1961

Geology of the NW 15-minute Ural Quadrangle Lincoln Co. Montana

Arthur W. Shelden

The University of Montana

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GEOLOGY OF THE NW 15-MINUTE URAL QUADRANGLE, LINCOLN CO., MONTANA

by

Arthur W. Shelden

A THESIS (Master's Thesis)

Submitted to the Graduate Faculty

in

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for the degree of

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at

Montana State College

Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

Bozeman, Montana

May 1961
Errata Sheet

Geology of the NW 15-Minute Ural Quadrangle, Lincoln Co., Montana

Page 4, line 1; for: southwestern
read: southeastern

Page 12, line 2; reads: detrital or diagenetic minerals.
should read: detrital or diagenetic sulfide minerals.

Page 17, line 15; for: massive
read: marine

Page 18, line 2; reads: and may be diminishing
should read: and the quartzites may be diminishing

Page 19, line 17; for: Bands of an anhedral,
read: Bands of anhedral

Page 19, line 19; for: mosaic
read: matrix

Page 26, line 4; for: grade
read: grades

Page 35, line 12; for: They
read: The

Page 39, line 7; for: (Fig. 2)
read: (Fig. 3)

Page 43, last line of table; reads: Base conformable to Wallace formation
should read: Base conformable on Wallace formation

Page 46, line 18; for: differentiated
read: undifferentiated

Page 47, line 16; for: microscopically
read: macroscopically

Page 53, line 3; for: sentence beginning Column 2 is the average composition--
read: Column 2 is the average composition of a normal tholeitic basalt and Column 3 is the average composition of a normal alkali basalt (Nockolds, 1954, p. 1021).

Page 58, line 18; for: projection in Canada.
read: projection of this zone in Canada.

Page 61, line 25; for: throughout stringers
read: throughout stringers of

Page 62, line 2; for: was
read: were
Errata Sheet continued

Page 32, line 10; add this sentence after the word Mountains: There is general agreement among geologists that the Grinnell and Appekunny argillites of Glacier Park and the Flathead region are equivalent to the Ravalli group as exposed in the Cabinet and Purcell mountains.

Page 54, add this paragraph at bottom of page:

The Purcell lavas are considered to be genetically related to the Purcell sills because of (1) the similarity in composition and (2) the absence of related intrusive rock overlying the lavas. Biotite samples from Purcell sills in southeastern British Columbia give $^{40}A / K^{40}$ ages of 558 to 835 million years with the latter figure being assumed to indicate time of intrusion (Hunt, 1960). Pillow structures are common in the lavas in adjacent areas and the presence of thin beds of argillite between flows strongly suggest the same, if not all, of the lava was extruded into the shallow waters of the Beltian seas as several individual flows with sufficient time for cooling between flows.
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ABSTRACT

In the NW 15-minute Ural quadrangle 50 miles north of Libby in Lincoln County, Montana, about 14,000 feet of Belt strata are exposed. The pre-Ravalli, Ravalli and Piegan groups are recognized. Lithologic units are distinct and are correlatible with the Glacier Park and Libby quadrangle stratigraphic sections. Specifically, the Prichard formation is believed equivalent in part to the Altyn formation. The Wallace formation (believed equivalent to Piegan group of the Fentons) is subdivided into a lower gray-ish-green argillite, a middle blue-gray limestone unit (equivalent to the Siyeh formation of Ross), and an upper greenish-gray argillaceous quartzite unit which includes the Purcell lavas and the overlying Shepard formation at the top. A hiatus of unknown magnitude occurs between the Purcell lavas and the Shepard formation.

The Prichard formation is characterized by euhedral biotite, chloritoid and garnet porphyroblasts and is locally moderately recrystallized, but sedimentary structures are not deformed. Octahedra of secondary magnetite occur in Ravalli and younger rocks. Though mild, the intensity of metamorphism increases in older formations.

The Belt strata have been broadly folded and broken by high-angle faults during the Laramide orogeny. Secondary magnetite octahedra concentrated on joint surfaces, and an erosional unconformity at the top of extrusive Purcell lavas imply mild pre-Laramide deformation, some of which is Late Precambrian.

The Cordilleran ice sheet blanketed the area during Late Pleistocene. Meltwater from younger cirque glaciers on the east flank of the Purcell mountains formed ice-marginal lakes along the restricted piedmont glacier that occupied the Rocky Mountain Trench.
INTRODUCTION

The previously unmapped NW 15-minute Ural quadrangle is characterized by a thick sequence of Late Precambrian Belt sediments that were gently folded and faulted during the Laramide orogeny. Strategically located between the Cabinet Range and Glacier Park (Fig. 2), the map area provides critical evidence for regional correlation of stratigraphic units of the Belt series of northwestern Montana. The area was studied as part of a current five-year program of regional reconnaissance geologic mapping and mineral resource investigation in the Kootenai-Flathead area directed by the Montana Bureau of Mines and Geology. The project is sponsored by the Great Northern Railway Company and the Pacific Power and Light Company. In mapping the geology of this area, the writer aimed to construct an accurate geologic map, compile stratigraphic and structural information, and evaluate mineral resources in the area.

Location and Accessibility: The area mapped, approximately 200 square miles, is the northwestern 15-minute quadrangle of the 30-minute Ural quadrangle, which is located in Lincoln County of northwestern Montana (Fig. 1). The map area lies on the eastern-most flank of the Purcell Mountains of Montana and is bounded on the east by a large topographic depression known as the Rocky Mountain Trench, on the south by the east-flowing portion of Big Creek, on the west by the 115° 30' longitudinal meridian, and on the north by the International Boundary. The area can be reached via State Highway No. 37 which parallels the Kootenai River and links Libby and Rexford, Montana. Many secondary Forest Service and logging roads leading from Highway No. 37 provide easy access to most of the map area (see Plate 1) and, with a few exceptions, are passable with modern cars during summer months.
Topography: The Purcell Mountains trend in a north-northwest direction parallel to the general strike of the regional structure. Within the map area these mountains exhibit a comparatively subdued topography, although the relief is considerable and the slopes are generally quite steep. The prominent, high north-trending ridge centrally located in the map area acts as a pronounced drainage divide. This divide is the summit ridge of a physiographic unit within the Purcell Mountains called the McGillivray Range by Daly (1912). Streams east of the divide drain directly into the south-flowing Kootenai River, and west of the divide flow in a general westerly direction into the Yaak River which empties into the Kootenai River near the Montana-Idaho border. Peaks on the main ridge rise to an average of 6,000 to 7,000 feet, the highest of which is Robinson Mountain at 7,500 feet above sea level. The more subdued ridges rise to elevations of 5,000 to 6,000 feet. The stream valleys are approximately 1/4 to 1/2 mile wide.
and commonly reach depths exceeding 2,000 feet below adjacent ridge tops. Stream gradients are steep and locally exceed 800 feet per mile. The lowest point of elevation is approximately 2,300 feet where the Kootenai River leaves the map area.

**Field Work:** Field work was reconnaissance in nature and was done during the months of June, July, August and September, 1960. Geology was plotted directly on Forest Service planimetric maps (scale: 1 inch = 1/2 mile) by comparison of topography and drainage with the aid of aerial photographs and Forest Service topographic sheets (scale: 1 inch = 4 miles, 200 foot contour interval). Standard geological field mapping techniques were employed. All major ridges in the area were traversed, although in many cases outcrops were obscured over large areas by a thick mantle of residual soil and vegetation. Most of the valleys and subsidiary ridges are veneered with glacial till which supports thick virgin stands of ponderosa pine, spruce and a secondary growth of fir and lodgepole pine. Although geologic field mapping was severely handicapped by the cover, location of formational boundaries is considered to be reasonably accurate. Much of the information concerning the Prichard formation was obtained while mapping in the adjacent north half of the 30-minute Yaak River quadrangle during the latter part of September.

**Previous Field Work:** Previous field work in the map area is limited to reconnaissance surveys made by Daly (1912) who mapped a narrow strip along the 49th parallel, and by Calkins and MacDonald (1909) who made a hurried trip up the East Fork of the Yaak River to the head of Caribou Creek where they observed the Purcell lavas. Schofield (1915) and Leech
(1958, 1960) have mapped the geology of southwestern British Columbia. In nearby areas Gibson (1948) mapped the geology of the Libby quadrangle in detail and Alden (1953) has made significant contributions concerning Pleistocene glaciation in northwestern Montana. Information derived from Lambert's geologic reconnaissance mapping of Lincoln and Flathead Counties was used to compile the State Geologic Map of Montana. Johns (1959, 1960) has recently completed reconnaissance geological surveys of the south half of the 30-minute Yaak River quadrangle and the 30-minute Thompson Lakes quadrangle. Field work for similar surveys of the north half of the Yaak River quadrangle and the south half of the Ural quadrangle was completed by Johns during the 1960 field season. D. Sommers (unpublished Master's thesis, University of Rochester) mapped the NE 15-minute Ural quadrangle.

Acknowledgements: The writer wishes to acknowledge the assistance of several individuals including the Montana Bureau of Mines and Geology for financial support; Dr. William J. McMannis, Montana State College, for helpful criticism and discussion of the original manuscript and other phases of the investigation, including discussions in the field; Drs. Robert J. Foster and John de la Montagne of Montana State College for critically reading the original manuscript; Dr. Nicholas Helburn of Montana State College for making funds available for certain phases of the investigation; Willis M. Johns of the Montana Bureau of Mines and Geology, and Dave Sommers, graduate student at the University of Rochester, New York, for helpful discussions in the field. Also, the writer is deeply indebted to his wife for her encouragement and initial typing of the manuscript and to Mrs. Carol Tacke who typed the final manuscript.
Geomorphology and Glaciation: The mature topography of the Purcell Mountains is primarily the result of pre-glacial stream erosion which deeply dissected a broad mountain range formed by regional tectonism that occurred during the Laramide orogeny. Subsequent streams in the map area are dendritic in nature and locally appear to be structurally controlled. Examples of what may be structurally controlled drainage are Dodge Basin and Good Creeks, and the southeast-flowing section of Young Creek. An immense mountain ice sheet modified the subdued topography and many of the existing geomorphic features such as cirques, till deposits and kame terraces are directly related to Late Pleistocene glaciation.

As discussed below, two phases of Late Pleistocene glaciation are recognized in the map area. Elevations of glacial striae on bed-rock imply that the southward-flowing Cordilleran ice sheet covered all but the higher peaks of the Purcell Mountains during the initial phase of glaciation. The ice in the higher stream valleys averaged 2,500 feet in depth, and was approximately 5,000 feet deep in the Rocky Mountain Trench near the International Boundary (Daly, 1912, p. 585-587). Southwest-trending glacial striations were noted at elevations of 6,000 feet on Webb Mountain and adjacent ridges, and Daly observed glacial striae at a maximum elevation of 7,100 feet along the boundary. Discontinuous patches of glacial till and erratics consisting of Paleozoic sedimentary rocks and Late Mesozoic (?) igneous rocks were found at equally high elevations. The most impressive erratic is a porphyritic quartz monzonite boulder, exceeding 15 feet in diameter, that has been let down into the bottom of Young Creek. Since no post-Hercynian sedimentary or igneous rocks occur in the area, this till is be-
lieved to have been deposited by the Cordilleran ice sheet which carried the debris southward from Canada. The quartz monzonite boulder was probably quarried from stocks occurring some 50 miles north of the boundary.

During the later phase of glaciation, small valley glaciers carved out poorly developed cirques along the summit ridge. It is not presently known whether the cirques were formed as part of the recessional phase of the Cordilleran ice sheet or if they developed during a later stage of glaciation. The cirques are floored with a thick cover of fresh-looking till characterized by angular boulders of the local Beltian rock type. The floors of several independent cirques in the area occur at consistent altitudes of 4,400 to 4,800 feet, thus approximating the orographic snowline that existed at the time the cirques were formed. In profile, the present stream valleys are characterized by the usual U-shaped cross-section of glacial valleys above the snowline, and by the V-shaped cross-section of stream-eroded valleys in their lower parts.

A kame terrace containing lacustrine silts and clays occurs on Young Creek at an elevation of 3,400 feet. Stratified and sorted outwash gravels, approximately 100 feet above the creek-bottom, occur along the V-shaped canyon below the cirque floor at the head of Young Creek and upstream from the lake deposits. The implication is that a small lake formed on the drainage when meltwater from the cirque glaciers was blocked by morainal debris and ice of the piedmont glacier that occupied the Rocky Mountain Trench. The latter glacier is called the Flathead glacier by Alden (1953, p. 115). Although the evidence is not as conclusive, topography suggests that kame terraces also occur on the Dodge Creek and Sullivan Creek drainages.
The road leading from Dodge Creek to Young Creek follows a narrow canyon that is about 100 feet in depth and presumably guided the outlet stream from the ice-dammed lake. Similar sharp north-northwest-trending canyons are cut in bed-rock along the western edge of the Rocky Mountain Trench between Dodge and Sullivan Creeks. These small canyons are believed to have been cut by ice marginal streams that connected the ice-dammed lakes and carried the voluminous meltwater southward between the mountain front and the piedmont glacier to the "Pleistocene" Kootenai River.

As the ice in the Trench retreated, the drainage began a period of local readjustment. The ice-marginal lakes were drained and subsequently their silts were dissected. In pre-glacial time Dodge Creek and Young Creek probably flowed directly eastward into the ancestral Kootenai River. Their stream channels east of the mountain front, later filled with glacial debris, are now being exhumed by their respective streams. As it leaves the mountain front, Dodge Creek turns sharply to the southeast, then flows northeast and east to the Kootenai River. Where the road crosses it, Dodge Creek is incised approximately 8 feet into unconsolidated glacial debris. Before recent capture at that point by the stream that was excavating the pre-glacial Dodge Creek channel, Dodge Creek apparently flowed southeastward in what is now an intermittent stream called Poverty Creek. The present northwest-trending portion of the Dodge Creek road parallels this drainage (see Plate 1).

In addition to the fossil lakes on east-flowing drainages, a meltwater lake formed against morainal debris on Basin Creek. Eventually the natural dam was breached and the lake was drained leaving what is now a well-
preserved lake bottom.

A series of alluvial terraces extending to approximately 300 feet above the Kootenai River are preserved at the mouth of Sutton Creek. Just above the mouth of Gold Creek, Highway No. 37 was built on a gravel-veneered bed-rock terrace some 50 feet above the present river. The Quaternary erosional history of the Kootenai River was controlled by Pleistocene glacial events occurring many miles downstream and is too complex to describe here. Alden (1953) discusses the late Cenozoic geologic history of the river in more detail.

REGIONAL GEOLOGY

Northwestern Montana is underlain by an extremely thick sequence of strata consisting essentially of quartzites, argillites and carbonates which, by definition (Wilmarth, 1925, p. 108-112), are part of the Belt series of Late Precambrian age. This sequence of sediments is generally divided into the pre-Ravalli, Ravalli, Piegan and Missoula groups in ascending order. Locally, the groups are subdivided into formations. As discussed later in this paper, regional correlation of the Belt stratigraphy is not consistent. A maximum of approximately 40,000 feet of Belt sediments are exposed in the vicinity of Libby, Montana with an unknown thickness concealed at the base and eroded at the top. With a few exceptions in which Paleozoic sediments have been trapped by faulting and preserved, post-Beltian sediments have been completely eroded. Tertiary sediments may be present in the Rocky Mountain Trench and Pleistocene glacial debris occurs in all the larger valleys. Both intrusive and extrusive igneous rocks of Late Precambrian age occur in northwestern Montana as do a few Late Mesozoic
(?), and Tertiary (?), acidic intrusions.

Structurally, northwestern Montana is characterized by numerous broad, north-northwest-trending open folds in the Belt sediments. The folds, ranging from 1 to more than 10 miles in length, are commonly cut at or near the crests of anticlines and the troughs of synclines by high-angle longitudinal faults. Many of the faults can be traced for tens of miles and commonly displace sediments 3,000 feet or more stratigraphically, and locally as much as 26,000 feet (Gibson, 1948, p. 41). A system of younger northeast- and northwest-trending transverse faults which generally offset fold axes has been mapped by Johns (1959, 1960) and others. The major folding and faulting is considered by most geologists to have occurred during the Laramide orogeny, which is of Late Cretaceous to Early Tertiary age in western Montana. Tectonic activity continued throughout Tertiary time and may be continuing sporadically at the present time.

STRATIGRAPHY

All strata exposed in the NW 15-minute Ural quadrangle are part of the Belt series and total approximately 14,000 feet in thickness. In ascending order, the pre-Ravalli, Ravalli and Piegan groups (as used in this paper) of the Belt series are recognized. Neither the base of the Prichard formation nor the top of the Shepard formation was observed in the area. Unconsolidated Quaternary sediments include alluvium and widely distributed Pleistocene glacial till.

Conformably overlying the Purcell lavas are an estimated 600 feet of quartzites, silty dolomites and argillites. Daly (1912) mapped this sequence as being equivalent to his Gateway formation of the Galton Range, a
physiographic unit on the west side of and now included in the Whitefish Range (Fig. 2). He also believed that the lower part of the Gateway was equivalent to the Shepard formation of Glacier Park. The writer concurred in this conclusion and mapped this sequence of rocks as the basal part of the Missoula group (see Plate I). This was consistent with concurrent mapping in adjacent areas. However, as the result of a more thorough research of literature subsequent to the printing of the geologic map included with this paper, the writer now believes that the Shepard formation should be placed at the top of the Piegan group, and the Missoula group as defined in the text of this paper, i.e., the Kintla formation, Striped Peak formation and overlying units, does not occur in the area. The reader is referred to the section on Regional Correlation of Belt Sediments in northwestern Montana for more explicit details.

For the most part, the Belt section is poorly exposed and outcrops are rarely continuous for appreciable distances. Therefore, information concerning lithologic units is piecemeal, but descriptions are believed to be representative. Thicknesses of rock units were obtained graphically by plotting formational boundaries on a topographic map and are approximate. Depending on the proportional amounts of quartz and argillite, the following terms are commonly used in describing rock types: quartzite, argillaceous quartzite, quartzitic argillite and argillite. In this paper, the writer uses the term quartzite to refer to a recrystallized rock containing primarily quartz grains that rarely exceed 0.2 mm in diameter. This is consistent with terminology used by most geologists, but the rock would logically be called a siltite. Color designations are based on the Rock
Color Chart of the Geological Society of America (Goddard, 1951).

In general, the Beltian environment was that of a vast, featureless plain, void of vegetation, in what probably was prevailing moist, warm climate. Run-off water from torrential rains spread sheet-like over large areas, thus enhancing erosion and transportation of sediments. These sediments, possibly originally derived from a metamorphic terrain exposed to the west and north, were laid down in the slowly subsiding Rocky Mountain geosyncline. The seas for the most part, were quite shallow and discontinuous, and shifted from area to area as their basins were filled by mud and silt. Mild regional warping probably contributed to the migration of the seas. Occasionally, in the absence of abundant mud deposition, calcareous deposits were precipitated on the sea floors. The only life known to have existed was limited to algae and bacteria.

**Pre-Ravalli Group:** The pre-Ravalli group includes the Prichard formation of which only the upper 1,500 feet (estimated) is exposed along Big Creek in the southwest corner of the map area. Prichard rocks are also exposed at the mouth of Sullivan Creek where they occur in the core of the north-northwest-trending anticline.

The Prichard formation consists of a homogeneous sequence of thin- to medium-beded, evenly bedded, grayish-black and dark- to medium-gray argillite and quartzitic argillite. A few interbedded light-gray quartzites were noted. Most of the Prichard rocks contain randomly oriented euhedral biotite porphyroblasts up to 3 mm in diameter. Many of the dark-gray quartzitic argillites are characterized by small anhedral blebs of pyrrhotite that tend to be aligned parallel to bedding; textural relationships under a petrographic
microscope indicate that the pyrrhotite is secondary and most likely recrystallized from detrital or diagenetic minerals. These rocks commonly emit a strong sulfurous odor from fresh fractures. The presence of excess sulfur in these sediments is unique and may reflect the action of anaerobic bacteria in a stagnant, shallow sea or tidal-flat environment. Euhedral porphyroblasts of ilmenite up to 1.5 cm in length are common on bedding surfaces of slaty quartzitic argillite. The Prichard formation weathers to a distinct very dark-red color and in new road cuts, rapidly weathers to a reddish-brown or rust color. This characteristic weathering phenomenon is primarily due to the oxidation of the iron sulfides in the rocks.

At the confluence of Big Creek and Good Creek pronounced black bands in a very light-gray argillite are so uniform that one is reminded of varved clays. Similar banding is common in most Prichard rocks, but is not as striking. The argillite is spangled throughout with abundant biotite porphyroblasts, thus giving it a "salt and pepper" appearance (Pl. II, Fig. 1). In thin section the dark bands proved to be an unusually high concentration of detrital opaque minerals. The rock consists of abundant sericite and recrystallized angular quartz fragments with sparse grains of euhedral plagioclase up to 0.05 mm in diameter. The biotite is highly poikilitic and is very irregular along its outer margin (Pl. II, Fig. 2). It usually has inclusions of secondary opaque minerals, and pleochroic halos around radio-active zircons are common. A weakly pleochroic, bleached-looking biotite is also common and contrasts with the highly pleochroic, fresh-looking biotite, suggesting two separate ages of crystallization. Although not conclusive, textural relationships between the two biotites
Table I.—GENERALIZED STRATIGRAPHIC SECTION OF BELT STRATA

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>General Lithology</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piegan Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper grayish-green laminated argillite and silty dolomite. Top eroded. Basal pale-green indurated sandstone with graded bedding, 150 feet thick.</td>
<td>600±</td>
</tr>
<tr>
<td></td>
<td><strong>unconformity</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper greenish-gray rhyolite (?) overlying 75 feet of green quartzitic argillite, Lower greenish-black basalt, locally porphyroclitic and amygdaloidal.</td>
<td>600±</td>
</tr>
<tr>
<td></td>
<td>Upper greenish-gray siliceous argillite and argillaceous quartzite and quartzite unit, 2,400± feet thick. Middle blue-gray silty limestone and dolomite unit, 3,200± feet thick. Lower grayish-green argillite unit, locally calcareous, 2,000± feet thick.</td>
<td>7,600±</td>
</tr>
<tr>
<td>Ravalli Group</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light-gray quartzite with &quot;hieroglyphic&quot; structures. Thin-bedded, mud-cracked, dark- to medium-gray argillite and quartzitic argillite. Massive greenish-gray argillaceous quartzite with secondary biotite and magnetite.</td>
<td>4,500±</td>
</tr>
<tr>
<td>Pre-Ravalli</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thin- to medium-bedded, evenly bedded, grayish-black and medium-gray argillite and quartzitic argillite, minor limestone beds, commonly contains biotite porphyroblasts. Evenly bedded, interbedded light-gray quartzite and medium-gray argillaceous quartzite. Commonly contains biotite, chloritoid and garnet porphyroblasts (exposed near Northwest Peak).</td>
<td>1,500±</td>
</tr>
</tbody>
</table>
tend to support this hypothesis.

The contact between the Prichard formation and the overlying Ravalli group is gradational through a zone 500 to 600 feet thick and has been placed between interbedded predominantly dark- to medium-gray quartzitic argillites and quartzites, and predominantly grayish-green argillaceous quartzites. Locally, poorly developed mud cracks were noted in this interval. It is noteworthy that interbedded medium-gray limestones occur just below the Prichard-Ravalli contact in a road cut on the Boulder Creek road immediately south of Sullivan Creek. It is believed that this limestone represents a westward wedge-edge of the Altyn limestone which interfingers with the Prichard formation.

Late in the field season the writer had an opportunity to study the Prichard formation in the core of the Sylvanite anticline located in the northwestern part of the Yaak River quadrangle. Strata exposed in the vicinity of Northwest Peak (Fig. 2) and Rock Candy Mountain are several thousand feet below the Prichard-Ravalli contact. The rock type is generally a distinct lighter gray color than the upper Prichard rocks and is somewhat more quartzitic. Thick-bedded, light-gray quartzites interbedded with thick units of thin-bedded, medium-gray argillaceous quartzites are common. Some rocks resemble a very fine-grained muscovite schist, although original sedimentary structures are well preserved. Evenly bedded, alternately light- and dark-gray argillaceous quartzite beds ranging from 1 to 12 inches thick commonly contain small red garnet dodecahedral porphyroblasts in addition to the usual biotite. A few euhedral porphyroblasts of garnet up to 5 mm in diameter were noted and one rock cleaved parallel to bedding
contained several garnets up to 2 cm in diameter in a matrix of fine-grained biotite. The rocks contain abundant green porphyroblasts up to 8 mm in diameter (Pl. III, Fig. 1), which in thin section proved to be chloritoid. In the more indurated rocks, discontinuous whitish bands parallel to bedding have the appearance of strongly recrystallized quartz fragments. These bands usually include anhedral blebs of pink garnet.

Under the microscope it was noted that the porphyroblasts are contained in a matrix of sericite and recrystallized quartz grains up to 0.05 mm in diameter. Sparse euhedral grains of recrystallized albite were noted. Locally, the quartz is recrystallized by pressure solution processes to interlocking, poikilitic metacrysts up to 0.2 mm in diameter. Detrital and secondary opaque minerals and secondary muscovite are not uncommon.

Most of the mica porphyroblasts are poikilitic and contain numerous inclusions of opaque minerals and detrital zircons which are surrounded by strong pleochroic halos. The radio-active dating of these zircons might give a maximum age of the lower Belt sediments. The chloritoid contains sporadic inclusions of biotite. As suggested previously, the biotite appears to be of two ages. In some rocks the later biotite has a persistent preferred orientation at an angle of approximately 70° to bedding. The garnets are also very poikilitic and are euhedral to anhedral in crystal form. The anhedral garnets exhibit an irregular or sutured margin and clearly have advanced into the quartz grains of the matrix. Inclusions of micas and needles of ilmenite were noted, but are not common.

Textural relationships between minerals suggest the following generalized early to late order of crystallization of the porphyroblasts:
secondary opaque minerals—both biotites—chloritoid—garnet.

Recrystallization of the quartz grains was early and probably continued throughout the recrystallization process. With few exceptions, sharp-line contacts occur between the prophyroblasts, i.e., one mineral does not gradually replace another.

Several concretion-like masses of strongly recrystallized sediments were noted. Nearly all the concretions contain a biotite-chloritoid core rimmed by a distinct bleached, white recrystallized quartzite. A few amphibole and garnet porphyroblasts are also present in the core. The concretions appear to have been formed by leaching of the rock and inward migration of solutions with subsequent centralized recrystallization of new minerals.

Ravalli Group: The Ravalli group is exposed extensively in the southern half, and as far north as Young Creek on the eastern edge of the map area. Although generally thin-bedded, it weathers to large joint-bounded blocks and forms the bold, massive ledges seen along the Kootenai River from Big Creek to the vicinity of Rexford, Montana. Ravalli strata average 4,500 feet in thickness.

Although stratigraphic relationships within the Ravalli group are not clear because of poor exposures, three vague lithologic units seem to exist. The basal unit consists of a greenish-gray argillaceous quartzite spangled with biotite porphyroblasts and a medium- to light-gray, magnetite-bearing quartzite, both of which weather to distinct pale-green surfaces. The middle unit consists of thin- to medium-bedded, medium dark-gray to medium-gray argillite, quartzitic argillite, and argillaceous quartzite
that generally contains perfect octahedra of magnetite and coarse biotite. This unit is characterized by numerous large, well-developed mud cracks, and was probably deposited in a mud-flat or flood plain environment that was periodically wet and dried. The upper unit consists of medium- to thick-bedded and massive light-gray to white quartzite that commonly exhibits distinct narrow purple bands, some of which outline well-developed cross-bedding and channeling. Many of the bands are so distorted and irregular that they are descriptively called "hieroglyphic" structure (Pl. III, Fig. 2). In thin section there appears to be a slight concentration of opaque minerals along the bands. In view of the fact that the orientation of many of the bands is completely unrelated to sedimentary structures, i.e., they cut cross-bedding, etc., the conclusion is that the coloration or bands are essentially the result of solutions migrating along the more permeable zones in the rock. The cross-bedding, channeling and general absence of mud cracks in upper Ravalli sediments suggest deposition in a marginal massive environment. Magnetite octahedra do not appear to be as abundant in this unit as compared to the lower strata.

Along the eastern boundary of the area, some significant changes in lithology were observed. The basal greenish-gray argillaceous quartzite has changed almost entirely to a medium- to thick-bedded, medium- to light-gray quartzite and argillaceous quartzite. The middle unit has thickened at the expense of the upper unit and consists of massive weathering, but very thin-bedded, very commonly mud-cracked, medium-gray argillite containing abundant octahedra of magnetite. A few banded pale-green, argillaceous quartzites are interbedded in this interval. The upper light-gray, cross-
bedded and "hieroglyphic" quartzites are interbedded with medium-gray argillites similar to those of the middle unit and may be diminishing in thickness to the east. Along the Dodge Creek road the upper unit is partially represented by dusky and pale-green quartzites and argillaceous quartzites. As exposed along Young Creek, the upper unit of the Ravalli consists of a thin- to medium-bedded light greenish-gray argillaceous quartzite with interbedded buff-colored coarse-grained sandstone. A few ripple marks, flow casts and bulbous forms of unknown origin occur in this interval. Sparse flakes of specular hematite were noted on bedding surfaces.

The composition of these rocks as seen under the microscope is predominantly quartz with varying amounts of sericite depending on their original argillaceous content. The quartz is recrystallized from grains averaging 0.1 mm in diameter to an intricate mosaic or sutured texture. A few grains of recrystallized plagioclase feldspar (probably sodic in composition) and rare orthoclase and microcline are present. Other minerals include magnetite, biotite, sparse calcite and rare chloritoid, all of which are secondary. A few crystals of magnetite contain inclusions of quartz and zircon (?). A biotite-spangled specimen of quartzitic argillite that was collected on Sutton Creek from strata low in the Ravalli section contained an unusually high amount of detrital zircon and apatite.

The contact between the overlying basal green argillites of the Piegan group and the cross-bedded and "hieroglyphic" light-gray quartzite of the Ravalli group is gradational, but distinct, and little difficulty was experienced in locating it in the field. The contact is well exposed just under the crest of Webb Mountain.
Piegan Group: The Piegan group includes the Wallace formation of the Libby area and can be subdivided into three distinct mappable lithologic units, i.e., a lower grayish-green argillite, a middle blue-gray limestone and an upper greenish-gray quartzite. The Wallace formation occupies the trough of the large syncline traversing the central and northwest portions of the map area, and is approximately 7,600 feet thick. Mud cracks are noticeably less abundant in the Piegan than the underlying Ravalli.

The lower unit is well exposed in road cuts along the Boulder Creek road and subsidiary roads, and is 2,000 feet thick. It is a homogeneous, locally calcareous, thin-bedded, grayish-green argillite. Rocks at the base of this interval exposed on the Dodge Creek road are somewhat siliceous. A 100-foot thick sequence of thin-bedded, mud-cracked, medium-gray argillite and quartzitic argillite occurs about 100 feet above the Ravalli-Piegan contact. Cubes of pyrite, and limonite pseudomorphs after pyrite up to 4 cm in width were noted. Outcrops weather to a pale green surface. Under the microscope the rock consists entirely of a very fine-grained sericite in a recrystallized siliceous matrix. Bands of an anhedral, shredded, fine-grained detrital (?) green biotite in a slightly coarser-grained quartz mosaic probably represent the darker bands of argillite seen in hand specimens. Individual quartz grains do not exceed 0.05 mm in diameter.

Where it is calcareous, the argillite is characterized by elliptical, worm-like, whitish-colored pure calcite segregations aligned parallel to bedding. The segregation range up to 3 inches in diameter. As seen in cross-section, the thin laminae of sediments often split and are draped around the calcite segregation, and come together again on the opposite side. In
Figure 1. Evenly bedded argillite from upper Prichard formation exposed along Big Creek road. Dark bands contain detrital opaque minerals. Black blebs are biotite porphyroblasts.

Figure 2. Photomicrograph of poikilitic biotite porphyroblasts with inclusions of quartz. Dark bands are detrital opaque minerals. Specimen from upper Prichard formation. Plane light.
Figure 1. Evenly bedded argillaceous quartzite from lower Prichard formation exposed south of Northwest Peak. Dark-colored blebs are chloritoid porphyroblasts.

Figure 2. Typical "hieroglyphic" structure in quartzite from upper Ravalli group in road cut along Boulder Creek road.
Figure 1. Calcite segregations in green argillite from lower unit of the Piegan group. Shows argillite laminae outlining the larger segregation.

Figure 2. Weathered surface of lower argillite unit in the Piegan group formed by leaching of calcite segregations. Exposed along Boulder-Sullivan Creek cut-off road.
Figure 1. Molar-tooth structure on weathered surface of the limestone unit in the Piegan group along road 1 mile south of Red Mountain.

Figure 2. Photomicrograph of Shepard sandstone showing grains of basalt containing plagioclase microlites. Dark spots are magnetite. Plane light.
less well-developed specimens, the laminae of sediments can be traced through the segregations (Pl. IV, Fig. 1). In thin section the segregations consist of recrystallized calcite that is much coarser than the surrounding sediments. These calcite segregations are probably diagenetic in origin. The differential weathering of the calcite segregations and the argillite forms a characteristic deeply pitted weathered surface seen in no other lithologic unit (Pl. IV, Fig. 2).

The middle unit consists of thin- to medium-bedded light bluish-gray silty limestone and dolomitic limestone that weathers to a characteristic pale yellowish-orange color on most exposed surfaces. Invariably the soil overlying this unit has a persistent orangish color. Banding due to a slight variation in colors in the limestone is distinct. Pyrite cubes are common and oolites were noted near the top of the unit. Under the microscope the limestone is composed of a granular primary carbonate with scattered clastic quartz fragments and hematite. A partial chemical analysis of a specimen of limestone is included under Economic Geology of this report. This limestone unit is approximately 3,200 feet thick and is equivalent to the Siyeh formation of Glacier Park as restricted by Ross (see Regional Correlation of Belt Sediments in northwestern Montana, this paper).

On weathered surfaces the limestone commonly exhibits what is generally called molar-tooth structure by geologists describing this unit (Pl. V, Fig. 1). These particular structures are not the typical organically formed molar-tooth structure, but look more like a breccia in which the more resistant silicic limestone stands out in relief due to differential
weathering of carbonates. Indeed, on fresh fracture, the rock displays a miniature vein-like pattern which implies that it had been crushed and re-cemented by secondary calcite. Study of thin sections confirms this conclusion, although some recrystallization of the limestone has occurred along the fractures. Some calcite fillings clearly cut across earlier fillings, suggesting the possibility of more than one period of deformation and cementation.

The upper unit, approximately 2,400 feet thick, consists of a homogeneous sequence of thin- to medium-bedded, greenish-gray to light-gray siliceous argillites, argillaceous quartzites and quartzites. This unit is overlain by the Purcell lavas. Two 8-foot thick limestone beds are interbedded with the quartzites a few hundred feet below the lavas. Outcrops generally weather to platy units 1/4 to 4 inches thick and are greenish-gray in color. Locally, flow casts, mud cracks, rain-drop impressions, pyrite cubes, and octahedra of magnetite were noted. Many of the pyrite crystals are encased in secondary chlorite.

In general the lower Piegan sediments reflect a gradual change from a marginal marine environment of upper Ravalli deposition to that of comparatively clean seas in which limestone and dolomite were deposited. Flow casts, mud cracks, and rain-drop impressions in upper Piegan sediments imply a return of very shallow water and tidal-flat conditions.

**Shepard Formation:** The Shepard formation, here included as the upper part of the Piegan group, is exposed on the east-trending ridge just north of Caribou Creek and is an estimated 600 feet in thickness. A thicker section may be exposed north of the border. The formation immediately
overlies the Purcell lavas, and its basal 150 feet consists of thin- to
medium-bedded, but massive weathering, pale-green indurated sandstones,
locally separated by thin argillite partings. Graded bedding is prominent
and the rock greatly resembles a re-worked graywacke. The sandstone grade
vertically into light-gray silty dolomite containing laminae of argillite,
which in turn grades into greenish-gray magnetite-bearing quartzitic
argillites and wavy-laminated argillites. Pyrite cubes and salt casts are
present and peculiar structures that may be annelid trails were noted in the
upper argillites.

Thin sections cut from sandstones collected just above the Purcell
lavas contain well-rounded to sub-rounded quartz and abundant basalt grains
up to 2 mm in diameter in a matrix of sericite, chlorite and recrystallized
quartz. Leucoxene, needles of rutile and octahedra of magnetite are acces-
sory minerals. Plagioclase microlites are clearly distinguishable in the
individual grains of basalt (Pl. V, Fig. 2), which are unquestionably
derived from the underlying Purcell lavas. Rocks higher in the sandstone
sequence contain fewer grains of basalt.

Where examined by the writer, the contact between the Shepard formation
and the lavas is a flat plane, and the lavas do not exhibit structures
characteristic of the top of a normal lava flow. This and petrographic
evidence suggest that an erosional unconformity exists. It is doubtful
that this unconformity can be recognized in the absence of the lavas with-
out the aid of detailed petrographic studies and measured sections.

In contrast to the two flows in the map area, Canadian geologists
report the occurrence of several flows separated by sediments on Mount
Baker 30 miles due north of the International Boundary. A volcanic conglomerate is reported (Sommers, personal communication) between the Shepard formation and the Purcell lavas near the Canadian border just east of Roosville. Apparently regional uplift and/or a change in sea level that occurred soon after the volcanic flows were extruded, subjected the Purcell lavas to extensive erosion. This suggests a hiatus of unknown magnitude between the lavas and the Shepard formation.

Quaternary Sediments: Unconsolidated sediments recognized in the area are Pleistocene glacial deposits, stream gravels, and alluvium. In the reconnaissance field mapping, no attempt was made to map the Quaternary sediments in detail.

The glacial deposits are of two types: stratified lacustrine silts and clays, and heterogeneous till. Lacustrine deposits are exposed in a kame terrace on Young Creek and on a drained lake bottom on Basin Creek. These deposits are characterized by buff-colored, horizontally stratified, interbedded laminae of silt and clay. Some small pebbles are locally included. They are grouped with Quaternary gravels on the geologic map.

Two ages of glacial till are clearly discernable. Scattered, thin patches of the older ground moraine remain in secluded pockets and are best seen along the high ridges south of Boulder Creek. The older moraine can be recognized by the occurrence of rounded Paleozoic sedimentary and Mesozoic igneous erratics, which apparently were derived from Canada, in a matrix of silt and clay. The deposits occur as high as 6,000 feet in elevation and usually overlie striated bed-rock. The younger till occupies nearly all the higher portions of stream valleys, in places covering low
ridges, and is generally quite thick. It is mapped as glacial till only
where it exceeds an estimated 40 to 50 feet in thickness. This hetero-
genous till consists of large angular blocks of locally derived Belt
sediments in a matrix of silt and clay. This material is the morainal
debris left by small valley glaciers which remained after the Cordilleran
ice sheet retreated from the area.

Sub-rounded and rounded stream cobbles and boulder gravels containing
Belt rocks occur along Big Creek, Good Creek and Dodge Creek. Several
gravel terraces occur along the Kootenai River. These deposits are probably
reworked glacial till. Extensive recent alluvium is limited to the present
flood plain of the Kootenai River.

A small travertine deposit occurs on Young Creek in sec. 13, T. 37 N.,
R. 29 W. The deposit lies on the lacustrian silts, and talus slopes are
locally cemented by caliche. The hot spring activity is probably post-
glaciation in age and may be quite young. Cold water springs still exist
at this locality.

REGIONAL CORRELATION OF BELT SEDIMENTS IN NORTHWESTERN MONTANA

Most of the area underlain by the Belt series has been studied only
through large scale regional reconnaissance surveys. Consequently, there
is considerable difference of opinion concerning the use of nomenclature and
correlation of stratigraphic units. Although new nomenclature is not pro-
posed for recognizable lithologic units in the following discussion, a
comparison of existing nomenclature for recognizable stratigraphic units
in northwestern Montana and Canada is presented. For purposes of discussion,
the area referred to as northwestern Montana is limited to that part of
Montana west of the Rocky Mountain front and north of 48° latitude, including Glacier National Park. Nomenclature of the Purcell Range of British Columbia is included to illustrate the relationship between Canadian and American nomenclature as applied to a common sequence of sedimentary rocks.

Several geologists have made important contributions toward the understanding of the stratigraphy of the Belt series of northwestern Montana. In the early 1900's Calkins (1909) traced formational contacts and carried existing nomenclature northward from Coeur d'Alene, Idaho and adjacent areas to the International Boundary with the intention of correlating stratigraphic units with Daly (1912) who was working westward along the 49th parallel from Glacier National Park. With due respect to the many geologists who have worked in Glacier Park, Fenton and Fenton (1937) have done the most detailed stratigraphic work in that area to date. Ross (1959) has synthesized the results of earlier geologists working in the Glacier Park region and has mapped parts of the Flathead and Swan Ranges. Johns (1959) and others are currently engaged in a long range reconnaissance geological field mapping project of the Kootenai-Flathead area.

The ideas presented here are the result of local field study and a review of available literature. Three tables and an index map of northwestern Montana are included for convenience in the following discussion. Table II is a compilation of the nomenclature as used by geologists in local areas with the regional comparison implied by the writer. Tables III and IV illustrate the similarity of the lithology but differing interpretations of the stratigraphic sections as observed by the Fentons and Ross in Glacier Park and adjacent areas. These tables also show the similarity
FIGURE 2: INDEX MAP OF NORTHEASTERN MONTANA
of the Glacier Park stratigraphic section to that of the Purcell Mountains. Figure 3 is a stratigraphic cross-section designed to show the correlation of gross lithologic units in northwestern Montana.

Most geologists readily classify the Belt series into four main groups and recognize representatives of each group throughout northwestern Montana. In ascending order, these are the pre-Ravalli, Ravalli, Piegan and Missoula groups. However, as Table II illustrates, there is some ambiguity in the placement of boundaries between groups. Of these, the Piegan-Missoula boundary is the most inconsistently placed.

Pre-Ravalli Group: The pre-Ravalli group includes the Prichard formation and its Canadian counterpart, the Aldridge formation. Representatives of the pre-Ravalli group have not been recognized in Glacier National Park, although Ross (Table IV) suggests the possibility that the Altyn limestone may prove to belong in the upper part of the pre-Ravalli group. There is strong evidence supporting this belief. First, as indicated in Figure 3, the relative stratigraphic position of the Altyn limestone and the Prichard formation below the Ravalli group (as used in this paper) readily suggests a close relationship. Secondly, Daly (1912) recognized the Altyn limestone stratigraphically below Ravalli group equivalents as far west as the McDonald Range (eastern flank of the Whitefish Range). The writer has recognized minor interbeds of blue-gray argillaceous limestone in the uppermost Prichard formation exposed on the eastern edge of the Purcell Mountains. Johns (1960, p. 8) reports that similar calcareous rocks in the upper Prichard are exposed east of the Kootenai River near the boundary between the Ural and Thompson Lakes Quadrangles (Fig. 2). Limestone horizons are
not known in the overlying Ravalli group and the general conclusion is that upper beds of the Prichard formation in this area are a more clastic facies of the Altyn.

Ravalli Group: The Ravalli group is undifferentiated in the Purcell and Cabinet Mountains. Stratigraphically equivalent and lithologically similar beds are called the Creston formation in British Columbia. Daly (1912) defined the Wigwam, McDonald and Hefty formations in what is now called the Whitefish Range. In their broad aspects these formations are recognized (Shelden, this paper) along the eastern edge of the Purcell Mountains. In the Flathead and Swan Ranges, Ross (1959, p. 30) describes and maps a grayish-blue-green calcareous argillite unit that is transitional to the overlying Siyeh formation (as defined by him), and includes it as the upper member of his Grinnell argillite. For reasons discussed later, it is believed that this lithologic unit should be included in the Piegan group. As previously indicated, the Altyn limestone is here excluded from the Ravalli group.

Piegan Group: As originally defined in Glacier Park by the Fentons (1937, pp. 1890-1892), the Piegan group comprises all the strata overlying the Grinnell argillite, up to and including several hundred feet of sediments overlying the Purcell lava. In the Libby area, Johns (1959) has recently introduced the name Piegan group for a similar sequence of beds which are generally called the Wallace formation. Ross (1959, p. 33) has recently grossly restricted the Piegan group as formerly used in Glacier National Park. The term Siyeh formation or Siyeh limestone has been rather inconsistently used by geologists in northwestern Montana and
<table>
<thead>
<tr>
<th>Group</th>
<th>Formation</th>
<th>Libby Area (Gibson &amp; Johns)</th>
<th>Purcell Rge., Canada (Leech, R. B.)</th>
<th>This paper</th>
<th>49th Parallel (Daly, R. A.)</th>
<th>Glacier Park (Fenton &amp; Fenton)</th>
<th>Glacier Park &amp; Fltd. Rge. (Ross, C. P.)</th>
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</thead>
<tbody>
<tr>
<td>Libby</td>
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<td>Striped Peak</td>
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<td>Wallace</td>
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</table>

Dashed lines are tentative correlations.

* These units are recognized by Price as indicated elsewhere in this paper.

TABLE II.—COMPARISON OF NOMENCLATURE OF THE BELT SERIES IN NORTHWESTERN MONTANA
adjacent parts of Canada (Table II).

As mentioned previously in this paper, three distinct mappable lithologic units, i.e., a lower grayish-green calcareous argillite, a middle bluish-gray limestone, and an upper grayish-green quartzite and siliceous argillite, can be recognized between the Ravalli group and the base of the Purcell lava in the Purcell Mountains. Johns (1959, p. 12) recognizes the same three lithologic units in the Wallace formation west of Libby, Montana. It is also significant that Daly, in his Galton series, describes three similar lithologic units in the Whitefish Range, and called the entire sequence the Siyeh formation. His description of the Siyeh in the Whitefish Range is as follows (Daly, 1912, pp. 104-105):

Columnar Section of Siyeh Formation.

Top, conformable base of Purcell Lava.
1,200 feet.—Chiefly gray and greenish-gray, medium- to thin-bedded, siliceous, often dolomitic metargillite, weathering light brown and buff. At the top some 250 feet of the beds have a general reddish cast, owing to abundant intercalations of red-gray, ripple-marked sandstone. Between 400 feet and 700 feet from the top, several beds of light gray limestone, weathering gray to whitish occur; the thickest of these, 25 feet thick and about 600 feet from the top of the formation, was followed for several miles in the Galton range. Sun-cracks are abundant at many horizons in the metargillite.

2,000 feet.—Dark gray, argillaceous magnesian limestone or dolomite, in massive beds with typical molar-tooth structure. Occasional intercalations of metargillite. The lower part of the member is more siliceous than the average rock. Most of the beds weather brown or buff, a few weathering reddish. The individual beds vary in thickness from a fraction of an inch to two feet or more, but generally they are grouped or cemented together in massive plates three to ten feet in thickness.

600 " Rocks like those of the upper division but without red beds or gray limestone; chiefly medium-bedded to thin-bedded green and greenish-gray, highly siliceous,
sometimes dolomitic metargillite, weathering light brown and, less often, gray. Many sun-cracks and some ripple-marks occur at various horizons.

In his Lewis series, Daly (1912, p. 72) describes a similar section of his Siyeh formation in the Livingstone Range.

The Fentons' description of the sequence of beds overlying the Grinnell argillite and underlying the Purcell lava (Table III) is grossly similar to Daly's Siyeh in the Livingstone and Whitefish Ranges. In their opinion (Fenton and Fenton, 1937, p. 1893) their Collenia symmetrica zone is correlative with the lower unit and their Goathaunt member and Collenia frequens zone is correlative with the middle unit of Daly's Livingstone Range section. They sub-divide Daly's upper unit into an upper Spokane formation and a lower Granite Park member. Their Siyeh formation thereby includes the Granite Park member, the Collenia frequens zone, the Goathaunt member, and the Collenia symmetrica zone in descending order. They Siyeh and Spokane formations, the Purcell lavas and overlying Shepard formation were included in the Piegan group as originally defined by the Fentons.

In summarizing previous geologic work in Glacier Park, Ross recognized the upper two lithologic units and presumably the lower unit in the Piegan group as described in this paper and by Daly. He re-defined the Siyeh formation (Ross, 1959, p. 33) to include only the bluish-gray limestone unit and excluded argillaceous beds both at the top and bottom of the Fentons' Siyeh. In so doing, he also re-defined the Piegan group to include only his Siyeh formation, and assigned the overlying grayish-green argillites including the Purcell lava to the Missoula group and the underlying transitional
<table>
<thead>
<tr>
<th>Group</th>
<th>Formation</th>
<th>Member or zone</th>
<th>Character</th>
<th>Thickness (feet)</th>
</tr>
</thead>
<tbody>
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<td>Missoula</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Indifferentated</td>
<td>Argillite and sandstone</td>
<td>4,000.</td>
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<td></td>
<td></td>
<td>Mount Rose member</td>
<td>Mainly red argillite</td>
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<td>Roosville member</td>
<td>Argillite and argillaceous sandstone; largely greenish</td>
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<td></td>
<td>Kintla member</td>
<td>Argillite and argillaceous sandstone; dominantly bright red</td>
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<td>Sheppard</td>
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<td>Dolomite, argillaceous and siliceous, and magnesian limestone; dark gray, green, gray and brown.</td>
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<td>Spokane</td>
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<td></td>
<td></td>
<td>Granite Park member</td>
<td>Magnesian limestone, oolite, argillite, and quartzite; gray, greenish-gray, brown.</td>
<td>100-1000.</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Colonies of <em>Collenia wilkinsii</em> abundant.</td>
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<tr>
<td></td>
<td></td>
<td><em>Collenia frequens</em></td>
<td>Limestone, dark gray, in biostromes consisting mainly of <em>Collenia frequens</em> and <em>Collenia vertiformis</em> with thin beds of limestone and dolomite.</td>
<td>100-150.</td>
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<td></td>
<td></td>
<td>Southant member</td>
<td>Limestone, dolomite, and subordinate oolite, dolomitic sandstone, and argillite; prevailing dark gray, <em>Collenia wilkinsii</em> abundant.</td>
<td>2,000-3,200.</td>
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<td></td>
<td></td>
<td><em>Collenia symmetrica</em></td>
<td>Limestone, dolomite, and subordinate oolite, dolomitic sandstone, and argillite; prevailing dark gray, <em>Collenia wilkinsii</em> abundant.</td>
<td>500-900.</td>
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<td>Piegan</td>
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<td>Granite Park member</td>
<td>Magnesian limestone, oolite, argillite, and quartzite; gray, greenish-gray, brown.</td>
<td>200-1000.</td>
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<td></td>
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<td></td>
<td>Colonies of <em>Collenia wilkinsii</em> abundant.</td>
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<td></td>
<td><em>Collenia frequens</em></td>
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<td>granite Park member</td>
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<td>200-1000.</td>
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<td>Waterton</td>
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<td>Granite Park member</td>
<td>Magnesian limestone, dolomite, quartzite and intermediate rocks; blue gray, brown, and dark brownish red.</td>
<td>700-1000.</td>
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<td>Allwyn</td>
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<tr>
<td>Scenic Point member</td>
<td>Argillite, sandstone, conglomerate, mud breccia; green, purplish, buff, brown, gray, brownish-red.</td>
<td>200-700.</td>
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<tr>
<td>Appelkany</td>
<td></td>
<td>Argillite member</td>
<td>Argillite gray, green, silt-brown, and rusty-gray interbedded with greenish, white, and pink quartzite.</td>
<td>2,000-2,200.</td>
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<td></td>
<td></td>
<td>Simplex member</td>
<td>Argillite and quartzite interbedded with buff to greenish siliceous dolomite and dolomitic sandstone.</td>
<td>300-400.</td>
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<td>Carthew</td>
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<td>700-1000.</td>
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<tr>
<td>Hell Roaring member</td>
<td>Dolomite and dolomitic limestone; variably siliceous; blue gray and greenish gray; weathered buff. Contains <em>Collenia albertensis</em>.</td>
<td>1,000-1,300.</td>
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<tr>
<td>Waterton member</td>
<td>Dolomite, dark-gray and reddish, weathered gray, reddish brown, and buff.</td>
<td>200 with base not visible.</td>
<td>200-700.</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE III.--THE HOLE SERIES IN GLACIER PARK ACCORDING TO FENTON AND FENTON (from Ross, 1956, p. 10)
<table>
<thead>
<tr>
<th>Group</th>
<th>Formation or similar subdivision</th>
<th>Notes</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missoula</td>
<td>Grayish-green argillite</td>
<td>Top unit in several localities, but mapped only on Chair Mountain. Commonly absent.</td>
<td>Several hundred ft.</td>
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<tr>
<td></td>
<td>Main body</td>
<td>The principal map unit of the Missoula group. Includes all beds throughout the group not otherwise designated. Within the body subordinate units have been distinguished locally and others will be when further work is done. Consists mainly of red-purple and green argillite, in part calcareous. Includes limestone of varying purity, subordinate quartzite, and some conglomerate. Includes the Kintla argillite and parts of the Shepard formation of previous workers, also the &quot;Spokane&quot; of the Fentons. Contains stromatolite zones, one of which has been mapped as the Conophyton zone 2.</td>
<td>Over 5,000 ft., where not deeply eroded. In Flathead region may be as much as 20,000 ft.</td>
</tr>
<tr>
<td></td>
<td>Pale-pink quartzite</td>
<td>Mapped only near Union Peak, but small masses of similar relatively pure quartzite are present in several places in upper part of group.</td>
<td>Few hundred ft.</td>
</tr>
<tr>
<td></td>
<td>Limestone lenses</td>
<td>Intercalated in the main body. Only the larger and more definite masses are mapped. Similar to the Siyeh limestone lithologically but include a larger proportion of argillite beds. Stromatolites present.</td>
<td>From a few hundred to over 2,000 ft.</td>
</tr>
<tr>
<td></td>
<td>Shepard formation</td>
<td>Quartzite, calcareous quartzite, and dolomite with subordinate argillite. Includes the yellow-weathering beds rich in carbonate that overlie the Purcell basalt. One or more stromatolite zones.</td>
<td>400 ft.</td>
</tr>
<tr>
<td></td>
<td>Purcell basalt</td>
<td>Dark-greenish and purplish lava, much altered but originally basaltic. In the park the principal flows are at or somewhat above the top of the Siyeh limestone and below the Shepard formation.</td>
<td>Up to 200 ft.</td>
</tr>
<tr>
<td></td>
<td>Greenish calcareous argillite</td>
<td>Discontinuous basal unit grading into Siyeh limestone. Not mapped separately in northern part of the park, partly because basal beds there are more diversified lithologically.</td>
<td>Up to several hundred ft.</td>
</tr>
<tr>
<td>Piegan</td>
<td>Siyeh limestone</td>
<td>Limestone, partly magnesian and locally argillaceous, locally oolitic. &quot;Molar tooth&quot; markings are common. Dark bluish-gray on fresh fracture and yellowish-brown on weathered surfaces. Contains several stromatolite zones, one of which, the Conophyton zone 1, is mapped wherever recognized. Argillaceous beds at the top are here excluded and regarded as part of Missoula group.</td>
<td>1,000-5,000 ft. May be greater locally.</td>
</tr>
<tr>
<td></td>
<td>Grinnell argillite with a member consisting of grayish-blue-green calcareous argillite locally distinguished.</td>
<td>The grayish-blue-green argillite is a discontinuous gradational zone at the top of the unit, mapped only in the Flathead region. The main part of the formation contains red-purple, red, and green siliceous argillite, locally calcareous, with some light-colored quartzite.</td>
<td>1,000-4,000 ft. Probably near 3,000 ft. in most places.</td>
</tr>
<tr>
<td></td>
<td>Appekunny argillite</td>
<td>Dark-gray and greenish siliceous argillite, locally calcareous with quartzite prominent locally. Subordinate reddish beds in places.</td>
<td>2,000-5,000 ft.</td>
</tr>
<tr>
<td></td>
<td>Altyn limestone (Assigned to the Ravalli group provisionally. May prove to be pre-Ravalli.)</td>
<td>Dark, somewhat impure magnesian limestone and dolomite that weathers a distinctive grayish-orange. Contains stromatolite zones.</td>
<td>2,000 ft. with the base not exposed.</td>
</tr>
</tbody>
</table>

Table IV.—The belt series in Glacier Park and the Flathead Region according to Ross (1959, p. 19)
calcareous green argillites to the Grinnell argillite (Tables II and IV).

In describing the Grinnell formation in the Flathead and Swan Ranges, Ross recognizes and maps an upper grayish-blue-green calcareous argillite and states (1959, p. 30):

The uppermost member of the Grinnell argillite commonly consists of grayish-blue-green calcareous argillite and argillaceous limestone, constituting a transition zone below the Siyeh limestone to the Piegan group. This member contains a few red-purple beds, and the unit below it contains some green beds. Nevertheless, the distinction is sufficiently definite so that the transition zone at the top of the Grinnell has been shown on plate 2. Conceivably this transition zone, or some part of it, corresponds to the "Collenia symmetrica zone," which the Fentons (1937, p. 1894) define as the "upper phase of the transition between the argillitic and arenaceous Grinnell to the dolomitic and limy Siyeh" and place at the base of the Siyeh limestone as defined by them. On that basis the uppermost member of the Grinnell as mapped on plate 2 would become the basal unit of the Siyeh limestone.

He also remarks (1959, p. 31):

During the present investigation the Grinnell argillite was studied more closely in the southern part of Glacier National Park than in the area north of latitude 48° 40'. Where examined, the 3 sub-divisions noted in the Swan Range are probably present, but the distinctions between the lower 2 are inconspicuous. The transition zone at the top is certainly present in most localities but, where seen, is less conspicuous than in the Swan Range. This may be due to absence of prominent exposures of the unit along the lines of traverse rather than to any fundamental stratigraphic difference.

As Ross suggests it is conceivable, indeed probable, that this green calcareous argillite unit is correlative with the Collenia symmetrica zone of the Fentons which, in turn, is recognized as a lithologic unit overlying the Rafalli group (as used in this paper) as far west as the Whitefish Range by Daly, and in the Purcell Mountains by the writer. A similar lithologic unit overlying the Rafalli group is recognized by Johns (1959, p. 12) in the vicinity of Libby, Montana. In view of the fact that this argilla-
ceous unit is recognizable over a large area and is lithologically more similar to the Siyeh formation than to the Ravalli group, this writer proposes that the green calcareous argillite be given formational rank and be included at the base of the Piegan group as originally suggested by the Fentons. Ross' restriction of the name Siyeh formation to the middle blue-gray limestone unit, which is widespread as a distinct mappable unit throughout northwestern Montana, is logical in this writer's opinion (Fig. 2). With the establishment of a consistent upper contact between the Missoula and Piegan groups as discussed below, the upper greenish-gray argillaceous unit can be recognized throughout most of northwestern Montana and deserves formational rank in the Piegan group.

Canadian geologists recognize similar lithologic units between the Purcell lava and the Creston formation in the Purcell Range of British Columbia. The lower two lithologic units are called the Kitchener formation which is grossly equivalent to the Fentons' Siyeh formation (excluding the Granite Park member). The upper lithologic unit is called the Siyeh formation and is equivalent to the green argillite and argillaceous quartzite unit underlying the Purcell lavas in Glacier Park and the Purcell Mountains of Montana. Recent Canadian geologists (Leech, 1960, Map 11-1960) have suggested that their Siyeh formation should also include most of the Kitchener formation, i.e., the blue-gray limestone unit, or Siyeh (restricted) of Ross.

**Piegan-Missoula Contact:** Ambiguous placement of the upper contact of the Piegan group with the overlying Missoula group can be attributed to the lack of detailed geologic mapping in the Belt section of northwestern
Figure 3: Stratigraphic cross-section of the Belt series of northwestern Montana showing major lithologic units.
Montana. The comparison of nomenclature used for strata above the Purcell lavas as shown in Table II is an interpretation based on limited published and unpublished data. Although the relations are believed to be correct in a broad sense, the correlations may be subject to change with accumulation of additional information. It is important, however, to establish a consistent and recognizable stratigraphic horizon as the base of the Missoula group. In this respect the following discussion will be limited to the Kintla, Shepard, Gateway and Striped Peak formations with brief comments concerning other formations.

In describing the sequence of rocks overlying the Purcell lavas in the Whitefish Range (Galton series, Table II), Daly (1912) proposed the names Gateway, Phillips and Roosville formations in ascending order. He indicated that the lower part of the Gateway was equivalent to the Shepard formation as defined in Glacier National Park because of the similarity in lithology and the proximity to the Purcell lavas. Overlying the Shepard in Glacier Park is the Kintla formation which has recently been recognized as far west as Rexford, Montana by Sommers (personal communication). During the course of recent geologic mapping of that part of British Columbia north of Glacier National Park and the Whitefish Range, R. Price of the Canadian Geological Survey recognized several lithologic units above the Purcell lavas. Though it may be subject to revision, his description of these units and his interpretation of their relationship to Daly's Galton series is as follows (unpublished progress reports, Kootenai-Flathead project):
Kintla D, equivalent to Roosville

Kintla C, equivalent to Phillips

Kintla B, equivalent to upper Gateway

Kintla A, equivalent to basal Gateway

Shepard formation, equivalent to basal Missoula group

Purcell lava, at base of Missoula group

Mostly green argillite, some dolomitic and sandy argillite with some banding. 0-350 feet thick

Pink and red quartzite, some minor argillaceous sandstone. 700 feet thick

Green argillite and dolomitic argillite, considerable banding 800-1,000 feet thick

Purple-gray sandstone and argillaceous sandstone, some purple argillite partings. 1,000 feet thick

Some gray-green argillite, dolomitic sandstone, and oolitic dolomite. 700 feet thick

Two flows of dark-gray to green-gray andesite with flow and pillow structure. 300-500 feet thick

Thus it can be demonstrated that the top of the Piegan group as defined by the Fentons, i.e., the top of the Shepard formation, can be carried westward to the vicinity of Rexford, Montana. It is not possible to trace the Shepard formation as a lithologic unit southwestward into the Libby area because of Laramide folding and faulting and subsequent removal of strata by erosion in the intervening area.

Gibson (1948, p. 17) gives the following generalized section of the Striped Peak formation as exposed in the Cabinet Range with addition of correlatives by the writer:
In comparing the stratigraphic sections, it is apparent that the Striped Peak formation, which overlies the Piegan group (equivalent to the Wallace formation) of the Libby area, is correspondingly thick and lithologically similar to the Kintla A, B and C units described by Price. Therefore, they are tentatively considered to be equivalent. The overlying Libby, Roosville and Kintla D formations are quite similar in their lithologic characteristics and are also tentatively considered equivalent (Table II).

In view of the preceding discussion, the Shepard formation would be equivalent to undefined beds of the upper Wallace formation in the Libby area as well as to the basal Gateway of Leech and Daly. Indeed, in the absence of the Purcell lavas, it would be impossible to distinguish the Shepard formation from the underlying upper greenish-gray argillite and argillaceous quartzite unit of the Wallace formation in the NW 15-minute Ural quadrangle. Therefore, in this writer's opinion the upper contact of the Piegan group as used in the Libby area by Johns is consistent with the original definition by the Fentons. It is hereby suggested that the
Shepard formation be redefined to include the grayish-green argillite and argillaceous quartzite unit between the Siyeh formation (restricted) and the Striped Peak-Kintla equivalents (Fig. 3). All lithologic units above the Shepard formation and its equivalents, i.e., the Kintla and its equivalents, as well as younger strata, would be placed in the Missoula group according to this usage (Table II).

The Purcell lavas make an excellent time-stratigraphic horizon wherever they are present and exposed, and some geologists consider the top of them as the base of the Missoula group. However, the lavas are exposed only in the northern parts of Glacier Park, the Whitefish Range and the Purcell Mountains and are not known to extend more than about 10 miles south of the International Boundary. In this respect the Purcell lavas are limited in their potential as a means of regional correlation in Montana.

Ross (1959) encountered some difficulty in tracing Shepard and Kintla equivalents southward from Glacier Park into the Flathead and Swan Ranges in the absence of the Purcell lavas. For this reason and the fact that beds above the massive blue-gray limestone are more "clastic" in nature, he placed the base of the Missoula at the top of the Siyeh formation as defined by him (Table II). This contact may be the most easily recognized in the field in the absence of other correlatable horizons higher in the section. However, considering their widespread occurrence to the west, it is conceivable that Kintla equivalents in the area will be recognized with more detailed mapping. In consideration of the evidence supporting the original use of the name Missoula group by the Fentons in northwestern Montana, Ross' usage is believed somewhat extreme. In reality, even the use
of the term Missoula group (as used in this paper) is arbitrary since direct correlations northward from the type area near Missoula, Montana have not been made to date. However, in view of the fact that mappable lithologic units do exist throughout northwestern Montana, every effort should be made to be consistent in the use of existing nomenclature.

In conclusion, it is recognized that the Altyn limestone is equivalent to the upper Prichard beds and that both should be included in the pre-Ravalli group. The Ravalli group (undivided) is equivalent to the Creston formation of Canada and the Appekunny and Grinnell argillites, excluding the blue-green calcareous argillite unit described by Ross. The Piegan group as defined by the Fentons can be recognized throughout northwestern Montana, although during reconnaissance mapping in the Flathead and Swan Ranges, the upper contact could not be accurately mapped according to Ross. As used in this paper the Piegan group includes a lower green calcareous argillite unit, a middle blue-gray limestone unit, and an upper greenish-gray argillite and argillaceous quartzite unit, all of which are widespread in extent. Contrary to the variety of usage, the term Siyeh formation should be restricted to the middle limestone unit as suggested by Ross. The upper unit including the Purcell lavas could well be called the Shepard formation (redefined) and the lower unit is presently unnamed.

Sediments included in the Missoula group are restricted to those lying above the upper greenish-gray argillite and quartzite unit of the Piegan group (this paper), although use of the name Missoula group may eventually prove to be inconsistent with that in its type area. The suggested use of existing nomenclature for mappable lithologic units in northwestern Montana is
Illustrated in Figure 3.

IGNEOUS ROCKS

Igneous rocks exposed in the map area are limited to the Purcell sills and the Purcell lavas, both of which are of Late Precambrian age.

Purcell Lavas: Daly (1912) encountered basic extrusive rocks interbedded with belt sediments in the Purcell Range while mapping the geology along the 49th parallel and subsequently called them the Purcell lavas. The Purcell lavas are well exposed in the walls of amphitheater-like glacial cirques on either side of the main north-grending ridge in the northwestern corner of the map area where they occur in the trough of a northward-plunging syncline. These limited outcrops in the Purcell Mountains of Montana represent the southern-most extension of the widespread Purcell lavas of southeastern British Columbia. The lava-capped subsidiary ridges and Robinson Mountain owe their height and ruggedness to the resistant nature of the volcanic rocks. The Purcell lavas, which are interbedded with the upper-most strata of the Piegan group and are overlain by the Shepard formation, consist of a lower basic flow and an upper acidic flow separated by approximately 75 feet of thin-bedded greenish-gray argillites and quartzites. Locally, the two flows were differentiated because of the complexity of faulting and the paucity of outcrops.

Lower Flow: The lower flow is an estimated 450 feet thick and can be subdivided into three zones: a lower lava breccia zone, i.e., a lava containing angular fragments of sediments, a middle highly porphyritic, non-amygdaloidal lava zone, and an upper aphanitic amygdaloidal lava zone. The lava breccia zone ranges from 5 to 40 feet in thickness and is the result of
lava having flowed on soft, unconsolidated sediment, with subsequent incorporation of the sediment into the lava. Locally, blocks of consolidated, ripple-marked sediment, ranging up to several feet in diameter, have been included in the lava. The lava itself is a slightly amygdaloidal, aphanitic, pale greenish-colored rock containing lath-like dark green-black blebs. In thin section the groundmass is highly altered to sericite and chlorite, and the dark blebs proved to be a mixture of chlorite and secondary quartz which have almost completely replaced plagioclase (?) phenocrysts. The amygdules consist of quartz rimmed with chlorite. Generally, the contact between the lava and underlying strata is conformable and the unconsolidated sediments were rarely baked to a depth greater than 6 inches (Pl. VI, Fig. 1).

The middle zone averages 200 feet in thickness and consists of a massive, dark grayish-green porphyritic basalt containing lath-like plagioclase phenocrysts up to 4 cm long and 0.5 cm wide (Pl. VI, Fig. 2). The only other microscopically identifiable minerals are small octahedra of magnetite. Localized alternating bands of non-porphyritic and prophyritic lava suggest that the zone consists of several flow units. In thin section the lavas were found to be profoundly altered to a fine-grained matrix of chlorite, cryptocrystalline quartz and ilmenite surrounding the plagioclase phenocrysts. The plagioclase is highly sericitized, although a few of the less altered crystals gave maximum extinction angles of 16° as measured from the trace of albite twinning. Although Daly (1912) reports labradorite in rocks from the same locality, the composition of the less altered plagioclase, i.e., andesine, is more consistent with the high degree of alteration of
the basalt. Scattered masses of secondary ilmenite needles arranged parallel to cleavage planes in a matrix of chlorite are interpreted as being relict structures of amphibole and pyroxene (Pl. VII, Fig. 1). Blebs of penninite and green chlorite intergrowths in these rocks are also most likely the alteration products of ferro-magnesian minerals.

The upper zone of the lower flow includes numerous flow units ranging from 6 inches to several feet in thickness. The rock type is a non-porphyritic, highly amygdaloidal dark greenish-black basalt containing scattered plagioclase phenocrysts up to 0.5 cm long and sparse octahedra of magnetite. The entire sequence is approximately 200 feet thick. The lava adjacent to the contacts of each succeeding flow unit is a dusky-yellow color which grades into the characteristic greenish-black color of the basalt. As seen in thin section plagioclase phenocrysts along this contact are badly deformed and are arranged parallel to the flow unit contact in a manner implying flowage. The pronounced contrast in color may be due to rapid chilling of the lava at its upper and lower surfaces. Locally, the flow units are separated by thin beds of light-gray magnetite-bearing argillite. Many flow units are characterized by vertical pipe amygdules near the base that blend into round amygdules which in turn grade into a zone of horizontally elongated amygdules arranged in a parallel manner suggesting flowage near the surface of the flow (Pl. VII, Fig. 2). A few ropy surfaces on flow units were noted (Pl. VIII, Fig. 1). The amygdules consist of quartz with minor amounts of specular hematite, chlorite and calcite. Study of thin sections reveals that the lava is intensely altered to a mass of pale-green secondary chlorite, cryptocryst-
Figure 1. Contact between Purcell lava and underlying strata of upper Piegan group on ridge southwest of Robinson Mountain.

Figure 2. Plagioclase phenocrysts on a weathered surface of Purcell lava in the lower flow.
Figure 1. Relict structure of amphibole formed by alteration to ilmenite and chlorite. Specimen from lower Purcell lava flow. Plane light.

Figure 2. Four-foot thick flow unit in lower Purcell lava flow exposed on main ridge 1 mile north of Robinson Mountain. Shows chilled (?) contact and vertical and horizontal orientation of amygdules.
Figure 1. Ropy surface on boulder of Purcell lava in cirque south of Lake Geneva.

Figure 2. Photomicrograph of magnetite on contact between argillite and lava. Feathery opaque mineral in lava is secondary ilmenite. Plane light.
talline quartz, altered microlites of plagioclase and abundant needles of secondary ilmenite. In some flow units the plagioclase phenocrysts are somewhat coarser and exhibit a trachitic texture in thin section.

Upper flow: The paucity of outcrops prohibited a complete examination of the upper lava flow in the field and its total thickness is unknown, although it most likely does not exceed 100 feet. The lower 20 feet consists of a rhyolite or quartz latite flow and is unique in that it has no known counterpart in the Purcell lavas of other areas. The rock is a grayish-green porphyritic lava with phenocrysts of quartz up to 1 cm in diameter and plagioclase up to 4 cm in length. The plagioclase phenocrysts in hand specimen have a pronounced greenish tinge and examination of thin sections reveals their rather complete alteration to chlorite, sericite and cryptocrystalline quartz. Both the plagioclase and quartz are substantially embayed suggesting that they were somewhat out of equilibrium with the liquid lava. Potassium feldspar is present, but in subordinate amounts to plagioclase. The groundmass was probably once a glass, but is now completely devitrified to a mass of secondary chlorite, sericite and quartz with leucocene, apatite and zircon as accessory minerals. The overlying rock type is a grayish-green slightly vesicular basalt similar in appearance to the non-porphyritic basalt in the middle zone of the lower flow. The vesicles are commonly filled with quartz and brown calcite. As indicated previously, the upper contact of the flow was eroded to an unknown depth in this area before deposition of the Shepard formation.

Alteration of the Lavas: Comparison of the following chemical analyses indicates the high degree of alteration in the Purcell lavas. Column 1
is the chemical composition of a specimen of Purcell lava (porphyritic basalt in middle zone of lower flow) collected just north of Robinson Mountain by Daly (1912, p. 210). Column 2 is the average composition of a normal alkali basalt (Nockolds, 1954, p. 1021).

<table>
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<td>P₂O₅</td>
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It is readily apparent that the Purcell lava is abnormally low in silica and calcium oxide, and high in alumina and magnesium oxide. The latter is a reflection of the abundant secondary chlorite and sericite present in the lavas, and the low calcium content probably reflects the rather complete alteration of the calcic plagioclase to clay minerals. The analysis of the Purcell lavas does not lend itself to calculation of its normative mineralogy because of the intense alteration.

Textural relationships of opaque minerals can be used to interpret their petrogenesis and the alteration history of the lavas. Microscopic examination of thin sections cut normal to the contact between two successive flow units in the upper lava zone of the lower flow suggests that
deuteric alteration is responsible for their high degree of alteration. The abundant feather-like needles of ilmenite, which are clearly alteration products, are sharply truncated by the succeeding lava flow, i.e., the alteration of ferro-magnesian minerals to ilmenite, etc., was essentially complete before the next flow occurred. The hardened skin-like surface of a cooling lava flow conceivable could confine escaping gasses and residual solutions, thus enhancing deuteric alteration in the slowly cooling interior portions of the flow. Also, the sediments stratigraphically above and below the Purcell lavas are relatively unaltered, suggesting that the intense alteration was limited to the lavas during their cooling period rather than to pronounced epigenetic alteration. This does not preclude the fact that the lavas again underwent slight alteration during the mild regional metamorphism of the Belt sediments.

In contrast to the ilmenite, the magnetite octahedra are younger in relative age and their crystallization is not genetically related to the cooling of the lava flows. In view of the fact that the magnetite is also found in the thin lenses of argillite between flow units, as indicated below it cannot be regarded as a primary constituent of the lava or even a secondary constituent resulting from the deuteric alteration of the lavas. Figure 2 (Pl. VIII) shows a crystal of magnetite straddling the contact between the lava and sediment, thus indicating its age relative to both the lava and the sediment. Magnetite octahedra were also observed in argillites of the overlying Shepard formation. It is more likely that the magnetite in the lavas is genetically related to the magnetite noted in the Ravalli quartzite.
Purcell Sills: The Purcell sills exposed in the map area are limited to small metadiorite sills exposed in the northern part of the map area. The Young Creek sill was intruded into upper Ravalli sediments and consists of approximately 100 feet of aphanitic dark greenish-gray rock with no macroscopically identifiable minerals. In thin section the rock is composed essentially of highly altered plagioclase microlites in a matrix of chlorite and minor amounts of secondary quartz and ilmenite. The alteration of ferro-magnesian minerals to ilmenite and chlorite is very similar to that of the lavas. Accessory minerals include apatite and secondary calcite. The sediments in contact with the sill are baked to a hard, bleached quartzite through a distance of several feet.

Another small sill exposed in the cirque walls at the head of Caribou Creek west of Robinson Mountain has intruded strata of the upper Piegan group at a horizon approximately 300 feet below the Purcell lavas. This is an aphanitic green-gray rock with scattered plagioclase phenocrysts and resembles some of the Purcell lavas in hand specimens. It is conceivable that the magma in this sill broke through a local fissure and was extruded as a lava flow.

Metadiorite was found on talus slopes near the Big Creek Mine in the southwestern corner of the map area, but its source was not located. Hand specimens of this metadiorite are very similar to the rock type of the Young Creek sill.

STRUCTURAL GEOLOGY

The structure of the NW 15-minute Ural quadrangle is genetically related and comparable to the regional structure of northwestern Montana, and
is relatively simple in form. Its primary structural elements are a broad north-northwest-trending syncline on the west and a parallel anticline on the east. Several minor faults have been mapped. Recognition of faults in this area depends almost entirely on the apparent displacement of sediments. However, for the most part, the lithologic units of Belt strata are so homogeneous that marker horizons are essentially limited to formational boundaries, which are relatively few in number. Thus, many faults with displacements of several hundred feet may have gone unnoticed because of the lack of significant marker horizons, the paucity of outcrops, and the absence of the usual criteria that suggest the presence of a fault. Locally, intense shearing and anomalous attitudes of strata were noted, but their structural implication could not be deciphered.

**Folds:** The syncline trends N 20° W for most of the length of the map area and is approximately 8 miles wide. It is very slightly asymmetrical to the east with dips on either flank averaging 10 to 20 degrees. The fold, which dies out into slightly undulating Ravalli sediments to the south, plunges gently northward into Canada, thus exposing successively younger sediments from south to north. A complete section from upper Prichard to the Shepard formation overlying the Purcell lavas is exposed on the west flank and in the trough of the syncline. The west flank of this syncline is the common east flank of a north-northwest-trending anticline occurring just west of the map area. The Prichard formation is exposed in the core of the anticline.

The east flank of the syncline is the common flank of the north-northwest-trending northward-plunging anticline that occurs in the north-
east corner of the map area. The axial plane of this fold dips steeply to the west and its east flank dips eastward from 25 to 40 degrees. The crest of the anticline is offset by a longitudinal normal (?) fault with the downthrown block on the west. Projection of limited data suggests that the axis of the anticline is probably displaced to the east on the north side of a transverse fault paralleling Dodge Creek. Erosion has exposed the Prichard formation in the core of the fold east and south of the mouth of Sullivan Creek. The Wallace formation occurs on the northward-plunging nose of the anticline.

Faults: The high angle reverse fault mapped in the southwestern corner of the map area is the northward continuation of a large north-trending fault traced for several miles by Johns (personal communication) in the SW 15-minute Ural quadrangle. The fault zone, approximately 300 yards wide, is well exposed in the northwest-trending ridge north of Big Creek and is characterized by an apparent steep westward dip, the steep eastward dip (50 to 70 degrees) of Prichard strata, and intense vertical to steep west-dipping cleavage fracture. A small outlier of basal Ravalli sediments occurs on the crest of the ridge and appears to be in fault contact (up-thrown block on the west) with sediments of the transitional zone between the Prichard formation and the Ravalli group. Considering this stratigraphic relationship, it is doubtful that displacement on the fault at this point exceeds 500-600 feet. Numerous sharp, vertically discontinuous minor folds occur west of the fault zone, i.e., on the hanging wall, and are attributed to the compressional forces which formed the fault. In cross-section the strata in and adjacent to the fault zone are monoclinal in
form indicating that the fault may die out northward. This fault could not be traced northward because of the thick mantle of soil and glacial debris, although the linearity of the Basin Creek and Good Creek drainages suggests that the weakness zone may persist.

The longitudinal fault paralleling the anticlinal crest in the north-east corner of the map area is inferred, i.e., it was not actually observed in the field. However, there is considerable evidence for its existence:

1. A relatively abrupt change in the attitude of Ravalli strata exposed on Young Creek and Dodge Creek occurs over a short distance (Pl. 1).
2. Recent travertine deposits of hot spring origin occur on the fault trace just north of where it crosses Young Creek. Cold springs still exist at this locality.
3. The basal green argillite member of the Wallace formation appears to have been folded over the axis of the anticline, although the Wallace formation does not occur on what normally would be the east flank of the fold. Based on stratigraphic relationships alone, the inference is that a fault, downthrown on the west with considerable vertical displacement, exists (see cross-section A-A', Pl. 1).
4. Leech (1960, Map 11-1960) infers a fault along the northward projection in Canada. Normally, the fault would be expected to parallel the axis of the fold. However, the Prichard-Ravalli contact was thoroughly examined east of the map area and no fault displacement of the magnitude implied by stratigraphic relationships was found, although minor faults exist. Thus, the southward projection of this fault is arbitrarily placed. Anomalous attitudes in local hydrothermally altered (?) Ravalli strata were noted on the Boulder Creek road. Like the travertine deposit on Young Creek, these altered
sediments may be on the fault trace.

The inferred north-northwest-trending fault in the extreme northeastern corner of the map area is a projection of a fault mapped by Leech (1960, Map II-1960) and Sommers (personal communication) in adjacent areas. This fault delineates the western edge of the Rocky Mountain Trench in this area. Outcrops indicating that the middle blue-gray limestone unit of the Wallace formation is faulted against the Ravalli group were examined by the writer at a point just east of the map area on Dodge Creek. The fault is down-thrown on the east through a minimum stratigraphic distance of 2,000 feet.

The transverse northeast-trending fault that parallels Dodge Creek is mapped on evidence based largely on the abrupt change in the attitude of the Ravalli sediments exposed in cuts along the Dodge Creek road. The strata abruptly change from a persistent N 20° W strike and 35° E dip south of the fault to a persistent N 60° E strike and 10° S dip north of the fault. The outcrops nearest the fault are approximately 200 yards apart. Just east of the map area the Ravalli group on the south rests against the down-faulted blue-gray limestone unit of the Wallace formation on the north. The fault apparently dies out rapidly to the southwest as there is no discernable displacement of the Ravalli-PiegAN contact.

Several small vertical northwest-trending faults offsetting the Purcell lavas have been mapped. The maximum displacement on these faults is approximately 450 feet and occurs on the third fault north of Robinson Mountain (see Pl. 1). The faults would not have been recognized in the absence of the lavas as a marker horizon and cannot be traced over long distances.
Joints: The Belt sediments in the map area contain a complex joint system which, for the most part, is probably related to Laramide deformation. However, there is conclusive evidence that regional warping produced joints of pre-Laramide age. Pronounced concentration of hydrothermal (?) magnetite octahedra was noted on numerous joint surfaces in Ravalli sediments. These joints are clearly pre-magnetite. The magnetite is assumed to have formed during the regional static metamorphism of the Belt sediments. The unconformity at the top of the Purcell lavas certainly indicates that regional warping occurred during Beltian time, and some jointing may be related to this uplift.

ECONOMIC GEOLOGY

From an economic point of view, the NW 15-minute Ural quadrangle will be best remembered for its virgin stands of merchantable timber, although both metallic and non-metallic mineral deposits occur. The lumberman owes his livelihood to the thick mantle of glacial debris that so effectively conceals the quartz veins that the prospector is continually hunting. Perhaps the most efficient method of prospecting this area would be to inspect all the bulldozed skid trails and logging roads that have been or will be constructed. Geochemical prospecting, i.e., a systematic chemical analysis of stream water and soils, may aid the more diligent prospectors. However, considering the scant mineralization observed, there is very little to encourage methodical prospecting in the map area. Assays of rock and ore samples were furnished by the Montana Bureau of Mines and Geology.

Metallic Ore Deposits: Known ore deposits in the map area are limited to the Big Creek Mine and a few small, undeveloped quartz veins. None of
the ore deposits appear to be economical, although additional prospecting on Young Creek and on the ridge north of Caribou Creek may be worth-while.

Big Creek Mine: The Big Creek Mine consists of a 300-foot accessible adit driven on a small quartz vein in the Prichard formation. The portal of the adit is located about 150 feet above the North Fork of the Big Creek some 100 yards west of the Forest Service guard station in the southwest corner of the map area. The vein, which occupies a small fault just west of the major shear zone of the high angle reverse fault, pinches and swells from less than an inch to a maximum of 18 inches in width. For the greater part of its length the quartz vein is barren. However, where the vein thins to 1/4-3 inches wide and eventually pinches out entirely near the face of the adit, it contains appreciable amounts of galena and marcasite and minor amounts of sphalerite, pyrrhotite and native silver. A channel sample taken for 25 feet along the strike of the vein at this point ran 7.3% lead, 1.7% zinc, 0.1% copper, 5.1 ounces per ton of silver and a trace of gold. A trace of galena, pyrite and siderite was noted in a prospect pit dug on the surface exposure of the quartz vein. There is no known history of production from this property.

Miscellaneous ore deposits: Two short adits have been driven in a barren quartz vein located high on the ridge (NW 1/4 sec. 27, T. 35' N., R. 30W.) just north of the Big Creek Mine. The vein is in the strong shear zone of the north-trending high angle reverse fault and is strongly sheared by post-vein movement along the fault. Quartz found at a cabin a short distance from the vein contained a trace of gold, silver and lead.

Chalcopyrite, malachite and tenorite disseminated throughout stringers
coarse-grained sandstone interbedded with argillite in the upper horizons of the Ravalli group was noted in a cut (NW 1/4 sec. 20, T. 37N., R. 20 W., on the South Fork of Young Creek road. A grab sample ran 0.5% copper, 0.6 ounces per ton of silver and a trace of gold. The mineralization was exposed during building of the road and has been developed by a small prospect pit.

Vein quartz containing traces of galena, chalcopyrite, pyrite and native silver was noted on a skid trail on the south side of Young Creek in the SE 1/4 sec. 14, T. 37N., R. 29 W. The quartz is about 2-4 inches thick and appears to be coming from a shear zone exposed in the road cut. The actual vein was not observed. A selected sample of quartz contained 0.1% copper, 0.8% lead, 0.5 ounces per ton of silver and 0.005 ounces per ton of gold.

Several small north-trending quartz veins averaging less than 12 inches wide were noted in the Shepard formation exposed in road cuts on the north side of the east-trending ridge north of Caribou Creek (S 1/2 sec. 2, T. 37N., R. 30 W.). Mineralization is limited to traces of galena, chalcopyrite and pyrolusite. No sampled vein contained more than 1% manganese, with the average being somewhat less. A larger vein was developed by early prospectors, but all workings are now inaccessible.

Exposed at the top of the lower Purcell lava flow in the glacial cirque wall immediately west of Geneva Lake is a 6-to 10-inch thick horizon of lava and quartzitic argillite containing magnetite octahedra in such abundance that it would make low grade iron ore. A grab sample of the ore ran 14.2% FeO, 41.5% Fe₂O₃ and 0.26% TiO₂. The magnetite occurs in what may be the oxidized top of a lava flow. However, the apparent limited extent of this
horizon, and mining methods required for a commercial operation do not warrant exploitation.

Non-metallic Deposits: Non-metallic deposits investigated in the map area include quartzite, limestone and clay, none of which appear to be of commercial quality. A few light-gray to white beds of fine-grained quartzite in the upper Ravalli group contain as high as 82% silica and 1.5% iron. This silica content is not high enough to be considered a metallurgical grade, however. The more massive quartzite in upper Ravalli beds could be crushed and used as roadbed material or ballast. A representative sample of the better grade limestone collected from the bluish-gray limestone member of the Wallace formation exposed assayed 35.2% SiO$_2$, 8.8% Al$_2$O$_3$, 2.3% Fe$_2$O$_3$, 0.4% FeO, 7.0% MgO, 22.5% CaO and 23.8% CO$_2$. Silty lacustrine clay deposits along Young Creek were assayed for their alumina content, which ranged from 8.4% to 12.2%. These clays are not of commercial grade.
REFERENCES CITED


