The classification and character of the Belt series in northwestern Montana

by

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U. S. Geological Survey

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Introduction

A general paper summarizing all features of the Belt series (Precambrian) in Montana and neighboring areas is in preparation. This paper will include discussion of problems of various kinds relative to the genesis of the series and its relations with similar rocks in regions outside of Montana. For the purpose of making the data promptly available to anyone concerned with the Belt series, pertinent factual sections of the report in preparation are assembled here, leaving theoretical matters to be presented in the complete report when that is published. The present paper includes a stratigraphic classification that differs in some respects from any hitherto proposed and formal definitions of stratigraphic units. In some instances usage rather than exact, published definitions has determined the nomenclature employed. In addition, the different features that aid in recognizing the units and available information as to the lithologic character of the various units in the series are summarized. There is room for much additional work in determination of lithologic and other characteristics of the Belt series than is available at present. It is urged that all concerned in studies of these rocks concentrate on assembling as much quantitative information as possible as to composition, texture, fossils and similar features of each unit studied as circumstances may permit.

Revised classification

Foreword

The summaries already presented show the nomenclatures adopted by different students for the Belt series in Montana, with some data on names used in Idaho, Washington, and Canada. The classification presented below differs in details from any previously published. The group, rather than the formation, is taken as the essential unit in the classification. No single formation has been traced throughout western Montana. The definitions of groups offered apply primarily only to Montana but the scheme of classification could be extended to adjacent areas. These definitions are as precise and as nearly in accord with standards of stratigraphic nomenclature in present use for younger units as possible.

None of the formation names offered is original. Each is used in accord with established custom and the intent of the original authors. It has been necessary, however, to present here definitions intended to clarify and make as precise as possible the meaning attached to each of the names of major units involved in the revision of classification of the series here offered. Where previous definitions exist, they are cited. The descriptions below show past and present usage.

[redacted]

A basic concept in evolving the classification is that lateral variation is so prevalent that units of formational rank cannot be assumed to be recognizable very far from their type localities, in spite of the fact that most of them are very thick compared to formations in many other regions. The distances that particular formations have been traced vary widely, depending on their distinctiveness and on the present knowledge regarding each.

Plate 1 is a graphic representation of the concepts just outlined.

Plate 1. Fence diagrams showing stratigraphic relations of the principal units in the Belt series.

It should aid in coordinating the summaries on areas in northwestern Montana and northern Idaho presented later in this report. It is impractical to include in this diagram data on southwestern Montana and central Idaho. Present data prevent adequate correlations with the units shown on plate 1, in part because of the large distances involved. Posts are erected in plate 1 wherever stratigraphic data permit. Where districts lie close together information respecting them has had to be averaged into single posts in the diagram, and districts that include only fragments of the Belt series are omitted. Nevertheless, the wide spacing of the posts serves to emphasize the scattered character of available data. One post in Canada is shown to suggest correlations across the international boundary. The writer has no personal field acquaintance with rocks in British Columbia and feels less confidence in his Canadian correlations than the others. The names and correlations in plate 1 are those of the present report, rather than of the original author.

Most of the Belt series in Montana can be readily placed in four named groups, the Ravalli, Piegan, Missoula, and North Boulder, named in ascending order. In addition, a few formations are at present inferred to be older than the Ravalli group. As there is only one formation regarded as pre-Ravalli in each locality and mutual relations between the old units are unknown, no formal group is proposed to include them. Ultimately a fifth group will be named to include the oldest units of the Belt series unless future investigations show that none is actually older than the present Ravalli group. If a fifth group becomes desirable, one possibility would be to raise the Prichard to group rank much as has been done for the Ravalli. The Prichard formation is the thickest and most widely exposed of the pre-Ravalli units in the United States and, at least in Idaho, has subdivisions that may justify formational rank when better known. In Montana exposures of pre-Ravalli strata are scattered and mutual relations are obscure. Thus, a name for rocks of the series below the Ravalli group probably should come from Idaho, or British Columbia rather than Montana. Plate 1, in which the Prichard formation is treated much as the groups above it are, demonstrates these points.

The various correlations of the Belt series have been based largely on the assumption, expressed or implied, that certain carbonate-rich units are mutually equivalent. The units thus correlated have varied with the concepts of the different authors. The review already given shows that Walcott and Calkins assumed that the Newland, Altyn, Blackfoot, and Wallace are equivalents. In their early work the Siyeh and Helena were correlated and thought to be younger than the other carbonate units just listed. Later Walcott realized that his Blackfoot series and the Siyeh limestone are closely related. Daly thought of his Kitchener and the Siyeh, Wallace, Blackfoot, and Helena, among others, as being equivalents (table 2). The part of the eastern phase of Daly's Kitchener formation in which carbonate-rich rock predominates must be, as he thought (Daly, 1912, p. 133-135) equivalent to the Siyeh limestone. Schofield took the Siyeh limestone out of the Kitchener formation and regarded it as equivalent to the Striped Peak formation, whereas he thought the Wallace and Blackfoot were a little older. These and other variations in the use of the name Kitchener are among the reasons why correlations between stratigraphic units in Canada and those in the United States are not readily made.

Clapp and Deiss correlated the Newland limestone with the lower parts of the Siyeh and Wallace, as defined by them, and regarded the Helena limestone as equivalent to their upper Siyeh. In the present paper their idea of an upper and a lower Siyeh limestone, separated by red beds, is not followed. Instead all red beds above their lower Siyeh, plus all carbonate units interbedded therewith are placed in the Missoula group. This procedure is believed to restrict the name Siyeh essentially to the beds originally so designated by Willis. It also facilitates geological mapping by grouping together all the clastic beds that are similar lithologically. The carbonate beds above the Siyeh limestone as here defined are regarded as relatively discontinuous, local features. Attempts to correlate assemblages of these beds over long distances may lead to error. The general scheme of classification here proposed can be grasped by a glance at the correlation chart (table 1).

The present classification does not aid in correlating formations in and close to central Idaho with other parts of the series. Conceivably it will prove desirable to set up one or more groups to include these. More probably future work will permit correlation with existing groups. Suggestions as to correlations of formations have been offered (Umpleby, 1913, p. 30-32, Ross, 1934, p. 19-20) but the evidence in their support is tenuous and in part contradictory.

It should be emphasized that in the definitions and descriptions of units in this report reliance has been placed, necessarily, on published reports by numerous geologists, who were by no means consistent among themselves in the use of lithologic terms, color designation, and so forth. Observations by the writer and his associates have aided in interpretation of divergent usages but, except where specifically noted, the terminology of the original author is followed here. For example, a rock may be spoken of here as a red shale whereas the present writer might have called it in the field a red-purple argillite or, perhaps, even an impure quartzite.

Most rocks of the Belt series in Montana have been partially recrystallized and few, if any, show well-developed shaly fissility. Thus terms such as "shale and sandstone", although retained in accord with prior usage, are open to question. On the other hand, few of the rocks of the series in Montana are sufficiently metamorphosed so that slaty and schistose partings are well developed. In some places in Idaho and Canada the Belt series is more metamorphosed and rock names may appropriately show this difference. Unfortunately lithologic nomenclature is not sufficiently standardized so that subtle differences can be safely inferred from published descriptions, especially as some of the descriptions here drawn on were written many years ago.

Definitions

The pre-Ravalli rocks [redacted].--The units at present regarded as stratigraphically below the Ravalli group are the Prichard formation and the Neihart quartzite. The Prichard formation (or slate) is the argillaceous and arenaceous assemblage that constitutes the lowest exposed part of the Belt series in and near the Coeur d'Alene area in northern Idaho. It was named for Prichard Creek in that area (Ransome, 1905, p. 281). In part through actual mapping, in part through inference, the name has been carried almost as far east as longitude 113°, south of Philipsburg, Montana [redacted]. In Idaho the Prichard formation has been tentatively identified as far south as latitude 46°40' (Anderson, 1930b, p. 10). If the Orofino series of Anderson (1930b, p. 9-10) is, as he thinks, a part of the Prichard lower than any exposed elsewhere, the formation extends at least as far south as 46°30'. Recent work (Hietanen, 1956, p. 3-4) supports the idea that the Prichard extends southward but it must be remembered that the rocks so assigned are so intensely metamorphosed that diagnostic features are obscured.

The Neihart quartzite is the dominantly arenaceous unit that underlies the Chamberlain shale and rests on granitic gneiss near Neihart (Weed, 1899, Wilmarth, 1938, p. 1473-1474) in the Little Belt Mountains, Montana. As broadly similar quartzitic rocks are present at various horizons in the Belt series and the Neihart cannot be traced far from its type locality, the name is here restricted to the area in which it originated. Future mapping may reveal the same quartzite in parts of the Little Belt Mountains where it is not now known but use of the name in more distant areas would serve no useful purpose. Quartzite in small exposures south of Philipsburg (Calkins and Emmons, 1915) has been called Neihart quartzite but in a conversation in 1948 Calkins agreed that the correlation is open to question. [redacted] The exposures south of Philipsburg may belong to the Missoula group.

The type locality of the Neihart quartzite is so far from the localities where the groups into which the Belt series is divided were established that relationships are uncertain. The unit is surely low in the Belt sequence present near Neihart and has been regarded by Clapp and Deiss (table 30) as of pre-Ravalli age, an assignment that is here accepted as logical. However, the Fentons (1937b, p. 1880) speak of the Neihart as "basal Ravalli".

Among other units that might be regarded as of possible pre-Ravalli age, attention should be called to the Altyn limestone in Glacier National Park. At present (Clapp and Deiss, 1931, Fenton and Fenton, 1937b, p. 1880-1885) the Altyn is assumed to belong to the Ravalli group. It is the oldest formation in Glacier National Park, with its base not exposed. No limestone (or dolomite) in the Belt series stratigraphically as low as the Altyn is on record elsewhere.

The Ravalli group.—Calkins (1909, p. 37-38) applied the term "Ravalli" group to strata above the Prichard and below the formation he then called Newland, now commonly called Wallace, in northern Idaho and northwestern Montana. His usage is a modification of that of Walcott (1906, p. 7-9) who divided the Belt rocks in and near the Swan and Mission Ranges into three series, the Camp Creek, Blackfoot, and Ravalli, listed in descending order. These 3 series correspond approximately to the 3 principal groups of the present paper.

Here the Ravalli group is regarded as including all formations of the Belt series, other than the Neihart quartzite and Prichard formation that are below the Newland limestone or its stratigraphic equivalents, such as the Wallace formation and Siyeh limestone. This definition agrees with most present usage but is phrased so as to be both broad and definite enough to provide a basis for regional mapping. The name is inferred (Wilmarth, 1938, p. 1776) to have been taken from the town of Ravalli. As just noted, uncertainties remain as to assignment of certain formations to the Ravalli, a fact that may require modification of the above definition on the basis of future work. For example, it may be found that the Altyn limestone is stratigraphically equivalent to some part of the Prichard formation, or, conversely, that the Neihart quartzite should be placed in the Ravalli group rather than below it.

In and near Idaho the Ravalli group includes the St. Regis formation, Revett quartzite, and Burke formation (Calkins, 1909, p. 37-38), all names of localities in the Coeur d'Alene area in Idaho and not shown on maps in the present paper (Ransome, 1905, p. 281-282). Farther east, it includes the Appekunny and Grinnell formations and the Altyn limestone (Clapp, 1932, p. 22, Fenton and Fenton, 1937b, p. 1880-1890). The type localities of the Appekunny and Grinnell are mountains in Glacier National Park and the Altyn was named for exposures on Appekunny Mountain north of the former town of Altyn (Willis, 1902, p. 316-321). In the Philipsburg area Calkins (Calkins and Emmons, 1915, p. 3) used the term "Ravalli formation" in essentially the way Ravalli group is used here. From the Philipsburg area to near Neihart no rocks as old as the Ravalli group are known. In the latter locality the Chamberlain shale has been correlated with components of the Ravalli group (Clapp and Deiss, 1931, p. 693), an assignment that seemed probable. The name is derived from exposures near Chamberlain Creek (Walcott, 1899, p. 206, Weed, 1899, 1900, p. 282).

The Piegan group.--The assemblage above the Ravalli group in which carbonate rocks predominate has been variously designated by different geologists, most of whom use one or more formation names for it. It is here termed the Piegan group. The base of the group is the top of the Ravalli group and the top is at the place where largely carbonate-rich rocks give way to dominantly argillaceous ones, commonly reddish and greenish. Parts of the group, notably in the Wallace formation in and near Idaho, are carbonate-rich only by comparison with rocks above and below that are almost carbonate-free. The name Piegan group was first proposed by Fenton and Fenton (1937b, p. 1890-1900) from Piegan Mountain in Glacier National Park. In an earlier consideration of the Belt problem (Ross, 1947, p. 112-113) it was proposed, following Clapp and Deiss (1931, correlation table, p. 691) to restrict the Fentons' definition slightly and this usage was followed in the compilation of the geologic map of Montana(1955). The presently proposed definition still further restricts the group but places its upper limit at a horizon that is readily recognizable in most places. As nearly all formational contacts in the Belt series are gradational, local uncertainties as to the precise position of boundaries are unavoidable.

The Fentons originally placed the top of their Piegan group at the top of the Sheppard (now Shepard) formation. Clapp and Deiss (table 3) did not use a group name but clearly intended to correlate the Shepard with beds elsewhere well above the main mass of carbonate-rich rocks. The name comes from the Shepard glacier in Glacier National Park. Thus, if the term "Piegan group" had been in use when their paper was written, Clapp and Deiss would have excluded the Shepard formation from it. They did intend to group the carbonate rocks in the median portion of the Belt series together, and their exclusion of the Shepard may well have been because the unit was originally (Willis, 1902, p. 316, 324) called the Sheppard quartzite. Actually much of it is dolomite, a fact impressed on the writer in 1950 during fieldwork in Glacier National Park, although already known to the Fentons (1937b, p. 1899). In Ross's first correlation (1949, p. 111-113) the opinion of Clapp and Deiss was adopted. Further consideration, after additional fieldwork, strengthens this decision and leads to the opinion that the Shepard formation is only one of several carbonate-rich units at various horizons in the great assemblage of reddish and greenish argillaceous and siliceous beds that constitute the upper part of the Belt series.

Much further work should be done on the carbonate rocks in the upper part of the series but their mutual interrelations throughout Montana will be difficult, if not impossible, to determine. Much of the needed evidence is hidden by rocks. Besides the Shepard, the post-Piegan carbonate rocks include the Helena limestone and most or all of the beds called Upper Siyeh limestone by Clapp and Deiss (1931, p. 691). The contact between the thick mass of carbonate-rich rocks here included in the Piegan group and the reddish and greenish overlying beds, is as sharp and easily mapped as most contacts between units of the Belt series. If any of the carbonate-rich rocks above that contact are included in the Piegan group, as suggested by either Clapp and Deiss or the Fentons, uncertainties arise, mainly because so many of these carbonate units are discontinuous.

While several different formation names have been applied to beds of the Piegan group in the United States, each is used only in a single region. Nomenclature has varied but currently in northern Idaho and the most westerly part of Montana the term "Wallace formation", derived from Wallace, Idaho (Ransome, 1905, p. 282) is used. From near Missoula to the Little Belt Mountains similar rocks (richer in carbonate) are called the Newland limestone (Walcott, 1899, p. 206) from exposures along Newland Creek north of White Sulphur Springs. In Glacier National Park and the surrounding region Siyeh limestone, derived from Mount Siyeh, (Willis, 1902, p. 316-323) is the name commonly used. When more detailed mapping is done the Wallace, Newland, and Siyeh will be broken up into many new formations, based largely on subdivisions already known to exist. Thus, in each region, the Piegan group will eventually comprize numerous formations instead of the individual units now recognized. Many of the new units will be of more restricted significance than the thick assemblages now recognized.

The Missoula group.--The Missoula group, named for the city of Missoula, (Clapp and Deiss, 1931, p. 677-683) includes all of the Belt series above the Piegan group, except for parts of the North Boulder group in southwestern Montana discussed below. The Missoula group, as redefined here, embraces all the comparatively bright-colored reddish and greenish argillaceous and arenaceous strata high in the series. These strata commonly contain intercalated carbonate-rich masses and, locally, rather light-colored quartzite lenses. In some areas lateral variations in color and other features obscure the distinctive characteristics thus briefly summarized. As the thick assemblage of carbonate-bearing rocks of the Piegan group is commonly easily recognized, no major uncertainty as to the base of the Missoula group is likely to arise even where the distinctive features of the latter group are poorly developed. Confusion between the carbonate rocks intercalated in the Missoula group and closely similar strata belonging to the Piegan group is a possibility but only where relations to the clastic beds of the Missoula group are obscure.

As first defined (Clapp and Deiss, 1931, p. 677-683) the Missoula group contained all the Belt series near Missoula above the unit called Wallace limestone by Clapp and Deiss, more commonly called Newland in that area. This limestone, irrespective of its name, is the local representative of the Piegan group of this report. They speak of an "Upper Wallace limestone" (1931, p. 691) equivalent to the Helena limestone near Helena. The Newland and Helena limestones in the Helena region are separated by a great body of clastic rocks of the sort typical of the Missoula group (Mertie, and others, 1951, p. 18-20). Clapp and Deiss suggest that these two limestones thin westward and finally, by inference near Missoula, become indistinguishable from each other. However, Clapp and Deiss indicate that the two limestones remain separated by clastic beds near Salmon Lake, some 30 miles, air line, from Missoula (1931, p. 685) and that a similar separation is recognizable in Glacier National Park. Mapping is not complete but the writer's trips through country between Missoula and Helena to the east and Glacier National Park to the west lead him to the concept that the Newland, Wallace, and Siyeh are broadly equivalent to each other and that the Helena, in its type locality, is merely one of the several separate limestone masses included in the Missoula group of the present report. This concept was adopted in Glacier National Park (Ross, 1958, in press) and is the only one that furnishes a definite, practical basis for mapping the Piegan and Missoula groups there.

The Helena limestone in the Big Belt Mountains and in and north of Helena, which is the region in which the name is commonly applied, varies markedly in thickness and character from place to place. As the distance from Helena increases until the variations and interruptions introduce enough uncertainity so that one would be rash to select any particular exposure of such rock and attempt to equate it with the Helena limestone of the type locality. These remarks are illustrated by the descriptive data summarized later in the present paper.

The Missoula group contains many formations, few of which have been traced far from the localities where they were first recognized. In much of northern Idaho the sole representative is the Striped Peak formation, named from a peak in the Coeur d'Alene area (Ransome, 1905, p. 282) but along the boundary between Idaho and Montana the Libby formation, named for a town in western Montana (Gibson, 1948, p. 17-19) overlies the Striped Peak. Near Superior, Montana, the group has been divided (Campbell, in prep. 1958) into the Spruce formation, Lupino quartzite, Sloway formation, Banchard formation and an isolated, unnamed unit, listed in ascending order. As suggested on plate 2, some or all of these may well be equivalent to formations near Missoula but knowledge of the intervening area is insufficient to establish this.

In the Bonner quadrangle near Missoula the Missoula group includes the Miller Peak argillite, Bonner quartzite, McNamara argillite, Garnet Range quartzite and, at the top, the Pilcher quartzite. Most of these names were proposed originally by Clapp and Deiss (1931, p. 678-683) but have been redefined and redescribed as a result of later work (Nelson and Dobell, 1958 in prep.).

Reconnaissances by Nelson, Dobell, and the writer lead to the opinion that some of the formations recognized in the Bonner quadrangle persist southeastward to and beyond Philipsburg. Both in this region and between Missoula and Superior lateral variations hinder correlations. The Spokane formation near Philipsburg in the sense employed by Calkins (1915, p. 3) is not the Spokane of the type locality but, instead is almost synonymous with the entire Missoula group as that term is used here.

From near Philipsburg southward almost to latitude 45° rocks with the characteristics of the Missoula group have been seen in reconnaissances by the writer(Ross, Andrews, and Witkind, 1955) studied in places by others (Shenon, 1931, p. 45-46, Myers, 1952, p. 4-6, Guttormsen, 1952, written communication, see pl. 1, index map). Some of the rocks in this area are so coarse as to imply that they are related to the North Boulder group, defined below, which grades into the Missoula group. On both sides of the border of Idaho near latitude 45° there are wide expanses of the Belt series difficult to correlate with the scanty available data, but possibly belonging to the Ravalli and Piegan groups.

Northeast of Missoula further work is needed before the subdivisions of the Missoula group can be regarded as established. In published reports (Clapp and Deiss, 1931, p. 691, correlation chart, Deiss, 1943a, p. 211-218), the units above the Newland limestone are called the Spokane argillite, Upper Siyeh limestone, Miller Peak argillite, Cayuse limestone, Hoadley formation and, at the top, the Ahorn quartzite. To the writer it seems probable that the Spokane argillite of Clapp and Deiss north of Ovando is in large part equivalent to the Miller Peak argillite as redefined by Nelson near Missoula and that the Upper Siyeh limestone of Clapp and Deiss is one or more of the limestone masses in the Missoula group, not necessarily equivalent to any formally named formation, although called Helena limestone by them along Prickley Pear Creek (1931, p. 691). This statement is based on concepts gained in the Flathead and Glacier National Park regions (Ross, in press, 1958) and near Missoula, and a reconnaissance along two valleys north of Ovando with Nelson and Dobell in 1955. One of these valleys is that of McCabe Creek where Clapp and Deiss measured a section (1931, p. 685, correlation chart).

The mountains east and north of Helena contain some of the longest known exposures of the Belt series, including those in the Big and Little Belt Mountains where the series got its name. The formations in that region that belong to the Missoula group, as here defined, are, in ascending order, the Greyson, Spokane, and Empire shales, Helena limestone, Marsh shale (Walcott, 1899, p. 206-207) and, at the top, a newly recognized formation, the Greenhorn Mountain quartzite of Knopf (1950, p. 839). These same units, with some variations in thickness and character, extend southward to near Three Forks (Klepper and others, 1957, Robinson, in prep.). The type localities are in the Big and Little Belt Mountains and in neighboring areas to the west near Helena and Marysville. Most are stated approximately by Walcott (1899, p. 206-207). The Greenhorn Mountain quartzite has been recognized so far only on the Mountain of that name northeast of Helena.

<u>The North Boulder group</u>.--The name "North Boulder group" was originally proposed (Ross, 1949, p. 111, 113) for arkosic and conglomeratic components of the Belt series in isolated exposures near the Jefferson River southeast of Butte. The name was taken from the North Boulder River (Boulder River on some maps). The group is thought to rest directly on the pre-Belt complex of metamorphic rocks and where originally named lies without angular discordance beneath the Flathead quartzite (Middle Cambrian). It is known as far east as T. 2 N., R. 6 E. (Ross, Andrews, and Witkind, 1955) and may be represented some distance southwest of its type locality. Apparently few coarse rocks like the North Boulder group extend north of latitude 46°. The most westerly reported area in which the group may occur is near Wise River [redacted].

In the original definition (Ross, 1949, p. 111) it was suggested that the group might be equivalent in age to parts of the Missoula and Piegan groups. The revised classification adopted in the present report places in the Missoula group all the formations discussed at the time the original definition was set up. On the other hand, recent work farther east near Logan and Three Forks suggests that part of the North Boulder group may be much older than any in the type locality. It now seems appropriate to apply the name North Boulder group to the entire assemblage of strata of the Belt series in southwestern Montana that includes significant quantities of material decidedly coarser than is characteristic of most of the Belt series. The coarse rocks are near-shore deposits and may range in age through the whole of Belt time. The group seems to interfinger with strata of the Spokane and Greyson shales and with older units that may be correlative with the Newland limestone and even the Chamberlain shale.

The North Boulder group has not yet been divided into named formations. Probably it contains in each of several localities 3 or 4 subdivisions of formational rank. (Peale, 1896, p. 2, Tansley, Schafer, and Hart, 1933, p. 11-12, Berry, 1943, p. 6, Perry, E. S., personal letter of October 24, 1947, also 1950, Sahinen, 1950, p. 13-15, Alexander, 1955, McMannis, 1952, p. 11-14). The interrelations between the subdivisions in the different localities are not known.

Purcell basalt and similar rocks.--The only effusive rock so far recognized in the Belt series in Montana is the Purcell basalt of Glacier National Park and vicinity. The name was given by Daly (1912, no. 2, p. 207) because of its occurrence in what he termed the McGillliviary division of the Purcell mountain system. Within Glacier National Park it is confined to the lower part of the Missoula group, mostly between the Shepard formation and the top of the Siyeh limestone (Ross, 1958, in press). In Canada more lava of the Purcell type is known than has been found in Montana and its value as a horizon marker has long been recognized (Daly, 1912, p. 162, Schofield, 1914b, p. 86, 89). The name Purcell is restricted to beds high in the sequence, that is, to those in the Missoula group of the present report. However, north of Glacier National Park similar lava has been reported at much lower horizons (Fenton and Fenton, 1937b, p. 1887-1888).

In northern Idaho and Washington and in neighboring parts of British Columbia volcanic rocks of late Precambrian age have been called the Irene volcanic formation and the Leona volcanics. Petrographically both have resemblances to the Purcell basalt except that they are more metamorphosed and much thicker. Daly and most later students (1912, p. 144-147, Park and Cannon, 1943, p. 9-11, Kirkham and Ellis, 1926, p. 39-40) regard the Irene and Leona volcanic rocks as coextensive with and therefore equivalent to each other. They place these rocks so high in the sequence that it seems clear that they are stratigraphic components of the Missoula group of the present report. The suggestion (Kirkham and Ellis, 1926, p. 40) that they are essential equivalents of the Purcell basalt farther east is here held to be the most probable one. They are so much thicker than the Purcell basalt that precise age equivalence may be open to question. Okulitch (1949, 1956) does not discuss the volcanic rocks but from other publications (Walker, 1934, p. 3-6, Little, 1950) it is evident that the Irene volcanic formation, where present, is so high stratigraphically that it would be included in what Okulitch (1956, p. 728-730) proposes to include that part of the Windermere series that is older than Cambrian but younger than Proterozoic. He wishes to elevate this part of the Windermere series to systemic rank, making it the earliest system in the Paleozoic era. If the Irene and Purcell flows are stratigraphic equivalents, and Okulitch's idea should gain acceptance, part or all of the Missoula group would belong in the new Paleozoic system. So far his idea has not gained general acceptance (Lochman-Balk, 1956, p. 637-646).

Diagnostic features

Foreword

Most of the rocks that compose the Belt series lack features of color or texture that are striking enough to be readily recognized. Recognition of stratigraphic units, in consequence, has had to depend largely on the personal predilections of each observer, including his past experience with the series. To be of maximum value diagnostic features should be sufficiently quantitative to permit different observers to obtain comparable and consistent results. Various kinds of evidence that may help to eliminate the personal equation in this respect are outlined below. Inadequate data now hamper their effective application but recent studies and others that are planned are tending to decrease this disadvantage.

Lithologic criteria

The characteristics that have been relied on in the past and that, in large measure, must continue to be used by Belt stratigraphers are those that contribute to the overall appearance of the rock. These include color, texture, internal structural features, gross composition, and degree of metamorphism. Nearly all available descriptions are expressed in such nonquantitative terms as to be of limited utility.

Color.--Color is one of the criteria most widely used in Belt stratigraphy. Its use is essential but standardization is difficult. The lack of agreement as to the names of rock colors is well known. There have been many attempts to set up standard color names, at least two of which were intended for rock descriptions (Goldman and Merwin, 1928, Goddard, 1948). These postdate many published descriptions of Belt rocks and have not been widely used even in recent publications. Even where color names have been applied with care one cannot be sure of the exact color implied. In the present paper color designations are based so far as possible on the Rock Color Chart of the National Research Council (Goddard, 1948) but in descriptions taken from published reports the original color names have had to be used. Though of great assistance, the chart has obvious handicaps, especially as by no means all possible rock color variations are represented in it. More elaborate books dealing with color are available (Ridgway, 1886, 1912; Maerz and Paul, 1930; Cooper, 1941; Nickerson, 1946) but have been used little in geologic work, in part because of the odd-sounding color names employed.

Certain of the Belt units have sufficiently distinctive and uniform colors to be of great aid in correlation. Caution is needed, however, as particular beds in different units may be so nearly identical in color that this distinction, taken alone, is valueless. No single characteristic is a safe guide in correlation of the subdivisions of the Belt series.

Any method of visual comparison requires care and some measure of artistic ability on the part of the user. Hence it cannot be as rigidly objective or quantitative as could be desired. Means of actual measurement are available and have been applied to the Munsell colors (Judd and Kelly, 1939, Reimann, Judd, and Keegan, 1946). In spite of the obvious advantages in the elimination of the personal equation these devices have not come into use by geologists.

Texture.--Most of the clastic beds of the Belt series consist of fine grains, with original textures obscured somewhat by recrystallization. In some rocks the original grain shapes of quartz and feldspar may remain discernible, but clays and the decomposition products of other minerals have been largely converted into a micaceous mat that tends to mask original textures. Partial recrystallization of the quartz and feldspar contribute to this effect. The result is a rock sufficiently characteristic of the Belt series so that the experienced observer commonly can say that a particular rock mass does or does not have the general appearance of belonging to that series. That same observer would have difficulty in expressing in quantitative terms the reasons for his decision.

The carbonate-rich rocks are chiefly fine grained. Many are so impure as to grade into clastic rocks like those just commented on. The carbonate-rich rocks are distinctive because of color, internal structures, and fossil content rather than texture.

In general, with practice, the observer tends to associate certain textural peculiarities visible in the hand specimen with particular formations or groups. Such peculiarities should be used with caution. Diagnoses based on petrographic data are somewhat safer, but are available for a few areas only. In texture, as in color, variations within the formations that make up the Belt series are more plentiful and marked than might be inferred from many of the published descriptions.

Structure.--The structures that characterize the noncarbonate-rich rocks include ripple marks, raindrop impressions, salt casts, mud flakes, mud cracks, and variations in the bedding. Wavy laminations are characteristic of some units. Crossbedding is conspicuous in some of the more quartzose strata. In a few localities the quartzitic rocks also have bulbous masses of unknown origin on bedding planes.

The carbonate-rich rocks are replete with structures that have attracted the attention of all who have studied them but are still imperfectly understood. The most widely known of these features are the "molar-tooth" structures, seen as deeply etched patterns on weathered surfaces. Those that gave rise to the name simulate the irregularities on the grinding surfaces of the molar teeth of elephants. The etched surfaces, however, display a great variety of patterns, many of which have no resemblance to markings on teeth. One of the problems connected with the structures is whether the diverse patterns originate in one or several different ways. There are so many features in common and such a tendency for the different patterns to merge into each other that a common origin seems probable, though not proved. They result from an unequal distribution within the limestone of silica, magnesian carbonates, and possibly other components, producing variations in solubility during weathering. While the structures are conspicuous where weathering has been effective, they are nearly or quite invisible on freshly fractured surfaces in the same rock.

The structures most appropriately likened to molar tooth markings consist of series of sigmoid ridges with outlines irregular in detail. Each ridge rises a tenth of an inch or more above the background of the weathered joint face. Other structures are sufficiently unsystematic in shape or arrangement so that the resemblance to molar tooth markings is lost, although other characteristics are much the same. Both of these varieties may cover the entire side of a wide joint face or may be limited to a small area within that surface without apparent system in form or arrangement. Some structures are fairly straight, subparallel ridges, either nearly normal to or at some moderately high angle to the bedding, reminiscent of cleavage fractures. Some are assemblages of subparallel closely spaced short ridges that look like the edges of flattish cleavage fragments. These give the rock the appearance of a breccia. Many of them are areally associated with stromatolites. Some structures consist of numerous short, subrounded ridges, commonly with haphazard distribution. Others are identical except that they are depressions sunk in the weathered joint surface instead of ridges rising above it. In both these varieties individual ridges or depressions tend to have shapes that remind one of cuneiform writing. In still another variety the raised areas are oval, giving somewhat the appearance of an oolitic limestone in which the oolites are rather sparsely and irregularly distributed and of more than ordinary size. These oval bodies range up to over half an inch in maximum diameter. They do not have, so far as is known, the internal characteristics of oolites. A number of the carbonate-rich rocks in the Belt series are oolitic but the oolites are individually too small to be readily visible without the aid of the microscope.

Structures that arise from irregular mingling of aggregates of different carbonates are locally striking, especially in the Helena limestone near Helena. In these, dolomitic rock weathers in various shades of yellowish and grayish orange and that in which calcite predominates is gray. Dark, nearly black, nodules and layers of chert locally add to the variety. The result is a mottled rock of distinctive appearance. Limestone in the Belt series in other areas and in a wide range of stratigraphic positions includes material somewhat similarly mottled but in no locality familiar to the writer is such material as distinctively developed or as widespread as in the Helena limestone close to its type locality.

The igneous textures and, commonly, the conspicuous pillar structures render the lava easily distinguishable from the rest of the Belt series. Therefore such rock is valuable as a local horizon marker. In and close to Glacier National Park it is called Purcell basalt and occurs in the Missoula group, mostly low in that group. However, as noted on p. 121, lava may not be confined to this position throughout the Belt series. In addition to the possibility thus afforded for error in stratigraphic correlation, confusion might arise between lava flows and intrusive sills. The sills commonly show transgressive relations and may be associated with obviously crosscutting dikes. Further, sills that cut carbonate rocks commonly have conspicuous borders of light-colored marmarized limestone both above and below.

Paleontologic Criteria

by Richard Rezak

Stromatolites are of outstanding interest among the structures of the rocks of the Belt series. Like the molar-tooth structures described above these are particularly abundant in the carbonate-rich rocks although they are by no means limited to these facies. The stromatolites are somewhat more visible than other structures on freshly broken surfaces because of the greater difference in composition from one layer to the next. On weathered surfaces the laminae are often etched into strong relief. The stromatolites of the belt series, especially those in and near Glacier National Park, have recently been studied and described by the writer (Rezak, 1957). This paper contains a classification with descriptions of the distinctive forms. The work demonstrates that stromatolites with distinctive characteristics are widespread in the Belt series. Where adequately mapped, they will prove of value for correlation within a given area and as a means of subdividing parts of the Belt series not susceptible of satisfactory

[redacted]

subdivision on other bases. At present, stromatolite zones have been used for such purposes only in the Glacier National Park region. Even there, limitations of time and base maps have prevented full use of these aids to stratigraphic study. Future work is expected to increase the number of subdivisions in that region that can be mapped on the basis of stromatolite zones and to disclose zones that can be used similarly in other areas. Comparisons between stromatolite zones in widely separated areas have little or no stratigraphic significance. One would not expect the same zone to be continuous over the entire basin of sedimentation. However, some zones in one area may interfinger with zones of an adjacent area and by gradually working out their relationships over the entire basin long range correlations will be materially assisted.

Eight stromatolite zones useful for local correlation are recognized in the Glacier National Park region. These zones have been described in detail (Rezak, 1957, p. 135-140). The zones range throughout the formations of the series that are represented there, being absent only in the Appekunny argillite. They vary in thickness, composition, and areal extent. Some are widespread and extend into neighboring regions, while others occur only in restricted areas. Only two of the zones have been mapped. Visits to other localities in northwestern Montana and northern Idaho resulted in finding stromatolites at each locality, and give basis for the expectation that the Belt series in these areas is susceptible of subdivision on the basis of stromatolite zones.

Stromatolites are significant from other standpoints than that of stratigraphic correlation. They give clues as to the mode of origin of the series, and of Precambrian rocks in other regions. The author (Rezak, 1957, p. 141-149) has discussed the environmental implications of stromatolites in some detail. It may be remarked here, however, that the stromatolites serve to show that the beds containing them were laid down in shallow water, possibly on marginal mud flats that were periodically wet and dried. They also tend to support the concept of marine rather than lacustrine origin of the Belt series, as the stromatolites more nearly resemble present marine forms than those of lacustrine habitat (Rezak, 1957, p. 149, Ross and Rezak, 1958, in press). The Belt algae may have formed under conditions approximating those of the Bahama Banks or some of the coral reefs in the southern Pacific Ocean.

The term stromatolite (Kalkowski, 1908, p. 68) has been generally accepted to designate laminated structures such as those that occur in the Belt series. These structures are developed through the growth of mats consisting of unicellular green and blue-green algae. Stromatolites are distinguished from fossil algae because they do not exhibit microstructures of a kind that would enable determination of the true biologic relationship of the organisms that contributed to the growth of the fossil. Consequently, classification of stromatolites necessarily involves the use of a purely artificial classification based upon "form genera" and "species", not true biologic entities.

In the Coeur d'Alene mining region, Idaho stromatolites occur in the Prichard and Burke formations. To date the only recognized genus in this area is Newlandia Walcott. Several good exposures of these structures in the Prichard formation occur along the east side of Little Pine Creek valley about two miles southeast of Pinehurst, Idaho. [redacted] The structures are sparingly scattered throughout a 15-foot-thick zone of greenish-gray argillite beds, but are especially abundant in a 2-foot thick argillite bed that can be traced for 250 feet along the strike. This horizon is about 600 feet stratigraphically below the contact of the Prichard formation with the overlying Burke formation.

Another occurrence of the genus has been observed near the middle of the Burke formation in an outcrop on a rocky spur east of the elementary school house in Kingston, Idaho. The bed containing the structures is a buff, fine-grained, slightly sericitic quartzite. The exact stratigraphic position is not known because of faulting in the vicinity and the lack of an index horizon. This occurrence is probably 1,500 to 2,000 feet stratigraphically above that in the Prichard formation.

Near Troy and Libby, Montana, stromatolites occur in the Wallace and Striped Peak formations. The Wallace formation contains an abundance of Collenia symmetrica Fenton and Fenton. The following section shows the typical relationships of the stromatolites in this formation.

Section measured one-half mile north of Troy Ranger Station, on northeast side of road along northeast side of Kootenai River, T. 32 N., R. 34 W., SW1/4 sec. 36.

	feet	inches
Pale orange and gray, fine grained, calcareous sandstone	6	0
Pale red stromatolitic limestone (*Collenia symmetrica*)	3	0
Light-gray, fine-grained, calcareous sandstone; weathers to dark yellowish-orange	2	8
Pale red, stromatolitic limestone (*Collenia symmetrica*)	3	0
Pale brown, finely laminated, calcareous argillite; massive but breaks into thin slabs	2	0
Yellowish-gray, calcareous sandstone with thin black bands	2	6
Dusky red purple, very fine grained, thinly bedded dolomite; weathers rusty brown	2	0
Stromatolitic limestone, matrix moderate red and laminae black; species indeterminate	0	6
Pinkish-gray, calcareous oolite; bed contains pebbles of oolitic rock up to 2 inches long and 3/4 inch thick	1	6
Red, very fine grained, calcareous sandstone with laminations at base of unit	15	0
Total	38	2

Another exposure of *Collenia* beds worthy of mention occurs beneath the south abutment of the suspension bridge across Kootenai River just west of Kootenai Falls picnic ground, sec. 36, T. 31 N., R. 33 W. Here from 10 to 20 feet of greenish-gray stromatolitic limestone occur in the Wallace formation. These stromatolites are quite similar to *Collenia symmetrica* and attain maximum diameters up to 10 feet. [redacted]

The writer has not observed stromatolites in the Striped Peak formation. However, C. E. Erdmann mentions (written communication) stromatolites in association with oolitic limestone and gray, sandy limestone about 200 feet above the base of the Striped Peak formation on the south slope of Mount Berray above Windquist's prospect, at an elevation of about 4,500 feet, T. 27 N., R. 33 W. unsurveyed. Another of Erdmann's localities is in the Trout Creek quadrangle. Here stromatolites occur associated with oolitic limestone and pink shaly limestone about 1,000 feet above the base of the Striped Peak on the ridge east of East Fork Elk Creek, 2 miles south of Delravik's ranch, T. 26 N., R. 33 W. unsurveyed.

The Helena limestone near Helena, Montana, contains stromatolites. Gigantic specimens of Collenia symmetrica may be observed on a hill 0.7 mile from the west end of the Mount Helena Scenic Drive, SE1/4, sec. 26, T. 10 N., R. 4 W. [redacted] Stromatolites are found on the top and both flanks of the hill but the best exposures are found high on the west flank.

South of Helena, near Radersburg, Montana, the Greyson shale and Spokane formation both contain abundant stromatolites. In the Devil's Fence Quadrangle, NW cor., NW1/4NE1/4 sec. 22, T. 4 N., R. 2 W., the Greyson shale contains limestone beds similar to Collenia multiflabella of the Glacier National Park area. These beds occur about 600 feet below the contact of the Greyson with the overlying Spokane shales [redacted].

The Spokane shale contains stromatolite beds about 200 feet above its base. On the Ida Mine Quadrangle, SE1/4SE1/4 sec. 23, T. 4 N., R. 2 W., several limestone beds crop out in gulches and ridges. These contain Collenia symmetrica and Cryptozoon occidentale. [redacted]

Farther south, in the Horseshoe Hills area near Logan, Mont., Peter Verrall reports (p. 24-25)_/ the existence of a basal stromatolite

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_/ Verrall, Peter, 1955, Geology of the Horseshoe Hills area, Montana: Doctoral dissertation series publication no. 13,737, Princeton University, Microfilms, Ann Arbor, Michigan.

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unit in what he regards as the Newland limestone. He identifies the stromatolites as Collenia symmetrica and using these fossils correlates the basal Newland with the basal Siyeh of Glacier National Park, some 200 miles to the north. Earlier in this section it has been indicated that long-range correlations on the basis of stromatolites is hazardous. Considering the rapidity of facies changes in the Belt series, Verrall's correlation is quite vulnerable.

C. D. Walcott (1914b) and C. L. and M. A. Fenton (1937b) have described the occurrence of stromatolites in the Belt series of northwestern Montana. These papers are readily available and the occurrences will not be reviewed at this time.

Fossils other than stromatolites have been reported from the Belt series, mainly by Walcott (1899, 1914, 1915) and Fenton andFenton (1931, 1933a, 1936, 1937b). These fossils include bacteria, algae, crustaceans, brachiopods, and indirect evidences of life such as burrows and trails.

The earliest report of the presence of fossil bacteria in the Belt series was by Walcott (1915, p. 256). He described and illustrated specimens of Micrococcus sp. from the Gallatin formation (of Keyes) on the north side East Gallatin River, 5 miles east of Logan, Gallatin County, Mont. The writer has attempted without success to locate the slides from which Walcott described his material. The discovery of structurally preserved plants in the Precambrian Gunflint formation of the Canadian Shield (Tyler and Barghoorn, 1954, p. 606) seems to corroborate the presence of these primitive organisms in ancient sedimentary rocks. It seems improbable, however, that such fossils would be preserved for any great length of time in limestones. Black cherts appear most favorable for the preservation of these fossils. Unfortunately, the Belt series contains very little chert. One of the few places in which chert beds may be observed is on the ridge between Dry Gulch and Deep Creek, SE1/4, sec. 35, T. 14 N., R. 21 W., Missoula, Montana-Idaho quadrangle. Here several stromatolite beds in the Wallace formation are composed of alternations of light-gray and black chert. Specimens of the black chert have been macerated in hydrofluoric acid and the residues examined under magnifications up to 1,200 times. The residues appear to be an organic hash too poorly preserved to permit positive identification of its components. Further searching for black cherts will undoubtedly turn up well-preserved fossils.

C. L. and M. A. Fenton (1933b, p. 190) have reported the discovery of oboloid brachiopods in the Newland limestone. In a later paper (Fenton and Fenton, 1936, p. 616) they described a new species: Lingulella montana from the middle and upper Newland in cliffs along Little Birch Creek, NW1/4, sec. 15, T. 9, R. 4, Meagher County, Montana. Examination of the types gives no reason to doubt that the fossils are brachiopods. The area in which the fossils are found is cut by numerous faults which the Fentons (1936, p. 610) state are of small throw or follow bedding planes, and do not introduce Cambrian into the sequence. However, the measured sections included in the paper show that the brachiopods are found 27 to 30 feet above beds containing Walcott's Precambrian flora. Unit 2 of their Section A (1936, p. 611) and unit 8 of their Section B could well represent faults that might have resulted in the displacement of Cambrian strata to rest directly on the upper Newland. The inclusion of later rocks with the Belt series is not peculiar to this area. See page 277a in connection with the work of Willis Nelson near Missoula, Montana.

Fossil crustaceans have been described by Walcott (1899, p. 238) from the Greyson shales, in Deep Creek canyon, near Glenwood, and Sawmill canyon, 4 miles above Neihart, Mont. He proposed the name Beltina for carbonaceous films that he supposed to be fragments of Merostomata. David White (1929, p. 393) and the Fentons (1936, p. 616) conclude that these are partly inorganic and partly the remains of the soft fronds of brown algae.

Clyde P. Ross, while examining thin sections cut from specimens of the Altyn limestone collected near Appekunny Falls in Glacier National Park, discovered a structure that has been tentatively identified by J. Harlan Johnson as organic although he is not sure what it represents. [redacted] Johnson adds (oral communication) that if found in lower Paleozoic limestone, he would not hesitate to say that it belonged to a trilobite or chitinous brachiopod.

Occasionally traces resembling fossil burrows and trails are found in the Belt series. These have been described in some detail by C. D. Walcott (1899, p. 236) and the Fentons (1937b, p. 1950). The structures are attributed to the work of annelids, molluscs, and crustaceans.

Lithologic descriptions

Prichard formation

Distribution.--The Prichard formation (or slate) is rather widely exposed in Shoshone County, Idaho, especially south of the St. Joe River (Umpleby and Jones, 1923, pl. 1) and extends into Clearwater County (Anderson, 1930b, p. 10) as well as northward into Boundary County (Kirkham and Ellis, 1926, p. 15-16, 20-27). In Montana the Prichard formation is widespread from the northwest corner of the state southward almost as far as Superior. Small exposures referred to it with different degrees of certainty are found at intervals from near Lolo Pass to areas southwest of Anaconda.

Character.--Ransome and Calkins (1908, p. 29-32) say that in the Coeur d'Alene area the thickness exceeds 8,000 feet. All except the uppermost part consists of dark-blue-gray argillite with shaly partings and imperfect slaty cleavage interbedded with considerable indurated sandstone. The rock is reddish brown on weathered surfaces, mainly as a result of weathering of iron sulfides. Part of the sandstone is quartzitic and part grades into the argillite. The upper few hundred feet of the formation is more sandy and, near the top, greenish-gray siliceous shale, like that in the Burke formation, appears. In these upper few hundred feet ripple marks and sun cracks become conspicuous, with rain pits, intraformational conglomerate and "pseudoconglomerate". The last named is accounted for by Calkins as formed on a sloping shore by waves rolling up masses of water-soaked sand which became flattened by their own weight.

Under the microscope Calkins found that the rocks consist of angular to subangular detrital grains of quartz and feldspar with some muscovite of probable detrital origin in an abundant cement. The cement consists largely of sericite and quartz mingled with minute opaque particles, probably carbonaceous. Minor constituents, in part of hydrothermal origin, include leucoxene, rutile, zircon, and such minerals as tourmaline, siderite, pyrite, magnetite, biotite, and chlorite.

A more generalized description (Umpleby and Jones, 1923, p. 7) states that the formation consists of blue shale and slate with some gray sandstone and quartzite at least 8,000 feet thick. A massive quartzite middle member is 200 feet thick near Pine Creek, south of Kellogg, and a unit presumed to be the same member is 1,500 feet thick in the southern part of Shoshone County.

The Prichard (there termed "Prichard-Aldridge") formation in Boundary County, Idaho, is notably different from the type section in the Coeur d'Alene area (Kirkham, and Ellis, 1926, p. 15-16, 20-27). The thickness exceeds 10,000 feet, with the base not exposed. The formation consists of pure, light-gray quartzite, argillaceous quartzite and argillite. The argillaceous rocks are gray to black. Argillite is subordinate to quartzitic rocks, the reverse of the relationship in most other localities.

Specimens collected by Warren Hobbs from the Prichard formation and its transitional zone with the Burke in eastern Shoshone County consist of laminated argillite containing quartz and white mica with some biotite, hornblende, tourmaline, and epidote. The quartz grains range up to 0.06 millimeter in diameter and some of the amphibole metacrysts are 0.3 millimeter long. Those rocks are more metamorphosed than most of the Belt series in Montana.

Another description (Shenon and McConnel, 1939, p. 3) gives the maximum thickness as over 12,000 feet, with the base not exposed, and says the formation consists principally of dark-gray to almost black laminated argillite, commonly with slaty cleavage. According to this description the formation contains at least 2 well-defined quartzitic zones, 1 near the top and the other about 10,000 feet lower.

In northern Bonner County (Anderson, 1930a, p. 14-15) the formation is more sandy than in much of Shoshone County. It consists of gray argillaceous quartzitic sandstone with interbedded shale and minor lenses of intraformational conglomerate. The thickness is in excess of 20,000 feet, of which only the upper 1,500 feet resemble the typical slate of the Prichard in the Coeur d'Alene region.

op. cit. p. 207

In Kootenai and Benewah Counties, Idaho, (Campbell, 1950, p. 7-8) only a small part of the formation is exposed. This is chiefly dark-gray to black argillite with some argillaceous sandstone and quartzite, particularly near the top. The argillite is thinly laminated, with various shades of gray and black. In places the rock is reported to have a distinctly varved appearance. Slaty foliation is especially prominent low in the sequence. Mud cracks and ripple marks have been noted.

In Mineral County, Mont., (Wallace and Hosterman, 1956, p. 578-579, Campbell, in prep. 1958) the Prichard formation includes fine-grained, medium-gray and greenish-gray quartzite and siliceous argillite in beds 2 inches to 2 feet thick. The rock here is similar to that in the Coeur d'Alene region, Idaho, except that it is more uniformly siliceous, with fewer argillite beds. Along the Clark Fork below its junction with the Flathead River, in Saunders County, the Prichard is exposed essentially continuously and appears to be 17,000 feet thick, with the top cut off by a fault. The possibility of duplication by faulting within this thick section remains, but is supported by no evidence now at hand. Further, as in all other areas, the base of the Prichard is not exposed. In this locality the Prichard formation consists mostly of fine-grained quartzite and siliceous argillite. Common colors are medium gray and greenish gray. Some of the argillite has pronounced cleavage parallel to the bedding.

Tweto, (p. 12-13, op. cit., p. 155) speaks of rock from the Prichard formation a mile north of Camas Hot Springs, Sanders County, Mont., as quartz-sericite phyllite or quartzitic argillite. It is steel gray and weathers drab or green, and consists of quartz, sericite, and biotite with minor amounts of graphite, tourmaline, epidote, grossularite, chlorite, titanite, and muscovite. Campbell (1958, in prep.) noted most of these and, in addition, some feldspar and pyrite.

The Prichard in the Libby quadrangle (Gibson, 1948, p. 10-11) consists mostly of dark-gray to blue-gray, sandy, laminated argillite, interbedded with some light-colored sandstone and quartzite and a little thin-bedded shale. Some beds contain carbonate, possibly ferruginous. Sun cracks and ripple marks are sparingly present. Sandy beds that were studied petrographically were found by Gibson to be composed of quartz and sericite, mainly 0.01 to 0.03 millimeter in diameter. Some chlorite and a little detrital zircon, tourmaline, apatite, and rutile are also present. The formation is so deformed as to be difficult to measure but at one place a minimum of 9,700 feet is exposed, with the base hidden. Presumably the rock in the Libby quadrangle is representative of most of the formation in western Montana. Most other areas there are known only on a reconnaissance basis.

East of Lolo Pass the Prichard is reported (Langton, 1935, p. 36) to be predominantly brownish sandstone, containing feldspar, mostly highly metamorphosed to biotite-muscovite schist. Still farther southeast (Calkins and Emmons, 1915, p. 3-4) the formation consists of micaceous schist and gneiss, dark gray on fresh fractures, deep reddish brown on weathered surfaces. These metamorphic rocks were derived from clay shale with some sandy layers, now represented by quartzite. The least metamorphosed of the argillaceous rocks is reported to be laminated and to resemble the slate of the Prichard formation in Shoshone County, Idaho. The exposed thickness in this part of Montana has been estimated at about 5,000 feet.

Calkins and Emmons distinguished a unit composed of white to gray quartzite with micaceous partings and, in the upper part, layers of mica schist, about 1,000 feet thick, with the base not exposed. They called it Neihart quartzite. Outcrops of the unit are small and relations to other rocks not clear. So many uncertainties are involved that such a correlation seems unwarranted at the present time. Neihart, the only other locality where the name has been used, is nearly 140 miles away. Possibly part of the quartzite they regarded as Neihart is interbedded with the argillaceous rocks supposed to belong to the Prichard formation. Even the correlation of the argillaceous rocks with the Prichard is far from proven as the outcrops are small, metamorphosed and far from the type locality of that formation in Idaho.

Obviously the various descriptions just summarized indicate significant differences in character and thickness within rocks assigned to the Prichard. Some of the differences are in areas close to each other. It so happens that the formation crops out in so many mining districts that rather more is known about it than about some other Belt rocks. Lateral variations as marked and frequent as those indicated for the Prichard formation may exist in less well known areas that contain later parts of the Belt series.

Neihart quartzite

The Neihart quartzite is definitely known only in a small area close to Neihart in the southeast corner of Cascade County, Mont. At present the use of the name should be confined to this area, there being no means of equating the quartzite at Neihart with others. The quartzite rests in depositional contact on coarse granitoid gneiss, the only place in Montana or Idaho where such a relationship is unequivocal. In the few other localities where rocks of the Belt series are close to older rocks faults are known or suspected.

The Neihart quartzite is described (Weed, 1900, p. 281-282) as quartzite that grades into sandstone, largely massive, but with distinct bedding locally. The color is "creamy white to gray or pink". Quartz pebbles, in part in thin lenses, occur but well-defined conglomerate beds have not been found. The basal 300 feet of the formation is a compact, uniform body of white and pink quartzite, forming conspicuous escarpments. The higher rocks are thinner bedded with greenish mica. Still higher in the sequence micaceous shale is interbedded with the quartzite, increasing upward to a gradational contact with the overlying Chamberlain shale. The shale in the upper part of the Neihart is reported to be blackened by carbonaceous matter. The total thickness is 700 feet.

Specimens collected from the same general locality by Richard Rezak include light, faintly greenish-gray and coarser, pinkish-gray quartzite consisting mainly of quartz, in part in well-rounded grains, in part in a tightly packed mosaic of grains that have been crushed and recrystallized. Grain diameters range from 0.01 to 0.50 millimeter, the largest being uncrushed, rounded detrital material. The quartz is surrounded by thin films of micaceous minerals, in part sericite, in part probably clay. There are also a few grains now composed of similar aggregates of micaceous habit that may be altered feldspar. A little chlorite, biotite, epidote, apatite and tourmaline are present.

Ravalli group

Foreword

In most places in Montana the Ravalli group is undivided or is split into the Appekunny below and the Grinnell at the top. In Glacier National Park the Altyn limestone is the lowest exposed unit of the Belt series. It is provisionally included in the Ravalli group but could be older than any of the units referred to that group elsewhere. Similarly the Chamberlain shale, near Neihart, is at present assigned to the Ravalli group, but may be older. In Idaho and in adjacent parts of Montana the Burke, Revett, and St. Regis formations, in ascending order, are assigned to the Ravalli group. Each of the formations named above is described below, roughly in order from west to east. There are wide areas in western Montana where the Ravalli group has been so little studied that its components have not been distinguished and only the most general statements as to the group have been published (Walcott, 1906, p. 7-9, Calkins, 1909, p. 37-38, Clapp, 1932, p. 22).

Burke formation

Distribution.--The Burke formation is widely distributed in Shoshone County, Idaho, especially near Burke and from there into Montana (Umpleby and Jones, 1923, pl. 1). It is also present in adjacent areas in Idaho (Sampson, 1928, p. 6-7, Anderson, 1930a, p. 15-16, 1940, p. 11). It, or at least a unit that resembles it, is reported to be abundant in Boundary County (Kirkham and Ellis, 1926, p. 16). While rocks equivalent to the Burke formation are present in western Montana, only scattered information is available [redacted] (Gibson, 1948, p. 9-12, Wallace and Hosterman, 1956, p. 588, Campbell, in prep. 1958).

Character.--The rocks of the Burke formation in the Coeur d'Alene region, Idaho, range from nearly pure quartzite to siliceous shale (Ransome and Calkins, 1908, p. 32-34) and the upper and lower parts approach the Revett and Prichard respectively in lithologic character. The upper boundary, particularly, is gradational and indefinite. Many of the rocks are pale greenish gray; some light purplish. A few beds have brighter green and purple tints. Some of the quartzite is white. Sun cracks and ripple marks are seen in almost every outcrop. The rocks differ from those of the Prichard chiefly in containing less carbonaceous dust. The coarse thick beds in the formation contain "rather angular grains of quartz and feldspar and flakes of presumably clastic mica in an abundant sericitic paste". Much of the quartz and sericite is secondary. A few beds are calcareous.

Specimens from eastern Shoshone County furnished by Warren Hobbs represent finely laminated rocks consisting of quartz, micaceous minerals and some plagioclase. Chlorite is in large flakes. The quartz is in an intricate, recrystallized mosaic of grains that range in diameter from less than 0.01 millimeter to 0.30 millimeter.

In Kootenai and Benewah Counties, Idaho, (Campbell, 1950, p. 8-10)_/

_/ Campbell, A. B., 1950, Geology of the Fernwood 2 northeast quadrangle, Shoshone, Kootenai, and Benewah Counties, Idaho: U. S. Geol. Survey unpub. report.

extensive faulting, plus poor exposures hinder stratigraphic studies. About 75 to 85 percent of the formation is quartzite of various degrees of purity, mostly sericitic. Most beds are from 2 inches to a foot thick, with a few as much as 3 feet thick. Extremely thin, widely spaced laminations within the beds are common. Most of the quartzite is gray to light tan, with purple tints locally and, in the more sericitic beds, green casts. Many beds have numerous brown spots resulting from weathering of small groups of sericite crystals. Thin-bedded gray-to-green siliceous argillite is scattered throughout the formation, especially in the lower part.

Hershey (1912, p. 750) used a central purplish-gray bed as a basis of subdivision into two members near Wardner. The thickness of the formation varies somewhat from place to place but approximates 2,000 feet. Possibly the thickness increases west of the Coeur d'Alene region as a recent report on an area in Kootenai and Benewah Counties, Idaho, (Campbell, 1950, p. 8-9, op. cit. p. 207) notes that the thickness there "does not exceed 3,000 feet". In western Montana the Burke and Revett formations have been mapped as a unit. Near the Idaho border the two together total at least 3,000 feet (Wallace and Hosterman, 1956, p. 560-581) and somewhat farther east (Campbell, in prep. 1958) the estimate is 4,500 feet.

In Mineral County, Montana, a major fault zone passes south of the St. Regis River and the two formations together appear to be different on the two sides of the zone (Wallace and Hosterman, 1956, p. 580-581). South of the fault zone they consist of fine-grained greenish gray quartzite with beds commonly 1 to 4 feet thick. White, vitreous quartzite, such as characterizes the Revett farther west in Idaho, is rare. Further, as the purplish-gray color characteristic of the St. Regis formation in Idaho is absent, there is difficulty in fixing the upper limit of the Revett. North of the fault zone light-colored, thick-bedded, vitreous quartzite such as is typical of the Revett is present in several localities. Likewise greenish-gray thin-bedded impure quartzite similar to that which characterizes the Burke in Idaho was noted. The deformation is so intricate that mutual relationships and thicknesses were not satisfactorily determined.

Campbell describes the Burke and Revett formations together in the St. Regis-Superior area. They vary from fine-grained, argillaceous quartzite near the lower contact to purer quartzite above. The rocks are commonly medium to light gray or greenish, the more quartzitic beds being lighter colored, locally with purple tints. Many bedding planes are lined with sericite. Ripple marks and muds cracks are common. Some of the quartzite is crossbedded.

Revett quartzite

The Revett quartzite (Ransome and Calkins, 1908, p. 35-36) is best known in the Coeur d'Alene region in Shoshone County, Idaho, although its equivalents undoubtedly extend beyond that region. Most of it is a pure, rather thick-bedded, white quartzite, although impure, sericitic beds are included. Ripple marks are reported only in the upper and lower parts of the formation. The thickness is approximately 1,000 feet where measured by Ransome and Calkins but locally exceeds 3,400 feet (Shenon and McConnel, 1939, p. 4). Recent work in the Coeur d'Alene region (Hobbs, Warren, written communication, March 28, 1955) indicates that apparent discrepancies in thickness measurements from place to place are due to marked variations in the thickness of the formation within short distances. As an example he cites a measurement of 1,800 feet for the Revett at one place and of 3,400 feet for the same unit less than 5 miles away.

In the purer quartzite, distinctive of the formation, the clastic grains are subangular to rounded, except for secondary quartz overgrowths. While quartz is the principal constituent, a little feldspar and muscovite, apparently of clastic origin, are generally present. Fragments of seemingly detrital slate are also common. Accessory constituents include zircon, magnetite, rutile and tourmaline. Secondary siderite is locally present. The quartzite in Mineral County, Montana, believed to correspond to the Revett, has been grouped with the Burke quartzite in recent studies and available data on it are summarized in the description of the Burke given above.

In Kootenai and Benewah Counties, Idaho, the Revett is composed of medium- to thick-bedded, white-to-tan vitreous quartzite. The more sericitic beds show fine black laminations. Some of the sericitic beds are greenish. A few quartzite beds have small groups of carbonate grains scattered through them. Argillaceous material occurs as partings and thin beds but is nowhere abundant. Ripple marks are present in the sericitic beds but are rare in the massive, vitreous quartzite. The thickness is 1,800 feet at a place where a measurement was made but apparently thickens westward as Anderson (1940, p. 12) reports up to 3,000 feet in the southern part of Kootenai County.

St. Regis formation

Exposures of the St. Regis formation are widely distributed in Shoshone County, Idaho, and probably extend into Boundary County and into neighboring parts of Montana. The formation consists of argillaceous and quartzitic beds with some limy quartzite throughout (Shenon and McConnel, 1939, p. 4). Most of the formation as reported by Shenon and McConnel consists of thin, fine-grained beds in rather bright tints of green and purple, especially the latter. In recent studies (Hobbs, Warren, written communication, May 2, 1956) the color of the St. Regis formation has been found to be very subtle, really bright colors being present locally only. The arenaceous beds are coarser textured and thick. Many of these are purple but some are white. The limy beds weather to an ocherous color. It has been suggested that green colors result from hydrothermal alteration (Shenon and McConnel, 1939, p. 4). Obliteration of the characteristic purple color through alteration is a possible source of misidentification during mapping (Campbell, 1950, p. 12, op. cit. p. 207). Shallow-water features, including intraformational conglomerate, are present throughout the formation. The composition as seen under the microscope is essentially like that of formations already described. The components include quartz, feldspar, perhaps some fine-grained slaty rock, mica, rutile, zircon, and tourmaline. The purple and green colors result from specular hematite and chlorite respectively.

In the Coeur d'Alene region the St. Regis formation is about 1,000 to 1,400 feet thick (Shenon and McConnel, 1939, p. 4). Farther west, where the formation is otherwise similar except that purple is less prevalent, the thickness is about 1,800 feet (Campbell, 1950, p. 12, op. cit. p. 207) and in the north central part of Kootenai County it has been estimated to be about 4,000 feet (Anderson, 1940, p. 12).

Near Mullan, Idaho, (Hobbs, Wallace, and Griggs, 1950, p. 2-5) the St. Regis formation has been divided into two members. The lower member, 1,200 feet thick, is about 60 percent argillite, with subordinate quartzite, 35 percent interlaminated quartzite, and argillite containing more than 25 but less than 75 percent quartzite, and the remaining 5 percent is quartzite with subordinate argillite. Carbonate is recognizable in over 45 percent of the beds in the formation here. Most of it is ankerite but locally the composition approaches that of siderite. It rarely constitutes as much as 20 or 30 percent of the rock and is most abundant in the quartzitic beds. The carbonate is commonly in discrete crystals and clusters of crystals, generally many times larger than the grains of the rest of the rock, but is also found in the cement between detrital grains.

The upper member, 150 to 450 feet thick, is a zone of transition between the St. Regis and Wallace formations. It consists of very fine-grained, in part porcellaneous, light apple-green, thinly laminated siliceous argillite. Rock of this character was formerly grouped with the Wallace formation but is now regarded as more closely allied with the St. Regis.

Near Pend Oreille Lake, Bonner County, the Revett and St. Regis have been grouped together as the Blacktail formation (Sampson, 1928, p. 7). The lower part of the Blacktail is mainly pink quartzite with red shale partings and the upper part consists of alternating red and green argillite, with the red beds in the majority. The aggregate thickness is 8,300 feet.

In Mineral County, Mont., (Wallace and Hosterman, 1956, p. 14-18) the beds of the St. Regis formation differ to the north and south of a major fault zone, in a manner analogous to the Burke and Revett formations previously described. North of the fault zone the St. Regis has essentially the characteristics it has near Mullan, Idaho. To the south a marked facies change begins almost immediately east of the state line. Purplish colors, which in most places are characteristic of the St. Regis formation, become uncommon. They are confined to quartzitic beds, whereas thinly laminated greenish-gray argillite becomes the dominant component of the formation. This argillite is similar to that of the upper member in the Mullan area but far thicker. Five miles east of the state boundary the thickness of the argillite is about 3,000 feet, 3 miles farther east it is over 5,000 feet and 15 miles still farther east it is approximately 1,700 feet. Wallace and Hosterman say that the facies difference might correspond to deposition near a shore in Idaho and offshore farther east in Montana. They add that the thick part of the St. Regis in Montana might include beds that are time equivalents of parts of the Revett below and of the Wallace above, as these formations are mapped in Idaho.

In the St. Regis-Superior area the formation is composed of 1,900-2,200 feet of thin-bedded quartzose argillite, with a few beds of sericitic quartzite. South of the Osborn fault the predominant color is greenish gray varying to dusty yellow green or medium light gray. North of the fault greenish-gray and purplish-gray colors are present. Purple rocks like those in the Coeur d'Alene area are present in sec. 31, T. 18 N., R. 25 W.

Altyn limestone

The Altyn limestone is known within the United States only in Glacier National Park (Ross, in press, 1958). Even here exposures are not widespread and the base is not visible. Most of the formation is a very light gray magnesian limestone or dolomite that weathers a grayish orange, rendering it conspicuous on distant cliffs. Chemical and petrographic data now available indicate that so much of the formation is dolomitic that it would be more appropriately called Altyn dolomite rather than Altyn limestone. The latter name has, however, been in general use for so long that no change is here proposed.

The light gray dolomitic rock that makes up the bulk of the formation is mostly in beds 1/2 to 4 feet thick. Some is siliceous and sandy and a few beds of grit and conglomerate, with a carbonate-rich groundmass occur. Locally, especially near the top of the formation, thin beds of green argillite are intercalated. Some of the carbonate-rich beds weather brown and brownish red, rather than the light buff that characterizes much of the unit.

Rock representative of the major part of the formation has a groundmass of crystalline dolomite with grain diameters ranging from a few hundredths of a millimeter up to about 0.2 millimeter. Rounded bodies, up to at least as much as 2 millimeters in maximum dimension, are scattered through this groundmass and locally concentrated in layers. Some of these may be pebbles but the majority are probably oolites, even though many have lost their internal structure. Rounded to subangular clastic grains, up to several millimeters in maximum diameter are also present. Most of these consist of quartz but many are alkalic plagioclase and some are microcline [redacted]. Some of the grains appear to be bits of a rather coarse-grained granite. Others are fine quartz aggregates that may include silicified oolites. Some of the feldspar is sericitized but much is strikingly fresh. Small amounts of montmorillonite and illite are present. Intraformational conglomerate (edgewise mud breccia) occurs locally. In some specimens (Tweto, 1937, p. 13, 14, op. cit. p. 155) carbonaceous dust is present. Otherwise his description approximates that just given.

The Altyn limestone contains stromatolites at several localities and apparently at several horizons. None seem sufficiently persistent to be of value in stratigraphic correlations. It also contains carbonaceous films that may be fossil remnants. One thin section (Ross, in press, 1958) shows a structure that resembles a piece of a spine of a trilobite or of a chitinous brachiopod [redacted]. This single fragment is indeterminate but it does suggest that some living things in addition to those from which the stromatolites originated existed in Altyn time.

The Fentons divide their Altyn formation (Fenton and Fenton, 1937b, p. 1881-1885) into three members called, in ascending order, the Waterton, Hell Roaring, and Carthew. The lowest of these, reported to be 280 feet thick, is exposed only in Canada, where it has been regarded as a separate formation underlying the Altyn, and with its base not exposed. The Carthew member, 700-900 feet thick, is likewise known only in Canada. Hence the Hell Roaring member of the Fentons corresponds essentially to the Altyn limestone as originally described (Willis, 1902, p. 316, 321). Willis spoke of an upper member of argillaceous ferruginous limestone, 600 feet thick, and a lower member of massive, siliceous limestone with concretions, 800 feet thick. His total thickness is close to the 1,200-1,300 feet that the Fentons assign to their Hell Roaring member of the Altyn but is less than the total thickness of the formation within Glacier National Park which has been estimated (Ross, in press, 1958) at 2,000 to 2,300 feet.

Appekunny formation

Distribution.--The Appekunny formation (or argillite) is best known in and near Glacier National Park but can be traced with considerable confidence southward past Flathead Lake to Ravalli. It is also present near Missoula (Langton, 1935, p. 36, fig. 3) and has been recognized as far east as northeastern Powell County (Clapp and Deiss, 1931, chart opposite p. 691, p. 693). Probably a considerable part of the Ravalli group in Montana west of 114° longitude belongs to the Appekunny formation.

Character.--The original name given these rocks is Appekunny argillite (Willis, 1902, p. 316, 322). However, some of the argillaceous rocks contain considerable carbonate. Quartzite in varying degrees of purity, and, locally in Glacier National Park, some slate is included. The diversity in lithologic character seems to justify changing the name from Appekunny argillite to Appekunny formation. A large part of the formation contains more than 70 percent silica and originated as a sandstone rather than a mudstone, so that argillite is an inappropriate name for many, probably most, of the beds. The somber colors of many outcrops give a deceptive impression of the proportion of argillaceous matter present. The descriptions here given are based mainly on data assembled by the writer and his coworkers in and near Glacier National Park.

Most of the rocks are thick bedded, and weather in joint blocks with dimensions of one to several feet. Thin-bedded members occur locally and in areas of marked deformation show slaty cleavage. Most beds are gray to black with various tints of green and blue, few are reddish. The comparatively pure quartzite beds are nearly white. Many beds contain thin, indistinct laminae, some of which appear to have been broken since the consolidation of the rock. Ripple marks, mud cracks, and intraformational conglomerate are common and rain and sleet impressions have been reported.

The principal minerals include quartz, feldspar, (mainly sodic plagioclase), sericite, bleached biotite, chlorite and carbonate, largely magnesian. The more quartzitic beds have not been studied microscopically. In many of the others original, detrital rounded to subangular grains of quartz and feldspar are fairly common but many rocks consist mainly of quartz mosaics in which the original texture has been obliterated. Few grains exceed 0.1 millimeter in maximum dimension and in many beds the grain size is much less. The micaceous minerals and the carbonate are probably secondary. Part of the feldspar, also, appears to have been recrystallized. None of the rocks appear to contain more than about ten percent feldspar and in some it is rare or absent. Very small amounts of montmorillonite are present and some of the rock contains illite. One sample appears to contain kaolinite. [redacted]

The Fentons (1937b, p. 1885, 1887), who saw the Appekunny in the northern part of Glacier National Park and in Waterton Lakes Park across the border in Canada, consider it to be made up of three members. The lowest of these, the Singleshot, includes dolomite and dolomitic rocks interbedded with argillite and quartzite. It is allied to and has probably been included with the underlying Altyn limestone by most workers. The second and thickest of the Fentons' members is the Appistoki. It corresponds in character and thickness to the Appekunny as originally defined (Willis, 1902, p. 322). The Fentons describe it as containing gray, green, olive-brown and rusty-gray argillite in thin minor but thick major beds, interbedded with thickly stratified greenish, white, or pink quartzite. Intraformational conglomerate and other features of shallow water deposition are prevalent. The thickness is 2,000 to 2,200 feet. The uppermost or Scenic Point member of the Fentons appears from their description to resemble parts of the Grinnell. Perhaps it should be included with that formation. They describe it as argillite, sandstone, and "gravelly conglomerate"; green, purplish, buff, brown and dull brownish red at the type locality, which is in the southeastern part of Glacier National Park. Presumably the term "gravelly conglomerate" is intended to indicate that intraformational conglomerate is not meant. To the north and south the member is reported to grade into thickly bedded, coarsely mud-cracked argillite, which gives way to thick quartzite and subordinate gray and iron-stained argillite. The member is 200 to 700 feet thick. The Fentons' subdivisions of the Appekunny formation cannot be traced far enough to be valid as formally named units (Ross, in press 1958).

The Fentons estimate the Appekunny formation in "its eastern phases" (1937b, p. 1885) as 2,500 to 5,300 feet thick. South of Glacier National Park the thickness is surely as much as 2,000 feet and in the Swan Range it may exceed 5,000, as estimated from mapping by the writer (Ross, in press, 1958). Clapp's (1932, p. 22) estimate of thickness is 3,500 to 10,000 feet but he cites no specific localities. Langton (1935, p. 36), presumably for the area south of Missoula, speaks of the formation as predominantly massive, bluish-gray and light-gray quartzite grading downward into massive gray quartzite, the total thickness being over 6,000 feet.

The rock along Rock Creek southeast of Missoula believed to belong to the Appekunny formation is an argillaceous quartzite. It is a laminated rock predominantly medium gray on fresh surfaces, with some pinkish-gray laminae. It contains some nearly black clay spalls and some surfaces are ripple marked. This rock has a groundmass consisting mainly of interlocking quartz grains up to about 0.06 millimeter in diameter, with a few plagioclase grains and some others that may be altered feldspar. Green biotite, chlorite, sericite and montmorillonite are present and carbonate grains are locally segregated.

Grinnell formation

The distribution of the Grinnell is much the same as that of the Appekunny. It may not extend as far west as the Appekunny probably does but neither formation has been much studied west of 114° longitude. Like the Appekunny, the Grinnell seems more satisfactorily described as a formation than as an argillite. One of the samples analyzed contains about 69 percent silica, less than is recorded for beds of the Appekunny formation. On the other hand, one analyzed sample contains nearly 84 percent silica and some beds in the formation appear distinctly more siliceous than this. Carbonate rocks have not been recorded, except in the transition zone at the top of the formation. If a single lithologic term had to be used to describe the Grinnell formation, quartzite would be as much or more accurate than argillite.

Most of the formation is rather thin and even bedded, the characteristic color is red purple, with more distinctly purplish hues than most of the reddish beds in the Belt series. Greenish beds are locally common and the purer quartzite beds are nearly white. The colors noted in and south of Glacier National Park include pale and grayish blue green, grayish purple and grayish red purple. South of Missoula the rocks have purplish tints but are far less strikingly colored than in Glacier National Park. Ripple marks, mud cracks, and intraformational conglomerate are fairly plentiful. The surfaces of some quartzite beds have bulbous forms of unknown origin. Thin laminae of reddish argillite are interleaved with quartzite. Some of these were broken soon after deposition and slabs from them are incorporated in the quartzite [redacted]. In some of the argillaceous rocks also similar evidence of disturbance while unconsolidated is observable in thin section.

Microscopic examination [redacted] indicates that most of the Grinnell formation originally ranged from a siliceous mudstone to an arkosic sandstone. In the more argillaceous rocks individual grains are only a few hundredths of a millimeter in diameter but in the coarser layers the grain diameter ranges from 0.4 millimeter to over a millimeter. Locally large grains are irregularly scattered through a fine matrix. The argillaceous rocks now consist largely of quartz and fine-grained mica, with some feldspar and, locally, carbonate. Montmorillonite is common and some rocks contain illite. The coarser rocks are similar except that micaceous minerals are less abundant. Feldspar, largely alkalic plagioclase, is more conspicuous in these rocks but some of it may have escaped recognition in the finer rocks. Some grains are themselves fragments of fine-grained sedimentary rocks and some of the quartz grains had strain-shadows before they were incorporated in the rock. Original textures seem better preserved in the Grinnell formation than in the Appekunny formation but this impression may be based in part on the coarser grain of the rocks of the Grinnell that were examined petrographically.

Locally the Grinnell formation might be divided into members but it is doubtful if these could be traced far. In the northern Swan Range three poorly defined members have been noted. The lowest and thickest of these is dominantly pale and grayish-red-purple argillite. In the next member above the red-purple beds decrease upwards and much of the rock is quartzitic argillite and argillaceous quartzite, with thin argillite partings, generally rather dark red purple. Some partings more nearly resemble parts of the argillite of the Missoula group and of the purple-red argillite in the Grinnell farther north than any of the thicker beds in the Swan Range. The uppermost member commonly consists of grayish-blue-green calcareous argillite and argillaceous limestone, constituting a transition zone below the Siyeh limestone of 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 zone was mapped in the Swan Range whereas the two members beneath it, mostly poorly exposed, were not mapped. Even the transition zone is so poorly defined that it was not mapped farther north in Glacier National Park (Ross, in press, 1958). The presence of limestone raises a question as to whether the transition zone should not be regarded as part of the Piegan group, but the zone seems more closely allied to the Grinnell formation and is included therewith largely on the basis of content of argillaceous matter.

The Fentons (1937b, p. 1887-1890) studied the Grinnell argillite mainly in and north of northern Glacier National Park. They proposed three members that differ from those just described. The lowest, which they call the Rising Wolf member, contains white and pink quartzite interbedded with red argillite in layers that range from mere laminae to beds 5 feet thick. Some green beds are present. The member is reported to be 200 to 700 feet thick and not everywhere clearly distinguishable. The middle member is called the Red Gap member by the Fentons and is of varied character. It consists of argillite in thin minor and thick major beds, dominantly red but incidentally brownish or green, interbedded with pink, white, or greenish-white quartzite, brown sandstone, and sandy argillite. The maximum reported thickness is 2,800 feet but in places it thins to as little as 650 feet.

The upper part of the formation is called the Rising Bull member by the Fentons and is reported to contain argillite, quartzite and mud breccia (intraformational conglomerate) forming the initial transition between the Grinnell and the Siyeh. It shows gray, red, green, pink, and white colors. The thickness is given as 600 to 1,100 feet. In and west of Waterton Lakes Park in Canada, immediately north of Glacier National Park, a thin flow of amygdaloidal lava is intercalated in the upper part of this upper member but no lava has been found in the Grinnell formation anywhere south of the International Boundary. As suggested above, the Scenic Point member of the Appekunny as recognized by the Fentons may belong to the Grinnell rather than the Appekunny.

Note that the colors mentioned above are those of the Fentons and do not correspond to the usage of the Rock-Color Chart.

The wide range in estimated thickness and lithologic character of the Grinnell formation in and near Glacier National Park reflects much lateral variation. The poor exposures in the northern part of the Swan Range prevent accurate measurement but the total thickness there is roughly 5,000 feet. In the southern part of Glacier National Park, some 25 miles to the northeast, the thickness is close to 2,000 feet. Willis (1902, p. 322-323) estimated the thickness in the northern part of the Park as 1,000 to 1,800 feet. The Fentons (1937b, p. 1887) give a range in thickness of 1,500 feet to 3,500 feet. Dyson (1949, p. 7) says the thickness varies considerably but is greater than 3,000 feet in several localities in the Park.

Clapp (1932, p. 22) estimated the thickness of the Grinnell in the part of northwestern Montana shown on his generalized map as 2,000 to 3,500 feet. His map includes most of the definitely known exposures of the formation. Langton (1935, p. 36), whose work was south of Missoula, describes the Grinnell as composed of bluish-gray, fine-grained, thin-bedded argillite, grading downward into more massive-bedded gray quartzitic argillite, commonly ripple marked and with layers of reddish-gray quartzite, the aggregate thickness being about 7,000 feet.

On Rock Creek southeast of Missoula rock believed to belong to the Grinnell formation is light grayish red purple except in the immediate vicinity of intrusive masses, where it may be green. It is an indistinctly laminated quartzite composed of quartz with some plagioclase, minor amounts of bleached biotite and a little pyrite, hematite and leucoxene. Some grains consist of felted mats of sericite, montmorillonite, and illite. The quartz and feldspar are in interlocking grains, some of which exceed 0.1 millimeter in length.

Chamberlain shale

The Chamberlain shale is known only in the immediate vicinity of Neihart although possible equivalents have been reported farther south (Verrall, 1955). It grades into the Newland limestone (Piegan group) above and the Neihart quartzite below, but otherwise no evidence is available as to its stratigraphic relations. It is here assumed to belong to the Ravalli group.

The formation is described (Weed, 1900, p. 282) as composed of dark-gray, almost black shale, largely arenaceous, with some ripple marks. The rocks are slaty and jointed. At the base, transition into the underlying Neihart is shown by admixture of arenaceous and micaceous material. The middle part of the formation is mainly black shale. In the upper part calcareous shale appears, increasing upward until the unit merges with the overlying Newland limestone.

Tweto (1937, p. 14, op. cit. p. 155) describes a specimen from Sawmill Creek, southeast of Neihart, as dark green-black, thin-bedded, very fine grained fissile shale consisting essentially of colloidal clay minerals and sericite with small amounts of pyrite, dolomite, quartz, feldspar, and graphite.

Material collected by Richard Rezak [redacted] from the Chamberlain shale south of Neihart is a nearly black quartzitic shale, irregularly laminated and with clay spalls on bedding planes. It contains subangular to angular quartz grains up to 0.05 millimeter in diameter with a few mica flakes in a mat of quartz grains and micaceous shreds up to 0.005 millimeter in maximum dimension, which includes some illite.

Piegan group

Foreword

The Piegan group of the present report comprises the Wallace, Siyeh and Newland formations of most recent writers. Inasmuch as these three terms are roughly synonymous, the area in Montana within which each is to be applied must be decided arbitrarily. The basis here adopted is to speak of the Wallace formation in the area from the Idaho boundary eastward to the vicinity of 114°30' longitude. Where masses of carbonate rock believed to belong to the Piegan group cross this longitude they are mapped with the noncommittal group name [redacted]. Similarly in the mountains north of the Flathead Valley and west of the northern reaches of the Flathead River as well as in the Mission Range the term Piegan group is employed. Here "Siyeh limestone" is an alternative designation but the rocks are as yet so little studied that the group term is more appropriate. In and near Glacier National Park and from there to the southern part of the Swan Range the name Siyeh limestone is the most suitable. South of here and east of 114°30' longitude Newland limestone is the preferred designation, although usage has not been strictly uniform.

[redacted]

It will be seen from the above remarks that at any particular locality the Piegan group is represented at present by a single, named map unit. Each of these thick units, now termed "formations", is probably divisible, when detailed work is done, into subdivisions worthy of being ranked as formations, rather than members. This was done partially in early maps of the southern part of Shoshone County, Idaho (Pardee, 1911, pl. 2, Umpleby and Jones, 1923, pl. 1). The descriptions that follow show that additional subdivisions of the Wallace formation are known to be possible and that major subdivisions of the Siyeh limestone have already been suggested. Rocks now called Newland limestone are neither as widespread nor as thick as the Wallace and Siyeh but are not uniform, and may be susceptible of subdivision into units of the rank of formations rather than mere members.

Wallace formation

<u>Distribution</u>.--The Wallace formation is exposed at intervals in Idaho from south of latitude of 47° to the Canadian border. It is also fairly widespread in Mineral, Saunders, and Lincoln Counties, Mont. Another mass that has been so designed extends, with interruptions, from the northeast corner of Lincoln County southeastward to the vicinity of Kalispell. This mass is so little known that it might best be referred to merely as belonging to the Piegan group. Farther south near the Clark Fork between Rivulet and Missoula the rocks of the Piegan group have been called Wallace (Ross, Andrews, Witkind, 1955) but this decision was arbitrary. At one time all the rocks now called Wallace were given the name Newland (Calkins, 1909, p. 38).

Character.--The Wallace formation is the most heterogeneous in the Coeur d'Alene region (Ransome and Calkins, 1908, p. 40-43). It includes thin-bedded, fine-grained calcareous quartzite, impure limestone and shale, largely calcareous and with slaty cleavage. All these rocks are marked by mud cracks, ripple marks, and related indications of deposition in shallow water. The conspicuous lamination in many beds is one of the diagnostic features of the formation. According to Calkins (Ransome and Calkins, 1908, p. 40-43) the lowermost part consists mainly of gray-green slaty rock mostly calcareous or dolomitic. The middle part of the unit includes bluish and greenish argillite, limestone and calcareous quartzite, and presents a banded appearance in weathered outcrops because of the alteration of white quartzite, yellow-weathered limestone, and greenish and bluish argillite. In the uppermost part of the formation argillite predominates and the white beds of calcareous quartzite prominent in the middle part are absent. The argillite in the upper member is especially distinctly laminated. Clusters of weathered siderite grains such as are prominent in the formation below are present in argillaceous beds in the Wallace but absent in the quartzitic beds. Calkins thought most of the carbonate in the formation was distinctly magnesian but reported some calcite. Slaty cleavage is better developed in the lower than in the higher beds, and Calkins felt that this could not be explained entirely on lithologic grounds. The composition of the rocks of the Wallace formation as seen under the microscope has many similarities to that of rocks already described. Quartz, feldspar, sericite, muscovite, chlorite, carbonate plus such minor constituents as zircon, tourmaline, magnetite, leucoxene, and carbonaceous dust are reported. The calcareous quartzite of the middle member is arkosic.

In five specimens from the Wallace formation in eastern Shoshone County furnished by Warren Hobbs no carbonate is present. They include argillite, and quartzitic rocks, mostly with feldspar. They are strikingly laminated in different shades of gray. The component grains range from 0.01 to 0.10 millimeter in diameter.

Calkins emphasizes the difficulty in measuring the thickness of the Wallace both because it is broken by many faults and because the argillite is over-thickened because of minute folds. He concludes that the formation can hardly be less than 4,000 feet thick. Umpleby and Jones (1923, p. 8) estimate 4,000 to 6,000 feet. Anderson (1930b, p. 18) says the thickness north of the Coeur d'Alene region is more than 4,000 feet. Shenon and McConnel (1939, p. 5) say that locally the Wallace can be divided into four members. They estimate the total thickness in the Coeur d'Alene area as between 4,500 and 6,000 feet.

Between the southern Coeur d'Alene region and the St. Joe River five subdivisions of the Wallace formation have been mapped (Wagner, 1949, p. 12-13, pl. 1). The lowest is a heterogeneous sequence of thin-bedded, light-gray to dark-gray, laminated, impure and mostly calcareous quartzite, shale and sandstone with some limestone. The next consists of alternating calcareous or magnesian sandstone, with a few limestone beds, and black, mostly noncalcareous shale. The purer limestone beds in this unit show molar tooth structure. Weathered surfaces of the unit are strikingly banded. The third member consists largely of noncalcareous black shale, in part metamorphosed to phyllite or slate. The fourth member is a thin-bedded, light-gray-green to dark-gray, sandy, calcareous or dolomitic argillite. The uppermost member is largely black, noncalcareous shale or argillite with paper thin laminae. These beds grade upward into more arenaceous rocks in the transition zone at the base of the Striped Peak formation. Wagner estimates the entire thickness of the formation where he studied it as less than 4,500 feet.

In Kootenai County (Anderson, 1940, p. 12-13) the Wallace has 3 principal members much like those described by Calkins for the Coeur d'Alene region and is estimated to be not less than 5,000 feet thick. In the area in Kootenai and Benewah Counties studied by Campbell (1950, p. 14-15, op. cit. p. 207) the Wallace formation is much as it is where described by Wagner in the area immediately to the east. It is, however, composed only of the lower 3 of the 5 members described by Wagner.

Near Mullan, Idaho, (Hobbs, Wallace, and Griggs, 1950, p. 5-8) the part of the Wallace formation studied is thought to correspond to the 2 lowest members described by Wagner and to the lowest of the 4 described by Shenon and McConnel. In the Mullan area the rocks are very fine-grained quartzite and argillite and intermediate rocks. Ankerite and related carbonates are abundant throughout. Limestone is rare. In most carbonate-bearing beds the relatively pure carbonate occupies the cores of structures, 1 to 2 inches in diameter, that form layers along one or more bedding planes. The part of the formation exposed in the Mullan area is approximately 2,600 feet thick.

In the Libby and Trout Creek quadrangles [redacted] (Gibson, 1948, p. 13-16, Gibson, Jenks, and Campbell, 1941, p. 371-374) the Wallace formation is widespread, thick, and, as usual, is lithologically heterogeneous. The principal component is gray to greenish-gray sandy argillite, largely calcareous or dolomitic and slightly ferruginous, with intercalated thick- to thin-bedded gray, greenish-gray, and brownish calcareous sandstone. A very thinly laminated, soft sericitic, light-gray to buff, slightly calcareous shale is present at several horizons. This shale is readily recognized whereas some of the other components of the Wallace might be confused with parts of other formations.

Stromatolitic dolomite or dolomitic limestone is reported to be the most characteristic rock in the Wallace formation of the Libby area and is present at several horizons there. This rock is light gray, pale greenish gray, or nearly white on fresh fracture. The unweathered rock is seemingly homogeneous, without visible lamination or hint of organic origin. Where weathered, the rock is dark gray or buff, and at the exposed surface, brown of various shades. There curved laminae, with the shapes typical of stromatolites, are emphasized through slight differences in color, hardness, and mineral composition. Richard Rezak, after his studies of stromatolites in Glacier National Park, found many similarities in the Libby area. As noted earlier it is not now possible to use stromatolites as index fossils over distances comparable to those that separate Glacier National Park and Libby, but this remains among the possibilities to be born in mind. The carbonate rocks in the Wallace in areas south of Libby display "molar tooth" structures (Gibson, Jenks, Campbell, 1941, p. 373). Some beds near Libby are oolitic [redacted].

Gibson locally included some dominantly red beds with especially well developed ripple marks in the Wallace formation near Libby, noting that these beds resemble the overlying Striped Peak formation, here regarded as a component of the Missoula group. Presumably Gibson's red beds in the Wallace are approximately analogous to Clapp's (1932) "red band in the Siyeh". According to the definitions of this report, Gibson's red beds in the Wallace and any carbonate beds above them would be regarded as belonging to the Missoula group. Gibson notes that the Wallace formation in the Libby area is thick, possibly reaching a maximum of 17,000 feet. The red beds he thought of as in the upper third of the formation are a few hundred to as much as 1,000 feet thick, but it is not clear how much of the total thickness given in stratigraphically above the red bed horizon and therefore presumably to be correlated with the Missoula group as here used. Gibson indicates that the Wallace formation thins southward to only 7,000 feet in the southern Trout Creek quadrangle.

To the southeast, in Mineral County, Mont., the Wallace formation is widespread (Wallace and Hosterman, 1956, p. 19-21). It is similar to the equivalent rocks near Mullan, Idaho, except for a somewhat greater degree of metamorphism. In Mineral County the rocks are termed phyllite, crystalline limestone and limy quartzite. Four members were noted but not mapped separately. The thickness in the western part of the County appears to be at least 6,500 feet, with the top missing.

[redacted]

In the St. Regis-Superior area (Campbell, 1958, in prep.) the Wallace formation comprizes at least two lithologic units. The lower one is composed of 6,000 feet and of thin-bedded, dark-gray argillite or phyllite interbedded with thin-bedded light-gray quartzite, all more or less dolomitic. Impure limestone and dolomite are interspersed throughout the unit, and these show molar-tooth structures locally. The upper 1 of the 2 units composing the formation is about 4,000 feet thick and includes 65-70 percent of thin-bedded, light-gray, quartzite that is slightly sericitic and in part dolomitic. Black argillite accounts for 10-15 percent of the unit. The black argillite is interbedded with light-gray quartzite so as to form a conspicuously layered rock, characteristic of the upper part of the Wallace formation. The remaining 20-25 percent of the upper unit comprises medium to dark-gray silty dolomitic limestone to limy siltstone.

Little information in regard to rocks commonly called Wallace east of Superior is at hand. Near and east of Missoula their approximate stratigraphic equivalents are termed "Newland" formation or limestone and, to the north, "Siyeh" limestone and are described below under these names.

Newland limestone

Distribution.--Comparatively small parts of the Piegan group are now termed Newland limestone, or, if one prefers, Newland formation. The only masses incontrovertibly so named are in and near the Big and Little Belt Mountains. For some distance west of there the only components of the Belt series exposed are post-Newland. Near Philipsburg and Missoula the name Newland has been applied in the past and is retained in the present report for calcareous rocks stratigraphically beneath those here assigned to the Missoula group. Near Philipsburg the unit has been called Newland formation rather than Newland limestone (Calkins and Emmons, 1915, p. 4).

Character.--The western exposures of the Newland limestone are described first. Near Missoula few details are available. Clapp and Deiss (1931, p. 693) speak of the unit near Missoula as the "Lower Wallace limestone" and, in their figure 3, Correlation table of the Belt rocks of Montana, list it as Wallace limestone 7,800 feet thick, not divided in the table into upper and lower components. The reasons for their usage have already been discussed. Langton (1935, p. 36) cites the unit in a table as the Newland, 4,000± feet thick, comprising "impure argillitic, dolomitic, and sideritic limestones, with some blue, thin-bedded argillites grading downward into more massive-bedded gray quartzitic argillites commonly ripple-marked and with layers of reddish-gray quartzites". The chemical composition of a specimen obtained from the east side of Rock Creek just outside of the area mapped by Langton is shown in table 5 [redacted]. It is a highly impure magnesian limestone, with irregular structures that may be stromatolitic. Similar structures are common in limestone near Missoula. The stromatolite heads here, however, are not as distinctly formed as those in Glacier National Park. The rock analyzed and others nearby consist mainly of carbonate and quartz with some plagioclase and microcline, with lesser amounts of muscovite, chlorite, zircon, epidote, and rutile, of which the last three appear to be detrital. A little clay may be present. Grain diameters range from 0.005 to 0.06 millimeter. Some of the feldspar has crystal form but with rounded and broken corners and edges.

Near Philipsburg (Calkins and Emmons, 1915, p. 4, Emmons and Calkins, 1913, p. 41-45) the unit is called the Newland formation. Calkins entertained the possibility that the Newland as mapped by him includes the Greyson. This suggestion appears to have been made in an attempt to bring the stratigraphic succession near Philipsburg into harmony with that in the Big Belt Mountains. As the two localities are some 80 miles apart this does not now seem necessary. Calkins says that, in the Philipsburg quadrangle, the basal part of the Newland is dark argillaceous rock with thin beds of impure limestone, constituting a transition zone with the Ravalli formation below. Most of the Newland consists of fine-grained, thin-bedded, slabby calcareous rock, with a little interbedded calcareous quartzite or sandstone. The uppermost few hundred feet of the formation consist of drab- to greenish-gray, fissile calcareous shale. The total thickness of the formation is about 4,000 feet. In the second publication on the Philipsburg area Calkins notes that the formation, while distinctly more calcareous than those above and below "as a whole cannot very accurately be called limestone". The analysis quoted in table 6 [redacted], shows that carbonates constitute much less than half the rock. However, Calkins says that under the microscope the rocks of the Newland formation consist mainly of quartz and somewhat more abundant carbonate, thus an impure limestone. Feldspar can generally be identified in these rocks. Sericite is invariably present. Biotite, chlorite, zircon, carbonaceous dust, and tourmaline are subordinate constituents. The grains are measurable in hundredths or thousandths of a millimeter. In the Philipsburg area the Newland formation has undergone contact metamorphism locally.

Newland limestone is exposed northeast of Philipsburg, particularly along the upper Blackfoot River, but available details are meager. Tweto (1937, p. 15-16, op. cit. p. 155) has described a rock from this formation near the upper reaches of the Blackfoot River, east of Ovando, Powell County, as a pebbly, oolitic, siliceous limestone. It consists essentially of calcite and quartz with minor amounts of dolomite, ankerite, feldspar, magnetite, and argillaceous matter. The oolites are deformed, and the concentric structure is poorly preserved. They are partially or wholly surrounded by coronas of comb-structured quartz. The matrix in which the oolites lie is argillaceous limestone with abundant quartz. The quartz is in part secondary, in part in silt-size clastic grains.

Farther east and south in the Little and Big Belt Mountains, exposures are somewhat larger and information is more complete. The following summary is based largely on work in the Canyon Ferry quadrangle, (Mertie, Fischer, and Hobbs, 1951), supplemented by personal observations.

In the Big Belt Mountains the Newland limestone is reported to be a uniformly dense, dark-gray, dolomitic limestone, thinly and evenly bedded, except in its upper part. Much of it is more impure than this description suggests. Material from a gulch that reaches Lake Sewall near Canyon Ferry is only about half carbonate, the rest of the rock being mainly quartz plus some feldspar and mica. A little illite and probably montmorillonite are present. Much of it is in grains up to 0.03 millimeter long but a few elongate feldspar grains are over 0.10 millimeter long. This rock is indistinctly laminated on a microscopic scale. The limestone forms abundant float of brown platy fragments that superficially resemble a hard fissile shale. This feature is more conspicuous in the Big Belt Mountains, especially their western flank, than in any other locality familiar to the writer. Thin beds of limestone and shale alternate in the upper part of the Newland, constituting a transition zone between that formation and the overlying Greyson shale. The Newland has been estimated to be about 2,000 feet thick in the Big Belt Mountains (Mertie and others, 1951, p. 18; Walcott, 1899, p. 206).

Pardee and Schrader (1933, p. 124-125) described the unit in much the same area as consisting mainly of fine-grained to dense dark-bluish-bray beds that weather buff or yellow. The bedding is closely spaced and commonly obscured by slaty cleavage, locally very pronounced. The thickness is estimated as 4,500 feet.

[redacted]

In the Little Belt Mountains the Newland limestone has been studied in some detail near Neihart (Weed, 1900, p. 282-283). The lower part here consists of alternating limestone and shale with the limestone increasing upward. The central part consists of massive, dense, dark-blue limestone with streaks and irregular markings of white calcite, and carbonaceous stains. The beds are 366 feet thick. The rock weathers buff. Near Neihart the formation is about 560 feet thick but along Newland Creek, the type locality, the thickness is reported to be much greater.

Here Tweto (1937, p. 14-15, op. cit. p. 155) speaks of the rock as faded black, rusty-weathering, thick-bedded, fine-grained, argillaceous limestone. The principal component is calcite but quartz, feldspar, graphite, sericite, muscovite, garnet and chlorite are also present. The limestone is microcrystalline and contains rare, silt-size clastic grains. Presumably the latter are composed of quartz and feldspar. A specimen collected by Richard Rezak is a medium-gray, massive limestone. It consists of an even-granular aggregate of carbonate (mostly calcite) with some quartz. The grains are about 0.005 millimeter in average diameter.

Exposures of the Belt series east and northeast of Logan have recently been described by Verrall (1955, p. 115-30) who correlated much of the sequence with the Newland limestone and part with the Chamberlain shale. The beds he regarded as correlative with the Chamberlain include buff and gray argillite with minor reddish argillite, greenish, coarse micaceous arkose and gray, dense, thin-bedded limestone, totaling over 3,388 feet. As Verrall noted, this assemblage differs markedly in character and thickness from the Chamberlain shale of the type locality more than 60 miles to the north. Above this unit Verrall reported supposed Newland limestone made up of greenish-brown, coarse, micaceous arkose, interbedded with buff, pink and gray beds of argillite and medium to thin-bedded dense limestone with layers of dense, black calcareous concretions and some dolomitized limestone with features resembling molar tooth structures. At the base is a stromatolite reef, that Verrall regarded as similar to the <u>Collenia symmetrica</u> zone of the Fentons (1937b, 1894-1895, 1942-1947), a suggestion of doubtful validity in the present state of knowledge relative to stromatolites as stratigraphic indicators. The thickness of the supposed Newland limestone aggregates over 1,560 feet. Klemme (1949, p. 6-7) had previously regarded the unit as Spokane shale, as assignment now in serious doubt as Robinson (1959, written communication) has found that the Spokane pinches out west of Verrall's area. All of the beds described by Verrall include so much arkose that they are regarded here [redacted] as belonging to the North Boulder group; presumably stratigraphically low in that group.

Siyeh limestone

Distribution.--The only part of the Piegan group that remains to be described is the Siyeh limestone. This is recognized in the Lewis and Livingstone ranges of Glacier National Park, and the Flathead and Swan Ranges farther south. Carbonate rocks both west and south of these ranges are so similar to the Siyeh that they are likely to be assigned to that formation when further work is done. It may be noted, that the term "Siyeh" has been applied by some geologists as far south as the north side of the Blackfoot River a short distance south of latitude 47° (Clapp and Deiss, 1931, p. 683-684).

Character.--In the Glacier National Park region (Ross, 1958, in press) the limestone differs in many details from place to place, sufficiently so that local subdivisions will be required when detailed studies are undertaken. Lateral variation is so marked that many of these will prove to be valid only over a few score or a few hundred square miles. Within Glacier National Park the Siyeh limestone is mainly an impure and somewhat magnesium limestone, as indicated by the analyses in table 6, and table 8. Some strata are more argillaceous than those represented in the two tables and thin beds of argillite exist. However, the Siyeh limestone as restricted in the present report (p. 112-115) contains no assemblages of argillite or of distinctly argillaceous limestone.

Among the subdivisions of the Siyeh limestone that may be expected are the three suggested by Rezak (1957) on the basis of stromatolite content. His lowest subdivision or zone in the Siyeh is the Collenia symmetrica zone 1. This zone comprises the lower two-thirds of the formation and was divided into two unmapped members by the Fentons (1937b, p. 1892-1897). Rezak's second zone is called Conophyton zone 1 and corresponds essentially to the Collenia frequens zone of the Fentons. This zone forms massive gray ledges that were noted by the men of M. R. Campbell's parties even before they came to realize the probable organic nature of the material. It is the most conspicuous stromatolite zone in Glacier National Park and the only one that has been mapped (Ross, 1958, in press). This zone has itself three components, of which the lowest is characterized by Collenia frequens Walcott, the middle part by Conophyton inclinatum Rezak, and the uppermost by Collenia multiflabella Rezak and Cryptozoan occidentale Dawson. The colonies of Conophyton inclinatum in the middle part are the most conspicuous features of the zones and are identical with those previously called Collenia frequens in this same zone. Stromatolite names in the present report are those of Rezak and in many instances differ drastically from those of previous writers.

Nearly all of the Siyeh limestone is thick bedded or massive as viewed from a distance but close examination shows it to be thinly laminated. Some is oolitic. Fresh surfaces are dusky blue, or more rarely greenish gray, with variations related to the composition of the rock. Weathered surfaces show various orange and brownish tones and commonly display irregular etched marking that corresponds to differences in the calcium carbonate content of the rock. They include the forms termed "molar tooth" structures by Daly (1912, p. 72-76) but with infinite variety in the details so that many have no resemblance to molar-tooth markings. Under the microscope the rock is seen to consist of carbonate, and quartz with some sericite. In most beds individual grains of the major constituents are a few thousandths to a few hundredths of a millimeter in diameter and accessory minerals are in such minute grains and small amounts that they were not determined. Microscopic irregularities in texture, related to the "molar tooth" and similar structures so conspicuous in outcrops, are plentiful [redacted]. Well-defined oolites are not common but many of the rocks seem to contain recrystallized oolites. Where oolites are preserved some are roughly elliptical in section and 1 to 2 millimeters long. These retain no internal structure. Other oolites are circular in section and have well-preserved concentric structure within them [redacted]. The two varieties may occur in the same rock. Some of the round oolites are broken and others are invaded in their outer layers by grains of clastic quartz. Most of the round oolites are less than a millimeter in diameter and are themselves components of pebblelike masses embedded in the fine-grained limestone [redacted]. While the predominant constituent of the Siyeh limestone is carbonate, cryptocrystalline silica is common, clastic grains of quartz are discernible locally and some strata contain minerals of micaceous habit. The last mentioned are largely sericite but include some montmorillonite and illite.

Stromatolites are present throughout the Siyeh limestone of Glacier National Park and may be more abundant and well preserved there than in other parts of western Montana. However, they have been found in all exposures of the Piegan group in which they have been searched for and may be more widespread and abundant than is now realized.

Missoula group

Foreword

In the present paper the definition of the Missoula group has been more drastically revised than those of other groups of the Belt series. As a consequence the group extends lower stratigraphically than earlier usage would imply. The change results largely from work in the Glacier National Park region (Ross, 1958, in press). The group is more widespread than might have been supposed from earlier reports, a fact that seems implied in the paper by Clapp and Deiss (1931). The best known exposures specifically assigned to the Missoula group extend from Missoula northeastward but broadly equivalent rocks are known from northern Idaho eastward into the Little Belt Mountains and from near Dillon to beyond the Canadian boundary. The group, as now defined, includes a large part of the Belt series in the Big and Little Belt Mountains, where the series name originated. The revision of the definition transfers much of the material in these mountains that was included in the Piegan group on the Montana State Geologic Map into the Missoula. The revised definition and the reasons for it were discussed on pages 113-120 but the essential features may be summed up in the statement that the Missoula group includes all of the Belt series stratigraphically higher than the great thicknesses of carbonate-rich rocks of the Piegan group. Thus, the Missoula group is characterized by an abundance of red and green clastic rocks, although other rocks, including some limestone, are present within it.

Striped Peak formation

Distribution.--The Striped Peak formation was first named and is best known in the Coeur d'Alene region, Shoshone County, Idaho. In Shoshone County it occurs only in scattered remnants, being less widely distributed than any other formation in the Belt series (Umpleby and Jones, 1923, p. 9). It has been recognized farther west in Kootenai (Anderson, 1940, p. 13) and Bonner (Sampson, 1928, p. 8) Counties, Idaho. Strata that resemble the Striped Peak formation have been noted at intervals from the Coeur d'Alene region northward to the international boundary (Calkins, 1909, p. 38-39, 41). Apparently the localities are mainly in the northwestern part of Montana (Calkins, 1909, p. 41, pl. 1). No rocks that appear to correspond to the Striped Peak formation are reported in Boundary County, Idaho (Kirkham and Ellis, 1926, p. 17, 18, 27). The unit has been mapped in the Libby and Trout Creek quadrangles [redacted] Montana (Gibson, 1948, p. 16-17, pl. 1, Gibson, Jenks, and Campbell, 1941, p. 374-376). Presumably rocks equivalent in age to the Striped Peak formation are present elsewhere in Montana but these, where they have been described at all, are given other names. The distances between outcrops are such that direct correlation is impossible.

Character.--In the Coeur d'Alene region (Ransome and Calkins, 1908, p. 44) the Striped Peak formation is composed of thin-bedded shale and quartzite sandstone with ripple marks and sun cracks. Most of it is reddish purple and green. The thickness at the type locality is about 1,000 feet. Immediately to the south (Wagner, 1949, p. 13-16) the formation is reported to consist of alternating beds of pinkish-gray sandstone and greenish-gray shale in the lower 500 feet of the unit, and lavender sandstone and deep-purple shale above this. The argillaceous beds in the lower part are thicker and show less shaly partings than those higher in the sequence. Ripple marks and mud cracks are present. The sandstone, or perhaps more properly the impure quartzite, consists of grains of quartz with sericite and a little feldspar embedded in a dark, fine-grained matrix. Minor amounts of tourmaline, zircon, magnetite, hematite, and chlorite are present. Some of the sandstone contains carbonate. The maximum thickness reported is 2,000 feet.

Representatives of the formation collected by Warren Hobbs in eastern Shoshone County are grayish-purple to medium-gray impure quartzite. The rock is laminated on a microscopic scale. The principal component is quartz with subordinate amounts of alkalic plagioclase, microcline, and micropegmatite, and small subparallel flakes of colorless mica abundant in the narrower laminae and present between the clastic grains in the coarser laminae. Long flakes of bleached biotite are scattered throughout the rock. Hematite is sparsely distributed. In the coarser parts of the rock the quartz grains have diameters of 0.10 to 0.25 millimeter while most in the finer parts average about 0.01 millimeter.

In Kootenai County (Anderson, 1940, p. 13) the components are similar but vary markedly in proportions at different localities. Also some of the shale is made up of alternating dark-gray to black and yellow layers, only small fractions of an inch in thickness. The lower part includes calcareous beds difficult to distinguish from the underlying Wallace formation. The thickness of the Striped Peak formation here may locally be as much as 4,000 feet. In southern Bonner County, immediately north of Kootenai County, (Sampson, 1928, p. 9) the rocks assigned to the Striped Peak formation appear to lack the characteristic reddish beds, perhaps as a result of contact metamorphism. They are reported to include an olive-colored sandstone or quartzite and a laminated argillite with very thin alternating dark-gray and yellowish layers. Ripple marks and sun cracks are common. The exposed thickness is 9,000 feet.

Farther north, along the Clark Fork (Anderson, 1930a, p. 18-19), the formation has many reddish beds and thus resembles the same unit in the Coeur d'Alene region. Anderson notes that near Pend Oreille Lake the formation has lost its red color, and olive colors like those reported by Sampson farther south predominate. Anderson found the formation to be more than 4,000 feet thick, but as he notes that the characteristic reddish beds are absent in the upper part, this thickness may include some beds that in Montana have been assigned to the Libby formation. In all of the localities in Idaho mentioned, parts of the Striped have been removed by erosion so that the thicknesses given are less than the original ones.

Near Libby, Mont., (Gibson, 1948, p. 9, 16-19) the Missoula group comprises only the Striped Peak and Libby formations. The former consists mainly of dark-red to purplish feldspathic sandstone and quartzite, locally shaly, and with some interbedded sandy shale. Most beds are about a foot thick. Ripple marks, sun cracks, and crossbedding are common. A few light-green to olive-green argillite beds are present, especially in the upper part of the formation. Some of these grade laterally into red beds. Some of the sandy beds contain a little carbonate and stromatolitic dolomite occurs about 200 feet above the base of the formation. The thickness is about 2,000 feet, with a maximum of 2,500 feet at one place. Farther south in the Trout Creek quadrangle (Gibson, and others, 1941, p. 374-377) all the rocks of the Missoula group have been included in the Striped Peak formation, similar in general to the Striped Peak in the Libby area. Either the Libby formation is absent or it has been mapped with the Striped Peak formation, there reported to be thicker--3,000 to 3,700 feet--than near Libby. Oolitic dolomite and dolomitic limestone containing stromatolites are interbedded at two or more horizons.

Libby formation

Distribution and character.--The term "Libby formation" has been applied only in two small areas northwest and southwest of Libby, Montana (Gibson, 1948, p. 17-19). It consists largely of light-gray, dark-gray, and greenish-gray argillite, commonly sandy and less commonly sericitic and calcareous, in beds 1 to 3 feet thick. Some beds resemble the laminated, brown-weathering argillite in the Prichard formation. Thin-bedded gray sandstone and dark-gray, oolitic, ferruginous, magnesian limestone and a few beds of white ferruginous dolomite, in part stromatolitic, are also present. Along the Kootenai River there is a little greenish-gray argillite with calcareous layers that contain spherical and podlike argillaceous nodules. The Libby formation is at least 6,000 feet thick.

Beds of the Missoula group near Superior, Mont.

Beds of the Missoula group near Superior, Mont. comprise five formations (Campbell, 1958, in prep.). As already noted, some or all of the formations near Superior may be closely akin to formations close to Missoula.

The formation consists of three ill-defined, gradational units. The lowest part is grayish-yellow-green, quartzose argillite interlaminated with argillaceous quartzite. The basal part is slightly dolomitic. The middle unit is thicker bedded and more quartzitic than the lower one. It includes numerous beds of pale-purplish-gray quartzite. Many of the strata contain enough magnetite to deflect a compass needle. The upper unit is similar to the lower of the three and also to parts of the Wallace. It is mainly quartzite, largely dolomitic, and includes a few thin beds of siliceous limestone, with segregation structures.

[redacted]

Above the Spruce formation is the Lupine quartzite. This consists mainly of pale pinkish-brown (or gray) to grayish red-purple, fine- to medium-grained, vitreous to subvitreous somewhat feldspathic quartzite. Thin, widely spaced dark-purple or red-purple laminae and partings occur at intervals throughout the quartzite. Thin fragments of dark-purple argillite are present in many of the quartzite beds. The more argillaceous beds show mud cracks. A feature considered diagnostic is the presence of pale pink, thin, elongate lenses of dolomitic quartzite within some of the beds of noncalcareous quartzite. The Lupine quartzite is 2,750 feet thick.

The next unit upward is the Sloway formation which is quartzitic near the bottom and becomes progressively more argillaceous upward. Some beds are rich in hematite. Most of the beds low in the sequence are light-purple or light-green, medium-bedded, fine to very fine-grained argillaceous quartzite with some massive pink or white vitreous quartzite and numerous dark-colored laminae and thin beds of reddish-purple argillite with micaceous partings between the quartzite beds. Some of the quartzite is mottled with purple and green. Here and there calcareous nodules 6 to 12 inches long of possible organic origin, were noted. Higher in the sequence the rocks include thin-bedded argillite or quartzose argillite with striking red, red-purple and green colors of medium chroma. Mud cracks are plentiful and some salt casts are present. Some beds of dense, chertlike green or, less commonly, purple argillite occur. Small-scale scour and fill structures are common. As the Sloway formation has been seen only in fault blocks its thickness cannot be given with accuracy but it is thought to be fully 5,000 feet.

The Bouchard formation, as described by Campbell, is composed principally of interbedded micaceous quartzite and quartzose argillite. The prevailing colors are greenish gray with low chroma. Most of the rocks weather buff, olive gray or reddish brown. There are a few beds of white quartzite and others of dark, fissile shale. Quartz and sericite predominate in the formation but some feldspar and chlorite are present. The thickness is variable with a maximum of at least 4,000 feet. The differences in thickness are regarded by Campbell as resulting from erosion prior to deposition of a quartzite of Middle Cambrian age. Numerous individual calcareous stromatolites are present in the Bouchard formation in sec. 23, T. 16 N., R. 26 W.

An unnamed quartzite, inferred by Campbell to be the highest part of the group in the Superior area, has been observed only in a single small fault block with neither top nor bottom exposed. It consists of thick-bedded, medium- to coarse-grained, vitreous, pink, white and reddish-purple slightly feldspathic quartzite, locally crossbedded. The observed thickness is 700 feet, obviously less than the original maximum.

Rocks of the Missoula group near Missoula, Mont.

Distribution.--The subdivisions of the Missoula group established by Clapp and Deiss (1931, p. 677-688) and modified by Nelson and Dobell (1958, in prep.) are based on exposures in an area extending nearly 10 miles southeast of Missoula and eastward past Bonner, thence north and northeast along and near the lower reaches of the Blackfoot River. Similar subdivisions are present (Langton, 1935) from Missoula southward to beyond latitude 46°40'.

Character.--The table below shows the relations between the components of the Missoula group mapped by Nelson and those earlier described by Clapp and Deiss. The name Sheep Mountain formation used by Clapp and Deiss was found to be preoccupied and Pilcher quartzite was substituted. The Hellgate quartzite at its type locality was found to be such a local unit that it is best regarded as a member within the Miller Peak argillite. The mapping showed that another quartzitic unit (the Bonner) needed to be established higher in the sequence.

Subdivisions of the Missoula group near Missoula

According to Nelson	According to Clapp and Deiss
Pilcher quartzite	Sheep Mountain formation
Garnet Range quartzite	Garnet Range formation
McNamara argillite	McNamara formation
Bonner quartzite	
Miller Peak argillite (Hellgate quartzite member)	Hellgate formation
	Miller Peak formation

Langton (1935, p. 36, fig. 3) has mapped units south of Missoula that he speaks of as the Spokane and Helena formations, which he regards as stratigraphically above the Newland limestone. If they are actually above the Newland limestone, they belong to the Missoula group of the present report. Further work is needed on this point. From reconnaissance by the writer, from Langton's data, and from Nelson's work it is believed that the rocks called Spokane and Helena by Langton, belong to Nelson's Miller Peak argillite and the underlying Newland limestone. Clapp and Deiss show their basal unit in the Missoula group at Missoula (1931, fig. 3) resting on the Wallace (Newland) limestone, and do not employ the term "Helena limestone" in the area. They do, however, regard the upper part of their Wallace as correlative with the Helena limestone (1931, p. 69).

Langton describes his Spokane (1935, p. 36) as consisting of a lower part, 2,000 feet thick, of greenish-gray, in part calcareous argillite, with ripple marks, and an upper massive to thin-bedded lavender quartzite of unstated thickness. Sample ID-14950 in table 4 is considered to represent the Spokane of Langton. It also resembles the Miller Peak argillite, being a laminated grayish-red-purple argillite with ripple-marked bedding planes and with inconspicuous, small mud spalls. It consists largely of interlocking quartz grains 0.03-0.06 millimeter in diameter, most of which are clearly recrystallized. Carbonate grains are irregularly distributed and may constitute 10 percent of the whole. Mica and chlorite are scattered throughout. A little zircon is present. Hematite is fairly abundant.

Langton describes the rock he called Helena (1935, p. 36) as thin-bedded, argillaceous, and sideritic limestone, locally dolomitic. The beds weather buff or cream and many show "molar tooth" structure. Such a description would fit much of the Wallace, Newland, and Siyeh limestones of the surrounding region and does not accord at all closely with the Helena limestone of Helena. The sample supposed to represent Langton's Helena limestone, ID-14750 in table 6 [redacted] is a decidedly impure carbonate rock not at all like the Helena limestone near Helena. Langton assigns a thickness of 4,000± feet to his Helena, whereas the Helena limestone was originally described (Walcott, 1899, p. 199-215) as 2,400 feet thick and in parts of the Big Belt Mountains is far thinner (Mertie and others, 1951, p. 20). Thus, Langton's correlation is of doubtful validity.

The lowest unit in the Missoula area that is recognized by all as a component of the Missoula group is the Miller Peak argillite. Nelson (1958 in press) has redefined the unit so named to include the Miller Peak and Hellgate formations of Clapp and Deiss and the lowest of the three members of their McNamara formation, because he found it impossible to trace the Hellgate formation throughout his map area.

The Miller Peak argillite of Nelson is composed of reddish and greenish silty argillite, and argillaceous quartzite. Silty argillite is somewhat more abundant than argillaceous quartzite, and reddish hues more common than greenish ones. Locally pale-red, tan, and light-gray quartzite and light-gray impure limestone are present. Much of the argillite, irrespective of color, is laminated. Some of the laminae are rich in newly developed very fine grained chlorite and sericite, giving them a characteristic sheen. Detrital mica, oriented parallel to bedding, occurs in varying amounts, especially at the tops of the finer, more argillaceous layers. Small-scale (up to 20 mm amplitude) scour and fill structure is common. Mud cracks and ripple marks occur throughout the formation. Bedding planes in the quartzose rocks may be lined with thin layers of argillite, commonly ripple marked and mud cracked.

Nelson describes the lower few hundred feet of his Miller Peak argillite as light greenish-gray laminated argillite. The laminae are 0.8 to 12 millimeters thick and locally show small-scale scour and fill structures. The rocks weather readily and have a light-yellowish-brown rind on weathered surfaces. The argillite is slightly calcareous locally and contains a few intercalated lenses of carbonate rock.

The Hellgate quartzite member is composed of grayish orange-pink, pale-red, and grayish yellow-green medium-grained, somewhat argillaceous quartzite. The beds are 8 to 36 inches thick and are locally marked by thin layers of dark minerals, probably mostly hematite. Thin beds of reddish-gray argillite and siliceous argillite are scattered throughout the member. Two of the rocks Tweto studied are from the type locality of the Hellgate formation of Clapp and Deiss in the canyon of the Clark Fork near Missoula. One of these is a green-gray massive dolomite and arkosic quartzite. It contains quartz, dolomite, sericite, and feldspar with the usual minor constituents. Sericite is the principal component of the groundmass, and the dolomite forms distinct grains and masses. The clastic grains are angular. About two-thirds is silt, and the remainder the size of very fine sand. The other rock from this locality is a lavender, thinly laminated argillite. It contains dolomite, sericite, quartz, feldspar, and argillaceous material plus minor constituents.

The Hellgate formation of Clapp and Deiss, according to Nelson, cannot be mapped far from the railroad cut near Missoula where it was first recognized. It differs from the rest of the Miller Peak argillite of Nelson mainly in its higher ratio of quartzite to argillite. It is but one of several zones, probably all local, at various horizons with the Miller Peak argillite. Nelson reports no discernible differences between the rocks above and below the Hellgate unit. Thus, the Hellgate is best regarded as a member, mapped in one locality only, rather than as a formation.

According to Clapp and Deiss the lower 1,100 feet of their Miller Peak formation are overlain by 1,500 feet of mixed purple and green-gray, sandy, mud-cracked and ripple-marked argillite, interbedded with some massive argillaceous sandstone and a few thin beds of fine-grained, purple-gray argillite. The purple beds weather to a dull red-lavender color and the greenish ones to a dull gray. Above these are 300 feet of massive- to thin-bedded argillaceous sandstone, becoming increasingly sandy upward.

[redacted]

Nelson estimates the thickness of his redefined Miller Peak argillite as 5,200 feet, of which about 1,200 feet is represented by the Hellgate member where that has been mapped with 3,800 feet of beds below that member and 1,000 feet above it. Clapp and Deiss thought of their Hellgate formation as 2,200 feet thick and the Miller Peak argillite below it as 2,900 feet thick.

The descriptions of the Miller Peak and Hellgate formations by Clapp and Deiss (1931, p. 678-680) seem significantly different from the summaries by Nelson and Dobell (1958, in press). Some of the differences may well result from lateral variations so that the two field parties did not pass over the same rocks. Clapp and Deiss say that the lower 1,100 feet of the Miller Peak formation is composed of deep red-purple sandy argillite with some siliceous, sandy, massive- to thin-bedded purple argillite and a few thin beds of fissile, gray, sandy, mud-cracked argillite. Near the top of this lower part of the formation, beds of micaceous argillite appear. Most of the rocks weather to a characteristic dull purple-lavender color. This description leaves no room for the greenish-gray beds Nelson reports at the base of the formation. Either Clapp and Deiss did not encounter these rocks along their lines of traverse or included them in the underlying limestone unit. Attention may be called to the fact that, as noted above, the Spruce formation of Campbell near Superior, 3,000 feet thick, closely resembles the green argillites which Nelson describes, in stratigraphic position and character.

Nelson has introduced a new formation name, the Bonner quartzite, for the rocks immediately overlying his Miller Peak formation. The rocks are somewhat arkosic, pink or red quartzite in beds 4 inches to 6 feet thick. Crossbedding is common and readily discernible because of slight color differences. Bedding planes throughout tend to be marked by indistinct light-green layers. Thin beds of red argillite are interspersed among the quartzite beds. The mineral grains in the quartzite average about a quarter of a millimeter but some are as much as 12 millimeters across. A little montmorillonite and illite is present.

Clapp and Deiss describe their McNamara formation as composed of three members. The lowest consists of drab-green-gray to purple and maroon micaceous and sandy argillite. The proportion of sandy material increases upward and beds of massive, sandy quartzite appear in the upper part of the member. This part of the original McNamara formation should correspond to the part of the Miller Peak argillite of Nelson above the horizon of the Hellgate member. However, Clapp and Deiss credit it with a thickness of only 400 feet whereas the part of Nelson's Miller Peak above the Hellgate member should, according to him, be about 600 feet thicker than that.

The middle member of the McNamara formation of Clapp and Deiss corresponds approximately to the Bonner quartzite of Nelson. Clapp and Deiss say the lower 40 feet consists of massive, gray-green, coarse-grained, ripple-marked and crossbedded sandy quartzite. The rest of the member includes massive beds of pink-white and red-gray, pure coarse- to fine-grained quartzite. This rock is crossbedded and ripple marked and weathers to a dull-rusty-buff color. Toward the top several thin beds of sandy argillite appear. Clapp and Deiss report the middle member of the McNamara formation where measured as 810 feet thick. Nelson agrees for that locality but thinks that the best average thickness is 1,500 feet. Variations in thickness due in part to original differences, in part to the results of deformation are present.

Nelson proposes to restrict the name McNamara argillite to include only the upper member of that formation as defined by Clapp and Deiss. He describes his restricted McNamara argillite as composed largely of reddish and greenish argillaceous siltstone and argillite with minor amounts of more quartzose rock, all similar to some of the rocks comprising the Miller Peak argillite except that they contain less detrital mica, and new chlorite is less coarsely recrystallized. A little illite is present. Some of the beds of green argillite in Nelson's McNamara formation contain thin layers and rounded bodies of dense sericite which resemble chert and probably represent metamorphosed clay layers and galls. Nelson estimates his McNamara argillite to be 4,000 feet thick.

Clapp and Deiss say the corresponding rocks consist mainly of bright green and red, fine-grained, mud-cracked and ripple-marked argillite. Dense, fine-grained, chertlike green argillite is irregularly interbedded with the more massive strata. Clay galls are present in the upper part of the unit. They measured the upper member of their McNamara formation as 1,780 feet thick, in contrast to the 4,000 feet estimated by Nelson. Clapp and Deiss emphasize the gradational upper contact of the McNamara formation, which may account in part for the apparent discrepancy.

Tweto (1937, p. 45-46, op. cit. p. 155) describes a rock from the McNamara argillite (as restricted by Nelson) from the canyon of the Blackfoot River above Bonner. It is a dark-green, thin-bedded, ripple-marked chloritic and arkosic quartzite containing chlorite, quartz, feldspar, and the common accessories. The chlorite constitutes the cement and also masses resulting from the decomposition of mafic grains. The quartz grains are rounded to subangular and those of feldspar are subrounded to angular and poorly sorted. The grain size range is 7 percent silt, 33.0 percent very fine sand and 61 percent fine sand.

The Garnet Range quartzite is next above the McNamara. Nelson says this formation is composed predominantly of greenish-gray quartzite, mixed with slightly less dark-greenish and dark-grayish argillite, shale, and sandy argillite, with a notable content of detrital, mica, and a little montmorillonite. Wherever he observed it the Garnet Range quartzite is intricately folded and contorted, in large part isoclinally. Crumpling of this sort is so much more marked in this formation than in the others as to constitute a characteristic feature and to interfere with estimates of thickness. Nelson estimates the Garnet Range quartzite to be only 1,800 to 3,800 feet thick and explains the discrepancy between this and the 7,600 feet measured by Clapp and Deiss on the basis of structural complexities by fault repetition and the crumpling just mentioned.

Clapp and Deiss say the lower 1,600 feet of their Garnet Range formation is made up of brown, green-gray to gray, thin-bedded, micaceous, coarse-grained quartzite, with argillaceous and coarse-grained quartzite sandstone near the base. This member is followed upward by 600 feet of black-gray to dark-blue-gray sandy micaceous argillite. Next in succession is 1,000 feet of brown to green-gray argillaceous, micaceous sandstone and sandy quartzite, overlain in turn by 1,600 feet of thin-bedded, brown-gray-green-gray quartzitic sandstone.

The next member listed by Clapp and Deiss is composed of massive, coarse-grained, pink-white, crossbedded, pure quartzite about 3,000 feet thick. Nelson interprets this member as an infaulted block belonging to the Pilcher quartzite, (the Sheep Mountain quartzite of Clapp and Deiss), the next unit above the Garnet Range quartzite. If the beds below the supposedly faulted quartzite block correspond to the entire Garnet Range quartzite, crumpling must have thickened them 1,000 feet to correspond to Nelson's estimate of the Garnet Range quartzite as 3,800 feet. Clapp and Deiss report a thickness of 3,050 feet of brown, green-brown, and red-gray-brown micaceous and sandy thin-bedded, locally argillaceous, quartzite above the quartzite block. According to Nelson's interpretation this would constitute a repetition of part of the beds below the quartzite block. The summary here given is taken from the text of the report by Clapp and Deiss. It does not agree, particularly in the thicknesses of the components, with the measured section tabulated in the same report. Perhaps the thicknesses cited in the text are without allowance for overthickening because of crumpling.

Clapp and Deiss speak of a lens of limestone, 110 feet thick in the Garnet Range quartzite at one locality (Clapp and Deiss, 1931, p. 682). Nelson has found fossils of lower Paleozoic age in this limestone. These and the lithologic character of the limestone make a Middle Cambrian age probable. The rocks are decidedly dissimilar to the Devonian rocks of the region and all known pre-Devonian-post-Proterozoic carbonate rocks in northwestern Montana are believed to be of Middle Cambrian age (Deiss, 1933, 1936, 1938) and not a part of the Belt series. Thus the assignment by Clapp and Deiss must be in error. The limestone is not, as they supposed, a lens in their Garnet Range quartzite. Instead it is a separate body of post-Belt strata.

The highest part of the Missoula group in the Missoula area was named the Sheep Mountain quartzite by Clapp and Deiss. The name was changed to Pilcher quartzite by Nelson, because the name Sheep Mountain is pre-occupied. Nelson says it is composed of coarse-grained, crossbedded, light-pink to dark-purplish-red vitreous quartzite. The beds are 1 inch to 10 feet thick. The most striking feature is the crossbedding, rendered conspicuous by color contrasts. The bottom of one stratum may be moderate red and the top of the underlying stratum may be pale orange pink. Some beds, especially high in the sequence, are uniformly deep red and certain of these have spots and stringers bleached to a cream color. Near the top some beds are reddish black. The quartzite of the Pilcher quartzite is relatively pure but contains some argillaceous material, and a few scattered feldspar grains. It does not however, contain as much feldspar as similar rocks at lower horizons. In this respect it resembles Flathead quartzite. Nelson estimates the thickness as 1,000 feet. He says the formation appears to grade upward into quartzite of lower Paleozoic age and suggests that some of these and perhaps also of the beds now assigned to the Pilcher quartzite may be correlatable with the Flathead quartzite of Middle Cambrian age. If this proves to be correct, the upper part of the Missoula group in this area would be of Early Cambrian age.

The description of the Pilcher quartzite, (then Sheep Mountain formation) given by Clapp and Deiss is similar to that just given except that they call attention to clay galls near the top and bottom of the formation and regard the thickness as 2,300 feet. This suggests that they include with the Sheep Mountain formation the quartzite above it that Nelson says is of lower Paleozoic, presumably Middle Cambrian age. Clapp and Deiss make no reference to Paleozoic beds above the Sheep Mountain formation.

Rocks of the Belt series in and near the Ovando and Silvertip quadrangles

<u>Distribution</u>.--In the broad area between Bonner and Helena and the north as far as latitude 48° rocks of the Belt series are abundant. Most belong to the Missoula group but older units of the series are included, especially near Helmsville and Lincoln and in the Swan Range. The general distribution of the various units is known from published descriptions and unpublished maps by C. F. Deiss and C. H. Clapp (1931, Deiss, 1935, 1943a, 1943b). Large areas of the Belt series especially south of latitude 47°, have as yet been mapped in reconnaissance only but measured sections by Clapp and Deiss (1931) are available. Recent work near Bonner (Nelson and Dobell, 1958, in prep.) has resulted in minor modifications of the nomenclature of Clapp and Deiss there. Also, Clapp and Deiss carried some well-known names farther from their type localities than seems advisable.

The Miller Peak argillite, Cayuse limestone, Hoadley formation, and Ahorn quartzite of Clapp and Deiss have been recorded in the Ovando, Coopers Lake, Silvertip, and Saypo quadrangles.

Character.--For areas near and south of latitude 47° available lithologic descriptions are meager. In general the rocks have the characteristics displayed near Bonner, already summarized. Tweto (1937, p. 21-26, op. cit. p. 155) has described in detail many rocks from areas near this latitude. Of these, 8 are regarded by him as belonging to the Miller Peak argillite of Clapp and Deiss. Six of these came from a ridge a couple of miles southeast of Cottonwood Lake in T. 16 N., R. 14 W. One of this group is described as light-blue-green laminated arkosic argillite containing quartz, orthoclase, plagioclase, and argillaceous matter with minor amounts of chlorite, sericite, calcite, muscovite, epidote, apatite, zircon, green biotite, magnetite, and sillimanite. Another rock is a pink-gray, massive, coarse, mud-cracked ferruginous quartzite with interlaminated thin flakes of dark-maroon argillite. It consists of quartz and hematite with minor amounts of orthoclase, sericite, chlorite, magnetite, titanite, apatite, zircon, and calcite. The original quartz grains were rounded and subrounded but addition of later quartz has produced an interpenetrant mosaic. Grain sizes are silt size 1 percent, very fine sand size 4 percent, fine sand size 21 percent, medium sand size 61 percent, and coarse sand size 19 percent. A third rock is a laminated light- and dark-maroon argillite composed of quartz, orthoclase, plagioclase, and hematite with minor quantities of muscovite, tourmaline, calcite, chlorite, sericite, magnetite, ilmanite, apatite, green and brown biotite, epidote, grossularite, and zircon. The feldspar grains are much altered. Elongate hematite masses give a banded appearance to the thin section. Over 70 percent of the grains are silt size and the rest the size of very fine sand. Another of these rocks is a green-gray, thin-bedded calcareous quartzite showing mud cracks and ripple marks. Thin laminae of white calcareous quartzite alternate with light- and dark-green argillite. The essential minerals are quartz, orthoclase, plagioclase, calcite, and the minor constituents include argillaceous material, muscovite, sericite, chlorite, magnetite, hematite, titanite, zircon, grossularite, rutile, and tourmaline. The feldspar grains are altered. Calcite is in grains in the quartz mosaic. Some of the chlorite aggregates may correspond to original mafic minerals. The grains are subrounded and subangular. In the coarser laminae 3 percent are silt-size, 15 percent the size of very fine sand, and the remainder that of fine sand. Another rock is a green-gray, brown-weathering quartzitic argillite with laminae and flakes of dull-purple micaceous argillite. The constituent minerals are similar to those in rocks described above. The component grains are angular and subangular and 74 percent of them are silt size, with the rest a little coarser. Still another rock from the same locality is light-green, buff-weathering, thin-bedded argillite that consists mostly of argillaceous matter with a little quartz, sericite, feldspar, and sillimanite. The last of the group is a red and green calcareous quartzitic argillite with interspersed flakes and laminae of fine-grained ferruginous red and green argillite. The components are about the same as those listed above. The grains are poorly sorted and mostly subangular. They range from 60 percent of silt size through 30 percent the size of very fine sand to 11 percent of fine-sand size. Some specimens from the Miller Peak argillite contain small amounts of illite and montmorillonite but much of the rock has no detectable clay mineral.

The general description published by Deiss (1943a, p. 213, 215-216) shows that the Cayuse limestone includes dull-gray, crystalline, buff, tan-weathering, dolomite interbedded with pale-maroon and green-gray, fissile argillite which grades upward into alternating zones of shaly calcareous argillite and sideritic and dolomitic marble. The upper part of the unit is blue and dull-gray, thick-bedded, finely oolitic and coarsely crystalline algal limestone. The total thickness is about 1,000 feet.

Details have been provided by Tweto, who has described 14 specimens thought to belong to the Cayuse limestone, of which 4 are from T. 16 N., R. 14 W., and the rest from T. 17 N., R. 14 W. One of the first four is a green areanaceous and calcareous argillite composed of calcite, quartz, argillaceous material, and minor amounts of orthoclase, microcline, plagioclase, muscovite, chlorite, sericite, biotite, graphite, dolomite, and epidote. It contains angular silt grains of quartz and feldspar in a matrix of calcite and argillaceous material. Another is a laminated light- and dark-green and buff quartzitic argillite. A third is a green calcareous argillite with much the same composition as the first two. The feldspar is much altered. The grain size ranges from 32 percent silt through 47 percent very fine sand to 21 percent fine sand. The fourth rock is pink vitreous arkosic quartzite with sparse flakes of dull-maroon and purple, laminated argillite. The rock consists of quartz, orthoclase, microcline, and plagioclase with minor quantities of chlorite, biotite, hematite, ilmenite, graphite, epidote, titanite, apatite, tourmaline, zircon, and rutile. The grains are 65 percent silt size, 30 percent the size of very fine sand and the rest that of fine sand.

One is a light-green-gray impure cryptocrystalline laminated limestone. It consists dominantly of calcite but contains some pyrite, chlorite, muscovite, orthoclase, dolomite, plagioclase, quartz, and ilmenite. Another rock is a dark-green, thin-bedded argillaceous, calcareous quartzite of the usual composition. Chlorite is dominant in the groundmass. The feldspar grains are angular cleavage fragments, commonly much altered. The size range is 45 percent silt, 24 percent very fine sand, and 30 percent fine sand. A third rock is a light-gray-green and green laminated calcareous quartzite with thin laminae of green fine-grained argillite. It contains 51 percent quartz, 38 percent feldspar, 9 percent calcite and some muscovite, sericite, zircon, biotite, chlorite, monozite, rutile, tourmaline, grossularite, apatite, magnetite and ilmenite(?). The grain size range is 14 percent silt, 37 percent very fine sand, 41 percent fine sand, and 8 percent medium sand. Nearby a green impure dolomite was obtained. This consists mainly of dolomite with a ltttle pyrite, quartz, sericite, and graphite. A fifth rock is a light-gray-green vitreous quartzite with thin laminae of green argillite. It contains 57 percent quartz, 31 percent feldspar, and some calcite, chlorite, sericite, tourmaline, epidote, and siderite. The grain size range is 20 percent fine sand, 43 percent medium sand, and 39 percent coarse sand. Another rock is a green-gray, thin-bedded impure limestone consisting of calcite, quartz, orthoclase and plagioclase with some dolomite, muscovite, sericite, zircon, and chlorite. The rock is crossbedded on a microscopic scale. Another rock is a light-green siliceous limestone, consisting of calcite, quartz, and feldsper with some dolomite, muscovite, zircon, rutile, sericite, argilllaceous matter, chlorite, and graphite. Like the one just mentioned, it is microscopically crossbedded. An arkosic rock nearby contains quartz, orthoclase, plagioclase, perthite, and microcline, with the usual minor constituents. Half of the grains are silt size, the rest slightly larger. Another of the rocks is a green-gray, thin-banded impure limestone with structures that may be stromatolitic and veinlets of graphite bordered by argillaceous material.

The Cayuse limestone is one of the various limestone bodies intercalated in the Missoula group. Like many of the others it includes much clastic material. As already noted, some such units have been called Helena limestone but the correlation thus implied rests on an insecure foundation. The unpublished map of the Ovando quadrangle shows a unit termed "Helena limestone" below the Miller Peak argillite and one called Spokane quartzite below that. In accord with the usage of Clapp and Deiss, Tweto (1937, p. 18-21, op. cit. p. 155) assigned four of the specimens he described to the Helena limestone. One is from about 8 miles north of Ovando.

This rock is a dark-blue-gray oolitic limestone with scattered pebbles up to 25 millimeters long. It consists of calcite and quartz with some dolomite, and argillaceous material. The oolites show a little concentric structure and all show radial structure emphasized by limonite. The centers commonly consist of limonite-stained dolomite. The oolites are elliptical with their long axes parallel. Each oolite is partly or wholly surrounded by a corona of prismatic quartz. Two other specimens are from north of the upper reaches of the Dearborn River. One of these is gray, oolitic limestone consisting of calcite and some argillaceous cryptocrystalline limestone. The second rock specimen described is a portion of a stromatolite. Tweto speaks of this as a brown-gray argillaceous limestone. It consists of calcite and argillaceous material with rare collophane fragments and some limonite. It is finely laminated as viewed under the microscope. Another sample from north of Lincoln is far enough east so that it may be included in rocks assigned to Helena limestone. This is described as dark-blue-gray dense argillacous limestone containing a little quartz and carbonaceous matter.

Deiss (1943a, p. 213, 216-218) has described the Hoadley formation and the Ahorn quartzite above his Cayuse limestone. The Hoadley formation is dark-green-gray and maroon, thick-bedded, siliceous argillite with some vitreous quartzite, overlain by red and buff, arenaceous, calcareous argillite and fine-grained sandstone that grades upward into greenish-buff-weathering calcareous sandstone, pink sandstone and argillite. The upper part of the formation is brilliant and dark red, soft, thin- and thick-bedded platy ripple-marked sandstone, with some beds of pale-red argillite. The estimated thickness of the formation is 4,100 feet.

The Ahorn quartzite (Deiss, 1943a, p. 213, 217-218) is coarse- and fine-grained quartzite with occassional beds of red quartzite in the lower 1,700 feet, overlain by green and red-gray thin-bedded argillite and a few thin beds of fine-grained sandstone in the upper 400 feet of the formation.

Rocks from near Ovando and presumably from the Hoadley and Ahorn formations, or nearby strata, have been described by Tweto (1937, p. 37-44, op. cit. p. 155). Six of his specimens come from a ridge in T. 16 N., R. 14 W. Of these, one is a light-purple and maroon, coarse, vitreous quartzite consisting essentially of hematite, quartz and feldspar, with minor amounts of magnetite, muscovite, chlorite, dolomite, green biotite, epidote, titanite, sericite, and zircon. Under the microscope, the rock is laminated with the fine-grained laminae rich in hematite, and the coarser ones consisting of an intergrown mosaic of angular grains of quartz and feldspar with abundant chlorite and hematite. Magnetite is common and is derived from biotite. Microcrystalline dolomite is also abundant. The grain size range is 52 percent silt size, 40 percent very fine sand, 9 percent fine sand. A second rock is an impure, laminated maroon and pink dolomite with hematite laminae. It is composed of dolomite and hematite with minor amounts of quartz, feldspar, tourmaline, chlorite, muscovite, and magnetite. Angular quartz and feldspar grains are abundantly distributed in a micro- to cryptocrystalline dolomite groundmass. The grain size range is 29 percent silt, 31 very fine sand and 20 fine sand. Another rock is a buff to salmon, soft, thin-bedded arkosic sandstone. It contains quartz, feldspar, and sericite, with minor amounts of ilmenite, tourmaline, titanite, zircon, and muscovite. The cement is mainly sericite. The grain size range is 9 percent silt, 35 percent very fine sand, 30 fine sand and 5 percent medium sand. A fourth rock is a tan-pink arkosic quartzite containing quartz, sericite, and feldspars, with the usual accessory minerals. The grains are sharply angular and are arranged with their long axes parallel. The feldspars are sericitized in varying degree. A fifth rock is a bright-red argillite containing flakes or laminae of argillaceous quartzite. It consists of hematite and sericite with minor amounts of quartz, feldspar, dolomite, magnetite, muscovite, and titanite. The grain size range is 33 percent silt, 46 percent very fine sand and 21 percent fine sand. The sixth rock described is a buff-salmon, coarse, arkosic quartzite, consisting of quartz and feldspar with minor amounts of sericite, ilmenite, hematite, epidote, chert(?), and alteration products. The feldspar is fresher and the grains of quartz and feldspar are better rounded than in most specimens described. The grain size range is 7 percent silt, 3 percent very fine sand, 38 fine sand, 45 percent medium sand and 10 percent coarse sand, so this is an exceptionally coarse rock by comparison with others of similar stratigraphic position.

Three specimens from about the same horizon as those just described but from T. 17 N., R. 14 W., were studied by Tweto. One of these is a laminated, maroon, purple, and light-green argillaceous dolomite consisting of dolomite and argillaceous material, with minor quantities of quartz, feldspar, muscovite, titanite, sericite, zircon, hematite, and magnetite. Another rock from the same general locality is a laminated red, pink, and salmon vitreous dolomitic arkose. It contains dolomite, quartz, and feldspar with minor amounts of muscovite, hematite, magnetite, chlorite, tourmaline, and epidote. The dolomite constitutes the microcrystalline matrix of the rock. The feldspar, mostly orthoclase, is in sharply angular cleavage fragments. The grain size range is 35 percent silt, 41 percent very fine sand and 24 percent fine sand. A third rock is a thinly laminated red and pink, mud-cracked dolomitic and arkosic quartzite. It contains dolomite, hematite, quartz, and feldspar with minor amounts of magnetite, muscovite, zircon, and chlorite. The dolomite forms a crystalline cement for angular, silt-size grains of quartz and feldspar. A fourth rock, is a green, chloritic graywacke whose essential minerals are quartz, chlorite, and feldspars. Subordinate constituents include muscovite, green biotite, epidote, glauconite, grossularite, titanite, and sericite. The reported presence of glauconite is of interest in a rock of this character and age.

Rocks of the Missoula group in and south of Glacier National Park

Distribution.--Only fragments of the Missoula group remain mostly on the higher peaks, within Glacier National Park. West of the upper reaches of the Flathead River it is extensively exposed, although little known. From the southern border of the Park southward to the area near Missoula just described and east of Flathead Lake it forms broad expanses, especially on the northeastern flanks of the mountain ranges. It is, however, absent in the closely spaced ridges of the border of the mountains east of the North Fork of Sun River. The rocks of the Missoula group south of latitude 48°00' and in the general vicinity of Ovando and north of Lincoln have already been described.

Character.--Only a few of the components of the Missoula group in this broad region are sufficiently well-known to be assigned formal names. Even some of the formations named by Willis (1902) are inadequately or incompletely mapped. The rocks of the Missoula group in this region are broadly similar to those near Missoula except that carbonate rocks similar lithologically but not stratigraphically to the Siyeh limestone of the Piegan group are more plentiful.

In and close to Glacier National Park the Purcell basalt and various sedimentary components of the Missoula group have been mapped (Ross, 1958, in press). These include a stromatolite zone, an unnamed unit of greenish calcareous argillite, one of green and another of pinkish argillite, as well as several limestone masses. Each of these, and probably others are expected to become formations when detailed studies are undertaken in the region.

The greenish calcareous argillite locally distinguished at the base of the Missoula group, near Glacier National Park is transitional with the limestone of the Piegan group below, but is included in the Missoula because it is dominantly argillaceous. Also the lithologic change is sharper at the base than at the top of this argillite. The unit is nearly continuous in the northern Swan Range, and has been noted in the Flathead Range and locally farther north although it thins in that direction. Where it is especially well developed the thickness is 500 to 800 feet. This unit may correspond more or less closely to the basal part of the Miller Peak argillite near Missoula.

[redacted]

The Purcell basalt, that in places within the Park is conspicuously intercalated in the lower part of the Missoula group, is an irregularly amygdaloidal, effusive basalt with pillow structure. Fresh surfaces are greenish gray to almost black, locally purplish. Weathered surfaces are stained brownish. The rock is too highly altered for precise determination but originated as a basalt containing calcic plagioclase, augite and some olivine. Traces of diabasic texture remain. The feldspar now approximates oligoclase or albite-oligoclase but may originally have been labradorite. Much of the rock consists of a fine-grained, nearly opaque aggregate of secondary minerals that include chlorite, sulfides, calcite, quartz and possibly serpentine.

The basalt in the Park is 100 to 275 feet thick and in different localities consists of from 2 to 8 or more flows. In some places argillite separates the flows.

The Shepard formation is at present recognized only within Glacier National Park, where it overlies the Purcell basalt. The principal component is fairly pure dolomite but some beds are argillaceous and siliceous and a few are conglomerate with pebbles of lava. The dolomite weathers to a distinctive color that ranges from pale yellowish brown to grayish orange. The matrix consists of dolomite grains about 0.01 millimeter in diameter but embedded in this matrix are numerous oval masses up to 4.0 millimeters long that consist of carbonate grains up to 0.2 millimeter in diameter. Perhaps these ovals are thoroughly recrystallized oolites [redacted]. Some beds are reported to contain stromatolites. Some illite and montmorillonite are present. The maximum reporte thickness of the formation is 700 feet.

Unnamed, more or less lenticular bodies of carbonate rocks of mappable proportions are present in the Missoula group of the region at various horizons. Perhaps some of these may prove to be essentially equivalent stratigraphically to the Shepard formation. Most closely resemble the Siyeh limestone in appearance and composition except that they contain more argillaceous material especially in the thinner masses. Segregation structures of one kind or another are plentiful. Some are identical in appearance with the molar tooth structure for which the Siyeh limestone is noted; others are so irregular as to bear no resemblance to the markings on teeth.

Stromatolite zones are fairly plentiful in the limestone bodies of the Missoula group (Rezak, 1957). One of these, approximately 6,000 feet above the base of the group has been mapped locally as the Conophyton zone 2 (Ross, 1958, in press). This zone is about 100 feet thick, has 5 subdivisions and contains only 2 stromatolite species. These are Conophyton incluvium and Collenia frequens. Another zone, about 500 feet lower in the section, is 35 feet thick. It contains heads of Collenia symmetrica up to 5 feet high and 6 feet in diameter. Cryptozoan occidentale and Collenia frequens are also present.

The limestone masses just described vary widely in dimensions. Here and there throughout the Missoula group they occupy a few inches or a few feet of strata. Most of the bodies that have been mapped are hundreds of feet in maximum thickness and one is as much as 3,000 feet thick.

The different units above described are more or less local features of the Missoula group in and near Glacier National Park. The main body of that group consists largely of argillite that is softer and less siliceous than most of the Grinnell argillite. In most places purplish-red beds predominate, but yellow-green ones are rarely entirely absent and some beds are gray. Others are red to pink or, rarely, almost white. One mass of green argillite was mapped separately but most are individually too small to be thus distinguished. Distinctly purplish rocks are almost entirely absent, a feature that aids in discriminating between argillite beds of Missoula age and those of the Grinnell. Quartzite, of varying degrees of purity, is intercalated in the argillite in many localities. In places, near the top of the group, it is the dominant rock. Ripple marks are very common, and mud cracks and intraformational conglomerate are fairly so.

Much of the argillite in the main body of the Missoula is composed of more or less subangular grains with maximum dimensions of 0.05 millimeter or less. Some of the quartzite beds are made up of grains as much as 0.5 millimeter in diameter but most are distinctly finer grained. The components of the coarser beds are more perfectly rounded than those of the finer layers. Some of the rounded grains are coated with thin films of sericite. Some recrystallization has taken place but most of the grains have retained their original, clastic shapes.

The principal mineral in all the beds is quartz, but most contain some feldspar, mainly rather alkalic plagioclase. Sericite is plentiful; chlorite is locally present; and hematite dust is diffused through most of the rocks. Clay minerals also occur. Carbonate, mostly calcite with some magnesium carbonate therein, is present in many of the beds and conspicuous in some. The latter weather rusty.

The Missoula group near and east of Helena

<u>Distribution</u>.--The Belt series was named from the mountains east of Helena where most of it belongs to formations here correlated with the Missoula group. These include the Greyson, Spokane, and Empire shales, the Helena limestone, the Marsh shale, and also the Greenhorn Mountain quartzite recently named by Knopf (1950, p. 839). These formations extend fully 50 miles north and south of Helena and occupy large areas in the Big Belt Mountains to the east of Helena. Essentially the same formations are widespread in the Little Belt Mountains also but mapping there is inadequate to delineate them. Some of these units extend at least 25 miles northwest of Helena also.

<u>Greyson shale</u>.--In the Little Belt Mountains the Greyson shale has been described (Weed, 1900, p. 282) as composed of dark-gray or black, fine- and coarse-grained siliceous shale. The lower part of the formation is pearly gray because of the abundant sericite. The upper part is more siliceous and includes beds of sandstone a foot thick. The formation is 955 feet thick.

In the Big Belt Mountains the Greyson is prominent, thick, and, judging by descriptions, is variable. According to the original description (Walcott, 1899, p. 206) the lower part is dark, coarse, siliceous, and arenaceous shale that passes upward into bluish-gray almost fissile shale, resembling a poor quality of porcelain. This is succeeded upward by dark-gray, siliceous, and arenaceous shale with beds of buff sandy shale and sporadic layers of hard, compact, greenish-gray and drab siliceous rock. In the northern part of the Big Belt Mountains (Tweto, 1937, p. 16, op. cit. p. 155) the formation includes dark blue-gray quartzitic argillite containing sericite, quartz, colomite, graphite, feldspar, zircon, muscovite, and tourmaline. Along Deep Creek, east of Townsend, the base of the formation includes quartzite interbedded with shale and with a basal conglomerate, composed of sand and pebbles up to 8 inches in diameter, derived from the underlying rocks of the Belt series. The formation is about 3,000 feet thick and the coarse beds along Deep Creek aggregate 100 feet in thickness. The latter must record a local unconformity between the Newland limestone and the Greyson shale and may represent the North Boulder group of the present report or an isolated occurrence of similar rock. Walcott calls attention to the absence of the coarse beds at the base of the formation in the part of the Little Belt Mountains described by Weed but the Fentons (1936, p. 610) report that horizon about 8 miles west of White Sulphur Springs. There they found the Greyson to consist of blue-green to olive-brown argillite and metaargillite, weathering to brown, shaly slopes, with, near the base, pink to brownish quartzite or arkosic sandstone of variable thickness and containing conglomerate lenses. Walcott (1899, p. 206, 235-238) reported trails and fragments of crustaceans in calcareous shale about 100 feet above the base of the Greyson shale both along Deep Creek in the Big Belt Mountains and near Neihart in the Little Belt Mountains. The Fentons (1936, p. 616) did not find the trails and note doubts as to the crustaceans (White, 1929, p. 393).

East of White Sulphur Springs the formation consists (Tanner, 1949, p. 12-14) predominantly of yellowish-gray to greenish-gray, thin-bedded, sericitic, fissile shale with few beds of hard argillite and some lenses of soft, calcite-cemented fine-grained sandstone. Immediately north of White Sulphur Springs thin beds of black limestone are common in the formation. The transition zone with the Spokane shale is 40 feet thick and contains buff, sandy, ripple-marked shale with lenses of deep red argillite and silty shale. The formation is somewhat over 2,000 feet thick.

According to Pardee and Schrader (1933, p.125) the formation is chiefly dark-gray shale that weathers rusty brown. It has markedly gradational contacts both at top and at bottom. The basal beds include much slate-gray shale in which some of the lighter-colored beds are thickly peppered with brown specks regarded by Pardee as oxidized grains of siderite. Next above the gray beds is soft, fissile light-gray to pale-buff shale whose layers have a shimmering pearl-gray coating. The rusty brown specks are abundant in these beds also. Commonly slaty cleavage is so conspicuous as to obscure the bedding. The middle part of the Greyson is mostly dark-gray shale, with which many thin quartzitic layers are interbedded. Above this is several hundred feet of dark-bluish-gray to brownish-gray, thinly laminated shale that weathers brown. The transition zone at the top is 500 feet thick but the dividing line with the overlying Spokane shale is so placed that practically all of the red layers are included with the latter.

The Greyson in the Big Belt Mountains is thought by Pardee to be 3,000 feet thick. In one place the apparent thickness is 5,000 feet but repetition by faulting is possible.

Near Canyon Ferry, east of Helena, the Greyson shale differs in detail from that in the localities described above. Here (Mertie and others, 1951, p. 18-19) the formation consists mainly of shale, siltstone, and fine-grained sandstone, all thinly and evenly bedded. These rocks are dark gray to dark brown where fresh but weather to sombre shades of brown or red. Medium- to coarse-grained sandstone, locally conglomeratic, is present in the upper few hundred feet of the formation. These beds are dominantly light brown or light gray but partly white or red. Some are crossbedded and ripple marked. The transition zone between the Greyson and the overlying Spokane formation, 200 feet thick, consists of red shale interbedded with light-colored sandstone. The contact was mapped at the top of the uppermost recognizable bed of sandstone. The thickness of the formation near Canyon Ferry is 2,000 to 3,000 feet.

One small exposure of rock supposed to belong to the Belt series is known in the Big Snowy Mountains in or near T. 11 N., R. 16 E., east of the area of the present paper. This was assigned to the Piegan group on the geologic map of Montana (Ross, Andrews, and Witkind, 1955) on the basis of the scanty descriptions on record (Calvert, W. R., quoted in Walcott, 1916b, p. 273-274, Reeves, 1931, p. 145, Tweto, 1937, p. 16, op. cit. p. 155). These rocks are mainly highly indurated limy shale, approximating a slate or, according to Tweto, shaly dolomite. The observed thickness is only 300 feet. Calvert suggested that the carbonate may have been derived from meteoric water percolating downward from Paleozoic limestone above. Tweto assigned the rock to the Greyson shale on the basis of petrographic character. With the limits of the groups adopted here, the most probable assignment of these isolated exposures is to the Missoula group rather than to the restricted Piegan group.

Near Marysville, north of Helena, (Barrell, 1907, p. 30) the Greyson shale consists of dark-gray to nearly black siliceous and arenaceous shale. Some portions are almost fissile; others consist of hard, cherty strata with cubical jointing. Deep-dark-red or purplish shaly beds are present locally.

South of Helena and east of the North Boulder River the Greyson is plentiful (Klepper and others, 1957).

Thick uninterrupted sequences of rocks assigned to the Greyson are reported (G. D. Robinson, written communication) just east of Toston and in the northern Horseshoe Hills. At the northern end of the Horseshoe Hills near Sixteen Mile Creek the formation is not less than 6,000 feet thick where it is overlain conformably by the Spokane shale. To the south the Spokane and the upper part of the Greyson are missing owing to pre-Flathead erosion, and at Big Davis Creek 10 miles south of Sixteen Mile Creek the Greyson is only about 3,000 feet thick. East of Toston, where the top of the formation is present but the lower part missing, owing to thrust-faulting, the formation appears to be much thicker, not less than 8,000 feet thick. Far more than half of the formation is dark yellowish brown and dark olive gray finely laminated platy argillite, partly derived from clay shale and partly from siliceous siltstone. In the basal 1,000 feet are scattered layers of coarse reddish-brown arkose and micaceous shale. At the top is more than 2,000 feet of lighter colored rocks, yellowish brown and yellowish gray, mainly argillite but with many thin beds of quartzite. Beginning about 3,500 feet below the top of the formation in the Horseshoe Hills, is a sequence about 400 feet thick of thin-bedded dark-gray limestone, interbedded with dark platy argillite. Only a little limestone appears at a similar stratigraphic position east of Toston.

Spokane shale.--Near Neihart in the Little Belt Mountains the Spokane is represented only by 210 feet of red shale (Weed, 1900, p. 283) and at one place in this area is missing entirely (Walcott, 1899, p. 207). Farther south in the Little Belt Mountains and also in the Big Belt Mountains the formation is widespread and conspicuous but available details are scanty (Walcott, 1899, p. 207, Pardee and Schrader, 1933, p. 125-126, Mertie and others, 1951, p. 19). It consists of siliceous argillaceous and arenaceous, noncalcareous shale, mostly deep purple red. Parts are altered to greenish in spots, layers, or along zones several tens of feet thick. The green material appears to be in part related to fractures or to igneous intrusions but locally may be original. Distinction between the Spokane and the overlying Empire shale is based mainly on the criterion of red versus green color. Insofar as the green may result from local alteration it is a weak stratigraphic criterion. Much of the Spokane shale in the Big Belt Mountains is soft and poorly bedded but some has slaty cleavage. The thickness there is 1,500 to 2,000 feet.

North of Helena the Spokane shale is widespread and thick. Along Little Prickly Pear Creek, south of the settlement of Wolf Creek, the formation (Clapp and Deiss, 1931, p. 691) is 4,500 feet thick.

Tweto (1937, p. 17-18, op. cit. p. 155) studied a rock from Arrastra Creek, west of Lincoln, that he, following Clapp and Deiss, regarded as a component of the Spokane formation. This rock is a purple-gray, thin-bedded arkosic quartzite containing quartz and feldspar with the usual accessory minerals. The clastic grains are subangular and subrounded, in a siliceous cement. The grain size range is 22 percent silt, 63 percent very fine sand, and 15 percent fine sand.

Near White Sulphur Springs (Tanner, 1949, p. 14-17) the basal part of the formation is argillite with numerous lenses of thin-bedded silty shale and some fine-grained sandstone, all deep red to chocolate except for occasional streaks of bright green which do not everywhere accord with the bedding. The next few hundred feet consists largely of argillite and shale in beds a fraction of an inch to several inches thick. Throughout this part there are thin zones of grayish shale indistinguishable from that of the Greyson. Near the top of the formation silty shale and fine-grained sandstone are more common than argillite. Those are thin bedded, ripple marked and mud cracked. Locally there are thin beds of buff, impure limestone and at one place a stromatolite reef was noted.

In the southern Big Belt Mountains the Spokane is reported (G. D. Robinson, written communication) to thin steadily from about 2,000 feet at Dry Creek in the southwest part of T. 6 N., R. 4 E. to 0 near Sixteen Mile Creek 9 miles to the south. Farther west, along the Missouri River, the Spokane seems to thin similarly southward, from something like 2,000 feet in section 12 and 13, T. 5 N., R. 3 E. northeast of Toston to no more than a few tens of feet 10 miles southwest in the Lombard Hills, but the situation is complicated by thrust-faulting.

In and near T. 6 N., R. 6 E., beds that have been correlated with the Spokane shale (Klemme, 1949, p. 6-7) are about 3,000 feet thick, in sec. 27, T. 4 N., R. 3 E., they are 800 feet thick and in sec. 31, T. 5 N., R. 4 E., they total less than 100 feet. Where the strata correlated with the Spokane shale are thin they are underlain by reddish-brown argillite, pale-green shale, green-to-pale-brown quartzite and argillite and some siliceous limestone, the whole being about 1,000 feet thick. This sequence is correlated (Klemme, 1949, p. 7) with the Greyson shale.

Empire shale.--In the Big Belt Mountains (Mertie and others, 1951, p. 19-20) the Empire shale is commonly a hard, dense, siliceous shale or argillite that is thinly bedded and laminated and includes some thin beds of limestone in its upper part. The shale is light to dark greenish gray except that red shale similar to the Spokane has been mapped with the Empire in its lower part. The lower part of the Empire shale is so gradational and variable that the base cannot be fixed within an interval closer than 200 feet stratigraphically. The upper contact is also gradational but only within a range of 25 to 50 feet. The formation has a maximum thickness of about 1,000 feet but in places pinches out entirely.

In the general vicinity of Marysville, where the Empire shale received its name (Walcott, 1899, p. 207) most of the formation is entirely contact metamorphosed. The unmetamorphosed portion there has been described (Barrell, 1907, p. 31) as finely laminated, soft limy shale, grayish green or buff, with a few reddish bands. Its lower members include yellow and reddish sandstone, in part shaly and in part calcareous. Barrell measured 520 feet of the Empire shale cut off by a fault but thought the maximum thickness in the vicinity of Marysville was much greater.

The Empire shale (or formation) is well exposed just northwest of Helena (Knopf, 1950, p. 837). There it contains pale-green argillite, brick-red, maroon, and lavender argillite identical with those in the underlying Spokane shale, and fine-grained light-green and white quartzite. Knopf regards the quartzite beds as the best means of distinguishing the Empire from the Spokane. He places the base of the Empire at the first place where quartzite appears. He regards the Empire as about 1,000 feet thick at this locality.

Helena limestone.--The Helena limestone covers large areas from near Helena northwest a short distance past longitude 112°30' north of Little Prickley Pear Creek and has also been recognized in the Big Belt Mountains east of Helena. West of 112°30', as already noted, the name has been used by some but the correlations implied thereby do not seem warranted on the basis of existing data. Some of the carbonate bodies west of 112°30' do not have accepted formation names.

Walcott (1899, p. 207) applied the name to rocks near Helena that consist of more or less impure bluish-gray and gray thick-bedded limestone. Weathered surfaces are colored in part buff, in part light gray. Irregular layers of broken oolitic and concretionary limestone occur at various horizons. Gray siliceous shale and greenish and purplish shale are intercalated in beds from one-half inch to several feet thick. The formation at Helena was estimated by Walcott to be 2,400 feet thick.

In the Big Belt Mountains (Mertie and others, 1951, p. 20) relations to other formations justify assignment to the Helena limestone but the rock differs in detail from that near Helena. It is composed of thinly but unevenly bedded, laminated, fine-grained to dense dolomitic limestone. Thin partings of shaly limestone or limy shale are locally present. The maximum observed thickness is at least 500 feet, but the formation thins westward and disappears. Mertie and his coworkers attribute this to an erosional unconformity prior to deposition of the Flathead quartzite.

Observations by the writer show that the limestone is oolitic. Both near Helena and in the Big Belt Mountains it contains stromatolites. The rather wide variations in chemical content of the Helena limestone recorded in table 7 [redacted] are in part related to the stromatolites or to apparently kindred features. These variations are reflected in various etched and differentially colored features on weathered surfaces that give a distinctive appearance to the rock. The etched figures are reminiscent of the molar tooth markings in the Siyeh limestone but are rather more broadly rounded, irregular, and of larger scale than these markings.

Knopf (1950, p. 837-838) calls attention to the presence of siliceous oolites, edgewise conglomerate and stromatolites. He supports Barrell's (1907, p. 32) estimate of 4,000 feet for the thickness of the Helena near Marysville. Knopf also thinks that the composition of the formation justifies changing the name from Helena limestone to Helena dolomite. The proportion of dolomite and calcite in the formation vary from place to place and the name change is not advocated here.

Marsh shale.--Walcott (1899, p. 207-208) speaks of the Marsh shale as occuring near Helena and at intervals for some 20 miles to the north of the city. He describes the unit merely as reddish shale and gives thicknesses in different localities that range from 75 to 300 feet.

In the Marysville area the Marsh shale has been reported (Barrell, 1907, p. 33) to consist of red shale in which the lower beds are calcareous in some places and quartzitic in others. The thickness in that vicinity was estimated to exceed 1,000 feet.

Knopf (1950, p. 838-839) says deep-red argillite, in part maroon, purplish, and violet, constitutes much of the Marsh, but quartzite in members as much as 500 feet thick, and cross-laminated siltstone are interbedded with the argillite. Some laminae contain casts of salt crystals. The top of the formation south of Marysville is deep-maroon, mud-cracked and ripple-marked argillite with thin quartzite beds. The reddish argillite in the Marsh is regarded by Knopf as indistinguishable from the similar argillite in both the Spokane and Empire formations. He thinks the most distinctive member of the Marsh is dark-red quartzite that weathers to a deep blackish red. On the basis of mapping from Helena northwestward to Marysville the Marsh shale thickens from 250 feet at Helena to 3,000 feet south of Marysville.

Tweto (1937, p. 27, op. cit. p. 155) describes an impure, mottled light-purple and light-green thin-bedded argillite from the Marsh shale in the city of Helena. This rock consists of quartz, feldspar, and minor amounts of calcite, chlorite, hematite, biotite, muscovite, limonite, sericite, epidote, and rutile. The feldspar grains are altered and some of the chlorite masses have shapes that suggest they may have been derived from amphibole. The grain size is chiefly silt and the rest very fine sand.

Greenhorn Mountain quartzite.--The Greenhorn Mountain quartzite of Knopf (1950) is exposed on the mountains of that name south of Marysville and may extend as far west as Nevada Mountain (Eleanor B. Knopf, written communication). The Greenhorn Mountains quartzite has been grouped with Paleozoic rocks by earlier workers (Pardee and Schrader, 1933, pl. 2) and, hence, may be more widespread than is now known. The lower portion is massive quartzite, in places showing festoon cross lamination; the upper third is well stratified in beds 1 to 2 inches thick. The Greenhorn Mountain quartzite contains notable quantities of clear microcline, which distinguishes it from the nonfeldspathic Flathead quartzite. The Greenhorn Mountain quartzite is reported to be 1,800 feet thick, with the top bounded by the erosion surface on which the Flathead rests.

North Boulder group

<u>Distribution</u>.--The rocks to which the name North Boulder group was originally applied (Ross, 1949, p. 133) are in T. 2 N., R. 3-4 W., T. 1 N., R. 1-4 S., T. 1 S., R. 4 W., as well as in and near T. 2 N., R. 3-6 E., and northward. Similar material is exposed east of Divide in T. 1 S., R. 7-8 W., (Sahinen, 1939, 1950). Rocks so coarse that they seem best regarded as belonging to the group are now known to be present west and south of Divide (Guttormsen, Theodosis, Myers, written communication). Other masses are expected to be recognized when further mapping is done in and near Jefferson and Gallatin Counties, and perhaps elsewhere in southwestern Montana.

Perry[/] reports that the lower part of the North Boulder group in its type locality consists of conglomerate with boulders, up to 2 feet in diameter, of schist, gneiss, pegmatite, marble, and quartzite, typical of the Cherry Creek series. That series is extensively exposed farther south. The conglomerate is estimated by Perry to be 2,000 to 4,000 feet thick. The rocks next above the conglomerate consist of well-bedded greenish to gray-green coarse sandstone (graywacke or arkose) composed of angular to subangular grains of quartz, feldspar, and other silicate minerals embedded in a dark matrix. These beds were estimated by Perry in 1947 to be 2,000 feet thick but in the guidebook published in 1950 (Perry, 1950, p. 40-43) he says "the thickness is in the order of one mile". They are overlain by arkosic shale. The shale is thin bedded and in different parts is colored red, pink, purple, black, green, and gray, the last being dominant. The thickness of the shale unit varies from zero to about 1,000 feet. The Flathead quartzite (Middle Cambrian) high on the north side of the valley of the Jefferson River rests on the shaly beds. Field inspection by M. R. Klepper and the writer shows that the shaly unit is largely composed of beds that resemble the Greyson and Spokane shales farther north. A large expanse covered by Tertiary sedimentary rocks intervenes between the exposures of the Belt series near North Boulder River and those south of Helena to which formational names have been applied.

_/ Perry, E. S., Letter of Oct. 24, 1947, and guide book of First Annual Field Conference, Billings Geol. Soc., 1950.

The beds in the area just cited have also been studied by Alexander (1955). He named them the La Hood formation, taking the name from a small settlement along the Jefferson River east of Whitehall. A composite section he measured in disconnected exposures in the SE1/4 sec. 12, T. 1 N., R. 3 W., and SW1/2 sec. 7, T. 1N., R. 2 W., has three major subdivisions. The lowest consists of 1,121 feet of olive-gray to dark-greenish-gray arkosic sandstone with irregular lenses of conglomerate and minor amounts of silty shale. The largest conglomerate lens noted is 240 feet long and 30 feet thick. The conglomerate grades both laterally and vertically into sandstone. Many of the boulders in the thickest lenses are over 2 feet in diameter, enclosed in a sandy matrix. Most of the boulders are well rounded but one lens contains angular fragments of light-colored, quartz diorite gneiss 2 1/2 feet long. The boulders consist of milky quartz, granite gneiss, garnet-hornblende-plagioclase schist, plagioclase, clear quartz, orthoclase, gabbro, diorite, and light-gray marble with tremolite needles. The middle unit in the measured section, 775 feet thick, consists of notably hard light-olive-gray sandstone with beds of silty shale up to 2 feet thick in its lower part. The upper unit, 820 feet thick, consists mainly of soft-gray to brown sandstone with a few erratic boulders and a little silty shale. The sandstone beds throughout the section are similar and contain 15 to 40 percent quartz, 35 to 60 percent feldspar, 1 to 17 percent pyribole, 12 to 32 percent micaceous matrix, and such accessory constituents as hematite, apatite, garnet sphene, muscovite, calcite, zircon, and magnetite. The sand grains are poorly sorted and subangular to angular.

Throughout the unit as described by Alexander the bedding is regular in resistant beds and highly irregular in soft beds. In places sandstone lenses 8 feet thick may disappear within 50 feet laterally. The beds vary from a few inches to 20 feet in thickness. Crossbedding, ripple marks, and mud cracks are absent but evidence of intraformational scour is abundant.

It appears from Alexander's description that the proportion of shaly beds in the North Boulder group increases northward as a result of facies changes. About 10 to 15 miles to the northwest of this section he records three units of what he regards as Greyson shale separated from each other and from the overlying Flathead quartzite by coarse beds such as characterize the North Boulder group. He does not mention the red shaly and sandy beds that resemble the Spokane shale. These crop out east of the lower reaches of the North Boulder River. Alexander could not measure the full thickness of the North Boulder group (his LaHood formation) but regarded it as between 2,700 and 5,000 feet with the larger figure approximating the total near Whitehall. Tansley and Schafer (1933, p. 11, 12) who worked mainly south of Whitehall, found similar rocks in the northern end of their area. They estimated the maximum total thickness as 5,000 feet but the unit thinned rapidly to the east and south.

Four miles northwest of Sappington, coarse rocks here assigned to the North Boulder group have been reported (Berry, 1943, p. 5-8). These beds are dark-greenish-gray, coarse arkosic sandstone, in part conglomeratic. The pebbles are of gneiss and white vein quartz. Micaceous shale is interbedded with the sandstone in the middle part of the sequence. The total recorded thickness is 4,000 feet.

The northern end of the Tobacco Root Mountains contains rocks whose reported character (Barnes, J. V., 1954, unpub. rept.)_/ warrants

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_/ Barnes, J. V., 1954, North end of the Tobacco Root Mountains, Madison, County, Mont.: Unpub. rept. Indiana Univ.

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assignment to the North Boulder group. These consist mainly of tan and gray conglomerate, arkosic sandstone and argillite.

In an area of 3 square miles in T. 1 N., R. 1 W., which includes part of that described by Berry, and in a smaller area in sec. 5, T. 1 N., R. 1 E., G. D. Robinson (in prep. 1956) has described rocks of the North Boulder group. These consist mostly of thick-bedded, dark-yellowish-brown, coarse micaceous, feldspathic sandstone. Some layers contain many flat pebbles. Thin laminae of micaceous, olive-gray siltstone separate many of the sandstone beds, especially in the upper part of the sequence. In the lowest, most southerly exposures, lenses of cobble conglomerate appear. A distinctive reddish-brown to grayish-red, coarse arkosic sandstone, 100 to 250 feet thick, is at the top of the exposed sequence. The average grain size throughout the assemblage decreases northward, both stratigraphically upward and down the dip. The exposed thickness is 4,000 feet.

These rocks are rich in mica, chlorite, microcline, and sodic plagioclase. The coarse sandstone, here the dominant component, contains 40 percent quartz, 30 percent white or colorless oligoclase-andesine, 15 percent orange-pink microcline, 5 percent mica, mostly biotite, and 10 percent matrix, largely chlorite, clay minerals, limonite-hematite, and locally carbonates. Minor constituents include zircon, apatite, sphene, and opaque oxides. The siltstone laminae contain much the same minerals but with chlorite, mica, and clay minerals dominant, and quartz and feldspar rare. The cobbles in the conglomerate include vein quartz, quartzite, granite pegmatite, diorite, gneiss, amphibolite, and dolerite. The red sandstone at the top of the sequence locally has as much as 25 percent of clay-size material. It is low in mica and high in chlorite and limonite-hematite. The plagioclase is thoroughly argillized though the microcline is fresh.

The Belt series in areas east of Three Forks and extending as far north as White Sulphur Springs has recently been described in three doctoral dissertations (Klemme, 1949, p. 6-8; Tanner, 1949, p. 12-17; Verrall, 1955, p. 15-30). The descriptions are summarized in preceding parts of the present report. They indicate that representatives of the Spokane shale, Greyson shale, Newland limestone, and possibly the Chamberlain shale, may be present. Toward the south, mostly in the area studied by Verrall, these rocks interfinger with coarse beds regarded by Verrall as stratigraphically lower than the LaHood formation of Alexander (1955). The North Boulder group of the present report includes all the coarse components of the Belt series in this part of Montana.

Coarse sedimentary rocks of the Belt series have long been known in the mountains in and near T. 2 N., R. 6 E. (Merrill, J. P. <u>in</u> Peale, 1893, p. 49, Peale, 1896, p. 2). These rocks have recently been studied in some detail by McMannis (1952, p. 11-14, 1955, p. 1390-1392). His description resembles that of the North Boulder group in its type locality so closely that the correlation can be made with confidence. The rocks include coarse conglomerate, coarse arkosic sandstone and, in the northern part, dark-gray argillite and a few beds of siliceous limestone. The conglomerate contains cobbles and boulders of gneiss, quartz, and schist in a sandy matrix. The sandstone is so massive that bedding is difficult to find. It is moderately dark gray green where fresh and weathers dark brownish green, locally reddish. It contains quartz, microcline, and orthoclase, with some plagioclase in a matrix composed largely of chlorite and altered biotite and amphibole. The assemblage of coarse sedimentary rocks is over 6,000 feet thick.

The rocks of the Belt series east of Three Forks and north of the lower reaches of the East Gallatin River were originally described as consisting (Peale, 1893, p. 16-20) of coarse micaceous sandstone and conglomerate, with beds of hard-brown, green-black, and red argillaceous slate and of thin-bedded dark-blue siliceous limestone. The sandstone is prominent in both the upper and the lower parts of the sequence. The limestone is mainly low in a sequence 2,300 feet thick measured by Peale. He quotes two analyses of the limestone, given in the table below.

Charles Catlett, USGS analyst

	I	II
Calcium carbonate ($CaCO_3$)	67.85	59.11
Magnesium carbonate ($MgCO_3$)	6.18	1.96
Iron oxide (Fe_2O_3) Aluminum oxide (Al_2O_3)	2.50	1.92
Insoluble (silica)	23.50	35.26
Total	100.03	98.25

An exposure here tentatively correlated with the North Boulder group is in and near T. 1 S., R. 7-8 W., east of Divide. These rocks are described (Sahinen, 1950, p. 13-15) as composed of a thick, conglomerate overlain by argillite, slate, quartzite, and quartzitic conglomerate. The basal conglomerate, which overlies schist unconformably (Sahinen, 1939, p. 14) is greenish gray and contains subangular to well-rounded pebbles and small boulders of quartz, quartzite, slate, and schist in a matrix of fine quartz sand and argillaceous material with appreciable amounts of white mica. The pebbles range from less than 1/4 to over 6 inches in diameter. The conglomerate passes upward into a coarse-grained dark-gray arkose containing feldspar, quartz, and white mica. The argillite, the predominant rock, is gray green, fine grained and irregularly laminated. The argillite weathers dark red. It contains quartz, feldspars, sericite, and clay minerals in grains 0.25 millimeter and less in diameter. Much of the argillite is still finer grained; in some the maximum observed diameter of quartz grains is 0.4 millimeter. Most of the quartzite is in pink and black layers and composed of grains 0.05 millimeter and less in diameter. Some of the quartz has been recrystallized into a mosaic and shows minute needle-shaped crystals and shreds of sericite. The conglomeratic beds have pebbles up to 4 inches in diameter in a pink quartzite matrix streaked with black. The quartzite can generally be distinguished from that of Paleozoic age by the dark-colored irregular layers or streaks.

Theodosis[/] mapped rocks that presumably belong to the North Boulder

[/] Theodosis, S. D., 1956, Melrose Area: geologic map accompanying unpublished Ph. D. dissert., Indiana Univ.

group in T. 1 S., R. 9 W., southeast of Divide. He estimated the thickness as over 4,000 feet and recorded black, gray, green, and red silty shale and argillite with conglomeratic quartzite in the lower parts of the sequence. The upper few hundred feet include purplish-red, white, yellow, and gray conglomeratic quartzite, intercalated with brown siliceous argillite.

Exposures west of Divide seem to be, at least in part, correlatable with the North Boulder group (Guttormsen, 1952, Myers, 1958, written communications). These beds include maroon sandy quartzite, buff to white quartzite and quartzitic sandstone, siltstone, argillite, and conglomerate. Unlike much of the conglomerate in the group, the contained pebbles and cobbles are well rounded and rather well sorted, with long axes tending to be parallel to the bedding planes. Diameters range from 1/8 inch to 8 inches, commonly about 2 inches. The pebbles and cobbles are mostly quartz and quartzite, with some jasper. The matrix is quartzitic and contains feldspar, sericite, and hematite. The sandstone above is crossbedded and locally shows ripple marks and mud cracks. Some beds contain garnet. The Hasmark formation (Upper Cambrian) is reported to rest directly on the rocks just described but the upper part of the Belt sequence here is quartzitic sandstone, leaving the possibility open that it may include representatives of the Flathead quartzite, which in most of the region is the lowest of the Cambrian formation.

The series in and near northeastern Washington

<u>Distribution</u>.--The Belt series is present in and near the northeastern corner of Washington but its components cannot at present be correlated with named units farther east. Rocks of the Belt series crop out in Boundary County, Idaho, west of the valley of the Kootenai River, in and near Pend Oreille County, Wash., and equivalent strata reach over large areas in British Columbia northward at least as far as the vicinity of latitude 52°. In British Columbia, and to some extent in Washington, the Shuswap complex (Geol. map of British Columbia, 1948) of metamorphic rocks probably includes rocks of the Belt series, that cannot be separately delineated on the basis of available data. The Priest River group, or terrane, once regarded as pre-Belt, (Daly, 1912, p. 258-271) is believed to be part of the Belt series for reasons outlined on p. 332, 335.

Character.--In northeastern Washington (Park and Cannon, 1943, p. 5-15) the stratigraphic sequence includes, in ascending order, the Priest River group, Shedroof conglomerate, Leola volcanics, and the Monk formation. In Daly's nomenclature (1912, p. 258-271) the Priest River group is the Priest River terrane, the Shedroof conglomerate is the Irene conglomerate, and the Leola volcanics is the Irene volcanic formation. In a later report (Little, 1950, p. 5-6) the Shedroof conglomerate becomes the Toby conglomerate, and the Leola volcanics are called the Irene volcanic formation. Little regards the Toby and Irene as belonging to the Windermere series, the Precambrian part of which corresponds to the upper part of the Belt series of the United States. The Priest River group is a complex sequence of metamorphic rocks that includes phyllite, schist, limestone, dolomite, quartzite, and volcanic rocks, regarded as unconformably below the Shedroof conglomerate. The conglomerate is a coarse, very poorly sorted, dingy-gray-brown rock. Most of the contained fragments are 1 to 8 inches across. Many are smaller and a few irregular limestone blocks have diameters of 5 feet or more. Some sandy phyllitic and dolomitic beds are intercalated in the conglomerate. The pebbles in the Shedroof conglomerate have probably been derived from the Priest River group, but the bedding in the latter appears to parallel the contact with the conglomerate. The thickness of the Shedroof conglomerate varies widely but is several thousand feet. The rock may be a fanglomerate but its origin is not clear. "The wide deposition of such immense quantities of uniformly coarse debris is difficult to explain" (Park and Cannon, 1943, p. 9). The Shedroof conglomerate grades upward into the Leola volcanics. The latter includes greenstone and green schist, regarded as metamorphosed lava and tuff. The thickness is variable and difficult to determine but is supposed to be over 5,000 feet.

The Monk formation overlies the Leola volcanics, apparently unconformably. It consists mainly of fine-grained phyllite but includes quartzite, grit and quartzitic limestone, with conglomerate at the base. Park and Cannon tentatively assigned the Monk formation to the Cambrian, as it is conformable with and grades upward into the Gypsy quartzite which has yielded Cambrian fossils. Two other formations of Cambrian age (Maitlen phyllite and Metaline limestone) lie above the Gypsy quartzite. In British Columbia the contact between the Precambrian and Cambrian has been placed tentatively somewhat higher on the basis of more recent work (Little, 1950, p. 10-11). The change is made mainly because the base of the Monk formation appears to be 12,000 to 14,500 feet below a horizon at which abundant pleosponges have been found. The latter are regarded and probably equivalent to the Olenellus zone of Lower Cambrian age. The fossils collected by Park and Cannon in their Gypsy quartzite are thought by Little to come from a horizon several hundred feet below the horizon that yielded the pleosponges. Little tentatively places the Precambrian-Cambrian boundary at the base of his Quartzite Range formation which appears to correspond to a horizon within the Gypsy quartzite of Park and Cannon. The latter is 5,300 to 8,500 feet thick. In any event, no hiatus has been suggested anywhere between the base of the Monk formation and the horizons that have yielded Lower Cambrian fossils. Hence the horizon selected as the base of the Cambrian system in the locality is necessarily arbitrary, chosen mainly on the basis of ready recognition in mapping.

In the northwest corner of Idaho (Kirkham and Ellis, 1926, p. 17-27, 39-40) the Irene conglomerate and Irene volcanic formation of Daly have been grouped as Purcell lava, although obviously sedimentary rocks make up a large part of the unit. At the base of the so-called Purcell lava is 5,000 feet of conglomerate in which the sand and pebbles are chiefly made up of sericitic quartzite and white quartzite supposed to have been derived from the Revett quartzite of Kirkham and Ellis, part of an assemblage they thought equivalent to the Priest River terrane of Daly. The conglomerate interfingers at the top with 6,000 feet of altered basaltic and andesitic lava flows, greenstone schist, tuff, conglomerate, breccia, and dolomite.

The rocks included in the Priest River terrane (Daly, 1912) are metamorphosed and he thought that they were bounded at the top by an unconformity. In northeastern Washington these rocks have been called the Priest River group (Park and Cannon, 1943, p. 6) and include phyllite, schist, limestone, dolomite, quartzite, and volcanic rocks. The unconformity at the top is noted. In British Columbia (Geol. map of British Columbia, 1948) the rocks Daly included in the Priest River terrane are mapped as belonging to the upper part of the Purcell series and the Windermere series.

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