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Geology of the East-Central Part of the Malad Range, Idaho

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GEOLOGY OF THE EAST-CENTRAL PART OF THE MALAD RANGE, IDAHO

by

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INTRODUCTION

Purpose and Scope

During recent years geologic investigations have been made in various parts of northern Utah and southern Idaho. In the Cache Valley area, the Bear River Range which bounds the east side of the valley has been studied and mapped. On the west side of the valley, the Wellsville Mountain and the southern part of Malad Range have also been studied. Still, little is known about the east-central part of the Malad Range. The study of this area will give additional information to the over-all picture of the geology of the region. The purpose of this thesis is threefold. The first purpose is to make a reconnaissance geologic map of the area; the second is to interpret the local structure in terms of the regional structure; and finally, the third purpose is to correlate the local stratigraphy to that of the region.

Location and Accessibility

The map area is located geographically at longitude 112°06' west and latitude 42°02' north and is in the northeast corner of the Basin and Range Province. It also lies in the east-central part of Malad Range which separates Cache Valley from Malad Valley. The area extends northward about 5 miles from the Utah-Idaho state line and has the average width of $5\frac{1}{2}$ miles. It lies in Township 16 South and Range 37 East, Boise base and meridian, Franklin County, Idaho.

The small town of Weston, located about 5 miles east of the present area, is about 25 miles north of Logan on the Idaho highway 35. The improved road from Weston to Malad Valley, intersecting U. S. highway 191 about 5 miles north of Malad City, passes through the northern part of this area. A graded road leading northward from the town of Clarkston, which is about 20 miles northwest of Logan, goes through the east margin of the map area. Access to the area from the main road is provided by dirt roads which are nearly impassable during the wet period.

Previous Investigations

The Malad River was named by Donald McKinsey in 1819 (Walgamott, 1927). Malad in French means sick. This name was probably given to the town and mountain range in a later period. In 1871 the geologic exploration group under the leadership of Hayden (1871, p. 20) took the trip from Ogden, Utah, to Fort Hall, Idaho, enroute to Yellowstone. His party passed through Cache Valley. Hayden described the mountain range on the west side of the valley which separates Cache Valley from Malad Valley as composed of the same kind of rocks found on the east side of the valley. Bradley (1872, p. 199-200), in reporting his trip along the Wasatch Mountains from Ogden to Fort Hall, gave a description of the rocks on both sides of the "Gates" and the Tertiary limestone in Junction Hills west of Cache Valley. He also mentioned that the Tertiary rock lies unconformably upon the older limestones. In 1877 the geologists of the Green River Division under Peale (1877, p. 521) traveled along the east side of the Malad Range and passed through the area of present study on their way from Franklin, Idaho, to Ogden, Utah. They recognized that the isolated hills that form the Malad Range seem to have formed the islands that rose above the old lake, and that the younger Tertiary rock is deposited against the old Paleozoic formations. Peale mapped the central part of Malad Range consisting of Silurian and Tertiary rocks (Hayden, 1883). Gilbert (1890, p. 351), working on the geology of Lake Bonneville, described briefly the fault scarp at Clarkston which followed the west margin of Cache Valley to the north and probably passed through the present study area. As a result of work by Walcott (1908, p. 5-9, 191-200) on the Cambrian section of northern Utah and southern Idaho, the formations of the Cambrian system in this area were named and studied. Work by Richardson (1913) on the geology of the Randolph quadrangle completed the remaining Paleozoic sections. Mansfield (1927) studied the geology of southeastern Idaho, giving useful information on the stratigraphy and structure of the region. To the north of the map area, the Pocatello quadrangle was worked by Ludlum (1942) and the pre-Cambrian rocks of that area were described and defined by him. Hanson (1949) studied and mapped the southern Malad Range. The Garden City limestone, which is prominent in the present area, was described by Ross (1951) with emphasis on its occurrence in northeastern Utah. Piper (1924) investigated the possibilities of petroleum in Power and Oneida Counties, Idaho, for the Idaho Bureau of Mines and Geology; and mapped the present area as consisting of undifferentiated Cambrian, Ordovician, and Tertiary rocks.

Field Work

The field work for this thesis was undertaken during the summer of 1956. The data obtained were plotted on acetate paper laid over United States Soil Conservation Service aerial photographs (scale 1:20,000). As a base map, the United States Forest map (scale 1:250,000) of the Caribou National Forest was used. The base map was enlarged from the original scale to the scale of the aerial photograph. Later the data were transferred to a base map of the same scale. A few control points were selected from the section corners as available.

Stratigraphic sections were measured with Jacob's staff, a 100-foot steel tape, and a Brunton compass. The data were changed into stratigraphic thickness with the aid of Mertie's chart (1947). Rock samples and fossils were collected for study in the laboratory. The color of rock samples was determined in the laboratory with the rock color chart of the National Research Council.

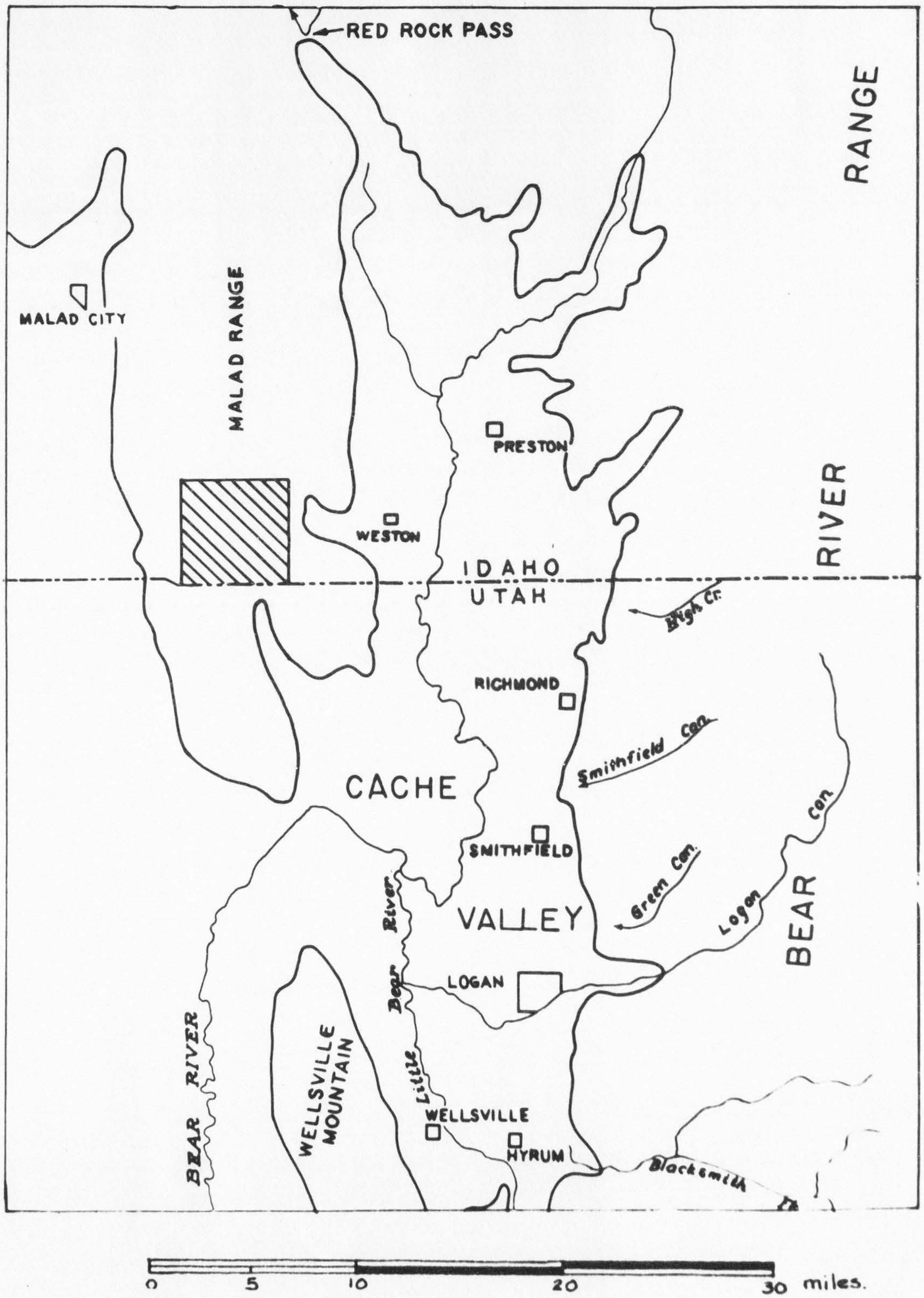

Figure 1. Index map of northern Utah and southern Idaho.

PHYSIOGRAPHY

The rugged mountain area of the southern Malad Range is separated by a low pass immediately south of the Utah-Idaho state line. The southern part of the area is low and smooth, with considerable vegetative cover. To the north, the mountains become more rugged and higher, with a scarcity of vegetation. The rocks in the area are limestone, dolomite, quartzite, and tuff. The land forms, however, are controlled primarily by fault-block structure and secondarily by the stratigraphic variation. The process of erosion, which operated through a long period of time with varying intensity, removed the less resistant tuff to form low passes while the more resistant quartzite and carbonate rocks stand as the mountains.

Topographically, the area can be divided into 3 types: (1) the rugged mountains of the Paleozoic rocks; (2) the smooth hills of the Salt Lake group; and (3) the flat bottom area of the Quaternary deposits. The rugged mountains of the Paleozoic rocks lie between Dry Canyon and Harris Canyon. To the north, the mountains become higher and more rugged, reaching the highest point at Square Peak. To the south, they are lower and are separated by the smooth hills of the Salt Lake group. The slope on the east face of the range is steeper and more rugged than that on the west face. Many small canyons have been formed along the east face; they do not have permanent streams. The average relief of this rugged mountain area is approximately 1,500 feet.

The smooth hills are developed in the southern part of the area. The rocks comprising these hills are tuff, tuffaceous sandstone, limestone, and marl of the Salt Lake group. Usually the hills are covered with thick vegetation which forms dark green patches and shows a contrast to the rugged mountains of the Paleozoic rocks.

The flat bottom lands are confined to the foothill area which once was the floor of Lake Bonneville. The marks of the lake levels were not formed very well in this area. Only the Bonneville level can be traced on the small hill west of Bergeson Hill and on the area west of Weston. The farm lands are both irrigated and not irrigated.

A parallel drainage pattern is well developed in the area. The main drainage is that of the east-flowing streams. The streams originate from springs which seep out from hills of the Salt Lake group. All the streams, except Steele Canyon creek, flow eastward to the foothill area and then sink down along the inclined bed rock. However, the water seeps out again in the area just west of Weston, and this is one of the main sources of water supply of this town. Drainage out of the area is by way of Dry Canyon, Black Canyon, Harris Canyon, and Steele Canyon. Only Steele Canyon has a perennial stream. On the west face of the central part of Malad Range the area is drained by Muddy Creek, Burnette Creek, and Trail Creek.

STRATIGRAPHY

The age of the rocks in the east-central part of the Malad Range and vicinity in northern Utah and southern Idaho ranges from Cambrian to Recent. All Paleozoic systems are present except the Permian system. The Mesozoic rocks were eroded away prior to the deposition of the Tertiary rocks. Any Paleozoic formation which is present in the adjacent areas and does not crop out in the map area is understood to be absent as the result of accident of exposure rather than through non-deposition.

Pre-Cambrian Rocks

Inasmuch as no pre-Cambrian rocks had been found in the map area, the information about their stratigraphic features is based on the evidence of the regional stratigraphy. Blackwelder (1935) separated the pre-Cambrian rocks in the Rocky Mountain region into 3 systems. The youngest system is a series of unmetamorphosed quartzites and slates best exemplified in the central part of the Wasatch Mountains. The Big Cottonwood series was included in this system. This system is also generally believed to be equivalent in age to the Beltian system of western Montana and the Grand Canyon system of northern Arizona. The intermediate system consists of metaquartzites and schists, and correlates to those of the Medicine Bow, Encampment, and Atlantic Pass districts of Wyoming. The oldest system consists of highly metamorphosed gneisses, schists, and metaquartzites. This system is represented by the Farmington complex of the Wasatch Range. It may be roughly correlated to the Vishnu schist of the Grand Canyon region. Eardley and Hatch (1940a, 1940b) worked on the pre-Cambrian rocks in north-central Utah and reported 2 major series--an ancient series of gneisses, schists, metaquartzites, granites, and pegmatites; and a younger, much less metamorphosed series of quartzites, phyllites, tillites, and limestones. Ludlum (1942) studied the pre-Cambrian rocks in the Pocatello quadrangle and correlated the tillites and varved slates of the Pocatello formation to those of the Wasatch region. Hanson (1949, p. 11) described the pre-Cambrian rocks cropped out in Trail Canyon, about 3 miles west of the map area, as consisting of several hundred feet of interbedded quartzites, slates, and phyllites. He tentatively correlated these rocks to the Cottonwood series in the Salt Lake area. Felix (1956), in his report of the geology of the eastern part of the Raft River Range, Box Elder County, Utah, reported the pre-Cambrian rocks of the Harrison series. He divided this series into 2 units, the lower unit being composed of schists while the upper unit contained metaquartzites and schists. He tentatively correlated this series to the "intermediate pre-Cambrian" as mentioned by Blackwelder (1935).

Cambrian System

The rocks of the Cambrian system are not well exposed in the area of the present study. Only some formations of the Middle and Upper Cambrian series are present. However, there is no complete section of any 1 formation in this area. The following Cambrian formations are partially exposed: Brigham quartzite, Langston formation, Nounan formation, and St. Charles formation. The total thickness of the Cambrian system in the map area is not known due to the lack of complete section. The rest of the Cambrian formations which crop out north of the map area at Two Mile Canyon (Resser, 1939) and to the south at Clarkston Mountain (Hanson, 1949) are not present in the map area. The Cambrian formations were named by Walcott (1908a, p. 5-9) as the result of his study at Blacksmith Fork Canyon and other localities in Bear River Range, northeastern Utah, and southern Idaho in 1906. As the result of a study by Maxey (1941) on the Cambrian stratigraphy of the northern Wasatch region, several misconceptions of the Cambrian stratigraphy were corrected. In his paper, the total thickness of the Cambrian system is given as approximately 6,500 feet. Richardson (1941, p. 7) reported more than 5,000 feet of the Cambrian system in the Randolph quadrangle. The greatest thickness of the Cambrian rocks ever known is over 18,000 feet, about 50 miles west of Virgin Mountain in southern Nevada (Nolan, 1943, p. 147); and the thinnest section of this system is in the Montana area where the Middle Cambrian rocks lie unconformably on the pre-Cambrian rocks. The present area probably lies west of the axis of the Cambrian geosyncline.

Lower and Middle Cambrian series

Brigham quartzite. The Brigham quartzite was named by Walcott (1908a, p. 8) from its type locality at the west front of the Wasatch Mountains, northeast of Brigham City, Box Elder County, Utah. He described this formation as massive quartzitic sandstone. According to Walcott's section at Blacksmith Fork Canyon, the Brigham quartzite is composed of gray to greenish quartzitic sandstone and greenish sandy shale, and has a thickness of 1,232 feet with no base exposed. Later this formation was measured and described by Eardley and Hatch (1940a, p. 811) at Baker Canyon, the type locality. They found no unconformity present between the Brigham quartzite and the underlying Algonkian formation, and reported the formation to consist of massive, gray to greenish-gray quartzite with interbedded conglomerate beds with a thickness of more than 1,775 feet. Resser (1939, p. 11) described Walcott's section at Two Mile Canyon, Franklin County, Idaho, north of the map area, as 740 feet of light-gray to reddish-brown, massive-bedded quartzitic sandstone and gray to greenish, arenaceous shale with layers of quartzite, no base exposed.

In the east-central part of the Malad Range, the Brigham quartzite occurs in the area of Dry Canyon, where it is bounded by faults. To the west at the north side of the canyon, the Weston fault brings the Nounan formation into contact with the Brigham quartzite. Across the canyon to the south, the intersecting of the Square Peak fault and the Weston fault brings the Garden City limestone into contact with it. The fault on the foothill separates this formation from the Tertiary Salt Lake group and intersects with the Weston fault, which marks the south end of the outcrop. The outcrop of the Brigham quartzite can be traced northward beyond the map area to Big Canyon.

The Brigham quartzite forms a reddish-brown, resistant ledge at the top of the mountain along both sides of the canyon, while the lower part of thin-bedded shale forms a slope. It is different from the bluish-gray slope of the Langston formation above it. The Brigham quartzite is a massive-bedded, medium to coarse-grained, brownish-gray to olive-gray quartzite with thin-bedded, fine-grained, olive-gray micaceous shale. Inasmuch as the base of the formation was not exposed, the total thickness could not be determined. The exposed portion of this formation measured 565 feet. The lower exposed portion of this formation is comprised of interbedded quartzites and shales while the upper part is massive beds of quartzite. Locally, the cross-bedding can be seen in the massive beds of quartzite as alternate light and dark bands. Quartz grains up to one-fourth inch in diameter occur in some quartzite beds. Scolithus is found in quartzite beds in the upper part of the formation. In the fresh surface, spots of yellowish-brown limonite interlocked between quartz grains suggest the alteration of the associated minerals.

A partial section of the Brigham quartzite at Dry Canyon, Franklin

County, Idaho, NE$\frac{1}{4}$ of section 2, T. 16 S., R. 37 E., is as follows:

	Thickness (feet)
Transitional member to Langston formation	
12. Quartzite and sandy limestone, first 2 feet of brownish-gray, coarse-grained, massive quartzite; then dark gray, medium-grained, sandy limestone . .	30
Brigham quartzite	
11. Quartzite, brownish-gray, medium to coarse-grained; massive, slope former	80
10. Quartzite, brownish-gray to pale olive, medium to coarse-grained; massive, ledge former	122
9. Quartzite, pale olive to olive-gray, coarse-grained; massive, ledge former, <u>Scolithus</u> . . .	60
8. Quartzite, brownish-gray, coarse-grained; massive, ledge former, cross-bedded, yellowish-brown spots of limonite are common	36
7. Shale, olive-gray, fine-grained, micaceous; fissile, slope former, containing few quartz grains	30
6. Quartzite, olive-gray, medium to coarse-grained; massive, ledge former, alternate bands of light and dark color	28
5. Quartzite, pale olive to olive-gray, coarse-grained; massive, slope former, containing thin-bedded micaceous shale in few horizons	43
4. Quartzite, olive-gray, medium to coarse-grained; massive, ledge former, containing quartz grains up to one-fourth inch in diameter, alternate in few horizons of micaceous shale up to 3' thick . .	50
3. Quartzite and shale; quartzite, brownish-gray, medium-grained, thin to massive from 1" to 8" thick. Shale, olive-gray, fine-grained; fissile . .	32
2. Shale, olive-gray, fine-grained; fissile, slope former, containing quartzite beds from 3/4" to 2" in few horizons	18
1. Slope covered	38
Total measured thickness of the Brigham quartzite	565

Fossils are rare in the Brigham quartzite and only fucoidal markings have been found in the map area. Walcott (1908b, p. 199) found annelid trails in the section at Blacksmith Fork Canyon. Fossils of middle Cambrian characteristics also were found by him in the upper part of the formation west of Liberty, Bear Lake County, Idaho. In the map area, the present writer collected fucoidal markings from the Brigham quartzite at Dry Canyon. The upper contact of this formation is drawn above the last quartzite bed and below the first sandy limestone bed of the transitional member (Figure 2). The lower boundary, however, is not exposed in the map area.

The age of the Brigham quartzite is uncertain. Williams and Maxey (1941, p. 227) found Albertella and Kochaspis in the basal member of the Langston formation within a few feet from the top of the Brigham quartzite. These and other fossils were thought to mark the base of the middle Cambrian, and the Brigham quartzite was assigned a lower Cambrian age.

Langston formation. The Langston formation was named by Walcott (1908a, p. 8) from Langston Creek, Idaho. However, the type locality of this formation is located at Blacksmith Fork Canyon, Bear River Range, Utah. Walcott described the Langston formation as massive-bedded, bluish-gray limestone in the upper part and massive-bedded, dark arenaceous limestone with calcareous and gray sandstone in the lower part. This formation has a thickness of 498 feet at Blacksmith Fork Canyon. According to his paper, he included 30 feet of the Spence shale as the basal member of the Ute formation. Later, Diess (1938, p. 1,116) studied the Langston formation at its type locality and reported that shale beds at the base of the Ute formation could not be correlated with the Spence shale of Idaho, as defined by Walcott. Resser (1939, p. 10) described

Figure 2. Contact of the Langston formation and the quartzite bed of the transitional zone above the Brigham quartzite.

Walcott's section of the Cambrian just above the Brigham quartzite at Two Mile Canyon, Idaho, saying these rocks are comprised of 6 feet of dark-gray, crystalline, very fossiliferous limestone containing the Ptarmigania fauna followed by 155 feet of bluish-black, calcareous shale, thin-bedded, dark-gray limestone, and dark argillaceous shale with the Spence shale fauna. He postulated a rapid change of thickness related to a major unconformity to explain the absence of the Langston formation in this section. Maxey (1941) reported 310 feet of the Langston formation in the Call's Fort section as consisting of 3 members, the upper member of alternate beds of limestone and dolomite, the middle member of the Spence shale, and the lower member of the Ptarmigania strata. This seems to explain the Two Mile Canyon section as the normal Langston formation, lying without unconformity upon the Brigham quartzite. This is the view adopted for this paper.

In the east-central part of the Malad Range, the Langston formation crops out in a small area at the northern part of the map area. It forms the slope near the top of the mountain at the mouth of Dry Canyon. The outcrop is bounded to the west by the Weston fault and to the east by the fault along the foothill. The intersecting of these 2 faults south of Dry Canyon marks the south limit of the outcrop. The outcrop of the Langston formation extends northward beyond the map area. There is no complete section of the Langston formation in the present area and the exposed portion of this formation measured 78 feet. It is composed of 3 members, the lower Ptarmigania member, the middle Spence shale member, and the upper limestone member. The Ptarmigania limestone member consists of 10 feet of dark-gray, medium to fine-grained, crystalline limestone, and is very fossiliferous. Next, in upward succession, occurs the dark-gray, fine-grained, thin-bedded shale of the Spence shale member with a thickness of 56 feet. The upper limestone member, however, is not complete in section, and is comprised of 12 feet of massive-bedded, medium to fine-grained limestone. The bed is crystalline in texture with occasional white veinlets of calcite. Tan weathering surface can be seen in some horizons. The lower contact of the Langston formation is drawn between the lowest limestone bed and the first quartzite bed of the transitional zone (see Figure 2). The Langston formation lies conformably on the Brigham quartzite with a transitional zone.

A partial section of the Langston formation at Dry Canyon, Franklin County, Idaho, NE$\frac{1}{4}$ of section 2, T. 16 S., R. 37 E., is as follows:

	Thickness (feet)
Upper member	
3. Limestone, bluish dark-gray, medium to fine-grained, crystalline; massive, ledge former. White veinlets of calcite are common; abundant trilobites and brachiopods	12
Spence shale member	
2. Shale, dark-gray, fine-grained; fissile, slope former and containing abundant trilobites	56
Ptarmigania limestone member	
1. Limestone, dark-gray, medium to fine-grained, crystalline; massive, slope former. Very fossiliferous	10
Transitional member to Brigham quartzite	
Quartzite and sandy limestone, first 2 feet of brownish-gray, coarse-grained, massive-bedded quartzite; then dark-gray, medium-grained, sandy limestone	30
Brigham quartzite	
Total measured thickness of the Langston formation	78

The Langston formation carries abundant trilobites and brachiopods. Fossils collected by the writer from the north side of Dry Canyon, Idaho, are listed below.

Fauna of the Langston formation, East-Central part of the Malad Range, Idaho

(*Ptarmigania* limestone beds 5 feet above the base of the formation)

Micromitra haydeni Walcott

Acrothele artemis Walcott

Acrothele paralis Resser

Acrotreta eucharis Resser

Lingullela eucharis Resser

Pagetia maladensis Resser

Pagetia clytia Walcott

Prozacanthoides alatus Resser

Prozacanthoides optatus Resser

Dolichometopsis stella Resser

Dolichometopsis cf D. comis Resser

Dolichometopsis cf D. lepida Resser

Ptarmigania cf P. germana Resser

Olenoides maladensis Resser

Kootenia granulosa Resser

Alokistocarella brighamensis Resser

Poulsenia granosa Resser

Ehmaniella maladensis Resser

Pachyaspis typicalis Resser

Taxioura typicalis Resser

(Shale bed of the Spence shale member 20 feet above the base of the formation)

Acrothele affinis sp.

Agnostus sp.

Hyolites sp. (?)

Micromitra sp.

Oryctocephallus Walcotti Resser

According to the evidence of the fauna found in this formation, the Langston formation is considered to be middle Cambrian. The transitional member suggests a gradational contact. Resser (1939) gave 2 alternate interpretations for the great thickness variations which he thought the Langston formation had, due to his adhering to Walcott's position for the Spence shale member. First, the formation is discontinuous and appears only in certain sections; and second, the Langston formation is absent in the northern part of the region and the thin, fossiliferous limestone are lenses or bioherms in the base of the Ute formation resting on the Brigham. Evidently, the great difference in thickness of the Langston formation does not exist. The Langston formation is continuous, and the lower dolomite thins northward and westward from its type locality and is replaced by the Ptarmigania limestone and the Spence shale.

Upper Cambrian series

Nounan formation. The Nounan formation was named by Walcott (1908a, p. 6) from its occurrence on the east slope of Soda Peak, west of the town of Nounan, in the Bear Lake Valley, Idaho. The type locality is in Blacksmith Fork Canyon, east of Hyrum, Cache County, Utah. Walcott assigned the age of the Nounan formation to middle Cambrian. Resser (1939, p. 9) described Walcott's section at Two Mile Canyon, Idaho, a few miles northwest of the present area, as massive-bedded, dirty to bluish dolomite and thin-bedded, bluish-gray, impure limestone with a total thickness of 1,088 feet. Maxey (1941) studied the Cambrian stratigraphy in the northern

Wasatch region and stated that the Nounan formation is comprised in the lower two-thirds of light-gray, fine-crystalline, compact, thin-bedded dolomite; and the upper third of light-gray dolomite interbedded in thick layers with dark-gray, argillaceous, thin-bedded limestone. Hanson (1949, p. 24) recorded a thickness of 1,408 feet of this formation from the southern Malad Range in Utah, and characterized it as, first, 908 feet of the lower member consisting of thick-bedded, medium-crystalline dolomite, mostly light gray in color; and second, 500 feet of the upper member consisting of thin to thick-bedded, light to dark-gray limestone.

The Nounan formation crops out in 2 areas in the east-central part of the Malad Range. In Dry Canyon, the Nounan formation forms a high cliff along the north side of the canyon adjacent to Square Peak, and the outcrop is bounded to the west by the Square Peak fault and to the east by the Weston fault. Here the light-gray cliff is comprised of a light to dark-gray, massive bed of dolomite passing into light-gray limestone above. The upper part of the Nounan formation crops out in the area north of Harris Canyon. It forms a light-gray cliff adjacent to the fault and passes upward to a brown ledge of the Worm Creek quartzite near the top of the mountain.

In the east-central part of the Malad Range there is no complete section of the Nounan formation and the exposed portion of this formation measured 457 feet. Where the lower member is exposed in the northern part of the map area, it consists of light to dark-gray, medium-crystalline, massive-bedded dolomite. The upper member consists of medium to dark-gray, medium to fine-crystalline, thin to massive-bedded dolomite interbedded in thick layers with light to medium-gray, fine-grained, massive-bedded limestone. Near the top of the formation, thin beds of yellowish-gray to pale-red siltstone are found interbedded with medium-gray dolomite. Locally, the cross-bedding can be seen in dolomite beds due to alternate light and dark bands in the rock.

Silty partings occur in several horizons and seem to increase toward the top. The limestone beds of light-gray, fine-grained rock, usually contain white veinlets of calcite and show some degree of dolomitization. The Nounan formation in the present area seems to match very well that described by Maxey (1941) in the northern Wasatch region. The upper contact of this formation is drawn below the first quartzite bed of the Worm Creek quartzite member of the St. Charles formation. The lower contact, however, is not exposed in the present area.

A partial section of the Nounan formation at the Narrows, north of Harris Canyon, Franklin County, Idaho, SW$\frac{1}{4}$ of section 15, T. 16 S., R. 37 E., is as follows:

	Thickness (feet)
St. Charles formation, Worm Creek quartzite member	
Quartzite, yellowish-gray to grayish-orange pink, medium to fine-grained; medium to massive-bedded varied from 2" to 3' thick, cross-bedded, ledge former	72.0
Nounan formation	
15. Dolomite, medium-gray, medium-crystalline; massive, weathering to brownish-gray surface	10.0
14. Dolomite, medium-gray, medium-crystalline; massive, silty parting from 1/8" to 1/2" thick	6.5
13. Siltstone, yellowish-gray to pale red; thin-bedded from 1/8" to 1" thick, interbedded with medium-gray dolomite	12.5
12. Dolomite, medium to dark-gray, medium-grained; thin to massive-bedded from 2" to 1' thick, cross-bedding near top. Alternate bands of light and dark-gray are common. Silty parting becomes increased downward	138.0
11. Limestone, light-gray, fine-grained to nearly lithographic; massive, ledge former, wavy structure near bottom	28.0
10. Dolomite, medium to dark-gray, medium-grained; massive, ledge former. Alternate bands of light and dark-gray are common and grade downward to silty parting	51.0

9.	Limestone, medium-gray, fine-grained to lithographic; massive, slope former	4.5
8.	Dolomite, dark-gray, medium to fine-grained; thin to massive, slope former	12.0
7.	Limestone, light-gray, fine-grained; massive, ledge former. White veinlets of calcite are common	30.0
6.	Limestone, light-gray, fine-grained; massive. Shows some degree of dolomitization	6.0
5.	Dolomite, light-gray, medium-crystalline; massive, ledge former	31.0
4.	Dolomite, dark-gray, fine to medium-grained; massive, slope former	24.0
3.	Dolomite, dark-gray, fine to medium-grained; massive, slope former	60.0
2.	Limestone, dark-gray, fine-grained; massive, ledge former. Small calcite veinlets are common	32.0
1.	Limestone, light brownish-gray, medium-grained; massive, silty parting from 1/4" to 3/8" thick. Intraformational conglomerates are common near base . .	12.0
	Total measured thickness of Nounan formation	457.0

Due to the scarcity of fossils in the Nounan formation and also to the fact that no complete section is exposed in the map area, the present writer made no attempt to collect fossils in this formation. Walcott (1908a, p. 6) reported a few traces of middle Cambrian fossils in the lower part and numerous annelid borings throughout. D. C. Duncan first discovered an early Cedaria fauna in the limestone beds in the upper part of the Nounan formation (Williams and Maxey, 1941). Hanson (1949, p. 28-29) listed the following fossils from the Nounan formation in the southern Malad Range:

Meteoraspis sp. (possibly Crepicephalus or Tricrepicephalus)

Blountina sp.

Blountia cf. B. beltensis Duncan

Clevelandella cf. C. arses (Walcott)

cf. Aphelaspis sp.

The above list of fossils indicates an early upper Cambrian age for the Nounan formation.

St. Charles formation. The St. Charles formation follows in upward succession from the Nounan formation and lies conformably above it. The St. Charles formation is a carbonate unit and contains a distinctive basal member, the Worm Creek quartzite. The Worm Creek quartzite was differentiated by Richardson (1913, p. 406) as the basal member of the St. Charles formation. In this thesis the Worm Creek quartzite member was mapped with the St. Charles formation. The St. Charles formation was named by Walcott (1908a, p. 6) from its occurrence west of the town of St. Charles in Bear Lake Valley, Bear Lake County, Idaho; but the most accessible locality is in Blacksmith Fork Canyon, east of Hyrum, Cache Valley, Utah. Maxey (1941, p. 26-28) reported 1,015 feet of the St. Charles formation from High Creek, approximately 7 miles northeast of Richmond, Utah, and described it as consisting of a basal quartzite member grading upward into light-gray, thin to medium-bedded, sandy limestone in the lower part; and neutral to dark-gray, medium to fine-crystalline, thin to thick-bedded dolomite in the upper part. Hanson (1949, p. 31-32) recorded 1,083 feet of the St. Charles formation from the southern Malad Range and characterized first, 75 feet of medium grained, tannish-gray quartzite, passing upward into thin to medium-bedded, silty limestone in the middle member; and second, the upper member of thin to massive-bedded, medium-crystalline, light to medium-gray dolomite with a few dark bands.

In the east-central part of the Malad Range, the St. Charles formation exposed in the area between Black Canyon and Harris Canyon forms isolated hills surrounded by patches of the Salt Lake group. Usually the outcrop forms a tan-weathering slope differing from the cliff-forming beds of the Nounan formation. The best exposure occurs in the area west of Harris Canyon where it forms a scarp adjacent to the fault. The total thickness of this formation cannot be determined due to lack of a complete section. The exposed portion, however, consists of massive-bedded, tannish-gray, medium-grained quartzite and massive-bedded, light to tannish-gray, fine-grained limestone with silty parting in the lower part; and thin to massive-bedded, dark-gray, fine-grained limestone graded upward into massive-bedded, medium to dark-gray, medium-crystalline dolomite in the upper part. Dolomite beds in the upper part contain brown chert nodules in several horizons. Intraformational conglomerates are common in limestone beds in the lower part.

In the present area, the St. Charles formation yields a considerable fauna. The present writer collected the following fossils:

SE$\frac{1}{4}$ of section 22, T. 16 S., R. 37 E. Limestone beds a few hundred feet above the base:

Acrotreta sp.

Billingsella sp.

Aphelaspis sp.

Drumaspis idahoensis Resser

Elvinia sp.

Lingullela sp.

Maladia sp.

Pseudagnostus sp.

Ptychasis sp.

Taenicephalus sp.

SW$\frac{1}{4}$ of section 15, T. 16 S., R. 37 E. Limestone beds approximately 100 feet above the Worm Creek quartzite:

Coosia sp.

Drumaspis sp.

Elvinia sp.

Billingsella sp.

Burnetia sp.

Heunella sp. (?)

Idahoia serapio Walcott

Idahoensis sp.

Meteoraspis sp. (?)

Plataspella sp.

$N\frac{1}{2}$ central of section 22, T. 16 S., R. 37 E.

Teanicephalus sp.

Idahoia serapio Walcott

These fossils represent the faunas reported by Maxey (1941) for the St. Charles formation, to which he assigned an upper Croixian age.

Ordovician System

The Ordovician system is represented by a series of limestones, dolomite, and quartzite. The Ordovician formations were named by Richardson (1913, p. 408) as a result of his study in the Randolph quadrangle, Utah-Wyoming, where the Ordovician system is separated into the following formations: the Garden City limestone containing a Beekmantown fauna, the Swan Peak quartzite containing a Chazy fauna, and the Fish Haven dolomite characterized by a Richmond fauna. Later, the Garden City limestone was studied by Ross (1951) as it occurs in northeastern Utah. He stated that the Garden City limestone can be divided into 2 members--the lower member, comprising approximately two-thirds of the formation, being composed of interbedded intraformational conglomerates, muddy limestone, and siltstone; and the upper member of limestone containing black chert.

Like the Cambrian system, the rocks of the Ordovician system are not all present in the east-central part of the Malad Range. Only the Garden City limestone and the Swan Peak quartzite are present. The total thickness of this system in the present area is, of course, not known due to lack of a complete section. The Ordovician system obtains a thickness of 2,000 feet in the Randolph quadrangle (Richardson, 1913, p. 408), 1,880 feet at Green Canyon, Bear River Range, Utah (Williams, 1948, p. 1,130), and about 2,461 feet in the southern Malad Range (Hanson, 1949). Rocks of the Ordovician system seem to overlie conformably the Cambrian system. Richardson (1913) found the evidence of unconformity at the top and base of the Ordovician system. Ross (1951) found no unconformity presented between the Ordovician and Cambrian system.

Lower Ordovician series

Garden City limestone. The Garden City limestone was named by Richardson (1913, p. 408) from its occurrence in Garden City Canyon, a tributary of Bear Lake, Utah. He described the Garden City limestone at its type locality as approximately 1,000 feet of thin-bedded, gray limestone containing throughout the formation a conglomerate or breccia consisting of elongated bits of limestone up to 2 or 3 inches in length irregularly interbedded in a matrix of similar composition. Diess (1938, p. 1,123-1,124) remeasured Walcott's section in Blacksmith Fork Canyon and included 777 feet of the original St. Charles formation in the Garden City limestone. Williams (1948, p. 1,135) reported 1,400 feet of the Garden City limestone in Green Canyon consisting of dark neutral-gray, thin-bedded, shaly limestone. South of the map area, the Garden City limestone consists of thin-bedded, medium-gray limestone to silty limestone grading upward into thin to thick-bedded limestone and dolomite containing black chert, and has a total thickness of 1,805 feet (Hanson, 1949, p. 41). As the result of work by Ross (1951) in northeastern Utah, the Garden City limestone is divided into 2 members--the lower member, comprising two-thirds of the formation, being composed of numerous alternations of interbedded and interlensed intraformational limestone conglomerates, crystalline, aphanitic, and muddy limestones, and some limy mud and siltstones. The upper member is characterized by the high content of black chert occurring for the most part in the irregularly laminated, aphanitic limestone and dolomitic limestone.

The Garden City limestone is well developed in the east-central part of the Malad Range. It crops out in the area between Black Canyon and Dry Canyon and forms a scarp adjacent to the fault along the east and west side of the present area. In Dry Canyon area the black chert limestone of the upper member of this formation forms a distinctive cliff along the south side of the canyon. Only the upper contact of this formation is exposed in the map area, and the total exposed portion of the Garden City limestone measured 1,030 feet. It is composed of 2 members. The lower member consists of thin to massive-bedded, light to medium-gray limestone with silty partings. Intraformational conglomerates are common in several horizons. Silty partings seem to increase upward. Limestone beds of coarse crystalline in texture are presented in several horizons and usually contain fossil fragments. The lower member measured 788 feet but is not all exposed. The upper member consists of 242 feet of massive, light to medium-gray, fossiliferous limestone containing black chert nodules and grades upward into medium-gray dolomite which marks the top of the formation. The lower contact of the Garden City limestone is not exposed in the present area and the upper contact is drawn above the top of the upper dolomite bed and below the slope-covered area which probably is the basal shale member of the Swan Peak quartzite.

A partial section of the Garden City limestone at the south side of Dry Canyon, Franklin County, Idaho, NE$\frac{1}{4}$ of section 2, T. 16 S., R. 37 E., is as follows:

	Thickness (feet)
Slope covered	65
Garden City limestone	
Upper cherty member	
15. Dolomite, medium-gray, medium-grained; massive, slope former. Black chert nodules are common	12
14. Slope covered	50
13. Dolomite, medium-gray, medium-grained; massive, ledge former	28
12. Slope covered	55
11. Limestone, medium-gray, fine-grained; massive, ledge former. Black chert nodules are common. Silty partings occur near bottom with <u>Ophileta</u> sp.	97
Lower limestone member	
10. Limestone, medium to dark-gray, fine-grained; massive, ledge former with irregular silty partings. Intraformational conglomerates found in few horizons. <u>Ophileta</u> and crinoid stem fragments are presented near top	40
9. Limestone, light to medium-gray, fine-grained; massive, slope former with irregular silty partings. Intraformational conglomerates are common	53
8. Limestone, medium-gray, fine-grained; massive, ledge former with irregular silty partings. Intraformational conglomerates are common. Trilobite fragments . .	83
7. Limestone, light to medium-gray, fine-grained to crystalline; thin to massive, ledge former with silty partings. Intraformational conglomerates are not common	250
6. Limestone, medium-gray, fine-grained; massive, ledge former, silty partings	43
5. Limestone, medium-gray, fine-grained; thin to massive, slope former. Intraformational conglomerates . . .	27

4.	Limestone, medium-gray, fine-grained; massive, ledge former with silty parting. Intraformational conglomerates	27
3.	Slope covered	18
2.	Limestone, medium-gray, fine-grained; thin to massive, slope former. Silty partings and intraformational conglomerates are not common	72
1.	Limestone, medium-gray, fine-grained to crystalline; massive, ledge former. Intraformational conglomerates are common in few horizons	175
	Total measured thickness of the Garden City limestone	1,030

Fossils are abundant in the Garden City limestone. The present writer collected the following list of fossils from the present area:

Fauna of Garden City limestone
East-central Malad Range, Idaho

SW$\frac{1}{4}$ of section 9, T. 16 S., R. 37 E. Limestone bed of uncertain position but evidently Garden City limestone:

Brachyaspis sp.

Isotellus sp.

Macluritella sp.

Macronotella sp.

Maclurites sp.

Ozarkina sp.

Ophileta rotuliformis Meek

SW$\frac{1}{4}$ of section 14, T. 16 S., R. 37 E. Approximately 1 mile south of Black Canyon (uncertain stratigraphic position):

Tentaculites sp.

Sponges

Cystoids

NW$\frac{1}{4}$ of section 10, T. 16 S., R. 37 E. Limestone bed immediately below the upper black chert dolomite:

Undetermined corals

Ozarkina sp.

Crinoid stems

Ophileta rotuliformis Meek

NE$\frac{1}{4}$ of section 2, T. 16 S., R. 37 E., Dry Canyon. Black chert limestone beds 83 feet below the top of the formation:

Orthis sp.

Orthambonites sp.

Nanorthis sp.

Archaeorthis sp.

Richardson (1913, p. 408) originally assigned the Garden City limestone to the Canadian series. Recent work by Ross (1951, p. 31-32) placed the Canadian-Champlainian boundary somewhere below the top of the formation.

Middle Ordovician series

Swan Peak quartzite. The Swan Peak quartzite overlies conformably the Garden City limestone. This formation was named by Richardson (1913, p. 409) from Swan Peak in the Bear River Range, Utah, $1\frac{1}{2}$ miles south of the Utah-Idaho boundary. It consists of a fine-textured, massive to thin-bedded, white to gray quartzite about 500 feet thick. In Green Canyon, the Swan Peak quartzite has, in addition to the gray quartzite, an upper member, a middle member of thin to thick-bedded, gray to vinaceous-brown quartzite with fucoidal markings, and a lower member of fuscous-black shale with thin beds of bluish-brown, sandy limestone. Here it has a total thickness of ~~340~~ 304 feet. South of the map area, Hanson (1949, p. 44) reported 606 feet of Swan Peak quartzite containing gray to brown quartzite in the upper part and a basal black shale.

In the east-central part of the Malad Range the Swan Peak quartzite crops out in Dry Canyon. In the west end of the canyon the Swan Peak quartzite forms a downthrown block of the Dry Canyon fault. At the mouth of the canyon, the Swan Peak quartzite forms a resistant ridge at the top of the mountain adjacent to the Weston fault on the south side of the canyon. In the present area, only the lower part of the Swan Peak quartzite is present, and the total exposed portion of this formation measured 150 feet. It consists of 2 lithologic units, a lower shale member and an upper quartzite member. The lower member forms a slope and is covered for the most part with quartzite float. However, shale fragments can be seen in many small outcrops which indicate the existence of the basal black shale member in the area. It obtains a thickness of 65 feet. The upper member is not all exposed and consists of 85 feet of massive-bedded, fine to medium-grained, white to grayish-red quartzite containing fucoidal markings. The lower contact of this formation is drawn above the black chert dolomite of the Garden City limestone and below the slope covered of the lower shale member. The upper contact, however, is not exposed in the present area.

A partial section of the Swan Peak quartzite at Dry Canyon, Franklin County, Idaho, NE$\frac{1}{4}$ of section 2, T. 16 S., R. 37 E., is as follows:

		Thickness (feet)
3.	Quartzite, white to dark reddish-brown, fine to medium-grained; massive, ledge former	55
2.	Quartzite, grayish-red, medium to fine-grained; massive, slope former. The outcrop is poor; containing fucoidal markings	30
1.	Slope covered	65
Garden City limestone		
	Dolomite, medium-gray, medium-grained; massive, slope former. Black chert nodules are common . . .	12

No fossils were collected from the present area due to poor exposure.

Hanson (1949, p. 46) collected the following list of fossils from the southern Malad Range:

Orthis sp.

Orthis michaelis Clark

Anomalorthis utahensis Ulrich and Cooper

Anomalorthis sp.

Eleutherocentrus petersoni Clark

Macronotella sp.

The Swan Peak quartzite is assigned to the Champlainian series.

Cenozoic System

The Tertiary system in the east-central part of the Malad Range is represented by a series of tuff, tuffaceous sandstone, limestone, conglomerate, lava flow, intrusion, and boulders. It lies unconformably upon the surface of the Paleozoic rocks. The following Tertiary rocks are exposed: Salt Lake group, Tertiary lava flow and intrusion, and Tertiary boulders (?). Following the Laramide orogeny, the Wasatch group may have spread over the present area. If so, it has been eroded away prior to the deposition of the Salt Lake group. However, a patch of the Wasatch group has been recognized by Williams (1948, p. 1,144) at the north end of Wellsville mountain. The total thickness of this system cannot be determined due to poor exposure of the rocks.

Salt Lake group

The Salt Lake group was named by Hayden (1869, p. 92) from its occurrence in the Weber Valley and Salt Lake Valley. This term was introduced into Cache Valley and southeastern Idaho by Peale (1879, p. 567). In his report, Hayden described the Salt Lake group as 1,000 to 1,200 feet of sands, sandstones, and marls of light color for the most part, and assigned this rock to upper Tertiary age.

Figure 3. Outcrop of the basal conglomerate of the Salt Lake group in the area south of Black Canyon.

In the east-central part of the Malad Range, the Salt Lake group is well developed and crops out in various parts which once were depression areas. The Salt Lake group was laid down, filling these depressions, and later erosion partly removed it to form the present landscape. Some of this rock is also believed deposited against the fault scarp of the Paleozoic rocks. The best exposure of this rock is in the area between Black Canyon and Steele Canyon, but the outcrop is not good enough that the complete section of the Salt Lake group can be measured. Williams (1948, p. 1,147) recorded 1,140 feet of the Salt Lake group from Junction Hill consisting in the upper part of thin-bedded, tuffaceous marl, limestones, calcareous oolite; and a basal unit of massive, white, calcareous oolite pebble conglomerate. In the map area, the Salt Lake group consists of tuffs, tuffaceous sandstones, limestones, and pebble conglomerate. Usually, limestones are light-gray to wood-brown and fine-grained to lithographic in texture except in Dry Canyon, where the limestones are petroliferous and contain abundant fossils. Tuffaceous sandstones are light-gray, medium to coarse-grained, and consist of reworked particles of volcanic materials. The member, which may be the basal conglomerate, was found in the area about one-half mile south of Black Canyon (see Figure 3). It consists of limestone and chert pebbles derived from the Paleozoic rocks. The Salt Lake group in the present area is considered part of the Cache Valley formation. Adamson (1955, p. 6) also reported the Cache Valley formation exposed in the fault scarp northeast of the present area, about 1 mile northwest of Weston, Idaho.

Fossils are rare in the Salt Lake group in the present area. Only in 1 place are abundant fossils. This is in the petroliferous limestone in Dry Canyon. Yen (1947, p. 485) studied the fresh-water mollusks from southeastern Idaho and suggested the Pliocene age to the Salt Lake group.

Figure 4. Lenticular of basalt flow showing alteration near the edge.

Figure 5. Lava flow intercalating in the Salt Lake group showing alteration of upper contact.

Figure 6. The upper contact of the lava flow and the Salt Lake group, showing no effect of alteration.

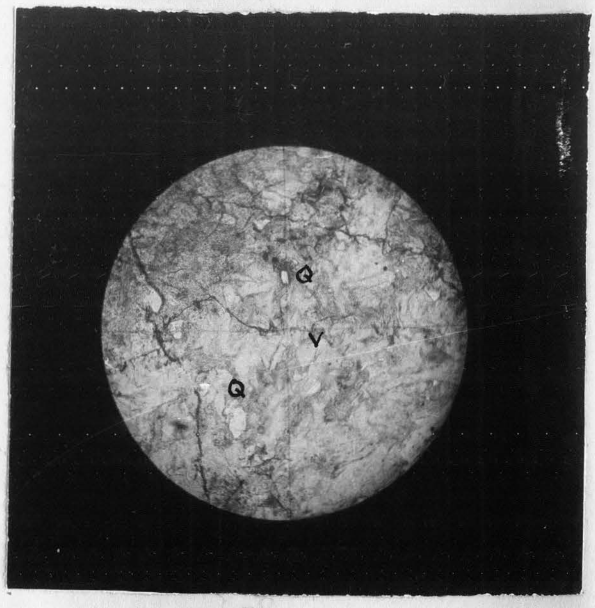

Figure 7. Alteration zone of the Salt Lake group under microscope, showing fragments of quartz and volcanic glasses. Q = quartz, V = volcanic glasses. Magnification 9X.

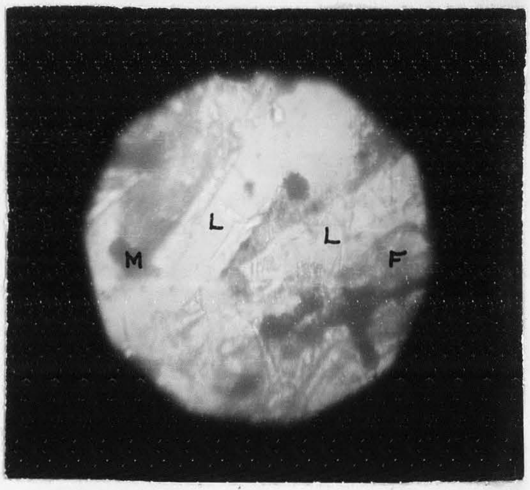

Figure 8. Lava flow under microscope.
L = Labradorite
M = Magnetite
F = Augite, Olivine
Crossed nicols. Magnification 27X.

Tertiary lava flow and intrusion

A number of basaltic rocks are found intercalating in the beds of the Salt Lake group in the present area. The outcrops are confined in the area between Harris Canyon and Steele Canyon. Usually they form a brown slope in contrast to the light color beds of the Salt Lake group. Hand specimens of these rocks show that they are dark brownish-green to dark reddish-brown, fine-grained, and highly scoriaceous. Under the microscope, the rock is composed of labradorite, olivine, augite, and small amounts of ilmenite and magnetite. The rock appears to be slightly porphyritic because the lathe-shape plagioclases (Figure 8) are somewhat bigger than the other constituents. Some of the vesicles are filled with calcite and zeolite. There are 2 lavas in the present area. The lower lava is an intruded mass with a thickness of approximately 50 feet. The lower contact of this lava with the Salt Lake group shows the effect of alteration. The altered rock is dark-green and somewhat glassy near the contact. Under the microscope, the altered rock consists mainly of volcanic glass and a small amount of magnetite and quartz (Figure 7). The alteration effect also occurs in the upper contact of this rock with the Salt Lake group. The upper lava is thinner than the lower one and cannot be readily correlated from 1 outcrop to another. The upper lava is overlain by an unaltered tuff bed (Figure 6). At the lower lava about one-fifth mile away the alteration effect can be seen in the upper contact (Figures 4 and 5). A lack of alteration seems to characterize the upper contact feature of the upper lava, and it is therefore classed as a flow. The alteration effect of the upper contact of the lower lava indicates an intrusion. The present writer thinks that the lava flows in the present area are relatively small and some of the fissures which supply the molten material do not reach the surface, so basalt dikes and sills are formed at the same time.

Because of the fact that the flows and intrusions are intercalated in the Salt Lake group, the age of these flows and intrusions is considered to be Pliocene.

Tertiary boulder gravel (?)

Several patches of boulder gravel are found in the present area. This boulder gravel caps the old Paleozoic rocks on the top of the range, as well as the Salt Lake group in the lower parts of the area. The boulders are well rounded and range from 4 inches to 2 feet in diameter. They were derived from the old Paleozoic rocks and consist of limestone, dolomite, and quartzite. The boulders and cobbles are also found on the top of Rendezvous Peak by Ezell (1953, p. 22), who suggested that they were derived from the Brigham quartzite and a small amount of pre-Cambrian quartzite. He assigned these boulders and cobbles to a pre-Salt Lake group age. It is possible that some of the boulder gravel in the present area may correlate with that in the Rendezvous Peak area, but some of this boulder gravel which caps on the Salt Lake group in the lower parts of the area seems to be much younger.

Pleistocene deposits

The Pleistocene deposits consist of lake beds and alluvial slope wash. Lake terraces are not well developed in the present area. Only the Bonneville level can be traced west of the town of Weston, passing to the south along the low divide west of Bergeson Hill. The elevation of the Bonneville level is approximately 5,135 feet. The lake beds consist of fine silt, clay, and a well-sorted gravel bed (Figure 9). The road cut west of the town of Weston exposed the contact of the Salt Lake group and the lake beds containing fine silt and lense of gravel (Figure 10).

8,000 tons of block and crushed salt were shipped in 1960 for livestock consumption. The salt is quarried, after a clay overburden of 25 to 30 feet is removed (Plate 6, Figure 2), and hauled by truck to Redmond to be crushed and screened or shipped in block form.

The following analysis of salt from the Redmond area has been reported by Gilliland (1951, p. 61):

	Percent
Salt, NaCl	95.60
Silica	2.16
Sulphates	1.10
Calcium	0.51
Iron and alumina oxides	0.04
Manganese	0.04
Iodine	0.03

On the east side of the valley, east of Redmond, there is an additional salt bed in the Arapien shale. This bed once was mined by the Great Western Salt Company, but the high clay content of the bed prevented its full development.

There are also salt beds in Salina Canyon and in Salt Creek Canyon, east of Nephi, where the Arapien shale is exposed. There is no attempt being made at the present time to work these deposits, however.

Sand and gravel

There are a great number of sand and gravel deposits within the Sevier River drainage. Possibly the most important of these in terms of present production are: the large deposit in Centerfield, which is owned and operated by Marwood Hale of Redmond; the deposit of the Johnson Sand and Gravel Company at the southeastern edge of Ephraim; the deposit worked by the Ferrell Adams and Sons Redi-Mix Company at

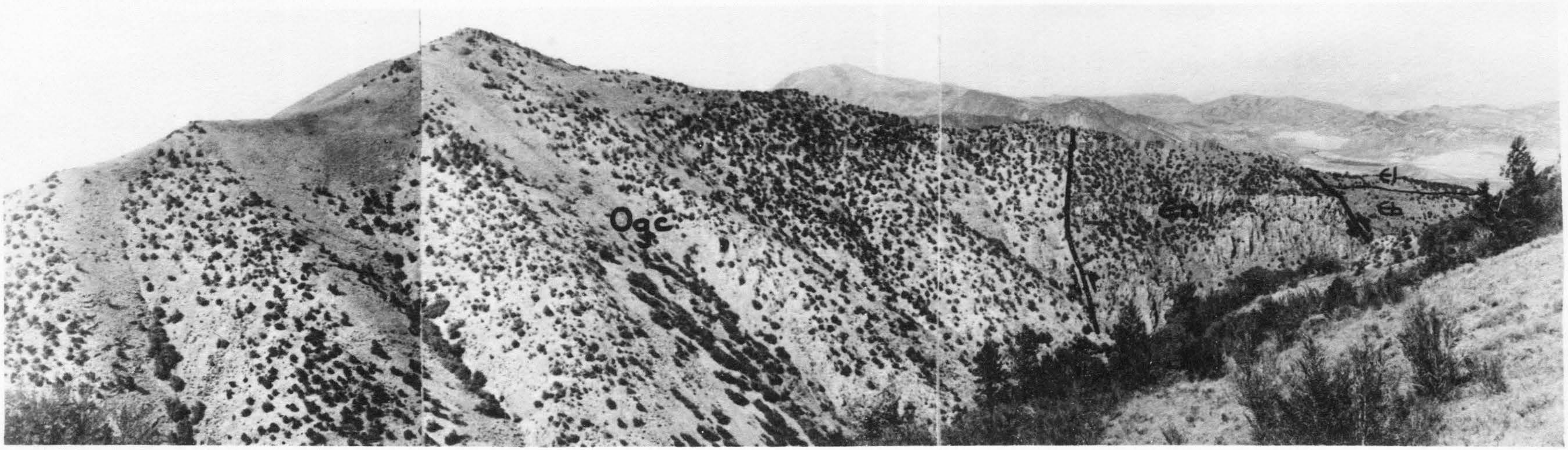

Figure 11. Panoramic view along Dry Canyon in east-west direction, looking north.

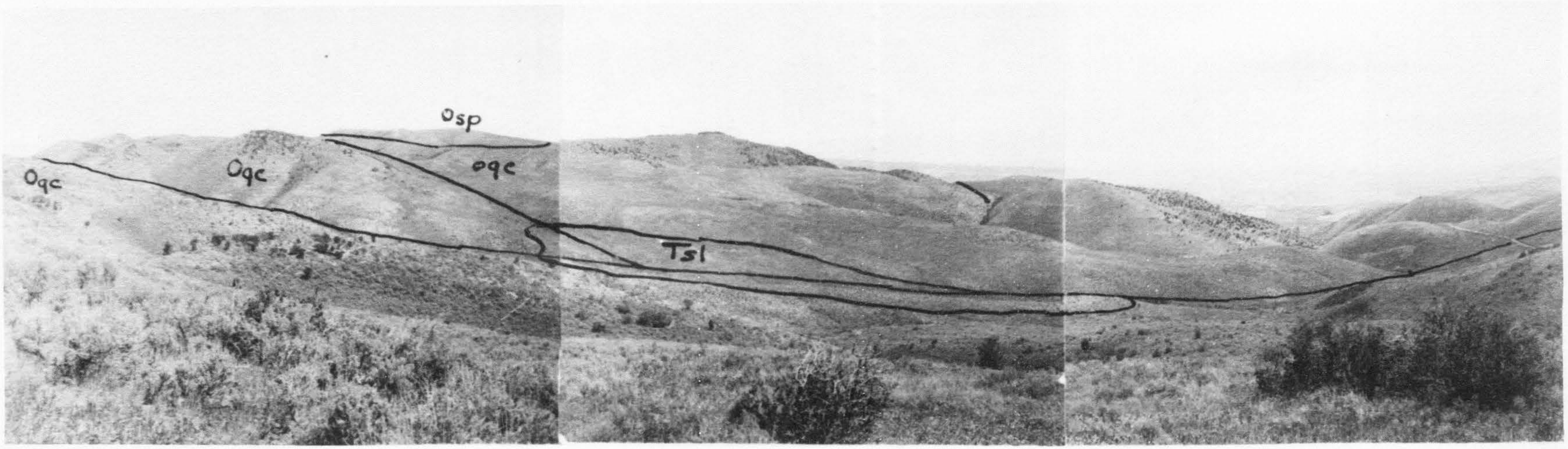

Figure 12. Panoramic view in north-south direction north of Black Canyon, looking east.

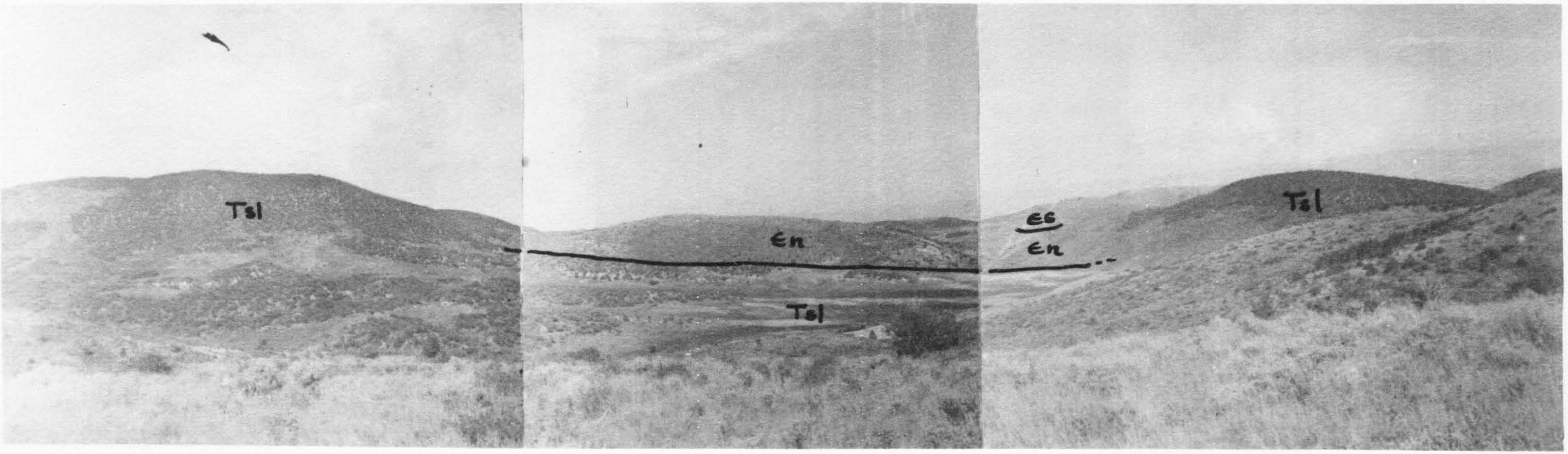

Figure 13. Panoramic view in north-west direction in the area west of Long Hollow fault, looking east.

Figure 14. Fault zone of the Dry Canyon fault at Dry Canyon, looking south.

Figure 15. Weston fault on the north side of Dry Canyon.

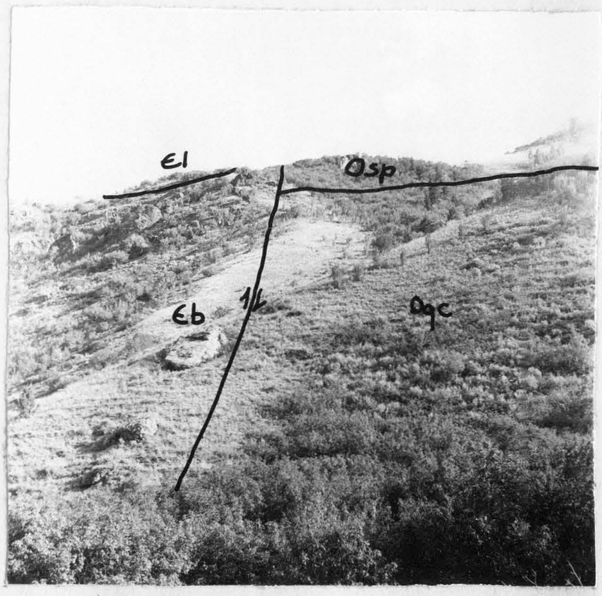

Figure 16. Weston fault on the south side of Dry Canyon.

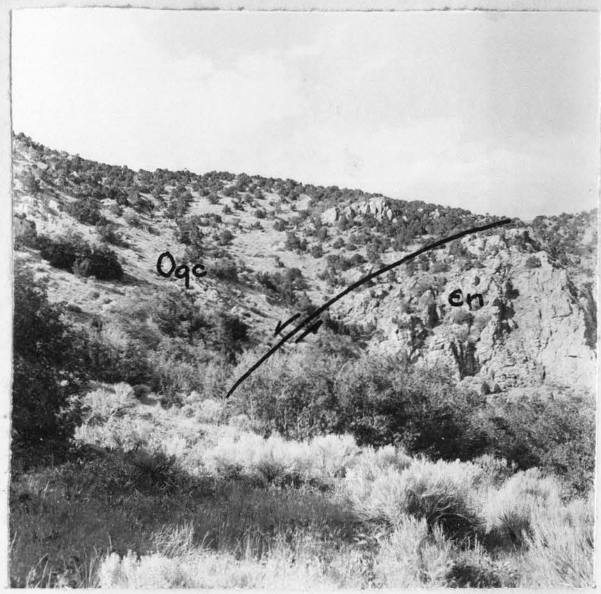

Figure 17. Square Peak fault at Dry Canyon.

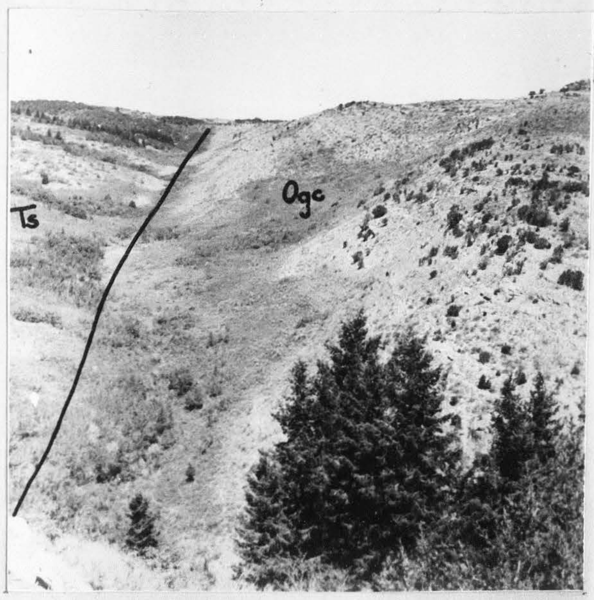

Figure 18. Fault-line scarp of the Garden City limestone at Black Canyon.

STRUCTURAL GEOLOGY

Regional Structural Relations

The east-central part of the Malad Range is located in the region of major thrust faults. To the east of the map area, the Randolph quadrangle, east of the Bear River Range, the Bannock overthrust can be traced from the area west of Bear Lake in Utah northward into Idaho for a distance of 270 miles. This overthrusting is northeastward and its maximum measured overlap is approximately 35 miles (Richardson, 1941, p. 39). The Willard thrust, at the town of Willard, Utah, about 13 miles north of Ogden, Utah, moved the Cambrian off-shore sequence westward over the near-shore sequence of the northern Utah highland (Eardley, 1939, p. 1,304). Both thrust faults originated during the Laramide orogeny. In addition to these thrust faults, the north-south trending folds of the Bear River Range, east of Cache Valley, were formed during the Laramide orogeny (Williams, 1948). The Basin and Range faults are best exemplified by the faults in the Wasatch region.

The major structure of the east-central part of the Malad Range is an east-dipping homocline which extends northward from the southern part of the Malad Range. This homocline has a general trend of 10 degrees west of north and an average dip of 30 degrees east in the east-central part of the Malad Range. High-angle faults of north-south trend cut the homocline. Most of them are approximately parallel to the general trend of Cache Valley. Later movement on some of these faults caused displacement of the Salt Lake group in the present area.

Geologic Structure

The east-central part of the Malad Range is broken by faults of 2 major trends, north-south and east-west. The north-south-trending faults are longer and more numerous than the east-west-trending faults. Most of the north-south-trending faults have the downthrown blocks on the west side.

North-south-trending faults

Weston fault. The Weston fault bounds the east side of the east-central part of the Malad Range and varies in strike from approximately 30 degrees west to 30 degrees east of north. It is a branch of the Clarkston fault and extends from a point about 2 miles south of the Utah-Idaho line northward to the Dry Canyon area. The actual intersection of this fault with the Clarkston fault cannot be found due to poor exposures of the Salt Lake group in the area south of Black Canyon. Then the Weston fault is traced, approximately, according to the topographic expression. It forms a scarp, however, in the area between a point about 1 mile south of Black Canyon and Dry Canyon. About one-half mile north of Black Canyon, the displacement on this fault can be observed in the Salt Lake group as the outcrop immediately west of the fault shows easterly dip while the one on the east shows opposite dip. North of this point the Garden City limestone on the east side is dropped down with a stratigraphic displacement of at least 1,000 feet. On the north side of Dry Canyon, the Weston fault brings the Nounan formation into contact with the Brigham quartzite (Figures 11 and 15), and south of the intersection between the Weston fault and Square Peak fault the Garden City limestone is in contact with the Brigham quartzite (Figure 16). Here the stratigraphic position of the rocks on both sides of the Weston fault indicates that the downthrown block is on the west side. The intersection of the Weston fault and the fault of the foothills marks the south limit of the Brigham quartzite.

Square Peak fault. On the north side of Dry Canyon, the Square Peak fault brings the Nounan formation into contact with the Garden City limestone with a stratigraphic displacement of approximately 1,000 feet (Figures 11 and 17). Here the reverse drag and stratigraphic position of the rocks on both sides of this fault indicate renewed movement in a direction opposite to the first movement. In the first movement, the Garden City limestone on the west block was pushed up while the east block was dropped down. Renewed movement dropped the Garden City limestone on the west block into contact with the Nounan formation on the east block. Increase in dip of the Garden City limestone near the fault suggests the upward movement of this block due to compression. On the south side of the canyon, the Square Peak fault intersects the Weston fault. The south branch of the Square Peak fault separates the Swan Peak quartzite from the Garden City limestone with a stratigraphic displacement of approximately 1,000 feet and is obscured under the Salt Lake group in the area north of Black Canyon.

Dry Canyon fault. The Dry Canyon fault, the major fault of the map area, extends from Dry Canyon to Harris Canyon through the middle part of the area. At Dry Canyon, the Swan Peak quartzite on the downthrown block on the west side is dropped in faulted contact with the Garden City limestone. The dip of the upthrown Garden City limestone increases near the fault (Figure 14) and the rocks are somewhat brecciated. These facts suggest faulting as the result of compression instead of tension. To the north, the Dry Canyon fault is obscured under the Salt Lake group; to the south, it is covered in most places by the Salt Lake group, but there is no displacement in the Salt Lake group caused by the Dry Canyon fault. The fault is traced to the south according to the topographic expression under the covering of the Salt Lake group. This fault is exposed again at Harris Canyon where it brings the lower part of the St. Charles formation on the upthrown side into contact with the upper part of the same formation on the downthrown side.

Long Hollow fault. The Long Hollow fault, marking the west margin of the map area, forms a fault-line scarp of the Paleozoic rocks in most places. In the right fork of Black Canyon (Figure 18), the upthrown block of the Garden City limestone forms a scarp sloping to the east. Passing to the south, this fault is obscured under the Salt Lake group. Likewise, as in the case of Dry Canyon fault, the fault zone can be seen in Harris Canyon where the rock increases in dip from 35 degrees to nearly vertical near the fault and the rocks are somewhat brecciated.

East-west-trending faults

Faults of east-west trend are found mostly in the area between Black Canyon and Harris Canyon, and are terminated at the north-south-trending faults. At a point about one-half mile north of Harris Canyon, a fault brings the Worm Creek quartzite into faulted contact with the upper part of the St. Charles formation. One fault, joining the above fault, shows small displacement within the St. Charles formation. The actual trace of this fault, however, cannot be seen due to covering of the Salt Lake group. Another fault of small displacement within the Garden City limestone occurs in the area north of Black Canyon. This fault can be observed on the slope on the east face of the range where the displacement brings the upper black chert dolomite into contact with the limestone in the lower part of the Garden City limestone.

Age of the Structure

The faulting in the east-central part of the Malad Range can be divided into 2 categories, 1 antedating the deposition of the Salt Lake group and another following the deposition of the Salt Lake group. The pre-Salt Lake group faulting produced the relief areas in which the Salt

Lake group was deposited and the post-Salt Lake group faulting displaced the Salt Lake group. The traces of some faults, however, are concealed under the Salt Lake group. The Long Hollow fault, the Dry Canyon fault, and the Square Peak fault, which are of north-south trend, are believed to be pre-Salt Lake group in age. Thus the Long Hollow and Dry Canyon faults pass under the Salt Lake group without causing a displacement. Although there is no direct evidence for the Square Peak fault, the similarity of drag on this fault to that of the other 2 faults suggests the close relationship among them, and probably they were formed at the same time. Renewed movement of this fault in the post-Salt Lake group age produced movement in a reverse direction. The displacement of the Salt Lake group along the Weston fault indicates post-Salt Lake group age. Moreover, it is conceivable that all the faults of the north-south trend were formed in the pre-Salt Lake group age, and the renewed movement only affected the Square Peak and Weston faults in post-Salt Lake group time. The exact age of the faults in the east-west trend is not known, but the termination of these faults at the north-south-trending faults indicates a pre-Salt Lake group age or even a Laramide age. However, it may be possible that they were formed at the same time.

The Clarkston fault, which separates the east-central Malad Range homocline from the southern Malad Range homocline, is pre-Salt Lake group in age. Judging from the outcrop of the St. Charles formation in the southern part of the map area and the outcrop of the Nounan formation in the north end of the southern Malad Range, the Clarkston fault has a stratigraphic throw of at least 1,000 feet. The relationship of the Weston fault to the north-south-trending faults of the map area, as mentioned before, and to the Clarkston fault as its post-Salt Lake group branch, may suggest a correlation in age of the north-south-trending faults, the Clarkston fault and other faults which bound the edge of Cache Valley.

The ages of faulting in the east-central part of the Malad Range area confirm those found by Williams (1948) in the Logan quadrangle. In the Pisgah Hills area in the southwest corner of the Logan quadrangle, a series of high-angle faults has a northeast trend and is interpreted as tear faults produced when the Wellsville mountain homocline was tilted during the Laramide orogeny. These faults are probably similar to the faults of Junction Hills and the east-west-trending faults of the map area.

GEOLOGIC HISTORY

Pre-Cambrian Eon

There are no rocks of pre-Cambrian age found in the map area, but information regarding this time may be obtained from the near-by areas. Hanson (1949, p. 81-82) reported the interbedded quartzites, slates, and phyllites in the area of southern Malad Range about 1 mile west of the present area, which he tentatively correlated with the Cottonwood series east of Salt Lake City. Probably pre-Cambrian was the time of the most emergence of land. Most of the pre-Cambrian deposits are regarded by Walcott (1914, p. 80-81) as of non-marine origin. However, Anderson (1931, p. 28) considered the Harrison series in the area of eastern Cassia County to be marine in origin. The pre-Cambrian sediments overlie unconformably, in some localities, the Farmington complex which is Archean age.

In an earlier time, probably early or middle pre-Cambrian, there was a period of great orogeny associated with igneous intrusion in which the ancient sediments were folded and metamorphosed. After the period of orogeny, the area was subjected to cycles of erosion, and the mountains were worn down. The deposition of quartzites, slates, and phyllites indicated the subsidence of the area in which sand and fine sediment settled, derived mostly from the northern Utah highland. The sediments were carried to the site and deposited in the shallow water where the agitating action developed ripple marks and cross-bedding. Crittenden (1952, p. 3) suggested a broad, gradual subsidence for the deposition of shale in the Big Cottonwood series. To the north, the deposition of metamorphosed lava, tuffs, and volcanic breccias in the area of Pocatello (Ludlum,

1942) indicates that there were short periods of volcanic eruptions. During late pre-Cambrian time or slightly earlier, the area of northern Utah and southern Idaho underwent a period of glaciation, and beds of tillite containing boulders and pebbles of old rocks were deposited widely in this area. The deposition of varves, slates, and limestones interbedded with tillites suggests areas in which glacial lakes were formed (Eardley and Hatch, 1940).

In the late pre-Cambrian era, after the youngest Algonkian beds of quartzites and shales were deposited, the region went through a long period of erosion until early Cambrian. Quartzites were deposited unconformably on this erosional surface.

Paleozoic Era

The area of northern Utah and southern Idaho is one of the important parts of the Cordilleran geosyncline where the greatest thickness of sediments has been deposited. The sediments were laid down in the troughs adjacent to the highlands. The northern Utah highland, one of the most important areas from which the sediments were derived, stood up probably from the time of late pre-Cambrian through the period of Cambrian time (Eardley, 1940) and was subjected to the long period of erosion. The process of weathering cut down the highland, which consists mainly of crystalline and non-carbonate rocks. The deposition of coarse-grained, well-sorted quartzites in the map area in the middle Cambrian or even earlier period was believed to occur in the shallow water of the beach on the shoreline. The weathered debris was carried down to the running streams, and the sediments were washed clean and sorted to uniform size by the effect of the waves and currents. The water was shallow enough that the cross-bedding was formed by the bottom currents. The deposition of shale and micaceous material interbedded with the Brigham quartzite in the map area indicated an interruption due to an increase in rate of subsidence. The occurrence of fucoids (?) and annelid borings in some areas supports the idea of the existence of a beach. Increased subsiding of the trough produced the deposition of the Langston formation in the present area. The fluctuation of the Middle Cambrian shoreline in the map area is represented by the transitional zone between the Brigham quartzite and Langston formation. Deepening of the geosyncline caused the development of the Middle and Upper Cambrian thick sequence of limestones and shales that have been deposited. However, a short period of uplift of the map area was recorded by the deposition of the Worm Creek quartzite member at the base of the St. Charles formation. There is not sufficient evidence to show the disturbance during the Middle and Upper Cambrian period causing unconformities or disconformities, but it might be possible that small breaks were formed in the map area. Marine life seems to have developed very early in this time, indicated by the variation of the faunas. Deposition in the map area was generally continuous under the shallow sea where the intraformational and oolitic limestones were deposited.

Following the deposition of the Cambrian system, a great thickness of limestones was deposited in the shallow sea during Early Ordovician time in the map area. The occurrence of black chert limestones near the top of the Garden City limestone suggests that the silica was derived from the volcanic activity along the western archipelago (Eardley, 1947, p. 340). Uplift of the area to the north and east of the map area at the end of Lower Ordovician caused erosion which provided the sands and shale of the Swan Peak quartzite. Renewed movement caused the withdrawal of the sea and a cycle of erosion took place during the later period of the Middle Ordovician. The returning of the sea in the Late Ordovician brought the deposition of the Fish Haven dolomite. Rising of the geosyncline at the end of the Ordovician time is indicated by the disconformity at the top of the Ordovician. Mid-Silurian time is represented by the Laketown dolomite.

Following Silurian time, the Devonian sea spread over the geosyncline area and brought the deposition of the Water Canyon formation. Gradual subsiding of the area deepened the sea and the Jefferson formation, in which are preserved primitive fish fossils (Branson, 1931), was deposited.

The presence of the unconformity between the Devonian and Mississippian formations marked a period of disturbance. The Carboniferous epoch was presented by a series of limestones and shales, and sandstones representing a variation in condition of deposition. Uplift of the area during the Mississippian time was indicated by the sandstone member of the Brazer formation. Following the brief withdrawal of the sea, the deposition of the Wells formation commenced in the Pennsylvanian time.

The presence of the Permian beds in northern Utah and southern Idaho (Richardson, 1941; Anderson, 1931; Boutwell, 1912) is evidence that the Permian sea spread over the present area. Probably it was eroded away during the later period of erosion.

Mesozoic Era

Although there is no rock of the Mesozoic age outcropping in the map area, Mesozoic rocks were found deposited in the near-by vicinity of northern Utah and southern Idaho. During the early time of the Triassic, the depression of the geosyncline in the northern Utah and southern Idaho area caused the sea to enter from the southwest and spread to the east (Hanson, 1949). This marine facies brought the deposition of the Woodside formation and the Thaynes limestone. The interfingering of the marine facies and the continental red bed suggests oscillation in the rate of subsidence of the geosyncline. The deposition of the red bed seems to be widespread from the Triassic to Jurassic time.

The end of the Jurassic time was followed by the Nevada disturbance when the Mesocordilleran geanticline arose and northern Utah was elevated into a mountain. This mountain area supplied the coarse sediments for the conglomerate tongue in the Morrison formation farther east (Williams, 1948). During the Cretaceous time, the sea invaded westward across the geosyncline in Colorado, Wyoming, and Montana, and brought a considerable thickness of sediment to these areas. However, the Mesozoic formations in the map area were eroded away during the late Mesozoic time.

During the Laramide orogeny, the Paleozoic rocks in the map area were deformed by a force mainly in the east-west direction. In the near-by area, folds and thrust faults were formed during this time (Williams, 1948; Eardley, 1944; Richardson, 1913).

Cenozoic Era

After the period of folding and faulting of the Laramide orogeny, the map area was subjected to a long period of erosion during which the mountain ranges were worn down. The coarse sediments of the Eocene Wasatch conglomerate were deposited upon the truncated surface of the old Paleozoic rocks. Although there is no evidence of deposition of this formation in the present area, Hanson (1949, p. 88) found an outcrop of probable Wasatch conglomerate in the northern end of Wellsville mountain. It might be conceivable that the Wasatch conglomerate was deposited in the map area and was eroded away during the later period of erosion.

Williams (1948, p. 1,159) pointed out the concordance of several mountain peaks as the existence of the peneplain. This peneplain surface was also mentioned by Eardley (1944, p. 873) as the Herd Mountain surface and by Walcott (1927, p. 14) as the Snowdrift peneplain. Both Williams and Mansfield assigned the age of this peneplain as Eocene to perhaps mid-Miocene, while Eardley thought it to be Miocene.

During Miocene or even earlier, the map area was subjected to the period of Basin and Range faulting in which high-angle faults broke the mountain range to form horst and graben structure. Prior to the deposition of the Salt Lake group, a short period of erosion took place along the fault block mountains, and the major topography of the map area--most likely that of today--was formed. The Salt Lake group deposited upon the erosional surface of the Paleozoic rocks and filled the low depression areas. Volcanic activity supplied a great volume of ash, tuffs, and glasses, and these sediments were deposited in the present area in the existing lake which filled in the valley. Locally, the deep part of the lake caused the deposition of limestone. Conglomerate beds representing the valley side deposition, intertongue with the Salt Lake group. Fluvial action reworked the volcanic sediments and caused the formation of the tuffaceous sandstone. Renewed movement in the post-Salt Lake group time caused the displacement of the Salt Lake group in the map area.

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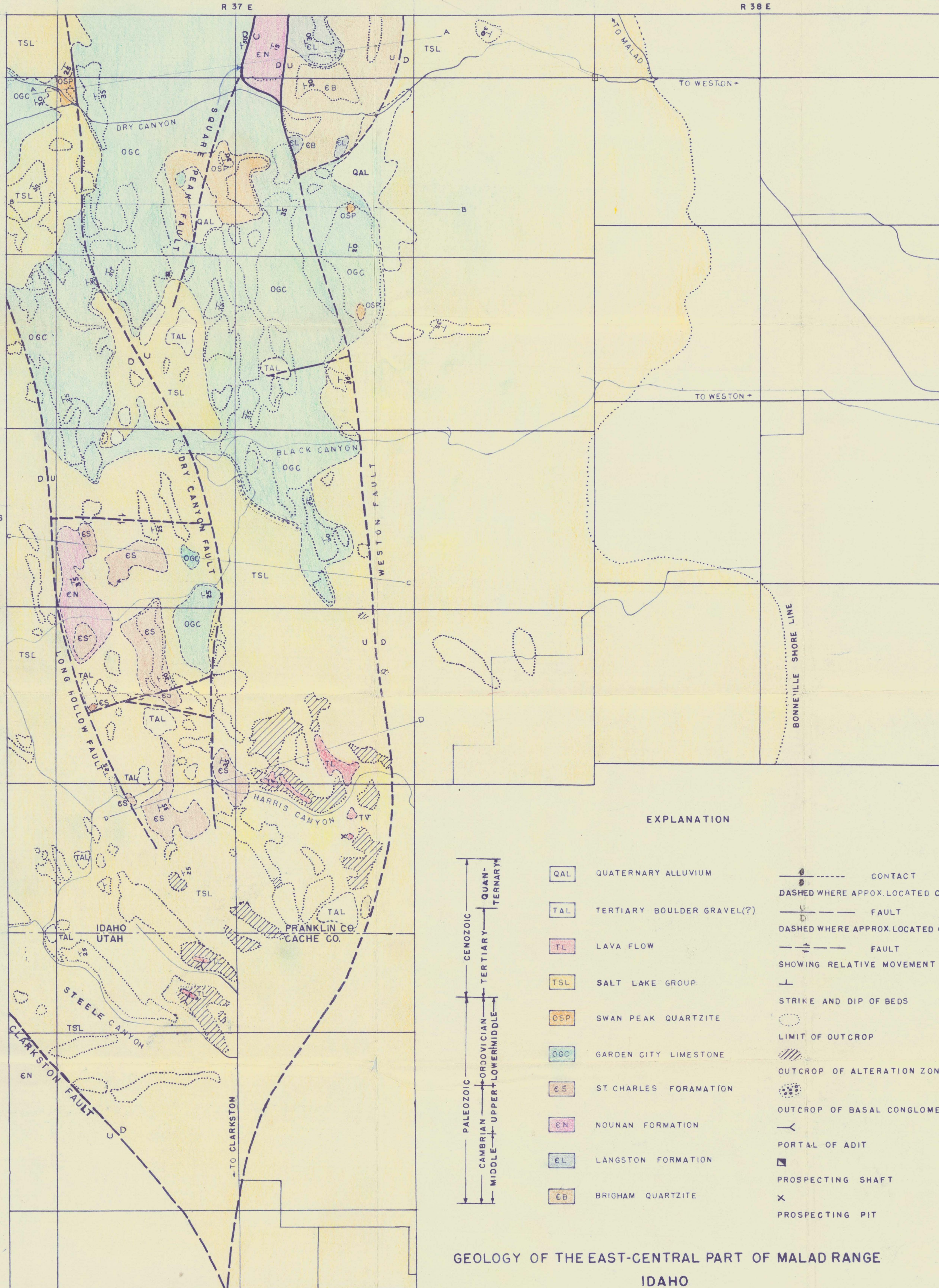

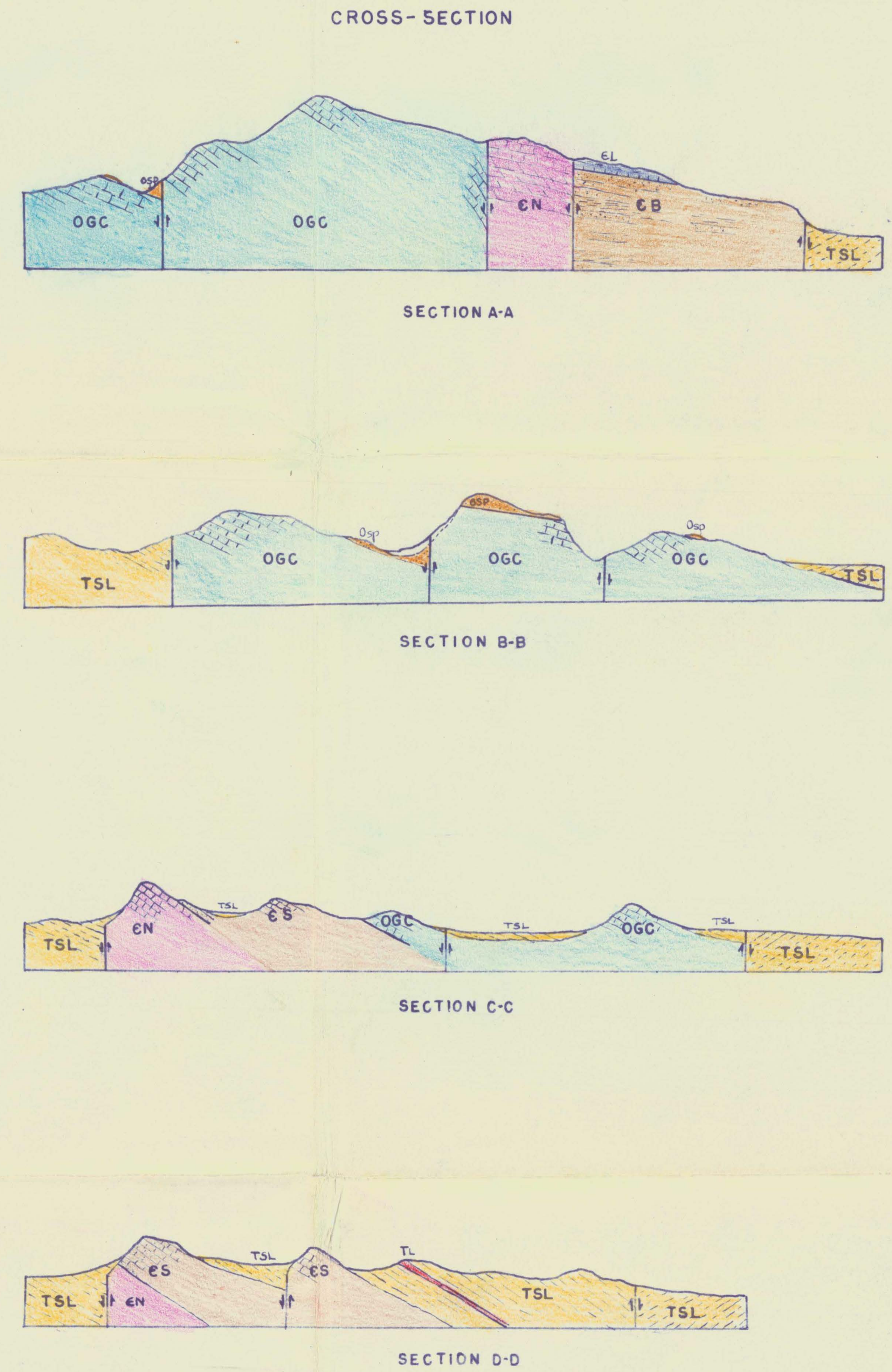

HORIZONTAL SCALE IS THE SAME AS GEOLOGIC MAP.

VERTICAL SCALE IS EXAGGERATED.

EXPLANATION

CENOZOIC	QUATERNARY	QAL	QUATERNARY ALLUVIUM
CENOZOIC	TERTIARY	TAL	TERTIARY BOULDER GRAVEL(?)
CENOZOIC	TERTIARY	TL	LAVA FLOW
CENOZOIC	TERTIARY	TSL	SALT LAKE GROUP
PALEOZOIC	ORDOVICIAN MIDDLE	OSP	SWAN PEAK QUARTZITE
PALEOZOIC	ORDOVICIAN LOWER	OGC	GARDEN CITY LIMESTONE
PALEOZOIC	CAMBRIAN UPPER	ЄS	ST. CHARLES FORMATION
PALEOZOIC	CAMBRIAN MIDDLE	ЄN	NOUNAN FORMATION
PALEOZOIC	CAMBRIAN MIDDLE	ЄL	LANGSTON FORMATION
PALEOZOIC	CAMBRIAN MIDDLE	ЄB	BRIGHAM QUARTZITE

CONTACT
DASHED WHERE APPOX. LOCATED OR INFERRED

FAULT
DASHED WHERE APPROX. LOCATED OR INFERRED

FAULT
SHOWING RELATIVE MOVEMENT

STRIKE AND DIP OF BEDS

LIMIT OF OUTCROP

OUTCROP OF ALTERATION ZONE

OUTCROP OF BASAL CONGLOMERATE

PORTAL OF ADIT

PROSPECTING SHAFT

PROSPECTING PIT

GEOLOGY OF THE EAST-CENTRAL PART OF MALAD RANGE IDAHO

BY P. PRAMMANI

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SCALE 1:19920

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