids?. Crinoidal hash is particularly prevalent in the uppermost portion of the unit.

Phosphatic member

In the southern East Humboldt Range, a weak saddle-forming unit consisting of about 150 feet of chert, phosphatic rock, siltstone, and shale, overlies the lower member of the "Park City formation". The unit yields a predominantly black, greyish red, brown, and yellowish brown talus. Outcrops are best observed on the crest of the southern East Humboldt Range (SW$\frac{1}{4}$, Sec. 16, T.33N., R.61E.), northwest of the Polar Star Mine. The unit's saddle-forming character is fairly well displayed for about one mile down the west flank of the range lying due south of the southwesternmost corner of the National Forest boundary.

Carbonate and chert member

Overlying the phosphatic member of the "Park City formation" (which was measured in the N$\frac{1}{2}$ of NE$\frac{1}{4}$, Sec. 31 and the N$\frac{1}{2}$ of NW$\frac{1}{4}$, Sec. 32, T.33N., R.61E.) is about 940 feet of essentially unfossiliferous grey limestone, dolomite, and tan chert. The basal portion of this essentially unfossiliferous succession consists of about 20 feet of yellowish to light grey weathering, fine-grained, light grey dolomite, overlain by about 70 feet of light brown to light orange brown massive chert. The chert is overlain by massive, light grey weathering, fine-grained limestones and dolomites which often contain orange weathering, brownish to dark grey chert pods and layers. Some white chert layers and some irregular "rings" of white chert one-half inch to 1$\frac{1}{2}$ inches in diameter are also present. One spiny productid was found in one of the limestones. These limestones form small ridges separated by talus-covered slopes of often orange to yellowish brown, argillaceous limestones. The upper portion of this chert and carbonate member of the "Park City formation" consists of about 50? feet of poorly exposed light brown chert, which is similar to the thick chert layer at its base.

Upper member

The phosphatic member of the "Park City formation" is overlain by 80 to 100 feet of mostly massive, very fossiliferous limestone. The limestone is ridge-forming, and near its base are numerous layers of black chert. At a distance the chert layering appears quite regular. In detail, however, there is considerable variation in the thickness of the chert layers and the distance between them. The tops and bottoms of the layers are not straight but form irregular undulations. The limestone is mostly yellowish to olive grey and fine-grained. Some portions of the limestone are argillaceous and weather in shades of yellowish brown and greyish yellow. This upper member of the "Park City formation" outcrops on the east side of the ridge that lies west and north of the Echo Mine, and also on the southern flank of an east-westerly trending ridge that lies about 1½ miles north of the Polar Star Mine.

W. H. Easton kindly identified the fossil collections from this member and indicated that they are Guadalupian in age. Specimens were collected from these localities (Map No. 4): B 19 (W½ of NW¼ of NE¼, Sec. 32, T.33N., R.61E.); J 8 (W½ of SE¼ of SW¼, Sec. 29, T.33n., R.61E.); O 12 (on the western boundary of the SW¼ of NW¼ of NE¼, Sec. 15, T.33N., R61E.). The following fauna are reported:

Fossil name	B19	J8	O12
Horridonia subhorrida	X	X	X
Yakovlevia? multistriata	X	X	X
Echinochonchus nevadensis	X	X	X
Neospirifer cf. *N. pseudocameratus*	X		
Neospirifer sp.		X	
Composita mira	X		X
Composita sp.		X	
Waagenoconcha sp.		X	
Punctospirifer hilli?			X
Punctospirifer pulcher			X
Polypora sp.			X
Fenestella sp.			X
Trepostome bryozoans		X	

Triassic System

Lower Triassic strata is present in the Polar Star Mine area in the southern East Humboldt Range.

J. P. Smith (1932) was evidently the first to report Triassic strata in northeastern Nevada, and since that time, H. E. Wheeler, et al (1949), Scott (1954), Snelson (1955), Harlow (1956), Nelson (1956), and Stokes and Clark (1956), have reported on various Triassic occurrences in this region.

The lower portion of the Triassic sequence in the southern East Humboldt Range consists of several hundred feet of shales and greyish brown limestones, overlain by some ridge-forming medium to dark grey terebratulid-bearing limestones with intercalated shales. Overlying these ridge-forming limestones is a succession of rather poorly exposed shales, siltstones, and limestones which yield a yellowish to reddish soil. The shales and siltstones rarely outcrop; the often argillaceous, platy to massive limestones weather in shades of grey, yellow, orange, and brown.

In surrounding areas the greyish "chocolate" brown limestones near the base of the succession yield a rich ammonite fauna. J. P. Smith (1932) reported a Meekoceras fauna in similar limestones near Phelan Ranch, Elko County, Nevada. In the southern East Humboldt Range, no identifiable ammonoids were found in this distinctive lithologic interval; however, in the overlying grey ridge-forming limestones Terebratula thaynesiana occurs, a small brachiopod commonly found in the Lower Triassic Thaynes group of Idaho (Mansfield, 1927, p. 435-6). Pectinoid pelecypods were found in several localities, and some incomplete specimens identified by the writer resemble Monotis superstricta (White) var. parksi Girty (M. superstricta = Aviculipecten superstrictus of White and others), a pectinoid which is also found in the Lower Triassic Thaynes group of Idaho. The terebratulids were collected at localities R 11 (NE¼ of SW¼, Sec. 21, T.33N., R.61E.) and B 46 (westernmost boundary of NW¼ of SW¼ of SE¼, Sec. 21, T.33N., R 61E.). The pectinoids were found at F 24 (NE¼ of SW¼ of SW¼, Sec. 28, T.33N., R.61E.), R 14 (NW¼ of NW¼ of NE¼, Sec. 28, T.33N., R.61E.), and R 21 (half-way between the section corners shared by sections 15 and 22). R 21 yielded the best pectinoid collections.

No formal published nomenclature exists at the present time for the Lower Triassic strata in northeastern Nevada, however, Wheeler et al (1949) reported that the Lower Triassic strata near Currie, Nevada, appeared lithologically similar to the Woodside and Thaynes formations. Scott (1954), in an unpublished Ph.D. thesis, reported a section at Currie and in the southern Pequop Mountains as the Thaynes(?) formation. In unpublished masters' theses by Snelson (1955), Harlow (1956), and Nelson (1956), essentially identical Lower Triassic successions were delineated into a basal Dinwoody(?) formation consisting of greenish shales and brownish limestones, and an overlying Thaynes(?) formation characterized by ridge-forming grey limestones at its base. These same two lithologic units were recognized in the southern East Humboldt Range, but they were not measured or separately mapped. Clark recently finished a Ph.D. thesis on the Triassic rocks of eastern Nevada, however he did not use formational names in his study (David L. Clark, written communication, 1957).

CENOZOIC STRATIGRAPHY

Tertiary

Introduction

Over 4800? feet of Tertiary continental sedimentary and volcanic rocks are exposed on the flanks of the East Humboldt Range. These have been tentatively subdivided into four units.

The lowest unit consists of a minimum of 1750 feet of heterogeneous fine-grained to conglomeratic strata particularly rich in volcanic and volcanic-derived material. This succession rests unconformably on pre-Tertiary rocks, and is characterized by an abundance of red and green beds. The unit is best exposed in the northwestern portion of Clover Valley and possibly the same unit is exposed in the area of the Secret Creek gorge in the vicinity of Dorsey Creek. This sequence will be referred to as the Clover Valley unit.*

The overlying succession is distinguished from the Clover Valley unit both in overall lithology and color. This unit is mostly light in color and is roughly estimated to be 2500? feet thick. It contains numerous platy mudstones and siltstones, as well as tuffaceous sandstones and grits, fresh water limestones, pebble conglomerates and limestone breccias composed of Paleozoic rocks, rhyolitic tuffs and flows? and layers of reworked ash. The unit is widely exposed on the west flank of the range just east of Starr Valley, and on the east flank of the range in the northern portion of Clover Valley. Portions of the unit rest directly upon pre-Tertiary rocks on the west flank of the range.

* The names for local Tertiary units in this report are tentative and are not intended as formal designations.

CENOZOIC STRATIGRAPHY

AGE	INFORMAL NAME	BRIEF DESCRIPTION	THICKNESS
Pleistocene - Recent	---------	alluvium, pediment and terrace gravels, glacial moraines and outwash	--
Pleistocene or Late Tertiary	Warm Springs unit	andesitic to basaltic rocks at the southern end of the East Humboldt Range	200?
Lower or middle Pliocene?	Willow Creek unit	mostly reddish brown porphyritic rhyolite	500 ?
Mio-Pliocene?	Starr Valley unit	light colored tuffaceous sanstone and siltstone; also conglomerate, fresh water limstone, vitric tuff, and lenses of Paleozoic-limestone breccia	2500?
Miocene? or earlier Tertiary	Clover Valley unit	Red, green, and buff fine-grained to conglomeratic beds containing volcanic and non-volcanic material; also small patches of acidic volcanic rock	1750?

This succession will be referred to as the Starr Valley unit.

A distinctive succession of essentially light olive grey to reddish brown rhyolitic to quartz latitic porphyry unconformably? overlies the Starr Valley unit. The rhyolite and its tentative correlatives are exposed principally in three areas; 1) at the northern end of Clover Valley where it is crossed by Willow Creek; 2) in the Ralph Creek area to the south; and 3) north of Stephens Creek on the west side of the range. It will be referred to as the Willow Creek unit.

The fourth unit consists mainly of dark-colored andesitic to basaltic lavas which outcrops at the southern tip of the East Humboldt Range southwest of the Warm Springs Ranch. The unit rests directly upon Lower Triassic and Paleozoic strata, and farther to the south, Sharp (1939b, p. 889) reports that it rests upon truncated Tertiary "Humboldt" beds. It will be referred to as the Warm Springs unit.

Previous Work

Local

This writer's Clover Valley unit and overlying Starr Valley unit were previously mapped as "Miocene Humboldt formation" by Sharp (1939b, see Appendix). The acidic volcanics within these two units and the separate overlying mass of Willow Creek rhyolite are shown on Sharp's map as "Rhyolite in Humboldt formation". The dark colored Warm Springs lava at the southern tip of the East Humboldt Range is shown on Sharp's map as "Pliocene? lava".

Regional

The Tertiary deposits in northeastern Nevada were first described by King and Hague in 1877 and 1878. They reported two stratigraphic sequences, an Eocene group which was correlated with the Green River formation of Colorado and Utah, and a sequence of Pliocene strata which was named the "Humboldt group".

with the Tertiary succession exposed in the Dorsey Creek-Secret Creek area on the southwestern flank of the East Humboldt Range. In both areas the sequence rests unconformably upon the pre-Tertiary rocks of the range. The steepest attitudes in the unit were observed in northwestern Clover Valley where beds dip easterly of the steep range flank at angles approximately between 45 and 55 degrees. The unit in Clover Valley is roughly estimated to be a minimum of 1750 feet thick. Its thickness in the Secret Creek gorge area was not calculated.

East flank

Locally, at the base of the Clover Valley unit in the northwestern portion in Clover Valley is a sharpstone conglomerate which consists largely of angular Paleozoic limestone fragments in a greyish red silty matrix. It is exposed in the SW¼, Sec. 34, R.61E., T.37N. Overlying this basal breccia is a sequence largely consisting of volcanic and volcanic-derived rocks. Many of these rocks are greyish red and greyish green indurated tuffs which contain varying proportions of both sedimentary and volcanic rock fragments, as well as crystal fragments in an often glassy matrix. Other tuffs in shades of yellow-orange and grey are also present. Porphyritic acidic volcanics are locally interbedded near the base of the succession.

Higher in the unit are conglomerates and coarse-grained sandstones which contain fragments of earlier sandstones, siltstones, limestones, black quartzite, vitric tuffs, basalts, and miscellaneous volcanic rocks. The volcanic pebbles suggest that at one time a volcanic sequence older than the Clover Valley unit was present in this general area.

West flank

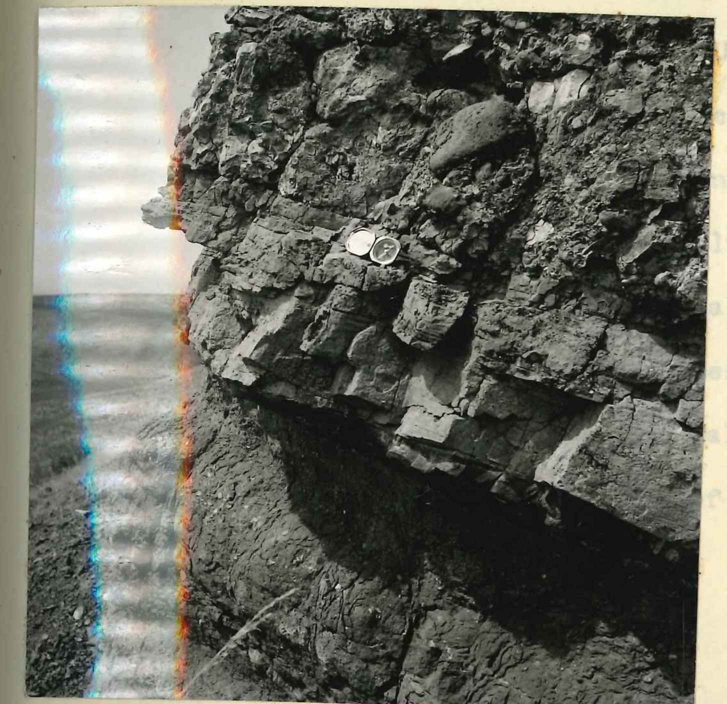
The exposures of the Clover Valley? unit in the vicinity of the western entrance to the Secret Creek gorge differ in stratigraphic detail but are similar in overall aspect to the succession in Clover Valley. This overall similarity of lithology, particularly the volcanic pebble-bearing conglomerates, and the fine-grained tuffaceous red beds, is the basis for tentatively correlating these units. Whether the two successions are exact time equivalents, cannot be proved. In this area, the Clover Valley? unit covers an area extending about a mile west and several miles north from the Secret Creek-Dorsey Creek junction.

The succession rests unconformably upon pre-Tertiary rocks, and this relationship is best observed in the western gorge area north of Secret Creek. Here a wide embayment of greenish-colored Tertiary strata extends eastward for over a mile from the west front of the range and rests directly upon both the metamorphic basement and Upper Paleozoic rocks.

The greenish beds which lap onto pre-Tertiary rocks apparently pass westward under a thick reddish succession of conglomerates and interbedded sandstones, siltstones, and tuffaceous sedimentary rocks. Green- and buff-colored beds are commonly interbedded in this overlying "red bed" succession, but their presence is often obscured by reddish colored talus and soil.

The conglomeratic beds in this area contain not only pebbles of earlier volcanic flows, vitric tuffs, tuffaceous sandstones, Paleozoic limestones, quartzites, and cherts, but occasionally also contain schistose metamorphic rocks. Metamorphics were not observed in the conglomerates of this unit in Clover Valley.

As in Clover Valley, acidic volcanic rocks are present near the base of the succession. A prominent mass of yellowish to reddish brown volcanic rock occurs about one-third mile north of the Secret Creek gorge where it appears to rest upon the green beds of the previously mentioned embayment succession. The rock contains varying proportions of quartz, sanidine, and calcic oligoclase in a partially devitrified dusty glass groundmass. An identical volcanic mass apparently rests directly upon Upper Paleozoic strata about a mile to the north at an elevation about 400 feet higher. In both localities the unit locally



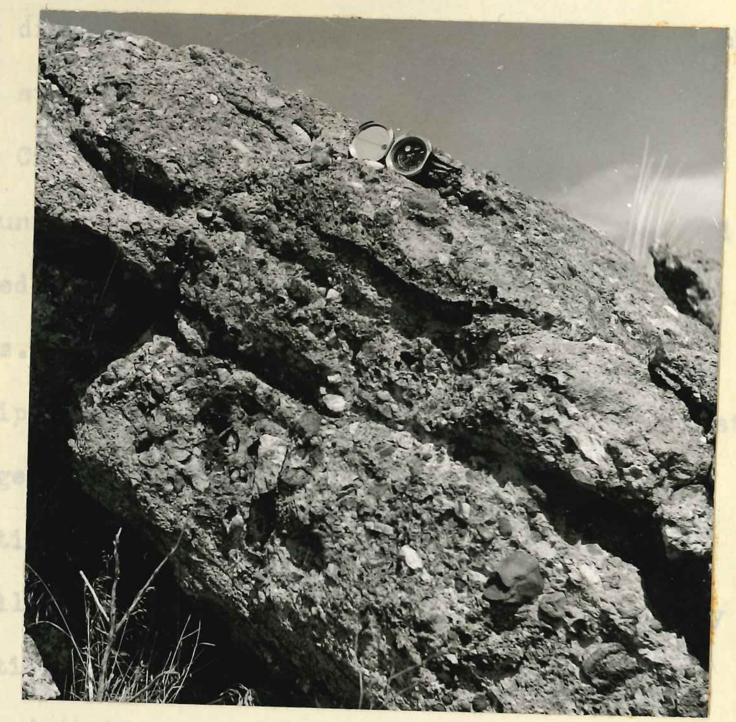


Fig. 52. Red and buff-colored beds tentatively correlated with the Clover Valley unit. These outcrops occur on the ridge north of the first unnamed creek south of Heelfly Creek, on the west flank of the East Humboldt Range. Fine-grained reddish beds in the upper left photograph are rich in vitric tuffaceous material. Conglomeratic beds in both photos are composed of pebbles of volcanic rocks; Paleozoic limestones, cherts, and quartzites; and some schistose metamorphic rocks.

shows small scale fractures filled with fine-grained silica.

Starr Valley Unit

The most widely exposed Tertiary succession in the area is the Starr Valley unit. It is mostly light-colored, and comprises the following rock types: light green to cream-colored claystones, siltstones, and sandstones, which often contain much fine-grained tuffaceous material; platy cream-colored siliceous rocks; white to light brown fresh water limestones; light grey to light brown, friable vitric ash deposits; orange-brown Paleozoic-pebble conglomerates; grey Paleozoic-limestone breccias; and patches of greyish, reddish and brownish acidic volcanics.

West flank

Most of the above rock types are exposed on the west flank of the range beneath a broad westerly-sloping dissected pediment and terrace platform, which is crossed by numerous permanent streams and their intermittent tributaries. The platform extends from Herder Creek southward down the length of the range and extends westward from the mountain flank for about 3 miles. When observed from the west, these light colored deposits form cream-colored bluffs below the pediment and terrace surfaces.

Stratigraphic relationships between the Clover Valley? unit at the west entrance to the Secret Creek gorge and the Starr Valley unit to the north is not known due to the lack of continous exposures. Although an unconformable relationship is suspected, actually the writer cannot disprove the possibility that the two successions are partially laterally continuous with one another.

Friable bedded vitric ash deposits occur high in the Starr Valley succession. They are exposed near the crests of several ridges in the area, and north of Stephens Creek their high stratigraphic position is confirmed by outcrops of the ash near the contact with the overlying Willow Creek? rhyolite.

Interbedded in the succession beneath the ash deposits are all the rock

Fig. 53. Looking northwest on the west side of the East Humboldt Range at bluffs of light-colored, fine-grained beds in the Tertiary Starr Valley unit.

types mentioned, with the exception of the Paleozoic-limestone breccias, which are limited to the east flank of the range.

East flank

The Starr Valley unit is well exposed in Clover Valley between Ralphs Creek and the northern end of the range. The succession here is lithologically very similar to the succession on the west flank of the range, but in addition there are lenses of grey Paleozoic-limestone breccia near its base. The unit may possibly unconformably overlie the Clover Valley unit in the northwestern portion of Clover Valley, as suggested by the divergence of strike between the two units.

The conglomerate beds in the succession are quite distinctive. They are mostly brownish and made up largely of Paleozoic limestones, quartzites, quartzitic chert-pebble conglomerates, and cherts in widely varying proportions. Noteworthy is the virtual absence of volcanic pebbles in these conglomerates, which is in contrast to the conglomerates in the underlying Clover Valley unit. The pebbles of conglomerates, quartzites, and cherts in many of these conglomerates were unquestionably derived from exposures of the Mississippian Diamond Peak formation. The abundance of Diamond Peak material in some of these conglomerates led the author to give the field description "pseudo-Diamond Peak" to these particular beds. They generally break down quite readily, forming brownish to reddish Diamond Peak-talus-covered soil.

An excellent exposure of thinly bedded white tuffaceous siltstone, and massive light grey to light brown ash which is rich in pumiceous glass and which possesses faint cross-bedding, is exposed on the north bank of Ralph Creek about three-quarters of a mile east of the range front. Local ripple mark-like features and penecontemporaneous intraformational folding (presumably due to gravitational slippage and perhaps significantly overturned to the north) of some of the thinly bedded members indicate that these deposits were water-

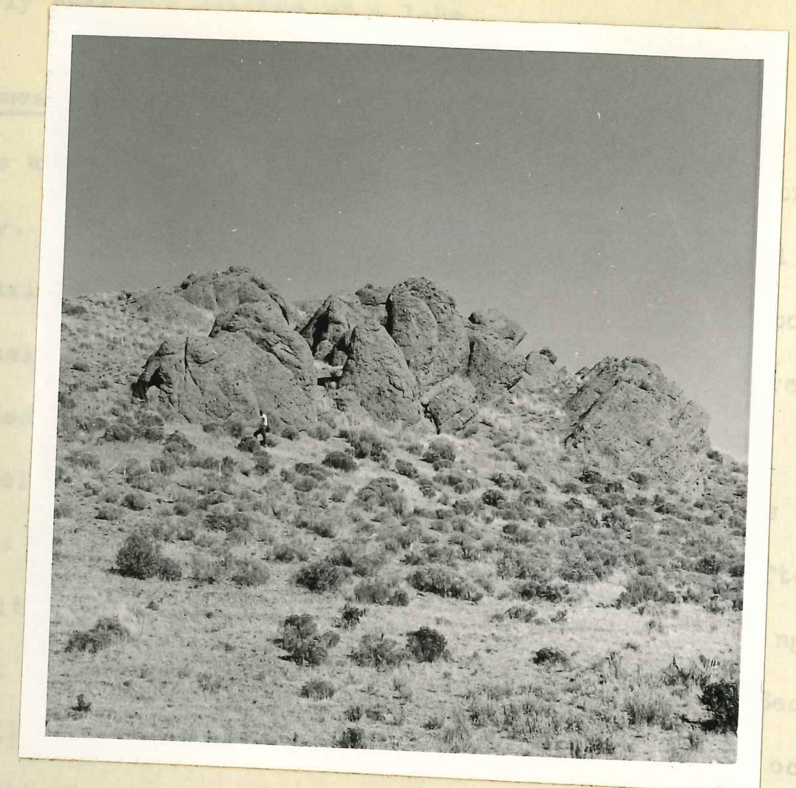


Fig. 54a. Steeply northeast-dipping Paleozoic-pebble conglomerate beds in the Starr Valley unit on the northeast flank of the East Humboldt Range. View is looking south at locality north of the Clover Valley Ranger Station.

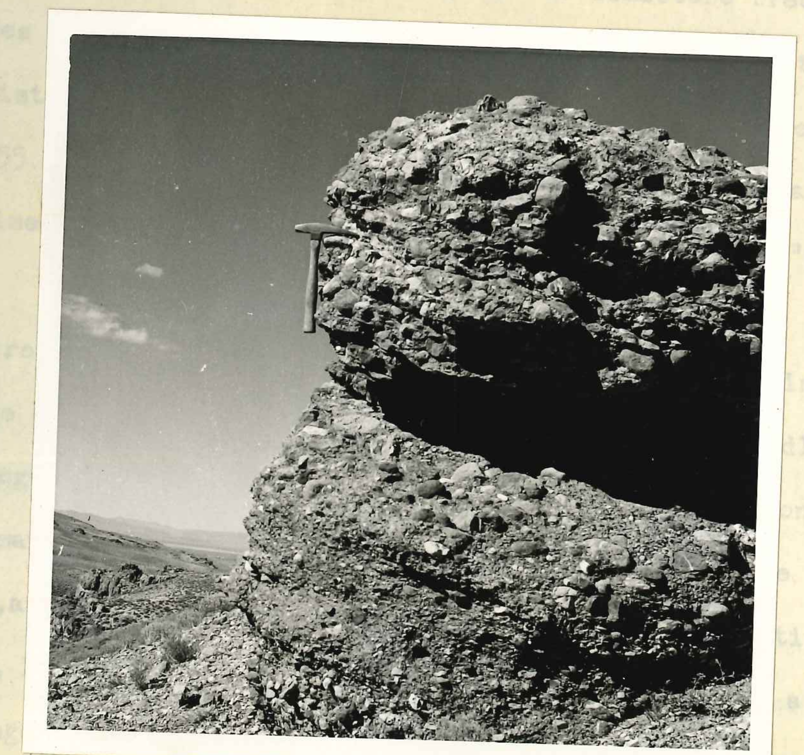


Fig. 54b. Paleozoic-pebble conglomerate in the Starr Valley unit. Looking northward at outcrop east of "Clover Hill" and north of McCarran Way.

laid, probably near the margins of a lake.

Paleozoic-limestone breccias in Clover Valley

There are well over 20 masses of Paleozoic-limestone breccia exposed in Clover Valley. The length of their outcrops vary from several feet to over 1500 feet. The maximum thickness observed at any one outcrop is about 100 feet. Because of their unusual character, these breccias and their relations to the Tertiary succession were studied in some detail.

The relatively resistant nature of the breccias causes them occasionally to form mounds or hogback-like ridges which rise above the softer under- and overlying Teritary strata. Several prominent northerly trending ridges occur in the central part of Clover Valley, north of McCarren Way (Secs. 26 and 30, T.37N., R.61E.). Numerous other patches of limestone breccia occur to the south, to the northeast and northwest.

In the northwest portion of Clover Valley (near Clover Valley Ranger Station), the stratigraphic relationship of the limestone breccias is very clear. Lenses of the breccia dip approximately 45 degrees to the east and occur at several distinct stratigraphic horizons near the base of the Starr Valley unit (Figs. 55 and 56). They are underlain and overlain by platy fine-grained freshwater limestones, siltstones, sandstones, and locally by "pseudo-Diamond Peak" beds.

The breccias vary in the types of limestone they contain and also in the percentage of matrix. In some breccias the matrix can hardly be discerned from the angular fragments, and makes up a very small portion of the rock. In these the matrix consists of a fine-grained limestone of the same color as the fragments,and which weathers flush with the fragmental portion of the rock. In some cases, however, the calcareous matrix is sandy, and is a contrasting yellowish orange color. Other limestone breccias consist of fragments within a less well-indurated matrix composed of limestone chips or calcareous clay-

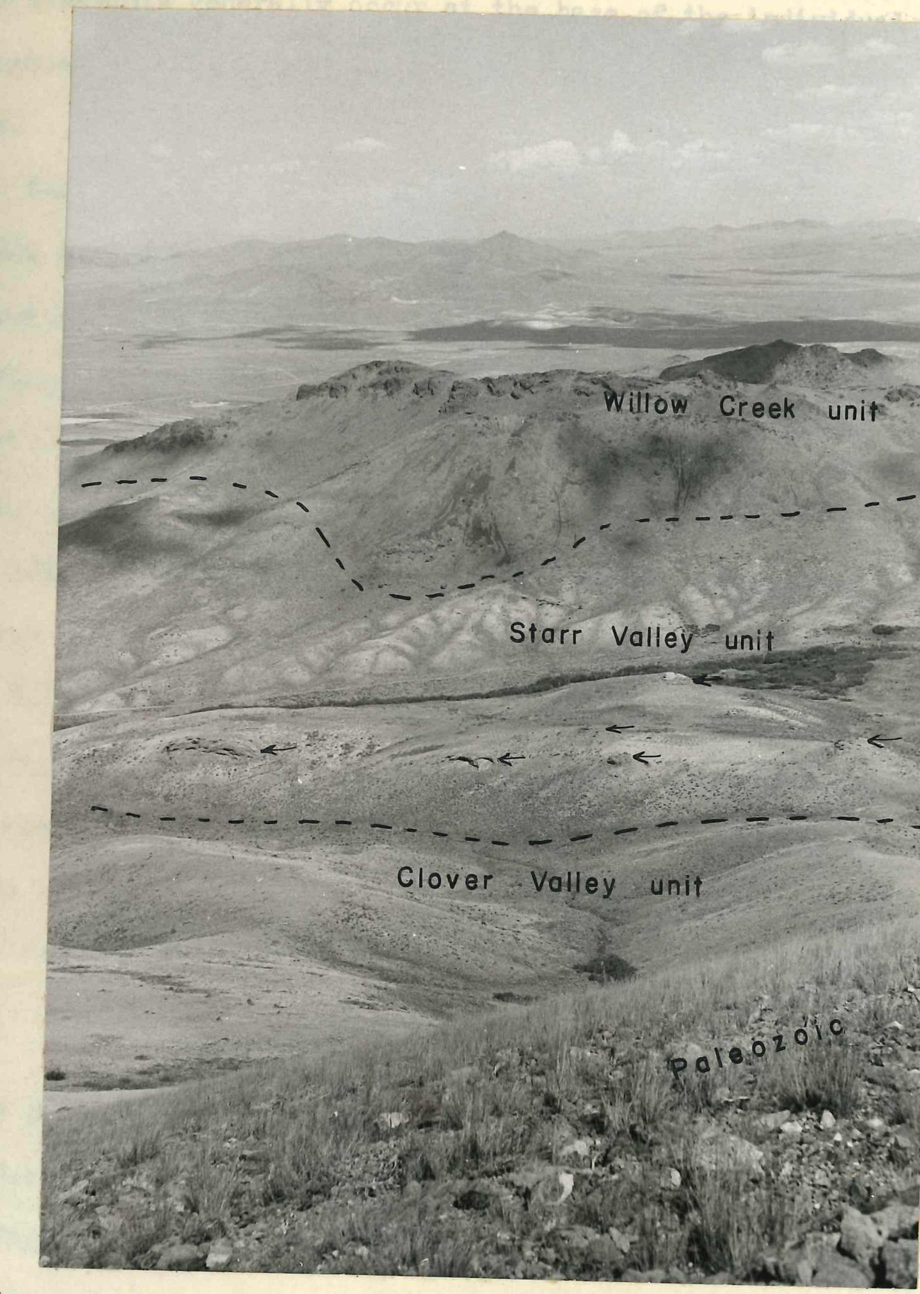


Fig. 55. Looking east and roughly down dip at the east-dipping Tertiary succession in the northwestern portion of Clover Valley. Arrows point to the lenses of Paleozoic-limestone breccia which are interbedded near the base of the Starr Valley unit.

like material. The matrix in these weathers more rapidly, and the larger individual limestone fragments stand out in relief. The size of the individual fragments in these breccias ranges from a fraction of an inch to several feet. The smaller fragments generally occur at the base of the individual breccia mass, and sometimes weather to form cave-like hollows beneath the coarser over-hanging breccia.

The breccias sometimes are composed of one and sometimes of several carbonate rock types. One breccia consisting of several types of Devonian carbonate rocks occurs in the northwestern portion of Clover Valley on a ridge immediately west of the Clover Valley Ranger Station. In this breccia, fragments of light olive grey-weathering Cladapora? -bearing dolomite are haphazzardly intermixed with very dark grey limestone which locally contains Atrypas (Fig. 57, fossil locality G 28). Significantly, no similar Devonian strata was noted in the presently adjacent northern East Humboldt Range.

R. P. Sharp (1939a, p. 137) regarded these breccias as depositional in origin, being interbedded in the Tertiary succession and postulated that they were "formed at the base of a steep slope, presumably a fault scarp, largely under the influence of gravity". The interbedded relationship recognized by Sharp is confirmed by the present study.

Willow Creek Unit

A mass of resistant reddish brown porphyritic rhyolite overlies the light-colored beds of the Starr Valley unit at the northern end of Clover Valley (Fig. 55). The rhyolite layers often dip as much as 45 degrees, the same as the underlying rocks, and clearly both successions were folded during the same episode of deformation. The rhyolite forms a bow-tie-shaped east-west trending hill which is about 3 miles long and up to $1\frac{1}{2}$ miles wide. The hill is traversed by northward-flowing Willow Creek, and the rhyolite is designated the Willow Creek unit.

Fig. 56. Distant and close-up view of east-dipping Paleozoic-limestone breccia lenses which are interbedded in the basal portion of the Tertiary Starr Valley unit on the east flank of the northern East Humboldt Range. Looking south with the mountain mass to the right.

Fig. 58. Paleozoic-limestone breccia interbedded in the Tertiary Starr Valley unit near the Clover Valley Ranger Station.

The rhyolite characteristically contains prominent phenocrysts of quartz, sanidine, and plagioclase which together make up about 5 to 15 per-cent of the rock. The size of these phenocrysts ranges from 1 to 10 mm., but most phenocrysts are 2 to 4 mm. in diameter.

Phenocrysts of quartz are more common than those of feldspar. Many quartz crystals are square-shaped in cross-section with rounded corners. Rounded anhedral quartz grains, however, are also common. Some crystals show arcuate fractures which are often stained with red-orange or red-brown iron material. Iron staining is a characteristic feature of this unit. Quartz grains show no undulatory extinction, and some crystals are locally embayed by projections of the microcrystalline groundmass. The margins of the phenocrysts are sharp, but some of the grains pass gradationally into the groundmass.

Sanidine phenocrysts are anhedral to subhedral. Some potash feldspar grains possess microcline twinning, but have the small 2V characteristic of sanidine. Most crystals, however, are not twinned. Marginal embayments and inclusions of the microcrystalline groundmass occur in many grains.

Plagioclase (oligoclase-andesine--about An_{30}) occurs as sub-rounded square-shaped phenocrysts as well as in anhedral and subhedral forms, and occasionally in glomeroporphyritic clusters. Like the quartz and sanidine, the plagioclase also contains microcrystalline inclusions and marginal embayments.

The groundmass of the rhyolite is microcrystalline and shows no flow structure. Rock chips etched in hydroflouric acid and stained with sodium cobaltinitrate indicate that the groundmass is rich in potash, and on this basis, the composition of most of the Willow Creek unit is presumed to be rhyolitic. Some portions, however, may approach the composition of quartz latite.

Massive outcrops of rhyolite between Ralph and Schoer creeks on the east side of the range, and a ridge-capping cliff of rhyolite one-half mile north of Stephens Creek on the west side of the range, appear quite similar to, and are tentatively correlated with, the Willow Creek rhyolite.

In the Ralph-Schoer creek area, porphyritic reddish brown rhyolite is exposed immediately adjacent to the range front, and also one-half mile to the east, where it forms an oval-shaped, northerly-trending hill about a third of a mile long. On the west side of this oval-shaped hill, the rhyolite is underlain by the very poorly exposed Starr Valley unit. At the range front the rhyolite is directly adjacent to Paleozoic limestone and here the base? of the unit is an unusual reddish brown weathering, black, clinopyroxene-bearing rhyolitic perlite. A black augite rhyolite in the East Humboldt Range area was mentioned in the Fortieth Parallel Reports (King, 1897) but the exact locality was not given. This may well be the locality where their collection was made. The matrix of the rhyolite is almost wholly composed of glass with a perlitic structure. Of structural significance is the fact that the perlite examined lacks any signs of brecciation although it was collected immediately adjacent to a reported range front fault that has an alleged displacement of 4800 feet (Sharp, 1939b, p. 901). The perlite was etched in hydroflouric acid and stained with sodium cobaltinitrate and the matrix proved to apparently be rich in potash. This together with the numerous phenocrysts of quartz in the rock, is the basis for calling the rock rhyolitic. Phenocrysts of oligoclase (?) and potash feldspar are present in addition to the clinopyroxene and quartz. The pyroxene is a rather dark green variety with high relief and high second to low third order colors. It has a 2V of about 60 degrees, a positive sign, and an extinction angle (Z:c) of 44 degrees. It has faint pleochroism in shades of dark green.

The rest of the rhyolite in this Ralph Creek area is essentially identical with, though locally more platy than, the rhyolite in the Willow Creek area.

On the west side of the range, north of Stephens Creek about one-half mile west of the range front, a resistant mass of reddish brown porphyritic rhyolite overlies the Starr Valley unit. It is seemingly identical to and is tentatively correlated with the rhyolite previously described.

The contact between the Willow Creek unit and the underlying beds is believed to be unconformable. This is indicated by certain field relations which suggest possible gulleying and erosion prior to Willow Creek time. (Note valley-like feature at the top of the Starr Valley unit in Fig. 54.) If the black perlite member of the Willow Creek unit rests unconformably upon pre-Tertiary rocks at the range front north of Ralph Creek and the contact is not a fault, a period of erosional removal of a considerable thickness of Tertiary beds prior to Willow Creek time would be indicated, unless this area was a high during earlier Tertiary time. A period of at least some erosion prior to Willow Creek time should not be considered unlikely since the uppermost Starr Valley beds exposed are water laid lacustrine deposits, whereas the overlying rhyolite is an extrusive, subareal deposit.

The thickness of the Willow Creek unit is not precisely known. It is thickest at the northern end of Clover Valley where probably more than 500 feet of crudely layered rhyolite is exposed.

Warm Springs Unit

Several hundred feet of late Cenozoic lava at the southern tip of the East Humboldt Range rest unconformably on Paleozoic and lower Mesozoic rocks. Farther south the lava apparently rests upon truncated upper Miocene rocks of the "Humboldt formation" (Sharp, 1939, p. 889 and Pl. 1). Sharp states, "A period of deformation and erosion ensued between deposition of the upper Miocene Humboldt formation and extrusion of the lavas. For that reason the lavas are thought to be Pliocene(?). They appear too old to be Pleistocene".

The lava is dominantly microporphyritic, and often is deep dusky red or green in color. Near the base of the succession are some tuffs and breccias.

Thin-sections show that both the basal volcanic breccias and the overlying lavas have a large percentage of glass in their matrix. The tuffs and breccias show pieces of labradorite, pyroxene and hornblende crystals, as well as volcanic

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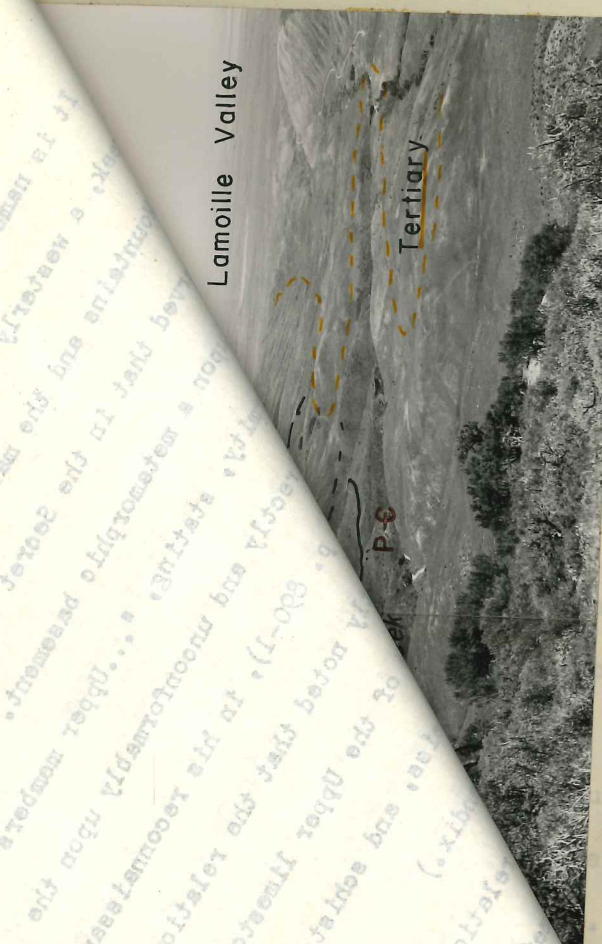

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A contact between the Warm Springs lavas and underlying Tertiary beds is not present in the mapped area, but to the south they are reported to unconformably overlie truncated beds of the upper "Humboldt formation" (Sharp, 1939b). The lavas are rather flat-lying and appear to have been deposited after the basic topography

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Secret Creek Thrust

Lateral Extent in the Mapped Area

The thrust plane which lies between the metamorphic basement below and the Paleozoic and lower Mesozoic succession above will be referred to as

* The term "Mesozoic" as it is previously, presently, and subsequently used in connection with thrusting is primarily for convenience. Although Mesozoic thrusting in this area is a likely possibility, the writer has no local evidence which would preclude the possibility of thrusting in early Tertiary time.

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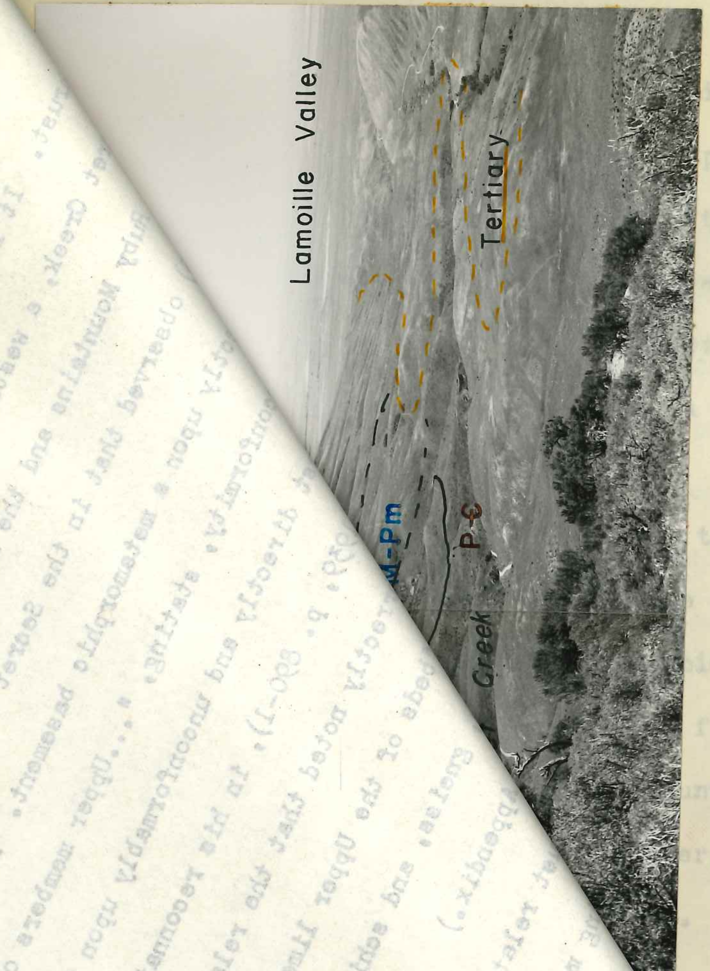

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MESOZOIC* STRUCTURE

General Statement

The Paleozoic and lower Mesozoic rocks in the northern Ruby Mountains and the East Humboldt Range rest upon a major thrust plane which overrides the regionally metamorphosed, higher-grade basement succession. A series of thrusts subordinate to the underlying sole thrust tectonically eliminate, truncate, and repeat many of the overlying Paleozoic and lower Mesozoic units. The age of the thrusting can be positively stated to be post-Lower Triassic based upon local data, and to be earlier than all of the Tertiary deposits described above, which include possibly early and almost certainly middle Tertiary rocks.

The basal thrust is present in both the northern Ruby Mountains and the East Humboldt Range. In the East Humboldt Range remnants indicate that the thrust plane is folded into a huge northerly trending and doubly plunging anticline, nearly 30 miles long. In the northern Ruby Mountains the thrust plane forms a broad northerly plunging anticline. Between the elongate dome formed by the folded thrust in the East Humboldt Range and the anticlinal nose of the folded thrust in the northern Ruby Mountains is an intervening northwest-trending syncline.

Secret Creek Thrust

Lateral Extent in the Mapped Area

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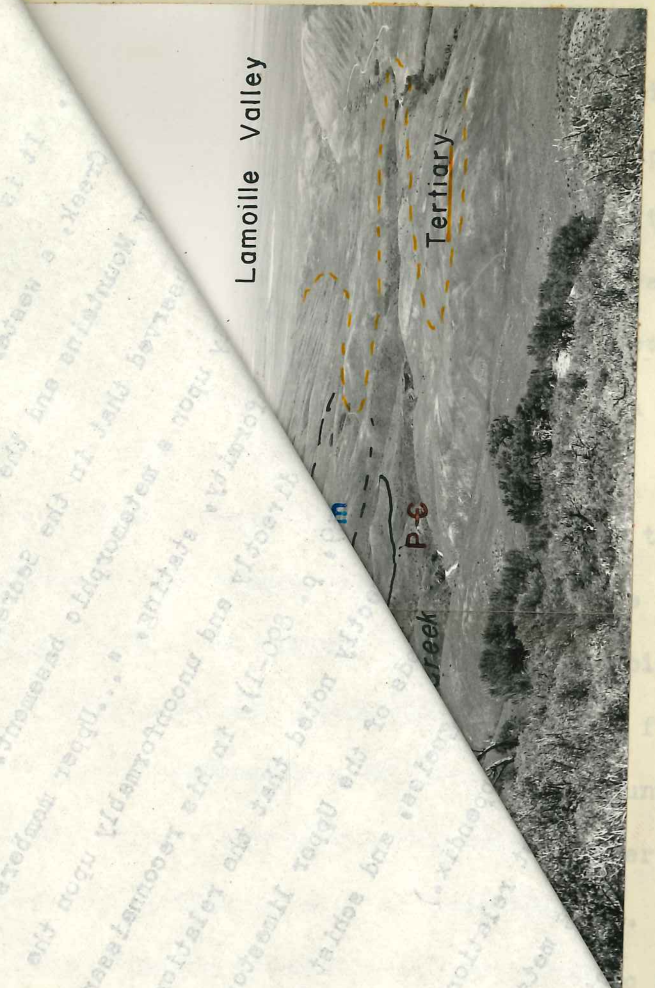

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* King (1878, p. 65) refers to this area as "Sacred Pass". Sharp used name "Secret Pass" for this area. Although "Secret Pass" is correct accord to local usage, it is nevertheless confusing. Secret Pass, as shown on both the Halleck quardrangle and U.S. Forest Service maps, is actually the name for the low divide between Secret Valley and Ruby Valley, two miles southeast of the gorge.

the Secret Creek thrust. It is named after excellent exposures of the thrust near the gorge of Secret Creek, a westerly trending stream channel between the northern end of the Ruby Mountains and the main mass of the East Humboldt Range.* King (1878, p. 65) observed that in the Secret Creek gorge area, Permo-Carboniferous rocks rest directly upon a metamorphic basement. King wrongly regarded the relationship an unconformity, stating, "...Upper members of the Lower Coal Measures are seen to rest directly and unconformably upon the ("Archean") schists. Later, Sharp (1939, p. 890-1), in his reconnaissance of the internal structure of the range, correctly noted that the relationship is actually a low angle thrust. He stated, "beds of the Upper limestone have been thrust over igneous intrusives and quartzite, gneiss, and schist of the Quartzite formation". (See Sharp's cross-section CC' in Appendix.)

Although Sharp locally recognized the thrust relationship between his "Upper ("Carboniferous") limestone" and the underlying metamorphosed "Quartzite formation" in this area, he evidently did not recognize the wide extent of this thrust.

In the Secret Creek gorge area the thrust plane is exposed both north and south of the creek channel. North of the creek, the thrust plane dips gently south and southeasterly. South of the creek the thrust plane dips gently north and northwesterly. The upper plate rocks in this area are Mississippian to Permian, and have been involved in subordinate thrusting.

From the Secret Creek gorge southward down the east flank of the Ruby Mountains the thrust plane dips easterly, and can be traced for 5½ miles. Northward from the Secret Creek gorge, the strata resting upon the south-

* King (1878, p. 65) refers to this area as "Sacred Pass". Sharp used the name "Secret Pass" for this area. Although "Secret Pass" is correct according to local usage, it is nevertheless confusing. Secret Pass, as shown on both the Halleck quardrangle and U.S. Forest Service maps, is actually the name for the low divide between Secret Valley and Ruby Valley, two miles southeast of the gorge.

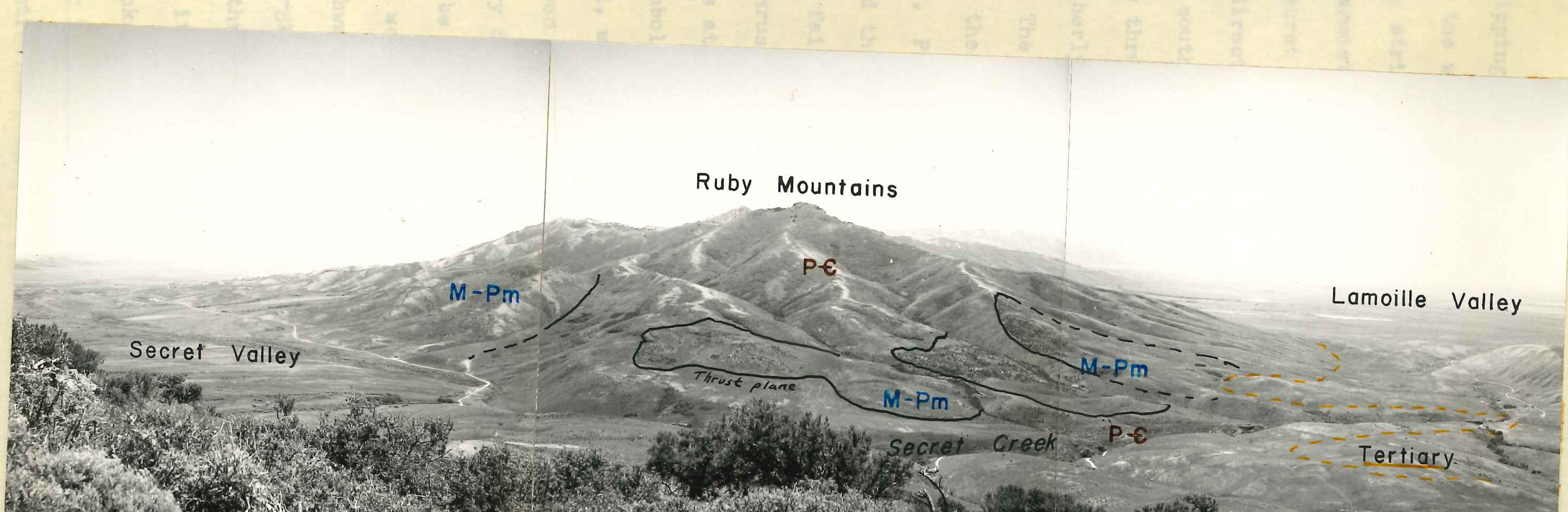

Fig. 59. Looking southward at the northern Ruby Mountains. Secret Valley is on the left (east) and Lamoille Valley is in the distant right (west). The Secret Creek gorge is seen in the middleground. The topography closely parallels the anticlinally folded and northerly plunging Secret Creek thrust plane. Permo-Carboniferous beds of the upper plate tectonically overlie the metamorphic basement. Tertiary rocks form an eastward-projecting embayment on the west and unconformably overlie both upper and lower plate units.

westerly dipping basal thrust plane can be traced for $3\frac{1}{2}$ miles. Farther northward along the west flank of the East Humboldt Range the upper plate rocks have been mostly stripped away. A relatively large remnant of the upper plate lies on the lowermost flank of the range in the Herder Creek area, located 11 miles north of Secret Creek gorge. This particular remnant is over a mile long in an east-west direction. A small outcrop of a thrust? breccia lies at the range front just south of the north fork of Lost Creek.

The thrust plane wraps around the northern end of the East Humboldt Range with a northerly dip, and then extends southward along the eastern flank of the mountains. The upper plate here is composed of Mississippian through Permian strata, and these rocks can be traced south down the east flank of the range for 6 miles. Primarily because of a rather extensive amount of glacial material, the inferred thrust plane in this area is covered. However, the outcrop pattern indicates a fairly steep eastward dip of the thrust plane.

A thrust plane bringing Lower and Middle Paleozoic strata over basement rocks occurs at "Clover Hill", which is located about 2 miles east of the northern East Humboldt Range. Upper plate rocks are present in the southwest portion of this hill, where the thrust has a gentle westerly to southwesterly dip. The valley between "Clover Hill" and the East Humboldt Range is formed in relatively soft Tertiary deposits. Because the thrust sheet rests on basement rocks, it is presumed to be continuous with the Secret Creek thrust in the East Humboldt Range to the west.

Southward, the steep eastern front of the central East Humboldt Range exposes high-grade metamorphic rocks of the lower plate.

The thrust plane recurs in the southern portion of the East Humboldt Range. Here it is folded into a southerly plunging anticline, and overlying Paleozoic rocks of the upper plate lie on the crest and on both flanks of the range. Lower Triassic strata also have been involved in the thrusting in this area. The anticline formed by the folded thrust is modified by a high-angle most of the range, leaving the metamorphic core exposed, the remaining outcrops are sufficiently numerous, 1) to indicate the original extent of the Secret Creek thrust, and 2) to demonstrate the present anticlinal pattern of the thrust in both the northern Ruby Mountains and the East Humboldt Range.

Movement Zone

The tectonic features associated with the Mesozoic thrusting are quite distinct from the deep penetrative mylonitization and minor feldspathization which is interpreted to have occurred in the Precambrian succession during Precambrian thrusting. The Mesozoic thrusting variously: 1) sheared, brecciated, fractured, and slickensided the truncated layers of the metamorphic basement; 2) in places formed a highly silicified thrust breccia unit along the thrust plane; 3) sheared and brecciated overlying Diamond Peak quartzite where adjacent to the thrust plane; and 4) variously pulverized, fractured, brecciated, and recrystallized overlying Paleozoic limestones adjacent to the thrust plane.

The superimposed effects of Mesozoic thrusting upon the metamorphic basement would be observed ideally at a locality where a single vertical uncovered outcrop displays both upper and lower plates. Another ideal locality would be where the overlying thrust plate has been eroded to the exact upper surface of the lower plate, that is, to the thrust plane itself. Understandably, such ideal situations are rare. Nevertheless, there are two such localities in the area. One occurs in a road cut at the western entrance to the Secret Creek gorge (Fig. 60) and the other occurs in the "Secret Hills" located between Secret Valley and Ruby Valley.

The Secret Creek gorge locality is one place in the area where exposures are such that one can put his hand on both upper plate Permo-Carboniferous limestone and the lower plate metamorphic basement. The thrust plane at this locality (SW$\frac{1}{4}$ of SE$\frac{1}{4}$, Sec. 36, T.35N., R.59E.) is folded into a very minor anticline (Fig. 61). In the immediate area the thrust plane dips gently west-

Fig. 60. Composite panorama of the Secret Creek thrust as seen looking north from the south side of the Secret Creek gorge. Note the truncation of the metamorphic Angel Lake succession which comprises the lower plate.

ward. Directly below the thrust plane the metamorphic rocks are so badly sheared that their original dip is beyond recognition. However, several hundred yards eastward, and farther below the thrust, essentially unsheared and steeply easterly dipping lower plate mylonites, when projected upward form a 35 to 40 degree angle with the gently westerly dipping thrust plane (Fig. 60).

Thin-sections of the lower plate strata at this locality clearly show two ages and two types of cataclasis, interpreted to be an earlier Precambrian stage and a much later superimposed Mesozoic stage. A black fine-grained magnetite?-rich cataclastic quartzite contains earlier-formed highly sheared quartz grains which are cross-cut by a network of veinlets composed of both white micro-crystalline quartz mortar and very locally fine-grained (up to .8 mm.) recrystallized granoblastic quartz. The fine-grained quartz in these latter veinlets, significantly, shows only very mild undulatory extinction in contrast to the immediately adjacent transected and highly sheared quartz (Fig. 62). If these quartz veinlets formed during late phases of Precambrian thrusting, their lack of strain could hardly have been maintained during Mesozoic time when thousands of feet of post-Precambrian strata were thrust over them. Therefore these veinlets almost certainly represent an entirely separate period of fracturing and healing, which quite possibly occurred during the last phase of Mesozoic thrusting. The 35-40 degree angular relationship between the easterly dipping lower plate mylonite layers and the westerly dipping Mesozoic thrust plane in this area would greatly weaken an alternative hypothesis that the mylonites themselves are the result of Mesozoic rather than Precambrian deformation (for further discussion on age of mylonites see pp. 95-96).

The overlying Permo-Carboniferous strata at this locality are fractured and are locally reduced to a fine breccia and pulverized gouge.

In the "Secret Hills", a remnant of silicified breccia and Permian? limestone tectonically overlie a portion of the metamorphic Snow Water unit. The remnant is elongate and northerly trending, and lies one-third mile east

Fig. 61. The Secret Creek thrust plane as seen looking north at a road cut near the western entrance to the Secret Creek gorge (see arrow in fig. 60 for location). The thrust plane at this locality is folded into a very minor anticline; the overall dip of the thrust plane is to the west. The upper plate rocks are essentially Permo-Carboniferous limestones which have been variously sheared, fractured, brecciated, and reduced to gouge. The lower plate rocks are a part of the Angel Lake unit.

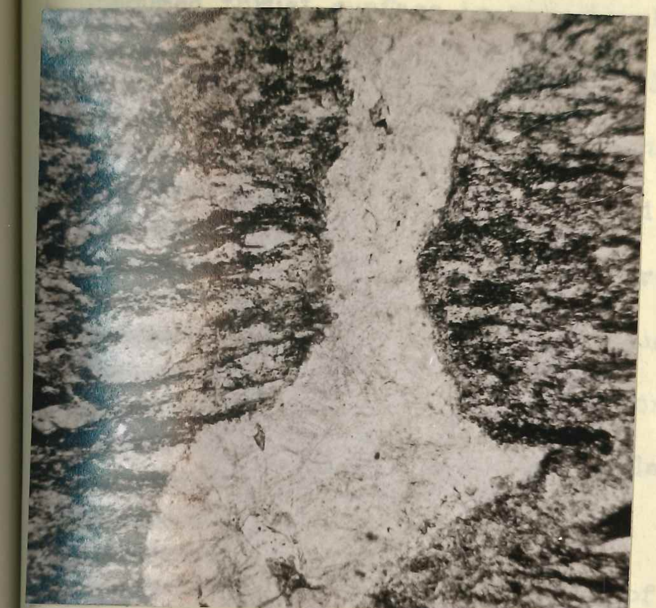

Fig. 62. Magnetite?-bearing quartzitic mylonite from the Angel ake unit which shows a late cross-cutting, non-cataclastic granoblastic uartz veinlet which may have formed during a late phase of Mesozoic hrusting. Specimen was collected about 2 feet below thrust plane at ocality shown in the preceding illustration. (plane light and crossed icols, 57 X magnification)

of Secret Pass (BM 6465). Between Secret Pass and the thrust mass is the essentially exhumed surface of the thrust plane. East of the thrust mass, the exhumed thrust surface is only locally preserved.

The Snow Water unit of the lower plate in this area is composed primarily of white to bluish grey quartzite, marble, and lesser amounts of white to cream-colored pegmatite. (The distinction between the white quartzite regarded to be Precambrian, and the Ordovician Eureka quartzite present elsewhere in the general area has been previously discussed.) The Snow Water unit is the upper plate to the underlying Horse Creek thrust plane regarded to be Precambrian in age, and is the lower plate to the overlying Mesozoic Secret Creek thrust plane.

In the field, one locality of slickensided bluish white quartzite of the Snow Water unit has been observed (SW$\frac{1}{4}$ of SE$\frac{1}{4}$, Sec. 23, T.34N., R.60E.). The slickensided surface plunges gently west-southwest. The slickensides strike N.70° E., and the transverse undercut fractures indicate that the now-removed overlying mass traveled easterly (Fig. 63).

In some thin-sections of the Snow Water quartzite near the thrust plane can be seen an earlier stage of highly sheared, elongate sutured quartz, and a later state of brecciation(Fig. 64). Angular fragments of the earlier sheared quartz are dislocated and scattered throughout a very fine-grained cataclastic quartz mortar. Thin-sections of the white quartzite from outcrops just east of Secret Pass and south of the east entrance to the Secret Creek gorge show similar features. Significantly, no superimposed brecciation is present in the thin-sections studied of the white Snow Water quartzite immediately above the Precambrian? Horse Creek thrust plane (Fig. 40), and presumably stratigraphically below the now-removed Mesozoic thrust plane. These relationships suggest that brecciation, fracturing, and slickensiding affected these quartzites during the later, Mesozoic period of thrusting; and that the earlier cataclastic textures represented by elongate, sheared, and highly sutured quartz occurred

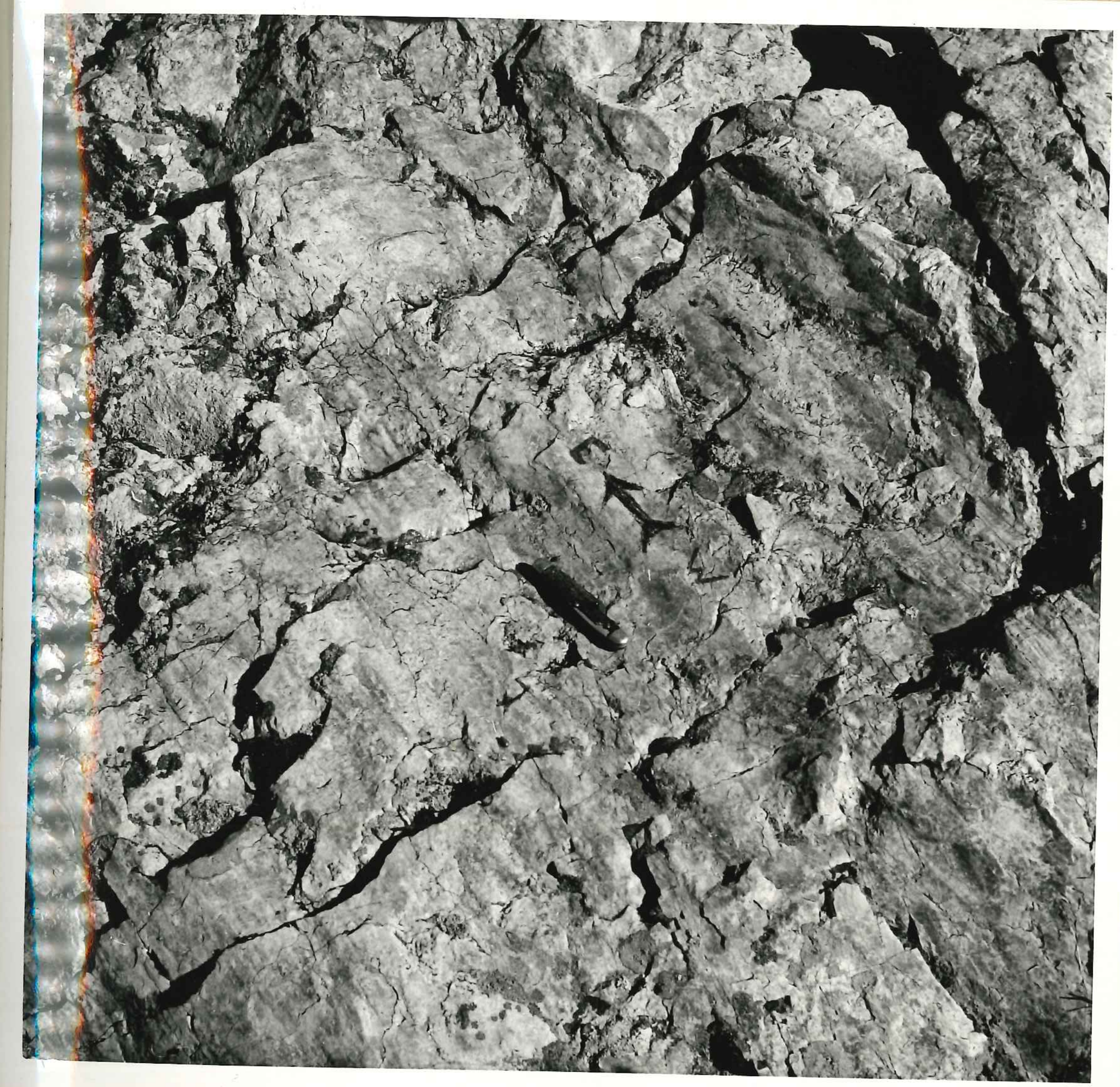

Fig. 63. Slickensided bluish white quartzite in the Snow Water unit as seen along the exhumed Secret Creek thrust plane at a locality in the "Secret Hills" (SW$\frac{1}{4}$ of SE$\frac{1}{4}$, Sect. 23, T. 34 N., R. 60 E.). The slickensides strike N. 70° E. and plunge gently west-southwest. Transverse undercut fractures indicate a relative easterly movement of the overlying thrust mass. View is looking down at gently inclined rock surface.

Fig. 64. Photomicrograph of a white cataclastic quartzite in the Snow Water unit which was collected near the Mesozoic Secret Creek thrust plane. The two types of cataclasis shown are discussed in the text.

during probable Precambrian thrusting.

A highly silicified group of rocks is locally sandwiched between the metamorphic basement and the tectonically overlying upper Paleozoic strata, and also occurs locally along subordinate thrust zones within the upper plate. The rocks are often reddish brown, black, or buff, extremely resistant, and form prominent outcrops in the Secret Creek-Dorsey Creek area, and also near Secret Pass. Where present, the unit vary in thickness from a few feet to about 50 feet.

In detail, the unit is often seen to be brecciated and the fragments within it vary in size and shape. Both angular and rounded fragments are present, and they are generally less than 3 inches in diameter. The fragments appear to have originally been limestone, cherts, and quartzites, but which are now silicified. Many of the limestone pieces have preserved their original finely crystalline texture. In fact, though these fragments outwardly resemble limestones, there is only a trace of carbonate left in them, and they cannot be scratched with a knife. Locally the brecciated portions of the unit contain angular cavities which are occasionally lined with tiny quartz crystals. In these occurrences the country rock is sometimes not completely silicified, and often complex networks of silica veinlets run through the brecciated mass (Fig. 66).

Portions of the unit appear to lack brecciation, and can only be described as dark masses of fine-grained silicified rock. The unit lacks any evidence of bedding. It often weathers to a smooth surface with rounded edges and corners.

Fig. 65. Outcrop of a silicified rock mass at the base of the Mesozoic Secret Creek thrust, south of the Secret Creek gorge and north of the fossil locality A 17 on Map No. 2.

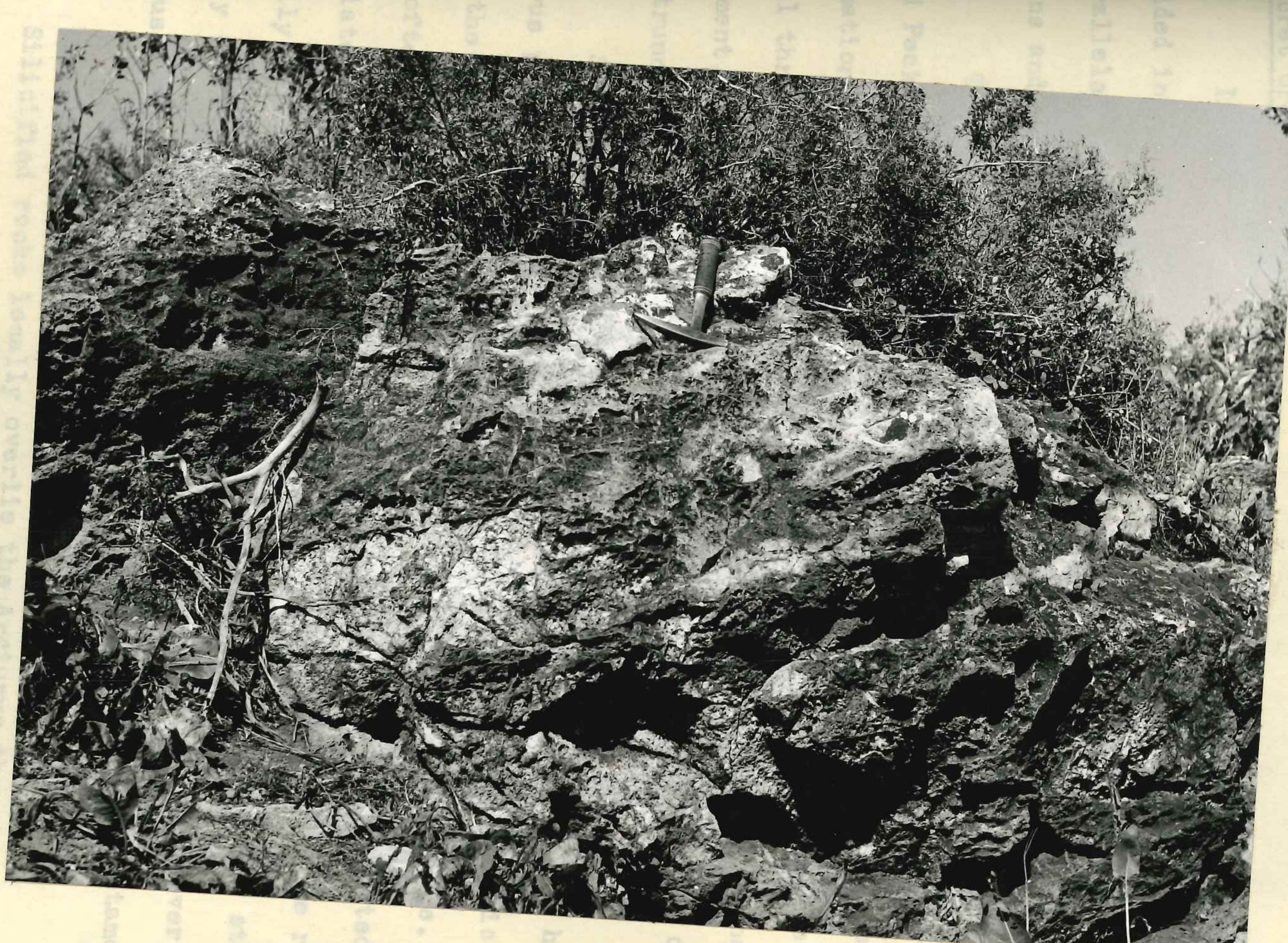

Fig. 66. Silicified thrust breccia outcropping on the ridge north of Reed Creek in the southwestern portion of the East Humboldt Range.

Structures within the Upper Plate

Secret Creek gorge area

In the Secret Creek gorge area (Map No. 2) the basal thrust plane is folded into a broad northwest-southeast trending syncline which rather closely parallels the present topographic depression between the northern Ruby Mountains and the East Humboldt Range.

The upper plate rocks exposed in this area are the Mississippian Diamond Peak formation, the Pennsylvanian Ely limestone, and the Permian Arcturus formation. All of these units at one place or another rest directly upon the basal thrust plane and override the often truncated layers of the metamorphic basement. The upper plate beds sometime parallel, but commonly dip into and are truncated by the thrust plane.

Subordinate thrusting within the upper plate succession has brought various portions of the Arcturus formation directly into tectonic contact with both the underlying Diamond Peak formation and the Ely limestone. The Arcturus beds often dip into the subordinate thrust plane and are truncated by it. Brecciated limestone, silicified rocks, or talus of igneous dike rock are occasionally found along the thrust zone. The Diamond Peak and Ely strata are completely eliminated in the areas where the subordinate thrust, overlain by Arcturus beds, roots in the basal thrust which overrides the metamorphic basement.

Silicified rocks locally overlie the Arcturus thrust mass north of Dorsey Creek suggesting that possibly another tectonic unit was at one time present above it.

A northerly trending high-angle fault occurs almost due north of the east entrance to the Secret Creek gorge. The fault has several hundred feet

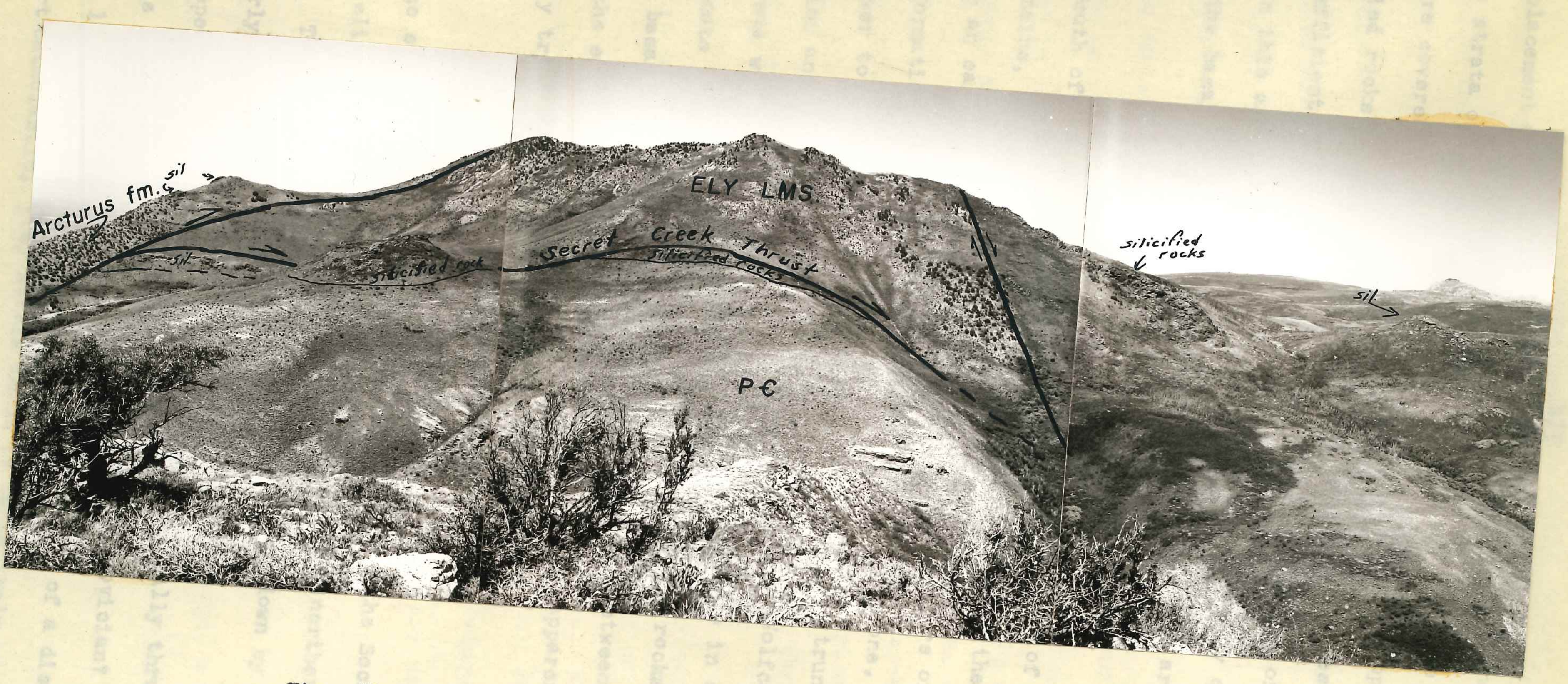

Fig. 67. Subordinate thrust slice within the upper plate of the Secret Creek thrust as seen looking north across Dorsey Creek in the southwestern portion of the East Humboldt Range.

of displacement and drops down both Permo-Carboniferous and underlying metamorphic strata on its east side. Much of the rocks on the east side of the fault are covered by heavy vegetation. A number of outcrops of resistant silicified rocks and Permo-Carboniferous limestone are present, but exposures are insufficient to determine structural relations. Some of the silicified masses in this area rest directly upon limestones and they quite possibly represent the basal zone of the higher tectonic units which are now eroded away.

Secret Pass Area

South of the Secret Creek gorge on the east flank of the northern Ruby Mountains, the Pennsylvanian Ely limestone overrides the metamorphic basement along an easterly dipping basal thrust plane. Members of the Permian Arcturus formation are in turn thrust over the Ely limestone.

Lower to Upper Pennsylvanian strata are variously truncated both by the overlying and underlying thrust planes; and both the Wolfcampian and Leonardian strata within the Arcturus formation are variously in contact with the subordinate thrust plane overriding the Pennsylvanian rocks.

The basal Secret Creek thrust plane in the area between the "Secret Hills" and the east flank of the Ruby Mountains forms an apparently shallow northwesterly trending syncline.

Southern East Humboldt Range

In the southern East Humboldt Range (Map No. 4), the Secret Creek thrust plane is anticlinally folded. The anticlinal axis trends northerly and plunges to the south. The east limb of the anticline is dropped down by a northerly to northwesterly trending high-angle fault.

The upper plate succession in this area is internally thrusted and faulted, and is composed of rocks ranging in age from Ordovician? to Lower Triassic. The lower plate succession is in part composed of a distinctive, at least in part cataclastic, grey marble which is tentatively regarded to be

Precambrian and a member of the Snow Water unit (see p. 72). The Secret Creek thrust plane truncates and virtually eliminates this lower plate grey marble to the north and west. Layers within the upper plate generally dip into the thrust plane and are truncated by it. (For example, note the abrupt truncation of the lower members of the "Park City formation" at the Secret Creek thrust as shown on Map No. 4).

By virtue of their contrasting lithology and the truncation involved, the thrust contact between the Permian and Triassic units and the underlying lower plate marbles is very sharp and easily recognized. However, the contact between the Devonian carbonates (bearing Amphipora?) and the underlying marbles is not sharply defined. The Devonian rocks show various stages of "marbleization" along the thrust zone, and near the Polar Star Mine appear to haphazardly converge in texture into the coarser-grained grey marbles of the lower plate. (Another abandoned mine is located along the basal thrust plane near the crest of the range in this area.)

The Devonian beds described occur in a structurally complicated tectonic slice which is mapped as a Ordovician?-Devonian unit. This unit is tectonically overlain by a thrust mass of the Permian Arcturus formation. The Arcturus beds are in fault contact with Lower Triassic beds on the west and south, but the exact nature of these faults is not known. Likewise, the nature of two adjacent northerly to northeasterly trending faults which truncate and repeat "Park City" and Lower Triassic beds is not known. It seems likely that these faults are related to the underlying Secret Creek thrust plane, and they are tentatively interpreted as such (see cross-section on Map No. 4).

On the east flank of the southern East Humboldt Range, a thrust slice of the Pennsylvanian Ely limestone overrides members of the Permian Arcturus formation. Two probable outliers of this subordinate thrust mass rest upon Permian strata at the ridge crest.

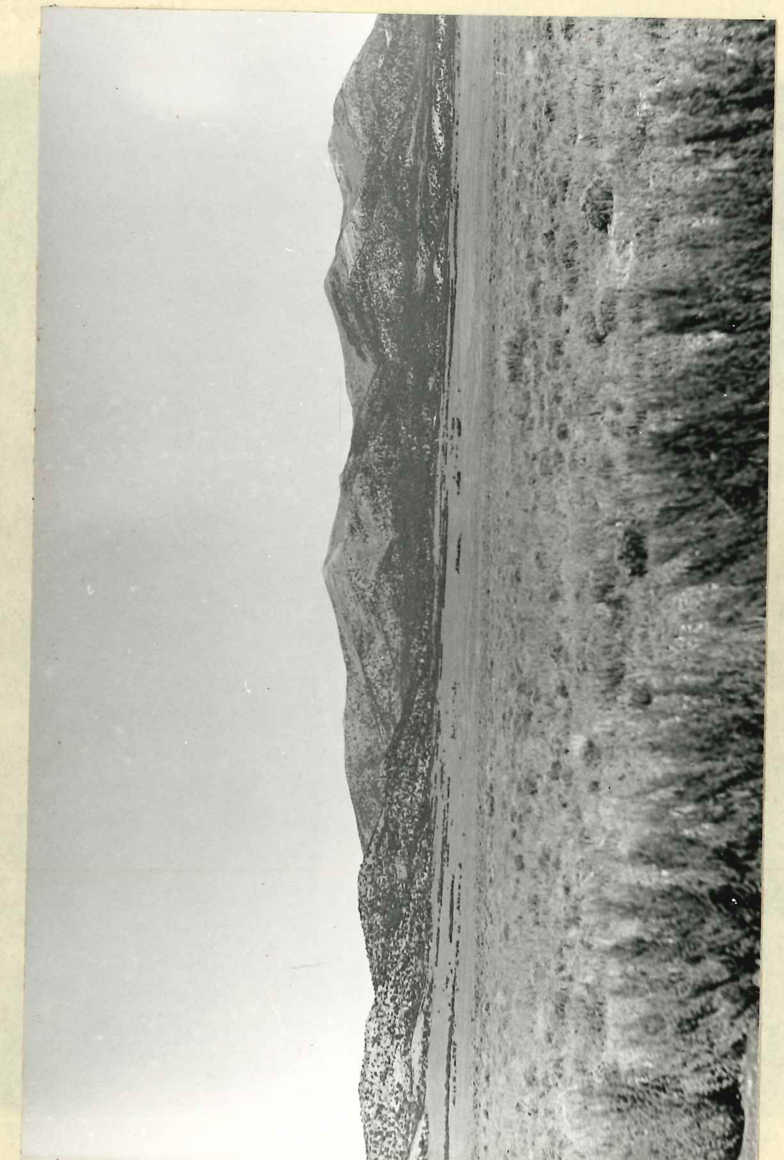

Fig. 68. General view of the southernmost East Humboldt Range. View is looking to the northwest.

Fig. 69. The Secret Creek thrust plane as seen looking westward at the crest of the southern East Humboldt Range (a closer view of the right hand side of Figure 68). Marbles tentatively mapped with the Snow Water unit form the grey slopes immediately below the thrust plane. The Permian Arcturus formation comprises most of the upper plate in this view and it is truncated at the thrust plane.

Northeastern East Humboldt Range

The upper plate succession on the northeastern flank of the East Humboldt Range (Map No. 1) is composed of Mississippian to Permian beds which are variously in thrust contact with the truncated layers of the Angel Lake unit. Much of the thrust plane in this area is concealed because of a rather extensive cover of morainal material.

Subordinate thrusting and faulting within the upper plate succession is exposed on ridges both north and south of Clover Creek. Two main tectonic units are recognized in this area, a basal unit composed of truncated layers of both the Diamond Peak formation and the overlying Ely limestone, and an upper unit composed of Leonardian members of the Arcturus formation. Field relations indicate additional thrusting occurs in the upper tectonic unit.

Breccia, jasperoid, and other silicified rocks are locally exposed at the base of as well as within the internally thrusted Arcturus unit; however, at some localities along the thrust planes, dispite obvious truncation, tectonic effects of faulting are imperceptible.

At one locality at the range front, the subordinate thrust plane beneath Leonardian beds of the Arcturus unit is partially exhumed and dips rather steeply to the east. Jasperoid and jasperoidal breccia probably related to the thrusting are locally exposed north and south of Willow Creek.

"Clover Hill"

In the southwestern portion of "Clover Hill", a structurally complex mass of essentially Lower and Middle Paleozoic strata overrides cataclastic lower plate marbles and marble breccias which are tentatively regarded to be Precambrian and part of the Snow Water unit (see p. 72). Within the upper plate succession are thin slices of possible upper Pogonip rocks, definite Eureka quartzite, Devonian carbonates, and some questionable Pennsylvanian limestone.

Fig. 70. Looking westward across Clover Valley at the northern East Humboldt Range. The Secret Creek thrust plane trends essentially north-south, separating the Angel Lake unit (snow-covered) from Permo-Carboniferous rocks (mostly grass-covered). Note the preserved pediment surface between Clover and Willow creeks.

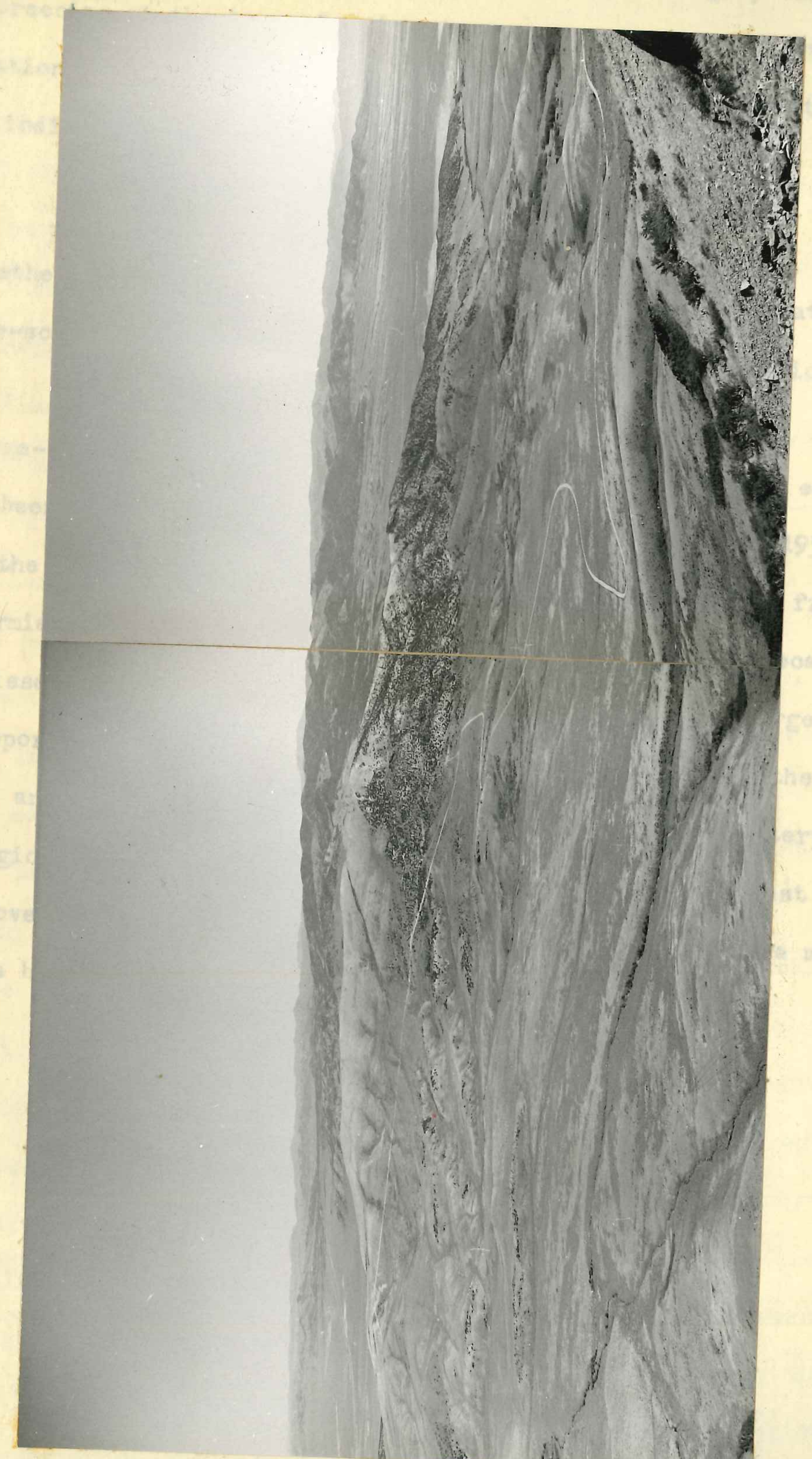

Fig. 71. Looking east across Clover Valley to "Clover Hill". Tree-covered slopes in the southwestern part of the hill roughly correspond to the Lower and Middle Paleozoic formations which are in thrust contact with the metamorphic basement.

The attitudes in the upper plate succession are highly variable, and tectonic breccias at the base of and within the succession are not uncommon. Field relations indicate a considerable degree of slicing and tectonic elimination, but individual tectonic units were not delineated.

Regional Setting

Whether the Secret Creek thrust described in this dissertation is related to large-scale thrusts described elsewhere in this general region is not known.

Large-scale shearing-off thrusting of décollement type in east-central Nevada has been described by Misch, Hazzard, Easton, and others (1953, 1954, and 1957). In the northern Snake Range, a Paleozoic sequence ranging from Cambrian to Permian was reported to rest in thrust contact with a Precambrian basement of gneisses, granites, schists and schistose quartzites. Large overthrusts were also reported in the southern Schell Creek Range, in the southern Cherry Creek Range, and in the Pequop Range. These thrusts have been interpreted as part of a regional shearing-off plane or décollement-type overthrust of Paleozoic rocks over Precambrian rocks. The thrust is reported to have moved eastward, and has been dated as probably mid-Mesozoic.

CENOZOIC STRUCTURE AND HISTORY

General Statement

The writer has subdivided the Cenozoic structural history of the northern Ruby Mountains and the East Humboldt Range into three broad episodes which are summarized below.

Evidence of the first episode is recorded in three Tertiary sequences which now flank the mountain mass, namely the Clover Valley, Starr Valley, and the Willow Creek units. It is believed that the areas of uplift and deposition during this first recorded episode of deformation were not necessarily similar to the present-day northerly trending topography. This first episode was perhaps the longest and the most complex of the three, and probably included several uplift and erosion cycles. Although local fossil evidence is lacking, regional data suggest the episode recorded here began possibly in early and almost certainly by middle Tertiary time, and closed sometime in the Pliocene.

During the second episode, a huge northerly trending asymmetric anticline was formed in the area of the East Humboldt Range; and a northerly plunging anticline was formed in the area of the northern Ruby Mountains. Folding was accompanied and/or followed by faulting. This second episode created the essential outline, shape, and trend of the northern Ruby Mountains and the East Humboldt Range as it is seen today. Subordinate transverse folds occurring in this general episode also have influenced the outline, shape, and internal structure of the range, and evidently the structure of the flanking Tertiary deposits. This range-forming episode probably occurred in an interval starting in the later Pliocene and extending into the Pleistocene. A period of erosional removal of Tertiary deposits followed, along with pedimentation, late Pleistocene glaciation, and further dissection.

The third episode of deformation was one of faulting. The episode is latest Pleistocene to Recent in age and has further modified the topography of the area. The faults of this episode locally follow the range front and elsewhere occur as much as 3 miles away from the range front, in the Tertiary basins. Faulting is represented by piedmont scarps which transect pediment surfaces, Wisconsin moraines, alluvial fans, and valley bottom alluvium. Displacement during this period of faulting evidently varied from place to place, but usually appears to be less than 100 feet.

The above summarized Cenozoic structural history of the Northern Ruby Mountains and East Humboldt Range differs in some respects to an earlier interpretation proposed by Sharp (1939b). In this earlier account the range was regarded as a "westward tilted horst", the present outline of which was determined solely by faults which originated in the upper Miocene, and which periodically had displacements up to Recent time. As a result of this earlier interpretation, the Ruby-East Humboldt Range became a common textbook example of typical "Basin-Range structure" (Eardley, 1951; Billings, 1954; Thornbury, 1955).

The present interpretation differs essentially in the nature of the major uplift. Both interpretations are in agreement, however, that the time of the major uplift which created the present relief of the range was in an interval extending from later Pliocene time into the Pleistocene. Further, both interpretations are in agreement as to the nature and time of the last episode of Cenozoic deformation, i.e., minor faulting in late Pleistocene to Recent time.

The writer's interpretations are based upon the areal mapping of the rocks and structures in the range itself, and is supplemented by a study of the Tertiary succession and its relation to the present range front. Rather critical evidence was found in the range, which was not studied or mapped in detail by Sharp. Since a detailed study of the rocks and structure within the range was not a part of Sharp's original investigation (1938), the data upon which some of his conclusions were based were understandably incomplete.

The writer has elsewhere described the similarity between the internal structure of the range and the present topography. In summary: A major low-angle thrust plane within the range lies between a structurally complex Paleozoic succession and a rigid metamorphic basement regarded to be Precambrian in age. This thrust plane now has the shape of a huge north-northeasterly to northerly trending anticline in the northern Ruby Mountains and the East Humboldt Range. Further, the present topography of the mountain mass strikingly conforms to the shape of the thrust plane where remnants of the thrust sheet have been preserved.

For example, in the northern portion of the Ruby Mountains the thrust plane dips easterly on the eastern flank, northerly on the northern flank, and northwesterly on the northwestern flank——thus forming a northerly plunging anticline which closely follows the present topography (Fig. 59). In the Secret Creek gorge area the thrust plane forms a roughly northwest to east-west trending syncline, approximately paralleling the topographic depression between the Ruby Mountains and the East Humboldt Range. At the northern end of the East Humboldt Range, the northerly trending, anticlinally folded thrust plane plunges to the north, and at the southern end of the East Humboldt Range the thrust plane plunges to the south.

If the internal structure of the range is basically a large anticline which conforms to the present topography, it is a logical conclusion that the anticlinal folding itself could be basically responsible for the topography. The folding observed is of a magnitude that could readily account for the differential elevation of 5000-6000 feet between the range crest and the valley basins; and if the folding can account for the present topography there is no need to postulate normal faults at the range fronts with as much as 5500-6000 feet of displacement (Sharp, 1939b, p. 882). It should be noted that this earlier minimum fault displacement on the east side of the northern East Humboldt Range was based upon topography, and not upon measured stratigraphic offset, that is, based upon "the difference in the altitude between the crest of the range and the base of the Miocene deposits...in the valleys" (p. 899); and farther south where no Tertiary rocks are exposed, the displacement judged "solely from the topographic relief" (p. 893).

Although there is apparently no longer a need to postulate large-scale normal faulting to account for the present topography, nevertheless certain relations do indicate that some faulting definitely did accompany and/or follow the major folding in the area.

<u>First Episode</u>

This episode was perhaps the longest of the three and the most complex. It was a time which included periods of vulcanism, uplift, erosion, and both fluvial and lacustrine deposition. There were times of upheaval and times of calm; but it is believed that the areas of uplift and the basins of deposition at this time were not necessarily the same as the present-day northerly trending topography.

Van Houten (1956, p. 2823), who has had access to well core data in northeastern Nevada, has stated that, "at least locally, the present pattern of the ranges and basins differs from that which prevailed during much of Cenozoic time. Some areas that are basins now were uplands during episodes of aggradation or they were uplifted and eroded after deposition...". This view, that some Nevada basins in earlier Cenozoic time were quite unlike present valley outlines, has been expressed to the writer by a number of workers in the region.

The lower or Clover Valley unit represents the first recorded history of the Cenozoic. It is a heterogeneous succession rich in volcanic and volcanic-derived material, as well as Paleozoic and presumably Precambrian debris. Some higher members contain pebbles of vitric tuffs and volcanic rich sandstones which appear to have been derived from upturned lower members of the succession. The exact location or trend of the source of these deposits is unknown, but the volcanic pebbles in the succession indicates an earlier episode of vulcanism in the region.

Where relationships are clear, these lower deposits rest unconformably upon the pre-Tertiary rocks of the range front. In the Secret Creek gorge area they unconformably overlie both the metamorphic basement and the tectonically overlying Paleozoic rocks, and form an embayment eastward about one mile from the western front of the range. The local thinness to complete absence of the Paleozoic succession at Secret Creek gorge when compared to the thousands of feet of Paleozoic rocks present elsewhere in the range, suggests that in places a considerable amount of erosion occurred between Mesozoic thrusting and the deposition of the Tertiary Clover Valley unit; and hence, at least portions of the area of the East Humboldt Range were presumably "highs" during this episode, and in some of these portions, much or all of the Secret Creek thrust sheet was eroded away.

In the Starr Valley unit, the abundant and widespread fine-grained deposits, such as tuffaceous sandstones, siltstones, reworked vitric ash, and fresh water limestones, suggest periods of relative quiet and lacustrine deposition. The occasional layers of Paleozoic-pebble conglomerates and limestone breccia lenses in the succession, however, suggest sudden episodes of nearby uplift and possibly temporary elimination of some local lake environments.

It has previously been postulated that the limestone breccias and pebble conglomerates which are exposed in Clover Valley one-half to 3 miles away from the range front were derived from a fault at the front of the East Humboldt Range in Miocene time (Sharp, 1939a, p. 137). These outcrops are, in fact, the only features used as evidence to support faulting along the range front in "Miocene Humboldt" time (1939b, p. 902-903). Although these breccias may be the result of a newly created scarp in "Humboldt" time, the writer found no evidence to indicate that the postulated scarp was located at the present range front at this earlier time. The only concrete evidence cited by Sharp (1939a, p. 137) to support this view was "The base of the present scarp exposes limestone similar to that composing the breccia." The writer does not believe that this would prove or disprove a particular source location for these breccias. Nevertheless, the statement is only partially accurate. While some breccias do resemble limestones of the mountain mass, some breccias at the northwestern end of Clover Valley (near Clover Valley Ranger Station) do not. Some of these breccias are composed of fossiliferous Devonian fragments. No similar Devonian strata is present anywhere along the east front of the East Humboldt Range.

Paleozoic-pebble conglomerates are absent in the uppermost part of the Starr Valley unit and deposits appear to be almost wholly lacustrine, tuffaceous, and fine-grained. The similarity of these uncontaminated tuffaceous deposits of the uppermost Starr Valley unit on both flanks of the range suggests that in upper Starr Valley time an essentially continous basin existed across the area where the East Humboldt Range now exists.

Furthermore, the Willow Creek rhyolite, now only locally exposed on both flanks of the range, assuming the writer's correlations are valid, must have originally been continous. The rather steep eastward dip of the rhyolite at the northern end of Clover Valley indicates that it was involved in the uplift of the range. These points suggest that at the close of Willow Creek time (perhaps lower or middle Pliocene), the area was essentially a lowland, much of which may have been covered by a cooling blanket of rhyolite.

Second Episode

Introduction

The second episode of Cenozoic deformation was responsible for creating the basic topography of the northern Ruby Mountains and the East Humboldt Range as seen today. This episode cannot be precisely dated, but it probably occurred in an interval extending from the later Pliocene into the Pleistoncene. Evidence available indicates that during this period the northern Ruby Mountains and the East Humboldt Range were created by large-scale northerly to north-northeasterly trending anticlinal folding which was probably accompanied and/or followed by some high-angle faulting. A period of transverse folding, which presumably occurred during this general episode, modifies the basic northerly trending structures.

The nature of and evidence for the anticlinal folding, which is regarded to have been significant in the formation of the northern Ruby Mountains and the East Humboldt Range, has been described elsewhere. The Plio-Pleistocene age for the uplift is based primarily upon steeply dipping beds in northwestern Clover Valley of probable Pliocene age which clearly have been involved in the uplift of the range. Also, one explanation for the apparent lack of Pleistocene glaciation earlier than the Wisconsin in the range (Sharp, 1938b, p. 305) might be that the range did not attain its present attitude until later in Pleistocene time---a possibility originally mentioned by Sharp. Furthermore, the present rugged and youthful topography suggests a late Cenozoic origin.

As previously stated, the magnitude of the folding was alone sufficent to account for the present topography of the range; and it therefore seems necessary to now modify Sharp's previous hypothesis which states that the range is structurally a "westward tilted horst" bounded by normal faults with a magnitude of up to 2000? feet on the west side and up to 5800 feet on the east side (Sharp, 1939b, p. 901). The main problem is learning, if possible, the extent to which faulting may have accompanied and/or followed anticlinal folding, and the displacement of such faulting.

Second Episode Structures on East Side of the East Humboldt Range

Most of the eastern side of the East Humboldt Range is devoid of exposed Tertiary deposits, and the range rises rather abruptly from an alluvium-covered pediment slope underlain in part by metamorphic rocks of the Angel Lake unit (see Physiography). Only at the northern end of Clover Valley are Tertiary strata exposed. Here a dissected pediment surface truncates Tertiary beds and ends at the bedrock of the range front. Both faulting and folding of the Tertiary succession have occurred in this area.

"Clover Hill" lies 2 to 3 miles east of the northern East Humboldt Range. The bedrock structure in the northern portion of the hill is a northerly plunging anticline. A northerly trending reverse? fault of relatively large displacement occurs along the west side of the hill (structure locality 1 on Map No. 1). Brecciated calcite-veined Tertiary rocks were collected in several localities along the fault. Patches of soil are locally stained orange to red, and some mineralization and brecciation was noted at an old mining shaft along the fault trace. Pseudo-Diamond Peak conglomerate beds and Paleozoic-limestone breccia lenses variously strike or dip into the fault plane. The conglomerates often yield a reddish to brownish soil which lacks the heavy tree growth found on the Paleozoic limestone on "Clover Hill." In fact, the fault trace coincides closely with this contrast in vegetation. If about 1750 feet of the Clover Valley unit underlies the limestone breccia in this area as do on the west side of Clover Valley, a displacement of somewhat more than 1750 feet is indicated. The inclination of the fault plane is steep and it may dip to the east. At lower elevations toward the southern end of "Clover Hill" the fault trace is farther east, suggesting it is a high-angle reverse fault. On geomorphic evidence Sharp mapped a fault on the east side of this hill, but he did not map the one presently described on the west flank.

North of "Clover Hill," Tertiary conglomerate beds strike into the hill. An east-northeasterly fault between the metamorphic basement and Tertiary beds may be present (structure locality 2).

On the steep linear northwest flank of the isolated hill lying due south of "Clover Hill" a vivid red to orange soil is exposed. The linear northeasterly trend is perceived on aerial photographs out in the valley to the southwest, suggesting that a high-angle fault could be present (structure locality 3).

Both faulting and possibly several ages of folding have deformed the Tertiary succession in the northern portion of Clover Valley. One prominent structural discordance between the Tertiary succession in the northwestern corner of the valley and the Tertiary sequence to the south is quite probably due to a northeasterly-trending fault (structure locality 4). Unfortunately, pediment alluvium covers the critical relations. The Tertiary rocks north of the discordance form a steeply eastward dipping homocline. To the south, the width of outcrop of both the Dorsey ... s evidenced along much greater, the succession is folde... and also is locally faulted.

Other faulting in the Te... where the creek emerges from ... tle compared Valley. On the east side o... very to dip gently to the south, then ... ent, apparently due to drag along an east-no... e. (structure locality 5). Alluvium-covered whi... rallels lain by fine-grained Tertiary deposits, occur imme... structures noted on the east side of the creek were not ... side, and, in fact, rhyolite is exposed roughly 900 feet farth... the west side. There is, therefore, a strong suggestion of a latera... nent of movement on a north-south fault along this segment of Willow Cree... Such a fault presumably would have originated after the east-northeast trending fault on the east side of the creek.

All of this subordinate faulting and folding east of the range front is believed to have variously originated during and after the main episode of major anticlinal folding of the range.

The extent to which faulting may have accompanied the anticlinal folding on the east front of the northern East Humboldt Range is not known. Since the major folding was of a magnitude sufficient to account for the elevation of the mountain mass, evidence for either the presence of faulting or for its magnitude cannot be based solely upon the vertical relief of the range. Furthermore, truncation of structure at the range fron can hardly be used as a criterion for high-angle faulting in an area which has been thrusted and then anticlinally folded. In this area, for example, the layers in the metamorphic basement are often truncated at the overlying Secret Creek thrust plane. Likewise, the overlying Paleozoic to Lower Triassic succession is often truncated at the thrust plane, and is subordinately thrusted and faulted. Hence there is no reason not to expect truncation of either upper or lower plate rocks which may be exposed at the range front at any stage of erosional retreat.

Further, because of the subordinate thrusting which has often brecciated, silicified, and fractured members of the upper plate succession during Mesozoic orogeny, the local presence of a silicified and/or brecciated mass of Paleozoic rock at the range front should not be assumed to be due to range front faulting. Such a breccia related to Mesozoic structure could have been exposed by erosion at the land surface prior to Tertiary deposition. It is definitely known that a considerable amount of erosion did occur prior to the deposition of the Tertiary Clover Valley unit, and partially because of this the upper plate succession is not everywhere present and where present its thickness varys. Only if the brecciation involves Tertiary beds, would the use of a breccia to prove range front faulting be valid. But even in this latter case, the magnitude of faulting would be often difficult to determine without drilling or geophysical work, since the base of the Tertiary succession in the valley can only be inferred.

What evidence is there for faulting along the east front of the East Humboldt Range? As Sharp has previously admitted, there is "little direct geologic evidence of faulting...available" (1939b, p. 892). Sharp reported only one locality along the entire east fron where the postulated boundary fault was exposed (1939b, p. 892). This was on the north bank of Willow Creek, NW¼, Sec.2, T.36N., R.61E. at structure locality 6. The writer is uncertain whether he saw the exact locality referred to, but the relations observed in this general area are as follows: A fault is present at this locality, and the fault dips steeply to the northeast as Sharp reports. By detailed mapping of the structures in the range itself it seems clear that the fault is actually a subordinate thrust plane involving upper Paleozoic rocks. A study of only range front relations is quite misleading because much of the thrust plane appears to have been exhumed prior to deposition of the Tertiary succession. Of significance is the fact that the Tertiary beds directly adjacent to this apparently exhumed fault surface show no evidence of brecciation, and are apparently in depositional contact upon the thrust plane. Critical remnants of the upper plate to this thrust fault are locally preserved at both the base and the top of the scarp. At the base of the scarp, Tertiary beds rest upon both upper and lower plate rocks. Fusulinids from the E½ of NW¼, Sec. 3, T.36N., R.61E. and SW¼, Sec. 34, T.37N., R.61E. indicate that the upper plate rocks are Leonardian. Megafossils in the lower plate are from the Pennsylvanian Ely limestone.

The upper plate rocks locally have been silicified and brecciated and in some places are jasperoidal. A mass of jasperoid forms a prominent outcrop at the range front just south of Willow Creek and may be related to the above described subordinate thrusting.

The above described Willow Creek locality was the only place where there was reportedly direct evidence of normal faulting along the east front of the range. South of Ralphs Creek, Sharp found that "the only geologic evidence of faulting is the relation of the internal structure and the range front." The rocks exposed south of Ralphs Creek are high-grade metamorphic basement rocks which have been subjected to pedimentation and extensive glaciation. Most of the exposures now seen occur 1 to 2 miles west of the range front. These rocks are a part of the truncated basement succession beneath the now-removed Secret Creek thrust. Any original truncation of structure beneath this thrust plane would logically be seen at the range front after the thrust plane is eroded, and therefore, truncation in this case would not prove normal faulting. But, in any case, the truncation now observed is due more to erosion than to anything else.

The lack of direct evidence for range front faulting does not mean, of course, that no high-angle faulting was associated with folding. Some evidence not mentioned by Sharp, in fact, suggests that in the vicinity of Ralphs Creek faulting may have occurred. Here what is tentatively correlated with the Willow Creek rhyolite rests adjacent to a small mass of pre-Tertiary limestone. The nature of the contact between these units is not known. The rhyolite adjacent to the contact is an unaltered and unbrecciated black perlitic glass. Because of this, an unconformable relationship with the Paleozoic is as likely as faulting. However, if the perlite escaped brecciation and the contact is a fault associated with the main folding, displacement would have to be equal to the unknown thickness of Tertiary beds which may or may not be present beneath the rhyolite at this locality. (At the northern end of Clover Valley about 4250 feet of Tertiary strata underlies the Willow Creek rhyolite).

In summary, available evidence indicates that the east front of the East Humboldt Range is basically the east limb of a huge northerly trending, doubly plunging, anticlinal fold. The presence, extent, or magnitude of previously reported normal faulting along the east front of the range is not known. The evidence previously used in this area to prove both the presence and magnitude of faulting, however, can no longer be regarded as indicative of normal faulting. But despite the apparent absence of conclusive evidence to prove high-angle faulting along the east flank of the range, there is likewise no conclusive evidence to disprove the possibility that some faulting was associated with or followed the major anticlinal folding. Faulting of significant magnitude during this episode did occur as evidenced along the west flank of "Clover Hill."

Second Episode Structures on West Side

of the East Humboldt Range

The western slope of the East Humboldt Range is very gentle compared to the rather abrupt eastern front. The inclination of the slope very closely approximates the dip of the layers in the metamorphic basement, which averages 10 degrees to the west in the central part of the range. Remnants of the Secret Creek thrust sheet show that the thrust plane parallels much of the metamorphic layers on this flank of the range. The trend and inclination of the range front closely approximate the attitude of both the basement succession and the Secret Creek thrust plane where they are exposed. Where the metamorphic terrane is subordinately folded into a broad east-west trending syncline, between Boulder and Herder Creek, the range front forms a prominent embayment about 2 miles deep. On the northwestern flank of the range basement the rocks dip more steeply, likewise the range front is steeper and parallels the strike of these beds (Fig. 47). Between Dorsey and Reed Creeks, Paleozoic rocks are exposed, and here the range front is more abrupt. In short, the close relationship between the internal structure of the range and the range front is one of the most impressive features on the western flank of the range.

Although evidence for small scale post-Wisconsin faulting (third episode) on this west side of the range is good 1) along the range front north of Hall Creek, 2) 2 to 3 miles from the range front between Herder and Reed Creeks, and 3) along the range front in the Ross Creek area, conclusive evidence for an episode of earlier second episode normal faulting is scarce.

In fact, the overall conformity between the structure within the range and the range front might be regarded as indirect evidence against such faulting. Nevertheless, in some places Tertiary beds do locally appear truncated by the mountain front, and some second episode faulting is suggested locally.

Just south of the northern end of the range Sharp reports remnants of a piedmont scarp cutting fan gravels. This scarp is certainly post-Wisconsin, and a part of the third episode of Cenozoic deformation which is to be described in the next section.

The evidence cited by Sharp (1939b, p. 896) for earlier faulting along the range front is as follows: "...Between Ackler Creek and Secret Creek good exposures of Miocene beds give ample geologic proof of faulting. In a number of places fine-grained Miocene beds dip directly toward the steep scarp of the mountain block. That these fine-grained beds could be deposited so close to a steep scarp does not seem possible and the attitude of the beds shows that the relations are due to faulting rather than folding".

The several localities where Tertiary beds dip directly toward the range front are certainly suggestive but not necessarily indicative of faulting. Actually, nowhere along the range front where Tertiary beds immediately adjacent to the pre-Tertiary bedrock seem to dip directly into the pre-Tertiary rocks. In fact, the only clear relation observed at the range front was where flat-lying Tertiary siltstones and volcanics rest unconformably upon nearly horizontal pre-Tertiary marble. This locality is on the west bank of Stephen Creek (NW$\frac{1}{4}$, Sec. 7, T.35N., R. 60E.) This single exposure displaying an unconformable relationship would not, however, preclude the possibility of faulting slightly farther westward, and such faulting may definitely be present here and elsewhere along the range flank. For instance, the Willow Creek? rhyolite mass which is exposed north of

Stephens Creek appears to strike northwesterly and dip gently to the northeast. It outcrops roughly 2000 feet west of pre-Tertiary rocks and strikes into the very gently westward sloping range front. If about 4250 feet of Tertiary strata underlie the Willow Creek? rhyolite here as at the northern end of Clover Valley, a large amount of displacement along a north-northeasterly trending normal fault would be indicated, in fact, more than the 2000? feet postulated by Sharp. Unfortunately, the thickness beneath the rhyolite here is unknown. Much of it could have been removed by either pre-Starr Valley or pre-Willow Creek erosion. Geophysical data would be helpful in solving this problem.

In Secret Pass, Sharp (1939b, p. 896) reported "...a wide brecciated zone separates the pre-Miocene rocks of the mountain block from the basin deposits. A minor subsidiary fault is exposed in the basin deposits along the south flank of Secret Creek half a mile west of the boundary fault. These features further substantiate the presence of a fault at the west base of the mountains." The "wide brecciated zone" was not described or located, so it is uncertain whether this writer observed the exact locality referred to. However, this general area was studied quite thoroughly and the breccia observed by the writer in this area is now described: A variously brecciated, fractured, and pulverized mass of Permo-Carboniferous limestone is exposed at the west entrance to the Secret Creek gorge (just north and west of BM 5818 in the S½, Sec. 36, T.35N., R.59E.) This mass has been previously described in the chapter on Mesozoic structure. Mapping of the internal structure of the range has shown that this breccia is at the base of the Secret Creek thrust sheet which here essentially dips gently westward. The breccia is clearly in thrust contact with the underlying metamorphic basement. Both north and south of the gorge, Tertiary beds rest unconformably upon both the lower plate basement succession and upper plate Paleozoic rocks. No brecciation of Tertiary beds was noted anywhere in this area. The minor subsidiary fault which Sharp describes (1939b, p. 898) lying one-half mile west of the "boundary fault" is of small displacement and "has brought Quaternary alluvium on the west side into contact with Miocene basin deposits." The fault was observed by the writer and is probably latest Pleistocene to Recent, and is not of major significance. These latest Cenozoic faults are not uncommon and are discussed in the next section.

South of Secret Creek, Sharp (p. 896) reported "...remnants of a piedmont scarp extend along the base of the mountains for $2\frac{1}{2}$ miles to the mouth of Ross Creek. This scarp appears to be composed entirely of fan deposits." This writer noted that the range front starting south of a point $1\frac{1}{2}$ miles south of Secret Creek, locally does appear to have been affected by latest Pleistocene to Recent faulting. This faulting is discussed in the next section.

Subordinate Transverse Folding of the Second Episode

Secondary transverse folding superimposed upon the major northerly to north-northeasterly structural trends appear to have had a direct influence in shaping the basic topography of the range and the outline of the range front.

In the area of the Secret Creek gorge a west-northwest trending syncline (as mapped at the base of the Secret Creek thrust) conforms to the transverse topographic depression separating the Ruby Mountains from the East Humboldt Range. To the north, several transverse folds have a distinct effect upon both the topography and the outline of the range front. The northermost fold is an anticline which trends roughly east-westerly, passing through Greys Peak and plunging to the west on the west side of the range. The southern limb of the fold was mapped north of the middle fork of Herder Creek where the Secret Creek thrust plane dips southeasterly. The metamorphic basement succession in the area is not greatly truncated by the thrust plane. The north limb of the anticline lies north of the north fork of Herder Creek. Along the axis of the fold the outline of the range front shows a prominent outward bowing on both flanks of the range (see main geologic map). In Clover Valley the superimposed structures cannot be directly mapped, but the east-west trending drainage divide in Clover Valley may represent the present expression of the fold axis. This drainage divide is a transverse "high" in Clover Valley which separates streams which flow northward into the Humboldt River, and those which drain into a closed basin to the south.

South of the above-described anticline is a broad transverse syncline. These structures have been mapped in the metamorphic succession on the west flank of the range, since the beds above the Secret Creek thrust have been removed. The dips of the metamorphic terrane on this flank, however, apparently closely conform to the dip of the thrust plane, as suggested north of Herder Creek and south of Lost Creek where very small remnants of the thrust sheet are preserved at the range front. The syncline plunges to the east, and is reflected by a prominent topographic embayment at the range front 4 miles long and 2 miles deep. The embayment lies between Boulder and Herder Creeks and is significantly deepest along the axis of the westward-plunging syncline. On the east flank of the range the axis trends so as to pass approximately east-westerly between Ralph and Schoer Creeks. Significantly, the Willow Creek? rhyolite which is exposed on an isolated hill north of Ralphs Creek has been oddly folded into a structure which appears to represent a northerly and an east-westerly structural trend, one superimposed upon the other.

Third Episode

Piedmont fault scarps and scarplets along the west front of the Ruby-East Humboldt Range are interpreted as representing the third episode of deformation in the area, which is latest Pleistocene to Recent in age. Some of these have been described by Sharp (1939b). The piedmont scarps locally follow the range front but appear mostly out in the adjacent basins in this area. They transect alluvial fans, terrace and pediment surfaces, valley bottom alluvium, and in the Lamoille area to the south, late Pleistocene moraines. The apparent displacement on these faults is relatively minor compared to the present relief of the range. The displacement on most appears to be less than 100 feet.

No piedmont scarps occur along the east front of the East Humboldt Range. Significantly, Wisconsin moraines at the mouths of Clover, Willow, and Angel creeks extend outward onto an earlier Pleistocene pediment surface and are undisturbed.

The highest scarp on the east flank of the East Humboldt Range is about 75 feet high. It occurs in alluvial deposits at the mouth of Greys Creek and can be traced northward for several hundred yards. On the north side of the creek, the northeast-trending scarp is paralleled by a lower southeast-facing scarplet about 20 feet high. These two opposing scarps form a distinctive graben-like trough. Similar, though less pronounced features were observed at the mouths of Burger Creek and another unnamed creek near the northern end of the range. At the northern tip of the range is a linear east-northeast trending scarp which may be due to this late episode of faulting. The presently mapped contact between the Tertiary sedimentary rocks and volcanics at the northern end of Clover Valley approximates a poorly defined, essentially east-west trending piedmont scarp which is quite possibly due to this late episode of faulting.

South of Herder Creek piedmont scarps do not follow the range front. A large dissected pediment platform underlain by beveled Tertiary strata extends southwestward for about 13 miles. The platform slopes gently to the west and ends rather abruptly at Starr Valley, $2\frac{1}{2}$ to 4 miles west of the range front. The termination of the platform is a dissected scarp often several hundred or more feet high. Northerly to northeasterly trending piedmont scarplets transect valley bottom alluvium at Boulder and Reed creeks. These scarplets occur where these creeks emerge from the pedimented Tertiary platform and enter Starr Valley, a distance of between 2 and 3 miles from the range front. This faulting suggests that the main termination of the pediment platform may in part be due to an earlier stage of faulting of greater displacement, and that the present scarplets reflect late movements along these faults. The northern termination of the pediment platform, however, may be due to lateral planation by Herder and Ackler Creeks.

A narrow, graben-like trough occurs west of the Starr Valley road between Reed and Heelfly creeks, $3\frac{1}{2}$ miles west of the range front.

Both the width and elevation of the Tertiary platform decrease sharply south of Secret Creek, and one mile south of the creek the Tertiary deposits appear to be entirely covered by range front alluvium. The range front for several miles south of Secret Creek is believed to approximate the western slope of the exhumed Secret Creek thrust plane. The range front may be modified by latest Pleistocene to Recent faulting as is suggested by a scarp at the mouth of Wilson Creek (next creek south of Ross Creek). A small pediment surface with a triangular outline (one-third of a mile in length along the range front), is preserved in back of this west-facing scarp. The scarp is about 200 feet high, and is probably a fault scarp.

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The range front in this area south of Secret Creek is distinctive because of several triangular facets exposed at the mouths of Ross and Murphy Creeks. Such facets have often been used as physiographic criteria for normal faults. These facets slope about 25 degrees to the northwest, and are believed to be essentially the exhumed western limb of the anticlinally folded Secret Creek thrust plane. As previously mentioned, however, a minor latest Pleistocene to Recent fault may lie at the base of the range front and these facets.

In summary, there is good evidence for a latest Pleistocene to Recent episode of faulting along and adjacent to the west flank of the East Humboldt Range and northern Ruby Mountains. This episode of faulting is evidently absent on the east flank of the East Humboldt Range. The faults are represented by piedmont scarps which occur at the range front, but mostly out in the flanking basins. Displacement along most of the faults is apparently less than several hundred feet and usually much less.

PHYSIOGRAPHY

General Statement

Much of the physiography has been discussed in the chapter on Cenozoic structure and history. This section will briefly discuss the drainage, glacial features, pediments and terraces, and lake shoreline features, which have been described in more detail by Sharp in his excellent papers on the geomorphology (1940) and glaciation (1938b) of the Ruby-East Humboldt Range.

Drainage

Distinctive because of their high relief and rugged alpine topography, the Ruby-East Humboldts are an unusual Nevada range in that they are often snowcapped in mid-summer months. Many streams flow from the mountain area throughout the year, and the range is dotted with over 30 small alpine lakes.

Most of the streams on the east side of the range empty into wide intermountain basins. Ruby, Franklin, and Snow Water lakes lie in lower parts of these closed basins. In contrast, the streams on the west side of the mountain mass have open drainage, and are tributaries to the well-known Humboldt River. The tributaries from the Ruby-East Humboldt Range are probably the most important source of water for this 300-mile-long river, which heads in the Elko-Wells area and empties into a basin about 65 miles east-northeast of Reno.

Glacial Features

The Ruby Mountains and the East Humboldt Range were extensively glaciated during Pleistocene time. U-shaped valleys (Fig. 72), moraines (Fig. 74), cirques, tarns (Fig. 73), and other glacial features are plentiful.

King (1878) was the first to record glaciation in the range. Blackwelder (1931, 1934) called attention to certain glacial features in the range in two papers on Great Basin glaciation. Sharp (1938) has dealt with the glaciation of the range in considerable detail, and the reader is referred to his excellent paper on the subject.

Both Sharp and Blackwelder found evidence of two separate glaciations in the Ruby-East Humboldt Range. These were termed the Lamoille (earliest Wisconsin) and Angel Lake (later Wisconsin) substages, and respectively correlated with Blackwelder's Tahoe (older) and Tioga (younger) stages in the Sierra Nevada.

During the Lamoille substage, the glaciers were of greater extent both in length and thickness than those of the younger Angel Lake substage. According to Sharp (1938), "The Lamoille substage glaciers descended to an average altitude of 7300 feet on the west side and 7200 feet on the east side of the range. Glaciers of the Angel Lake substage were shorter and descended to an average altitude of 7800 feet on the west side and 7600 feet on the east side." Sharp estimated that the ice attained a maximum thickness of 900 feet during the Angel Lake substage, and was thicker during the Lamoille substage. He calculated that approximately 17 percent of the East Humboldt Range was covered by glaciers in the Lamoille substage, and 14 percent during the Angel Lake substage.

Pediments and Terraces

Surfaces on the West Flank

Pediment and terrace surfaces are well developed on the west flank of the East Humboldt Range south of Herder Creek. In Sharp's (1940) discussion of the geomorphology of the range, he mentioned the development

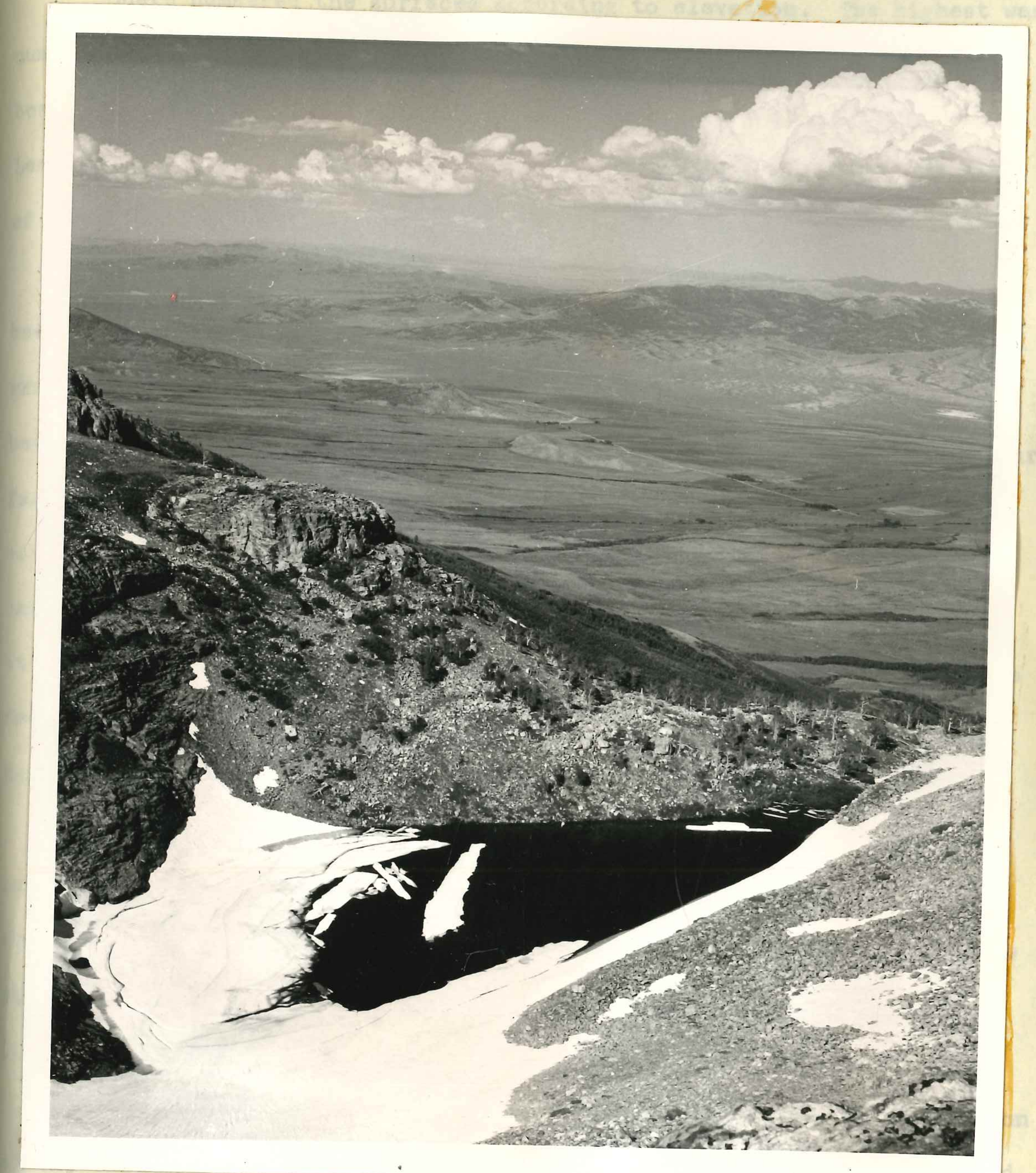

Fig. 73. Looking northeastward at Gibbs Lake, a tarn on the east side of the central East Humboldt Range. Clover Valley is in the middleground. The low tree-covered range in the right background is shown on some maps as the Wood Hills. Bedrock in foreground is a portion of the Angel Lake unit.

of two pediments correlated with similar surfaces on the west flank of the Ruby Mountains.

Sharp numbered the surfaces according to elevation. The highest was number 1, and the next highest was number 2. The number 2 surface is the best preserved and most extensive of all the surfaces. It was named the Lee surface by Sharp because of its distinctive development near the town of Lee, 20 miles south, on the South Fork of the Humboldt River.

The Lee surface on the west flank of the East Humboldt Range is best developed between East Fork Boulder and Herder creeks. It is a broad gravel-mantled pediment that bevels a platform of Tertiary deposits lying between the range front and Starr Valley. The boundary between the Lee surface and the range front is not abrupt, and for the most part appears to correspond fairly closely with the boundary between the Tertiary and the harder bedrock of the range itself. The surface is remarkably smooth and it slopes gently to the west for a maximum of about 3 miles from the range front. In most places it is 200 to 300 feet above the stream grade of Herder and East Fork Boulder creeks.

None of the four terraces below the Lee surface are very extensive in the East Humboldt area and occur only as small remnants between and along streams. The approximate average elevations of these terraces above stream grade in the Boulder Creek area as reported by Sharp are: Surface 3, 200 feet; Surface 4, 150 feet; Surface 5, 60 feet; Surface 6, 30 feet.

The presence of the lower four terraces indicate that the dissection of the extensive Lee pediment took place in stages. And as Sharp observed, the time lapse for each of the succesive stages must have been shorter than the time required to form the widespread Lee surface, otherwise the Lee surface would have been destroyed.

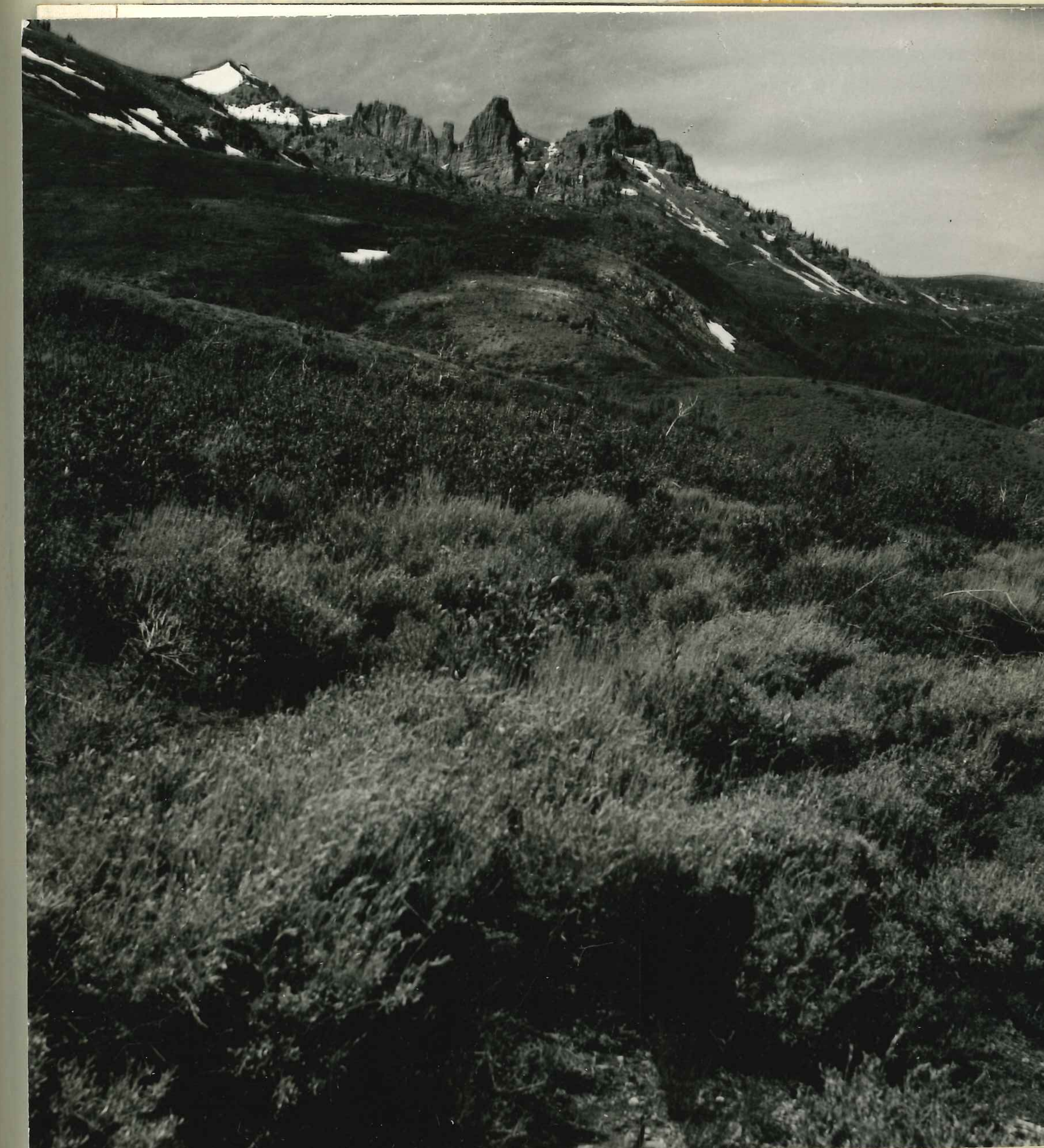

Fig. 74. Looking northward at lobate-like early Wisconsin (Lamoille substage) moraine which extends outward onto Clover Valley pediment surface between Ralph and Schoer creeks. Bedrocks in the upper left are members of the Angel Lake unit. Tree-covered "Clover Hill" lies in the right middleground.

Surfaces on the East Flank

Pediment surfaces truncating both metamorphic rocks and softer Tertiary rocks can be found on the east flank of the East Humboldt Range.

A dissected pediment across inclined Tertiary deposits occurs at the northern end of Clover Valley. It is best preserved between Willow and Clover creeks (Fig. 70). These two creeks, incidentally, are the only two creeks on the east side of the range that have exterior drainage. They flow northerly into the Humboldt River.

The pediment in Clover Valley truncates only the softer Tertiary deposits; it does not bevel the resistant bedrock units of the range itself or the hard Tertiary rhyolite units in the valley. Thus, the separation between the range and the valley corresponds closely to differences in rock resistance, and the break is often rather abrupt.

The pediment and the break in slope at the range front is evidently a pre-Iowan (early Wisconsin) feature inasmuch as lobate-like moraines of the Lamoille substage extend outward across this break and onto the pediment surface without interruption. These projecting moraines are prominently displayed between Willow and South Fork Angel creeks, and again to the south between Schoer and Ralph creeks (Fig. 74). It should be noted that this is in contrast to relations in the Heenen-Seitz Creek area on the west flank of the central Ruby Mountains, where projecting moraines have been cut by latest Pleistocene or Recent faults along the range front.

The east flank of the imposing East Humboldt range front from Ralph Creek south is characterized by: gentle gravel- and sometimes boulder-covered alluvial slopes; absence of visible Tertiary deposits; and in places, such as just south of and along the banks of Steels Creek, exposures of the metamorphic basement succession. In an embankment north of the east-westerly trending Warm Springs ridge, 4½ miles north of the southern end of the East

Humboldts, low-lying knobs of marble and quartzite, up to 1½ miles east of the range front, rise above a thin alluvial veneer. These features would suggest that much of the alluvium-covered slopes flanking the east face of the East Humboldt Range are veneered pediments at least in their upper parts.

Sharp (1940) describes a dissected barerock pediment encircling the southern end of the East Humboldt Range which has developed across both "Pliocene? lavas" and pre-Tertiary rocks.

Lake Shoreline Features

Snow Water, Franklin, and Ruby lakes are lakes, marshes and playas which lie in the valley areas east of the Ruby-East Humboldt Range. These lakes formerly had higher levels as indicated by often prominent old shoreline features.

Under normal winter conditions, Snow Water Lake is about 7 miles in diameter, and irregularly trends east-westerly. The highest observed shorelines above the lake lie roughly between roughly 120 and 250 feet above the relatively recent high water level, which according to the Halleck topographic map surveyed in 1930-31 was slightly below 5600 feet.

The highest observed shoreline features of Franklin and Ruby lakes lie approximately 6060 feet above sea level. The shoreline features of these lakes, which at one time coalesced to form one large lake hundreds of square miles in area, have been described by Sharp (1938b).

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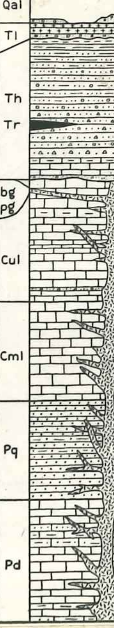
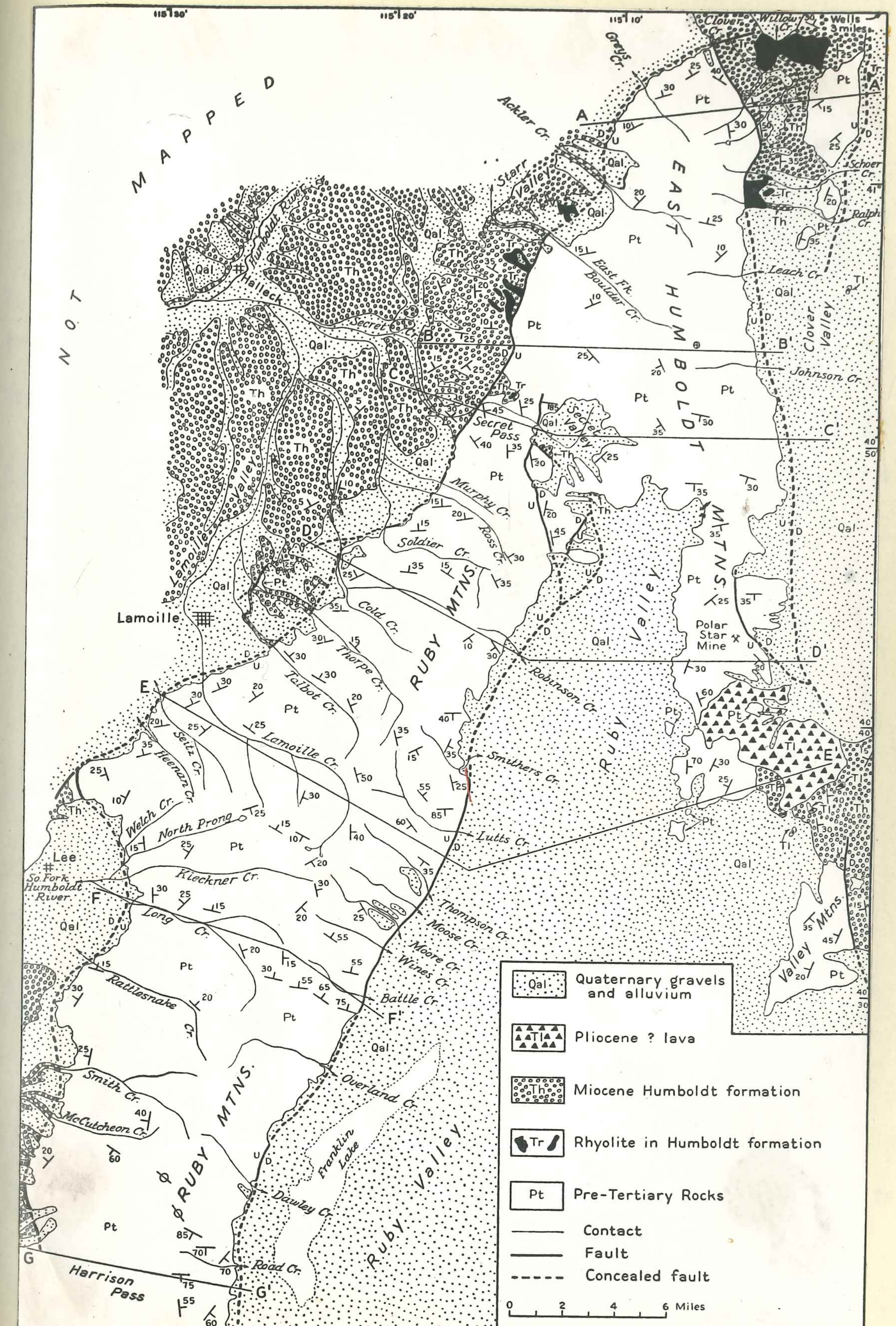
VITA

Sigmund Snelson, the son of Mr. and Mrs. Clifton Earl Snelson, was born in Santa Paula, California, on June 22, 1932. He attended Alexander Hamilton High School in Los Angeles, and was graduated in June, 1949. He majored in geology and minored in mathematics at the University of Redlands, and in June, 1953, he received a Bachelor of Science degree with distinction. Upon graduation, he was granted a Teaching Fellowship at the University of Washington, which he has held for four years. In June, 1955, he completed his thesis on "The Geology of the Southern Pequop Mountains, Elko County, Northeastern Nevada" for the Master of Science degree. In March, 1957, he was awarded a Fulbright Grant for graduate study in Austria for the school year 1957-1958. He is a member of Sigma Xi, and the Geological Society of America.

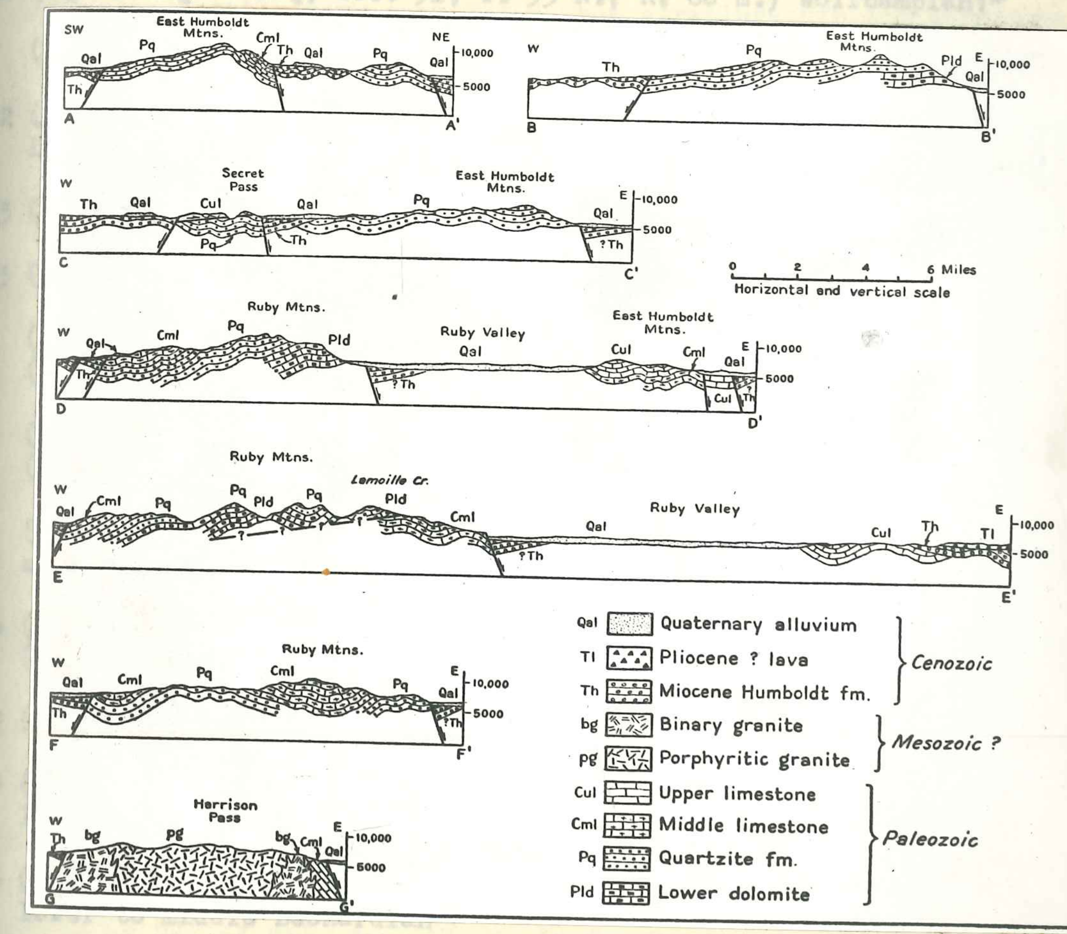


AGE	FORMATION	SYMBOL	COLUMNAR SECTION	LITHOLOGY	THICKNESS in feet
QUATERNARY	DRIFT, GRAVELS, ALLUVIUM	Qal		Pediment and terrace gravels, glacial drift, recent alluvium.	5-150
PLIOCENE ?	PLIOCENE ? LAVA	Tl		Pyroxene andesite and olivine-pyroxene basalt flows, breccia, and tuff.	200-400
	UNCONFORMITY				
MIOCENE	HUMBOLDT FORMATION RHYOLITE	Th Tr		Breccia, fanglomerate, conglomerate, sandstone, mudstone, shale, oil shale, limestone, ash, tuff, and interbedded rhyolite flows (Tr)	5800
	UNCONFORMITY				
EARLY TERTIARY OR LATE MESOZOIC	BINARY GRANITE PORPHYRITIC GRANITE	bg pg		Binary granite, porphyritic granite, pegmatite.	
CARBONIFEROUS	UPPER LIMESTONE	Cul		Gray, black, buff, thin-bedded limestone, fossiliferous	5000 + ?
	MIDDLE LIMESTONE	Cml		Massive gray, white, and buff limestone, fossils scarce.	4000 ± 1000
CARBONIFEROUS OR OLDER PALEOZOIC	QUARTZITE FORMATION	Pq		Quartzite, quartz-mica schist, marble, biotite gneiss, locally conglomerate and breccia	4000 ±
	LOWER DOLOMITE	Pd		Diopside granulite, quartz-mica schist, sillimanite-garnet schist, quartzite, and marble.	5000 + ?

Columnar section reproduced from Sharp (Fig. 3, 1939b)



Map reproduced from Sharp (Plate 1, 1939b)



Sections reproduced from Sharp (Plate 1, 1939b)

*AGE DESIGNATIONS AND LAND GRID LOCATIONS OF PERMIAN FUSULINID

ASSEMBLAGES LISTED ON TABLES 2 AND 3

A 20 (S$\frac{1}{2}$ of NW$\frac{1}{4}$, Sect. 17, T. 34 N., R. 60 E.) Uppermost Wolfcampian*

A 21 (SW$\frac{1}{4}$ of SW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 21, T. 34 N., R. 60 E.) Leonardian?*

A 25 (S$\frac{1}{2}$ of NE$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 32, T. 35 N., R. 60 E.) Leonardian*

A 26 (S$\frac{1}{2}$ of SE$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 32, T. 35 N., R. 60 E.) Wolfcampian?*

B 7 (SW$\frac{1}{4}$ of SW$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 20, T. 35 N., R. 60 E.) Leonardian*

G 32 (SW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 4, T. 34 N., R. 60 E.) Leonardian (good)*, likely lower Leonardian**

G 33 (just northeast of G 32) Wolfcampian (good)*, likely lower Leonardian**

G 43 (SW$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 33, T. 35 N., R. 60 E.) Wolfcampian (good)*

K 1 (talus in SE$\frac{1}{4}$ of NE$\frac{1}{4}$, Sec. 19, T. 35 N., R. 60 E.) Upper Wolfcampian (poor to very poor)*

K 2 (talus in SW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 20, T. 35 N., R. 60 E.) Upper Wolfcampian (poor to very poor)*

K 5 (SW$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 20, T. 35 N., R. 60 E.) Leonardian (good)*, likely middle Wolfcampian**

K 6a (talus in N$\frac{1}{2}$ of NW$\frac{1}{4}$ of SE$\frac{1}{4}$, Sec. 19, T. 35 N., R. 60 E.) Leonardian (fair)*, likely middle Wolfcampian**

K 27 (N$\frac{1}{2}$ of NW$\frac{1}{4}$ of NE$\frac{1}{4}$, Sec. 20, T. 35 N., R. 60 E.) Leonardian (good)*

K 29 (NE$\frac{1}{4}$ of NE$\frac{1}{4}$ ofNE$\frac{1}{4}$, Sec. 20, T. 35 N., R. 60 E.) Leonardian (fair)*, lower to middle Leonardian**

K 45 (SE$\frac{1}{4}$ of SE$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 32, T. 35 N., R. 60 E.) Leonardian (poor)*, lower to middle Leonardian**

P 3 (S$\frac{1}{2}$ of SW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 21, T. 34 N., R. 60 E.) Wolfcampian (fair)*

P 5 (NW$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 21, T. 34 N., R. 60 E.) Leonardian (poor)*, lower to middle Leonardian

R 1b (W$\frac{1}{2}$ of NE$\frac{1}{4}$ of NE$\frac{1}{4}$, Sec. 30, T. 35 N., R. 60 E.) Upper Wolfcampian (fair)*, likely middle to upper Wolfcampian**

S 1 (NE$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 4, T. 33 N., R. 60 E.) Leonardian (poor)*

---

* furnished by Gerald Marrall

** furnished by H. J. Bissell

S 2 (NW of S 1 in the NE$\frac{1}{4}$, Sec. 4, T. 33 N., R. 60 E.) Leonardian (good)*, middle to upper Leonardian**

S 7c (N$\frac{1}{2}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E.) Leonardian (good)*

S 8 (SW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E.) Leonardian (poor)*, middle to upper Leonardian**

S 11a(SW$\frac{1}{4}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E.) Upper Wolfcampian (fair)*, suggest middle Wolfcampian**

S 11b(geographically very near S 11a, but stratigraphic and structural relationship with S 11a is unknown) Leonardian (fair)*

S 12 (W$\frac{1}{2}$ of SW$\frac{1}{4}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E.) Leonardian (fair to good)*, suggest middle Wolfcampian**

S 13 (SW$\frac{1}{4}$ of NE$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E.) Leonardian (good)*, middle to upper Leonardian**

S 14 (S$\frac{1}{2}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E) Upper Wolfcampian or lower Leonardian*

S 15 (NE$\frac{1}{4}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$, Sec. 33, T. 34 N., R. 60 E.) Leonardian (good)*, middle to upper Leonardian**

S 22 (E$\frac{1}{2}$ of SW$\frac{1}{4}$ of SE$\frac{1}{4}$, Sec. 20, T. 34 N., R. 60 E.) Leonardian (poor)*, middle to upper Leonardian**

S 23 (N$\frac{1}{2}$ of NW$\frac{1}{4}$ of NE$\frac{1}{4}$ of NE$\frac{1}{4}$, Sec. 29, T. 34 N., R. 60 E.) Leonardian (fair)*

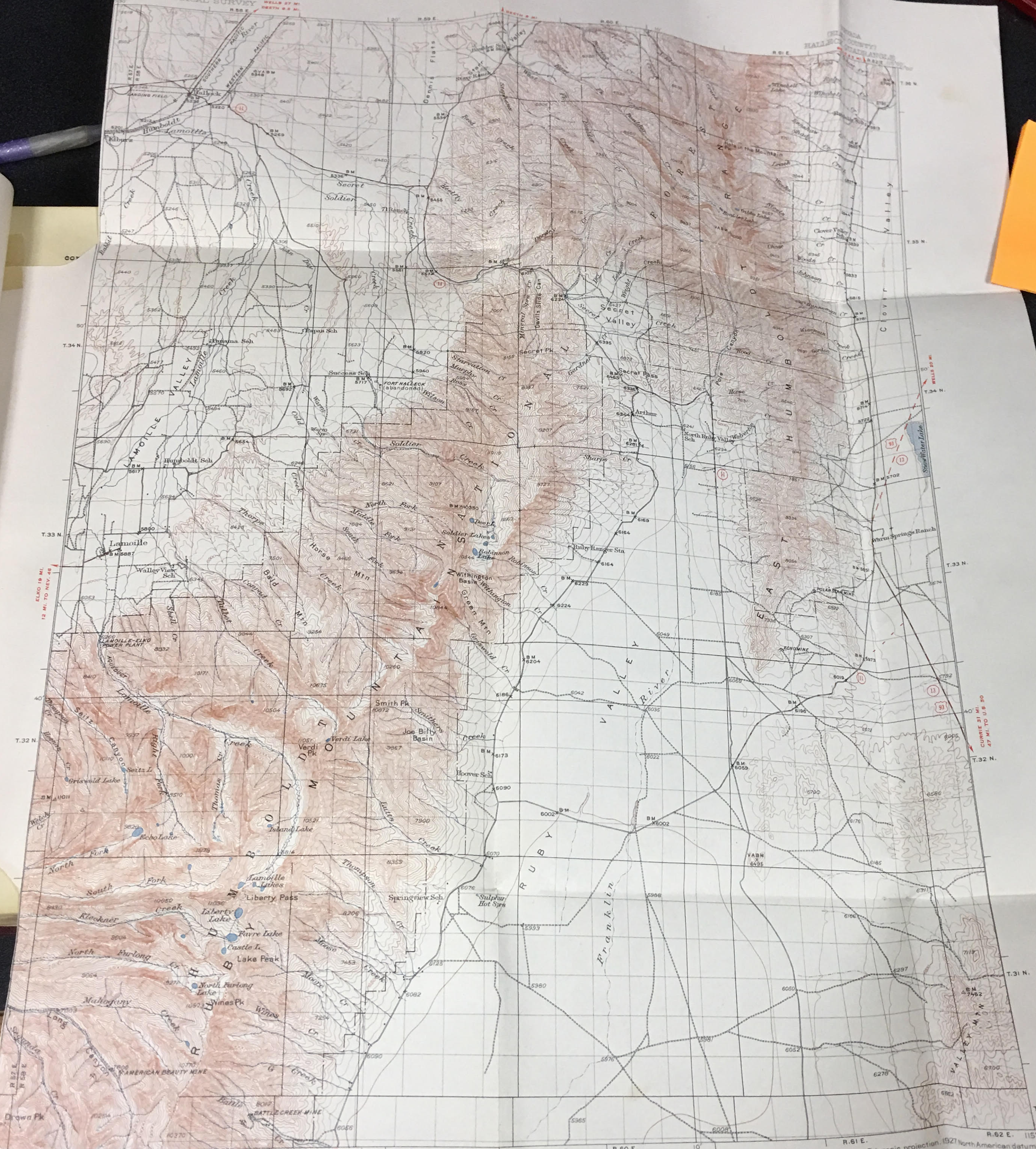
S 24 (S$\frac{1}{2}$ of SW$\frac{1}{4}$, Sec. 21, T. 34 N., R. 60 E.) Leonardian (fair)*, middle to upper Leonardian**

S 25 (NE$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 17, T. 34 N., R. 60 E.) Wolfcampian, probably lower half (good)*, middle to upper Leonard**

S 26 (between NW$\frac{1}{4}$ and the NE$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 17, T. 34 N., R. 60 E.) Upper Wolfcampian (fair)*

S 33 (S$\frac{1}{2}$ of NW$\frac{1}{4}$ of SW$\frac{1}{4}$, Sec. 17, T. 34 N., R. 60 E.) Wolfcampian (good)*

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



Topography by R.W. Burchard
Control by U.S. Geological Survey and
U.S. Coast and Geodetic Survey
Surveyed in 1930-1931

RUBY VALLEY P.O. 11 MI.

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1931

Scale $\frac{1}{125000}$

9 Miles

12000 Yards

25000 Feet

6 Kilometers

Contour interval 100 feet

Datum is mean sea level

DIAGRAM OF TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Polyconic projection. 1927 North American datum
5000 yard grid based upon U.S. zone system, F

ROAD CLASSIFICATION

HARD SURFACE ALL WEATHER ROADS — DRY WEATHER ROADS

Heavy-duty ... 4 LANE | 6 LANE — Improved dirt ....

Medium-duty ... 4 LANE | 6 LANE — Unimproved dirt

Loose-surface, graded, or narrow hard-surface

U. S. Route — State Route

HALLECK, NEV.
Edition of 1935
reprinted 1951
N4030-W11500/30

FOR SALE BY U.S. GEOLOGICAL SURVEY, FEDERAL CENTER, DENVER, COLORADO OR WASHINGTON 25, D.C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

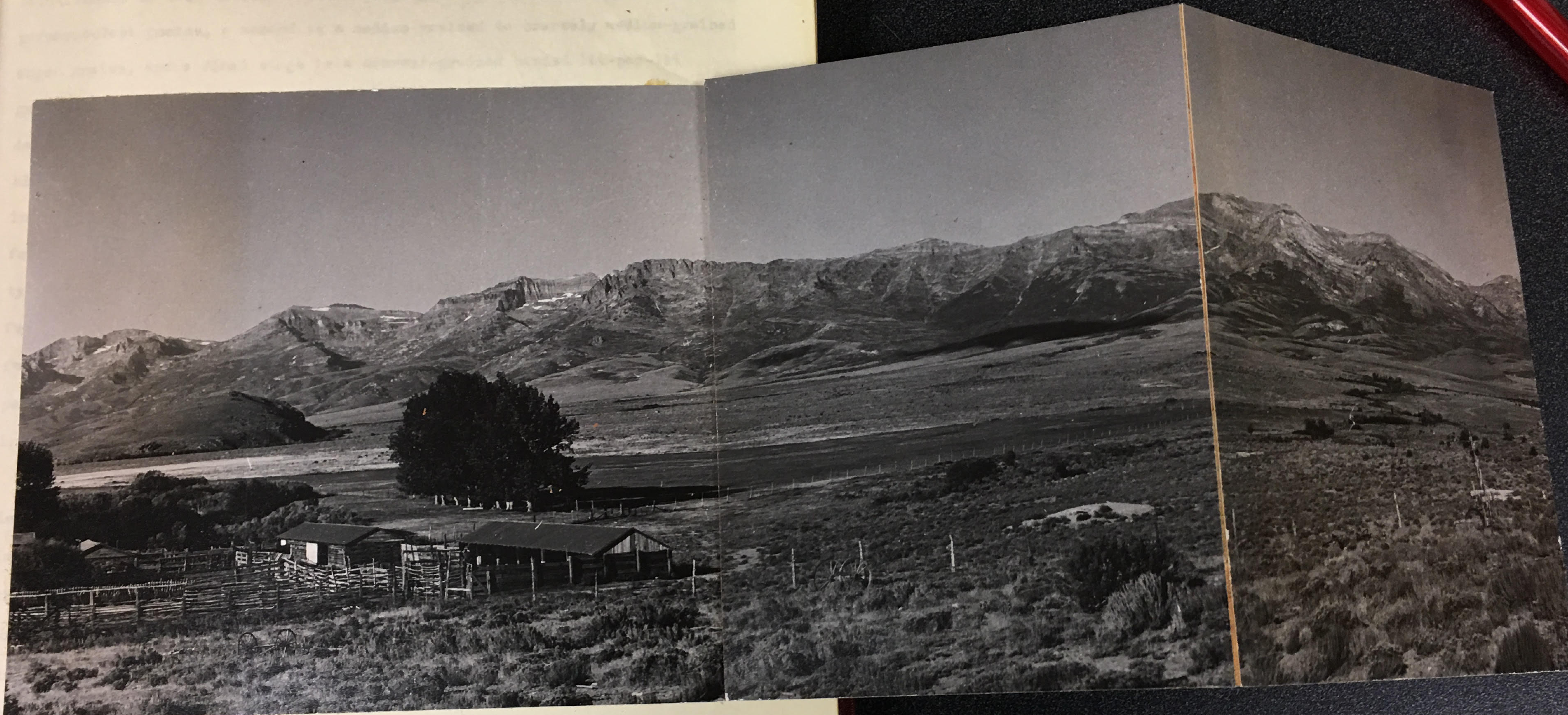


Fig. 11. The east front of the central East Humboldt Range. The dark gneiss member of the Angel Lake unit is exposed at the skyline in the central portion of the photograph, and can be traced northward for several miles.

Fig. 14. Looking westward at the Angel Lake unit here exposed on the southwest wall of the Boulder Lake cirque. Rock samples were collected at the localities shown, and these are described in the text.

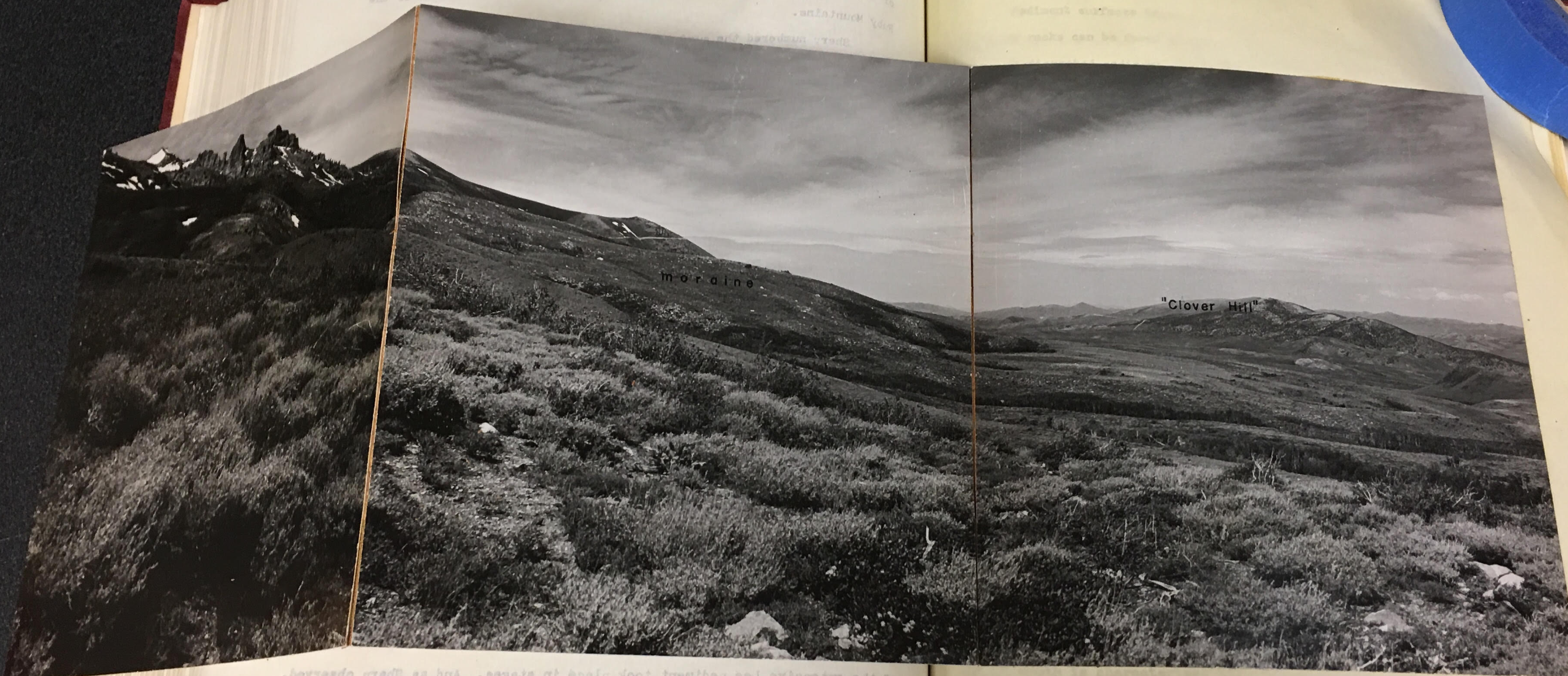


Fig. 74. Looking northward at lobate-like early Wisconsin (Lamoille substage) moraine which extends outward onto Clover Valley pediment surface between Ralph and Schoer creeks. Bedrocks in the upper left are members of the Angel Lake unit. Tree-covered "Clover Hill" lies in the right middleground.

INDEX MAP

AND

GENERALIZED GEOLOGIC MAP

OF THE

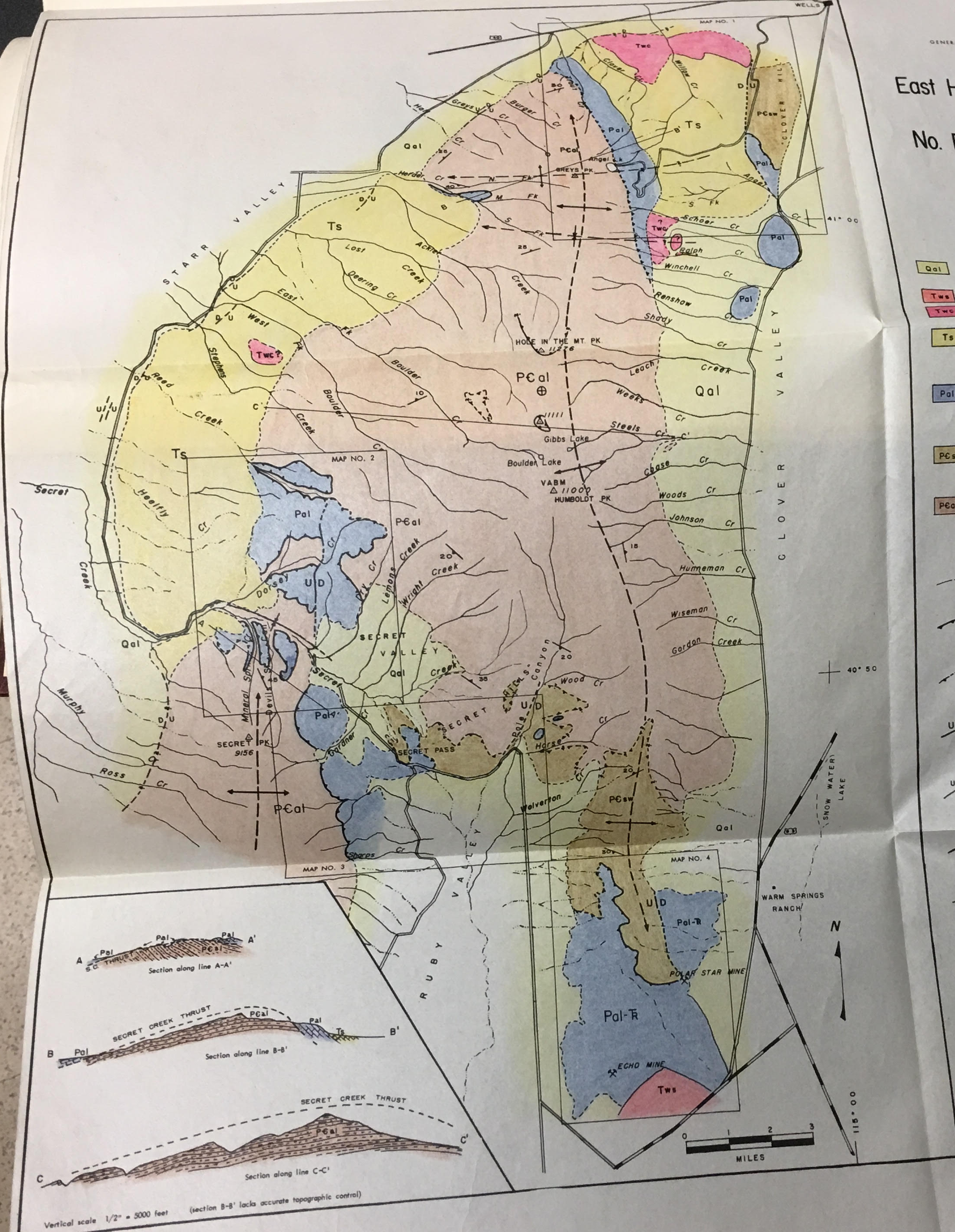
East Humboldt Range

AND THE

No. Ruby Mountains

GEOLOGY BY S. SNELSON

1955-57



LEGEND

Qal	QUATERNARY ALLUVIUM Pediment and terrace gravels veneering Tertiary deposits are not shown. Pleistocene moraines in the range are also not shown.
Tws	WARM SPRINGS UNIT
Twc	WILLOW CREEK UNIT
Ts	CLOVER VALLEY AND STARR VALLEY UNITS undifferentiated. In places covered by unmapped Quaternary alluvium.
Pal	MOSTLY PALEOZOIC ROCKS of Ordovician to Permian age. Includes Early Triassic strata in the southern East Humboldt Range. Formations delineated on accompanying larger scale geologic maps.
P€sw	SNOW WATER UNIT May include portions of the Angel Lake unit in the southern East Humboldt Range and at "Clover Hill"
P€al	ANGEL LAKE UNIT Includes portions of the Snow Water unit in the Secret Creek-Dorsey Creek area, and on the west flank of the northern Ruby Mountains and the East Humboldt Range.

CONTACTS
Dashed where approximately located, inferred or concealed.

MESOZOIC THRUST
Dashed where approximately located, inferred or concealed.

PRECAMBRIAN? THRUST
Dashed where approximately located, inferred or concealed; probably essentially accurate. Dashed and ? where hypothetical; may be inaccurate.

HIGH ANGLE FAULT
Dashed where approximately located, inferred or concealed. Questionable faults and minor faults not shown.

INFERRED LATE PLEISTOCENE TO RECENT HIGH ANGLE FAULT
Scarplets indicate relatively minor displacement. Question marks (?) indicate scarplets of possible fault origin.

APPROXIMATE AXIS OF INFERRED LATE CENOZOIC MAJOR ANTICLINE
Roughly conforms to bedrock structure in the East Humboldt Range, but not in the northern Ruby Mountains. See cross-sections.

APPROXIMATE AXIS OF INFERRED LATE CENOZOIC SUBORDINATE FOLDS

ATTITUDE OF FOLIATION

MINE

Base map below 41° latitude is from U.S.G.S. Halleck quadrangle (scale: 1" = 2 miles). Base map above 41° latitude is from modified U.S.D.A. Forest Service map (scale: 1" = 4 mi. highly inaccurate.

AREAS WITHIN RECTANGLES ALSO SHOWN ON LARGER SCALE MAPS NOS. 1 TO 4.

HOLE-IN-THE-MOUNTAIN PEAK THRUST

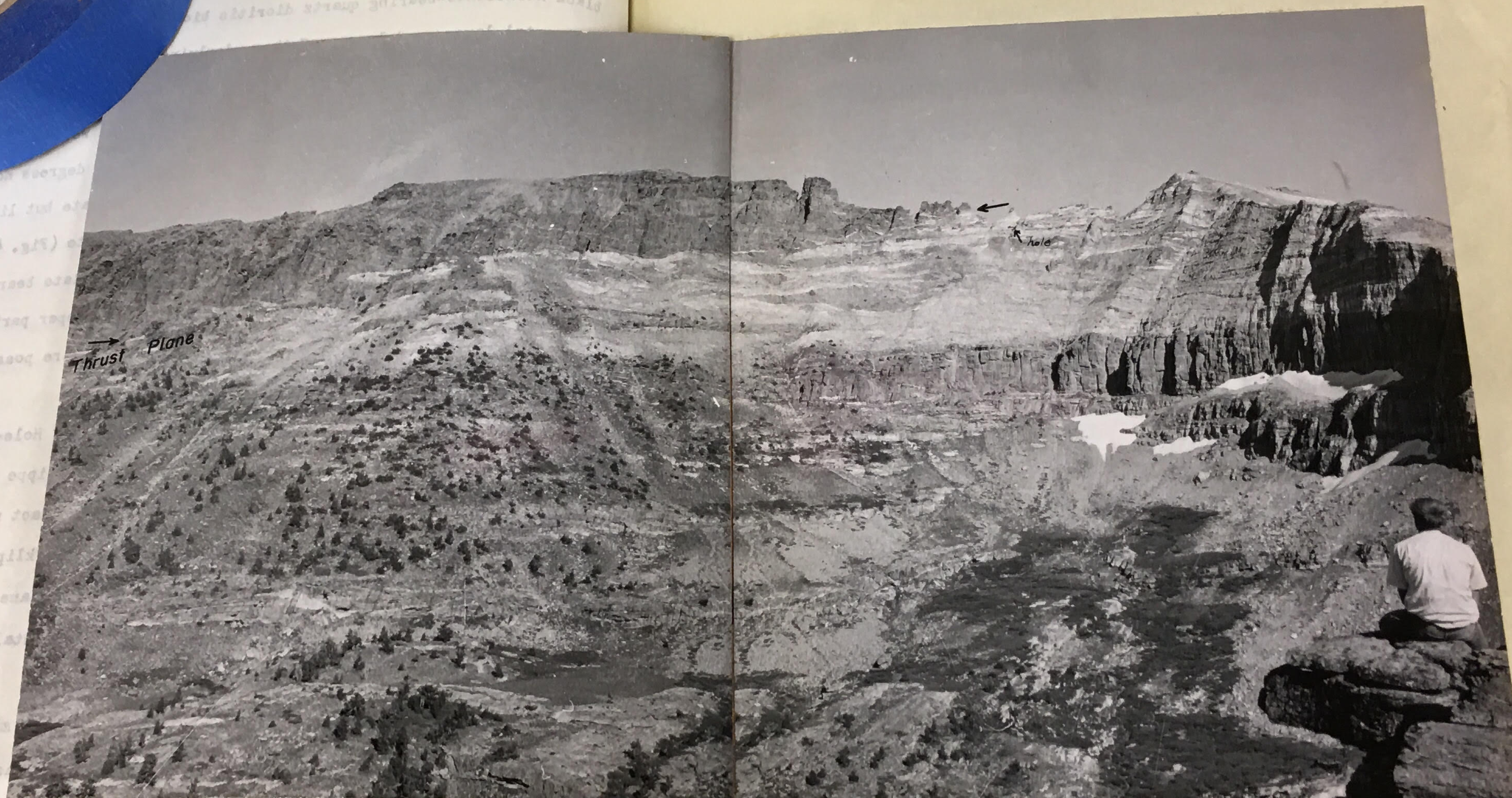


Fig. 42. Allochthonous mass of hornblende-bearing quartz dioritic biotite gneiss overlying and truncating the light-colored "transition" succession of the Angel Lake unit. Note truncation of layers in both the upper and lower plate rocks. View is looking east toward Hole-In-The-Mountain Peak.