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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT
OF THE ST. REGIS FORMATION OF THE
RAVALLI GROUP (PRECAMBRIAN BELT
MEGAGROUP) NORTHWESTERN MONTANA AND IDAHO.

University of Cinninnati, Ph.D., 1971
Geology

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STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT OF THE ST. REGIS FORMATION OF THE RAVALLI GROUP (PRECAMBRIAN BELT MEGAGROUP) NORTHWESTERN MONTANA AND IDAHO

A dissertation submitted to the

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1971

by

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UNIVERSITY OF CINCINNATI

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I hereby recommend that the thesis prepared under my supervision by Stephanie Vladimira Hrabar

entitled Stratigraphy and Depositional Environment of the St. Regis Formation of the Ravalli Group (Precambrian Belt Megagroup) Northwestern Montana and Idaho

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

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ABSTRACT

The Belt Megagroup (Late Precambrian) in westernmost Montana consists of about 30,000 feet of dominantly fine-grained terrigeneous clastics that has been subdivided into four major groups, which in stratigraphic sequence are: pre-Ravalli, Ravalli, Piegan and Missoula groups. These groups are 8000 to 20,000 feet thick and consist of two or more of five major lithologic types that recur throughout the stratigraphic sequence.

The Ravalli Group in the Coeur d'Alene mining district of Shoshone County, Idaho is subdivided in three lithologic units each about 1000 to 3000 feet in thickness and transitional into one another. These are from oldest to youngest the Burke, Revett and St. Regis formations. This group is overlain by the Wallace formation (Piegan Group), the lowermost member of which is carbonate-rich. Aside from the carbonate content, however, the lithology is similar to that of the underlying St. Regis.

Fourteen stratigraphic sections of the St. Regis and adjacent units were measured in detail and 292 cross-bed measurements and the strikes of 552 ripple marks were collected in the 300 square mile study area in western Sanders County, Montana and Shoshone and Bonner Counties, Idaho. A bed-by-bed study of bedding characteristics and petrography of different lithologic types (322 thin sections) provides additional information.

Two recognizable facies that occur within the Ravalli Group are (1) the basin facies which contains turbidites and (2) the base-of-slope facies which contains thick quartzites. Thin, interbedded to

interlaminated quartzite, siltite and argillite is the dominant lithology (basin facies) in the group. The thin-bedded quartzites are laterally discontinuous, have sharp bases, but grade vertically into siltite and argillaceous siltites. Parting lineation, ripple marks, convoluted bedding, and flame structure are among the most easily observed sedimentary structures. These structures are commonly arranged in a vertical sequence similar to that described by Bouma (1962) for turbidites. This monotonous sequence of alternating quartzite and argillite is interrupted by thick (50 to 200 foot) subarkosic quartzites in the middle of the Ravalli Group (base-of-slope facies); but north and east of the study area these quartzites disappear. The geometry of the quartzites cannot be determined, although limited exposures contain small scours and channels (5 to 20 feet deep) with the trough axes oriented almost parallel to the dip direction of the cross-bedding. Other sedimentary features in the quartzites include parting lineation, ripple marks, gradational bedding, thin to medium scale cross-bedding and minor flame structure and deformed bedding.

The St. Regis is interpreted to be a turbidite sequence that was deposited during a flysch phase of sedimentation based on the similarity of its sedimentological features to recently described turbidite and flysch sequences and supported by studies in recent sediments along the present continental margins.

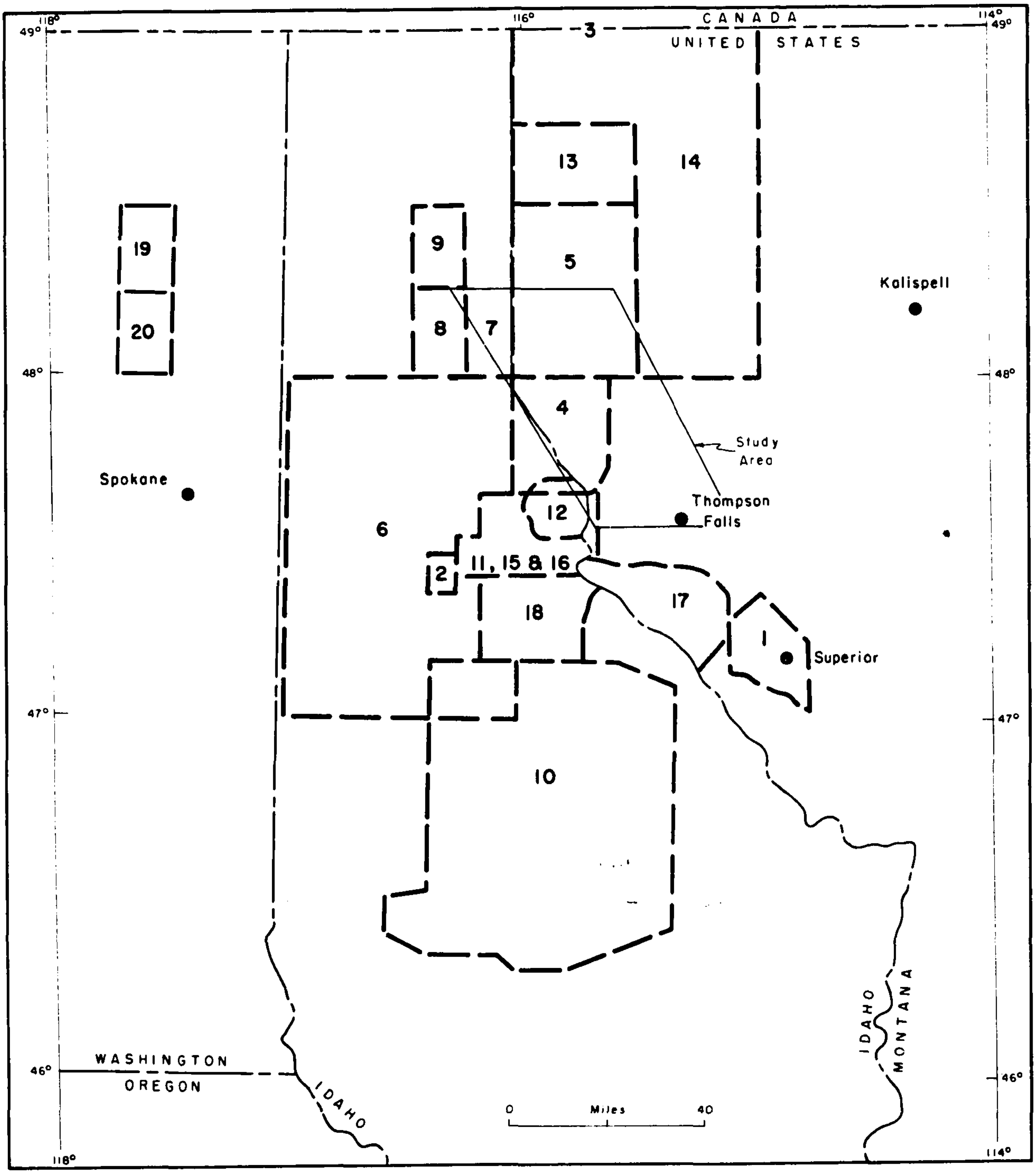
The fine sand and mud of the Ravalli Group were transported down paleoslope toward the northeast by turbidity currents and deposited on the basin floor. The quartzites (of the Revett) were deposited possibly as distributary channel sands on subsea fans along the break in slope near the basin floor and intercalate with the basin facies down dip. Erosional and depositional sites shifted due to variations in local topography, basin subsidence or local subsidence or faulting and produced a complex or overlapping sequences (or bundles) of base-of-slope and basin deposits. The St. Regis represents a transgressive sequence that was deposited on the older base-of-slope deposits as the basin subsided. The depth of water in which these sediments were deposited is unknown but is believed to have been between a few hundred to 5000 feet. This is in strong contrast to the earlier shallow water (beach and mud flat) interpretation by Ransome and Calkins (1908).

INTRODUCTION

Although the Precambrian Belt Megagroup has been studied for almost a century, no sedimentological studies have ever been published. Most of the previous geologic work in the Belt has been reconnaissance mapping, the primary objective of which was to determine the general stratigraphic and structural geology for a particular area. The geographic coverage of these reports is not uniformly distributed. Lack of correlation between the areas described in various reports has led to confusion in nomenclature and interpretation of the depositional history of the strata. Within the past 20 years extensive studies of the structural history and economic potential in the northwestern states have produced large-scale geologic maps (1:62,500), additional reconnaissance mapping of area between older published maps, and a few detailed studies.

The purpose of this study is to re-evaluate (1) the depositional environment of the St. Regis formation and (2) the regional sedimentological setting of the Ravalli Group in northern Idaho and western Montana within the framework of modern sedimentological concepts. The geologic maps and reports of northern Idaho and western Montana that are used in this study are given in Figure 1. These reports are part of areal mapping projects. No stratigraphic studies have been published.

Figure 1. - Index map of published geologic maps and reports in northern Idaho and northwestern Montana used in this study (1) Campbell, 1960, Superior-St. Regis area; (2) Campbell and Good, 1963, Twin Craigs area; (3) Daly, 1912, along 49th parallel; (4) Gibson, Jenks and Campbell, 1941, Trout Creek area; (5) Gibson, 1948, Libby area; (6) Griggs, in press, E. 1/2 Spokane AMS sheet; (7) Harrison & Jobin, 1963, Clark Fork 15' quadrangle; (8) Harrison & Jobin, 1965, Packsaddle 15' quadrangle; (9) Harrison, in press, Elmire 15' quadrangle; (10) Hietanen, 1963-68, Clearwater County; (11) Hobbs and others, 1965, Coeur d'Alene district; (12) Hosterman, 1956, Murray area; (13) Johns, 1959, Kootenai and Flathead counties; (14) Johns, 1961, Kootenai and Flathead counties; (15) Ransome, 1905, Coeur d'Alene district; (16) Ransome and Calkins, 1908, Coeur d'Alene district; (17) Wallace and Hosterman, 1956, western Mineral County; (18) Wagner, 1949, south slope of St. Joe Mountains; (19) Clark and Miller, 1968, Chewelah Mountain quadrangle; (20) Miller, 1969, Loon Lake quadrangle (21) Calkins and MacDonald (1909)


CANADA
UNITED STATES
3
13
14
19
9
5
Kalispell
20
8
7
4
Study Area
Spokane
Thompson Falls
12
6
11, 15 & 16
2
17
18
1
Superior
10
WASHINGTON
OREGON
IDAHO
IDAHO
MONTANA
0 Miles 40
118°
116°
114°
49°
48°
47°
46°

REGIONAL SETTING OF BELT MEGAGROUP

A. C. Peale (1893) first used the term Belt formation with reference to a thick sequence of alternating coarse micaceous sandstones, conglomerates, slate and thin-bedded, dark blue, siliceous limestones resting on Archean gneiss in the vicinity of Three Forks, Montana. This sequence had been provisionally called the East Gallatin group in 1884, because of the good exposures along the East Gallatin River. Its Late Precambrian age was assigned because the formation was believed to consist largely of Archean debris and lay stratigraphically below beds containing middle Cambrian fossils. The formation itself was barren of fossils.

The Belt Series was classified by the U.S. Geological Survey (Wilmarth, 1925) as a series of the Algonkian system; however, the Geologic Names Committee (1953) no longer recognizes time-stratigraphic subdivisions of the Precambrian and suggests that the provincial use of the term "series" be replaced. The term megagroup will be used in this report in place of the term "series" for a rock-stratigraphic unit larger than group and comparable in size with series and systems (Swann and Willman, 1961). A comprehensive review of the history of time and rock stratigraphic terminology, numerous stratigraphic correlations, and introduction to the plethora of literature on Belt rocks in Montana is given by Ross (1963).

The principal structural features and the location of the Precambrian Belt rocks are shown in Figure 2, and the characteristics of the megagroup are summarized in Table 1. The present structural

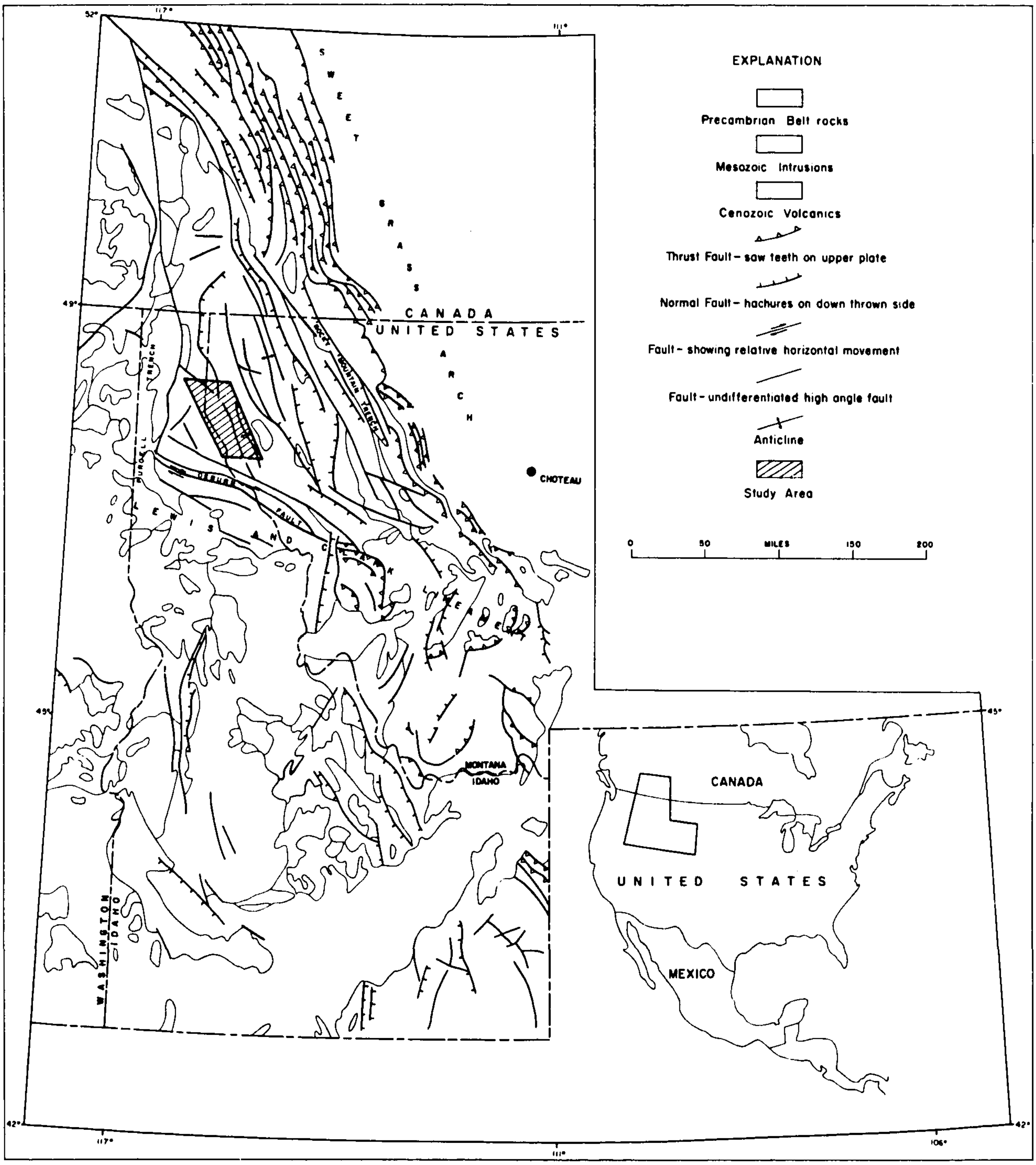


Figure 2. Regional structural setting and distribution of Precambrian Belt rocks in the western United States and Canada. Modified from U.S. Geological Survey "Tectonic map of North America," 1969.

Table I - Summary of the Precambrian Belt Megagroup

Age

Radiometric dating indicates maximum age of the youngest Belt rocks is greater than 530 m.y. (based on dating of overlying Cambrian rocks)basement dated at 1,800 m.y.

Geometry

Original boundaries of basin(s) largely unknown. Edges modified by faulting, intrusives and extrusives. Eastern margin of basin approximated by present eastern limit of Belt rocks.

Size

Estimated to be about 400 miles long, 300 miles wide and to contain at least 47,000 feet of fill; top eroded; base known at few places. This 120,000 square-mile area includes northeastern Washington, northern Idaho, western Montana and southeastern British Columbia.

Fill Kind

Very mildly metamorphosed silt and mud (70%), carbonates (13%), quartzose sands (15%), and conglomerates (2%). Shallow water sedimentation inferred from thick accumulations of fossiliferous carbonates.

Arrangement

Asymmetric distribution. Sources from northeast and east, west and southwest. Conglomerates limited to southeast basin margin. Carbonates more abundant in eastern portion of basin. Formations thin eastward as a result of depositional thinning and unconformaties that compound toward basin margin. Widespread marker beds rare. Fossils uncommon and not useful in correlation.

Current System

Unknown.

Tectonics

Precambrian deformation open folding and minor faulting. Up to five episodes of Cenozoic deformation producing close-spaced, high-angle faulting and overturned folds in western half. Thrusting and open symmetrical folds in eastern half. Basin inset in a stable craton? Orogenic thickness but no known orogeny!

setting of the Belt Megagroup consists of a northwesterly trending zone of closely spaced westerly dipping thrust faults, longitudinal normal faults, transverse faults and folds. Structural deformation during the late Precambrian was predominantly folding with minor faulting. The next major period of deformation began during the Mesozoic with the emplacement of batholithic masses in northern and central Idaho. Up to five episodes of deformation occurred during the late Mesozoic and early Cenozoic, producing closely spaced high angle faults and some overturned folds in the western part of the terrane and thrusting and open symmetrical folds in the eastern part of the outcrop belt (Mudge, 1970).

The presently known distribution of Belt rocks covers a 120,000 square mile area, that includes northeastern Washington, northern Idaho, western Montana and southeastern British Columbia. The stratigraphic sequence is at least 47,000 feet thick in the western part of the outcrop belt and thins to about 7,000 feet in the eastern part; the top of the sequence is eroded (Mudge, 1970). The north-northwesterly regional strike of the Belt rocks is coincident with the axial trace of an anticlinorium. The north, south and west boundaries of the Belt are modified by Mesozoic intrusives and Cenozoic extrusives and faulting. The eastern extent of the outcrop approximates the basin margin as indicated by the depositional thinning, marginal conglomerates and more numerous unconformities. In contrast, the western part of the outcrop belt consists of a very thick, conformable, and homogeneous sequence of rocks with no evidence of a basin margin.

These Precambrian rocks were deposited probably between 900 million years (m.y.) and 1300 m.y. ago (Obradovich and Peterman, (1968). The basin fill is composed almost entirely of clastic sediments, consisting of about 70 percent mud and silt, 15 percent quartzose sand and 13 percent carbonates. Thick fossiliferous (principally stromatolites) sections of carbonate rock that are useful in local correlations are more abundant along the eastern margin of the basin and add diversity to the otherwise monotonous clastic sequence. Coarse conglomerates, a minor constituent, are restricted to the southeast margin of the basin. The western part of the outcrop belt consists mainly of terrigeneous clastics; however, minor carbonate rock units are present.

The Belt Series generally has been subdivided into rock-stratigraphic units, formations and groups, that are characterized by one or more lithologic types. These major lithologic types include (1) medium to fine-grained quartzite, (2) thin-bedded to massive quartzose siltite, (3) thin-interbedded to interlaminated quartzite, siltite and argillite, (4) thin-interbedded argillaceous siltites and argillites, and (5) carbonate rocks. The boundaries between successive formations are gradational, and these transition zones range from tens to hundreds of feet in thickness. The four major groups (Figure 3) that have been established range from 5,000 to greater than 10,000 feet in thickness. From oldest to youngest these are the pre-Ravalli, Ravalli, Piegan and Missoula groups.

Correlation of these rock-stratigraphic units has been made by comparing the relative positions of similar-looking lithologies within the over-all stratigraphic sequence. Although this technique has been useful in small areas and parallel to deposition strike, the absence of widespread markers precludes correlation between the eastern and western parts of the outcrop belt.

Published stratigraphic and sedimentologic data are sparse. Most detailed studies have concentrated on the thick fossiliferous carbonates along the eastern margin, for example Rezak's (1957) study of the stromatolites, and no attention has been given to the study of the terrigeneous clastics that make up most of the Belt sediments. The study of the St. Regis Formation in western Montana and adjacent Idaho is an attempt to determine the depositional environment of a non-fossiliferous, terrigeneous lithology in the very thick, monotonous sequence in the western part of the Belt outcrop belt.

GENERAL STRATIGRAPHY AND STRUCTURE

The Belt Megagroup in northern Idaho and adjacent Montana consists of more than 30,000 feet of low-grade metasedimentary rocks that have been divided into eight lithostratigraphic formations. (Figure 3). The lower seven formations, as defined in the Coeur d'Alene district of Northern Idaho by Ransome (1905), are from oldest to youngest, Prichard, Burke, Revett, St. Regis, Wallace and Striped Peak. The Libby formation, which does not occur in the Coeur d'Alene area, was named later by Gibson (1948). These formations are characterized by several distinct lithologic types that recur throughout the stratigraphic section and any of the formations may contain one or more lithologic types. Field mapping has traced the formations of the Coeur d'Alene district north to Clark Fork, Idaho; northeast to the Clark Fork River in western Sanders County, Montana, east into Mineral County, Montana; and west into Stevens County, Washington. Southward extensions of these formations into Clearwater County, Idaho is complicated by higher grades of metamorphism, structure and heavy vegetation cover.

The Belt rocks have been affected by folding, faulting and intrusions of granodiorite and related igneous rocks. Folds trend mainly to the northwest, and the faults are separable into two major systems: a younger north-south system and an older northwest system. These faults are outlined by the courses of the major river valleys and trenches, although these topographic depressions have been recently modified by glaciation and alluvial processes.

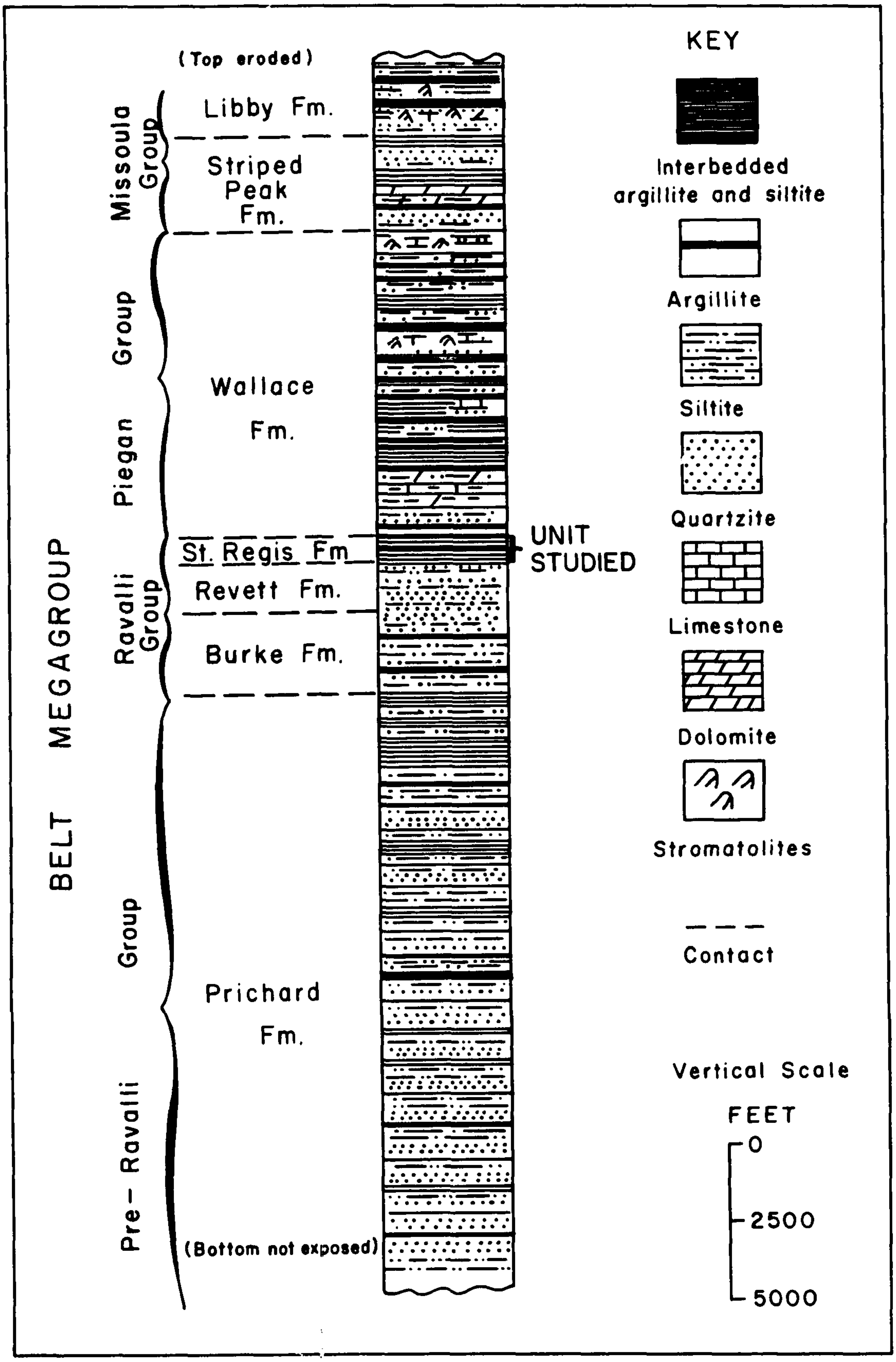


Figure 3. Generalized stratigraphic section for Belt Megagroup in northern Idaho and western Montana (modified from Harrison and Jobin, 1963).

Faults. Long, closely spaced, normal and reverse faults characterize the younger north-south fault system that developed during the early Tertiary. These faults, that are west of the thrust belt, (Figure 4) are younger than the thrusts and considered as Basin and Range type that may represent backsliding after the gravitional gliding that produced the thrusts (Mudge, 1970). Estimates on the amount of throw on these normal faults range from about 2,000 feet to at least 26,000 feet.

The Hope fault which bisects the study area is a major structural feature of the northwest fault set (Figure 4). Its mapped extent is from the northern end of Lake Pend Oreille in Idaho to Trout Creek, Montana. The Hope fault is a normal and strike-slip fault that dips steeply toward the southwest and has an estimated right lateral displacement of approximately 16 miles. Its stratigraphic throw is estimated to be about 20,000 feet near Clark Fork, Idaho (Harrison and Jobin, 1963).

Another major structural element in the northwest system is the Osburn fault zone that lies immediately south of the study area. This 100-mile long fault zone is a complex of faults, shears and shatter zones that ranges in width from 1,000 feet to two miles. The character of the fault changes along its length. Near Mullan Pass on the Idaho-Montana line the fault zone seems to be one fault with a shear zone several hundred feet wide (Wallace and Hosterman, 1956) but north of Superior, Montana, the fault is a zone of intense shearing several hundred feet wide (Campbell, 1960).

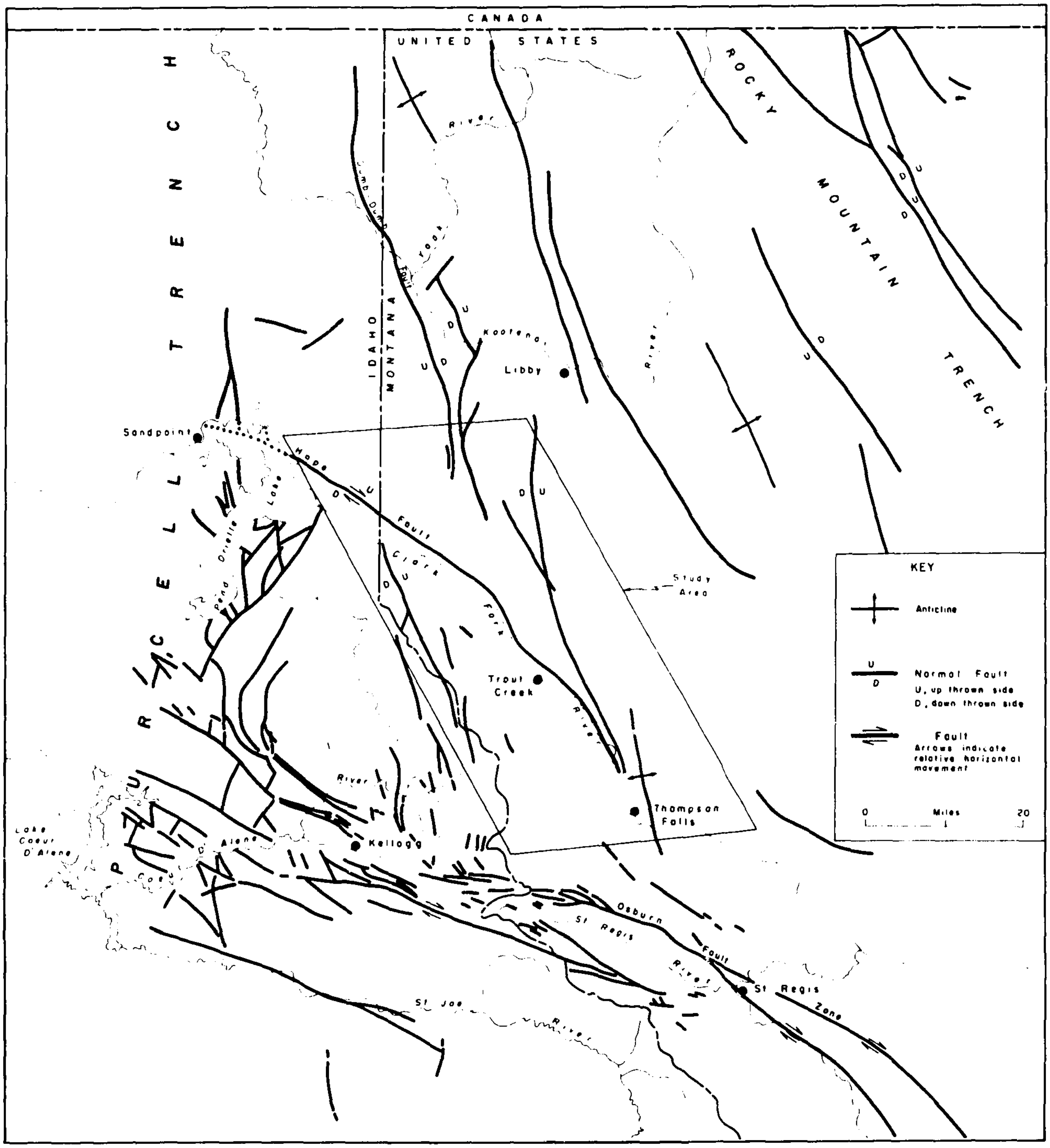


Figure 4. General structural setting of northern Idaho and northwestern Montana. Two major fault sets (1) a north-south set of closely spaced, high-angle faults and (2) a north-west set of high-angle faults with large displacements.

Wallace and Hosterman (1956) suggest a horizontal displacement of 16 miles for the Osburn fault; but the stratigraphic throw is variable and difficult to determine. Ransome and Calkins (1908) indicate a throw of considerably greater than 6,000 feet near Osburn, Idaho, although near the Idaho-Montana line, rocks of the same formation lie on either side of the fault and the throw is indeterminable.

The specific age of these major faults in this northwest fault system is unknown. Although the earliest recorded movements are post-Precambrian, the faults may have been a part of deep-seated zones of crustal weakness that were possibly active since Belt time (Campbell, 1960).

Folds. Folding in northernmost Idaho and Montana is expressed as broad, open anticlines and synclines the axes of which trend northwest, north and northeast and usually exhibit a gentle northward plunge. In Idaho and westernmost Montana the complexity of folding differs north and south from the Osburn fault zone. Deformation is more intense and overturned folds are common in the structural block north of the fault zone; whereas, few folds are overturned in the southern structural block (Wallace and Hosterman, 1956). This difference in structural complexity north and south of the Osburn fault is typical of the area between Kellogg, Idaho and the St. Regis-Superior, Montana area.

Igneous rocks. Intrusive igneous rocks in northern Idaho and western Montana include quartz diorite of Precambrian age, granodiorite and related rocks of Cretaceous (?) age and diabase of Cretaceous (?) age. Quartz diorite sills that are composed principally of hornblende, plagioclase, quartz, and biotite intrude the pre-Ravalli, Ravalli and Piegan. These sills range in thickness from a few inches to 800 feet and range in length from a few feet to 10 miles, although most are approximately 100 feet thick and can rarely be traced for a distance greater than two miles (Gibson, 1948). The quartz diorite is tentatively assigned a Precambrian age pending radiometric age determinations (Harrison and Jobin, 1963).

Granodiorite and related rocks intruded and locally metamorphosed the Belt rocks of northern and central Idaho and eastern Washington. A number of small granodiorite stocks occur in western Montana in and adjacent to the study area.

Small diabase sills and dikes cut outcrops of granodiorite in the Purcell Trench and Cabinet Mountains. These sills and dikes are generally less than 10 feet thick and are difficult to trace because the diabase is rapidly weathered to a vegetation-supporting soil cover. The altered rock consists principally of chlorite, biotite, calcite, sericite and some augite; the fresh rock is mainly labradorite and augite (Harrison and Jobin, 1963).

INTRODUCTION TO THE STUDY OF THE ST. REGIS

A detailed examination of the St. Regis formation and adjacent formations was carried out in northern Idaho and western Montana. The criteria used to define the formations are the same as those used in the Coeur d'Alene mining district by Ransome and Calkins (1908), and Table 2 summarizes the characteristics of these formations in the mining district. To determine the character and organization of the bedding in the respective formations thirteen stratigraphic sections were measured and described in detail (Figure 5); the quantative bedding terms are given in Table 3. Within the text the name of a measured section or station visited in the field is followed by a number in parentheses. This number refers to the location of the appropriate section in Appendix A.

All the measured sections include at least part of the St. Regis formation. The upper part of the Revett and lower part of the Wallace were measured wherever possible in order to determine the nature of the boundaries between the St. Regis and its enclosing units. The only well-exposed and undeformed outcrops of the St. Regis formation west of the Clark Fork River occur at Maple Cliff and Castle Rock (25) along the North Fork of the Coeur d'Alene River in Idaho and along the south-facing hillside along Trout Creek (6) west of Minton Creek Pass in the study area (Figure 5). Outcrops along Beaver (11) and Little Beaver (12)

Revett	St. Regis	Lower Wallace
Beds thick to thin. Laterally discontinuous.	Beds thin to laminated. Argillites continuous.	Beds thin to very thinly laminated. Argillites continuous.
Medium sand to clay.	Fine sand to clay.	Fine sand to clay.
Thick to medium quartzite beds commonly cross-bedded.	Occasional thin quartzite units; cross-bedding scarce.	Thin, discontinuous quartzite beds; cross-bedding scarce.
Sandstone bodies common.	Sandstone bodies absent.	Sandstone bodies absent.
Argillaceous zones between cross-bedded quartzite zones show graded bedding.	Graded bedding common.	Varve-like and graded bedding.
Quartzites have sharp tops and base; sharp base, graded top; graded top and base.	Quartzites have sharp base; top graded or sharp.	Quartzites have sharp base and top.
No channels observed; scours common.	Small scours.	Small scours.
Mud chips scarce; no burrows.	Mud chips; burrows common.	Mud chips; burrows common.
Mud cracks scarce.	Mud cracks abundant.	Mud cracks common.
Thin carbonatic beds scarce.	Thin-medium beds of carbonate mudstone common.	Thick carbonate mudstone beds. Molar tooth common.

Table 2. Lithologic characteristics of the Revett, St. Regis, and Wallace formations in the Coeur d'Alene mining district and in the study area. Distinguishing characteristics are (1) presence of sand bodies, (2) type of bedding (gradational, graded or ungraded) and (3) abundance of carbonates Description of Wallace refers only to the lowermost 500 to 1,000 feet of the formation.

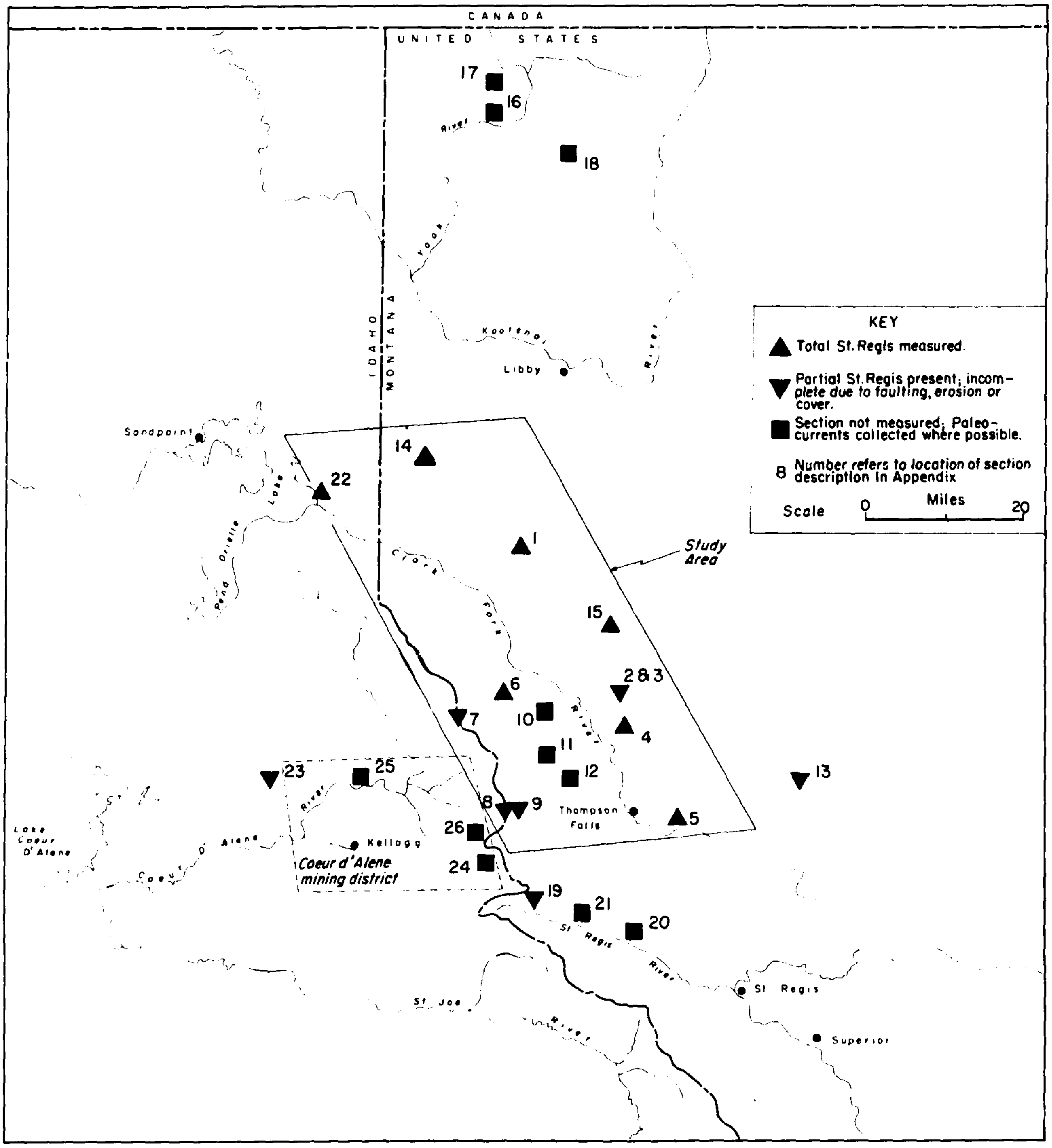


Figure 5. Location of sections examined in and adjacent to study area.

Stratification		Cross-stratification		Thickness	
				Centimeters	Inches (approx)
Beds	Very thick bedded	Crossbeds	Very thickly crossbedded	120	48
	Thick bedded		Thickly cross-bedded	120-00	48-24
	Thin bedded		Thinly cross-bedded	60-5	24-2
	Very thin bedded		Very thinly cross-bedded	5-1	2-1/2
Laminae	Laminated	Cross laminae	Cross laminated	1-0.2	1/4-1/12
	Thinly laminated		Thinly cross laminated	0.2	1/12

Table 3. Quantitive bedding terms used in this report (from McKee and Weir, 1953).

creeks in the study area are faulted and intruded, and the top of the Ravalli group, /Twenty-four Mile (8), Clear Peak (9) and Lost Peak (7) measured sections7 along the Idaho-Montana state line is truncated by the present erosion surface or faulted. East of the Clark Fork River the upper part of the Ravalli Group is well exposed in the Rock Creek drainage (1), near the head of Waloven Creek (15), at Graves Peak (4), and at the mouth of the Thompson River (5). Seven of the eleven sections measured in the study area contain the complete thickness of St. Regis.

Ravalli Group

The Ravalli Group is about 4000 feet thick in the Coeur d'Alene mining district in Idaho (Ransome and Calkins, 1908), increases to 10,000 feet in northwestern Montana (Gibson and others, 1941) and is estimated to be about 7000 feet thick along the International Boundary in northwestern Montana (Daly, 1912).

The group is comprised mainly of thin bedded terrigeneous clastics that commonly show ripple marks, mud cracks, mud chip or shale pebbles and cross-bedding. In the Coeur d'Alene district the Ravalli is subdivided into three rock-stratigraphic units that are 1000 to 3000 feet in thickness; in stratigraphic order these are the Burke, Revett and St. Regis formations (Figure 3). These formations are made up of varying proportions of thin interbedded quartzite, siltite and argillite; laminated to cross-bedded quartzite; and thin beds of carbonatic argillite. Fossils are absent, although burrows are common. Both the Burke and St. Regis are composed mainly of rapidly alternating sequences of quartzite, siltite, and argillite. Thick intervals of laminated to cross-bedded quartzites in the central part of the Ravalli Group characterize the Revett formation. These quartzites are 30 to 200 feet thick but are composed of individual sedimentation units averaging one foot thick. Northward and eastward from the Coeur d'Alene district the Revett quartzites gradually disappear (Calkins and MacDonald, 1908); Gibson and others, 1941; Gibson, 1948; Wallace and Hosterman, 1956) leaving a thick monolithic sequence of thin interbedded quartzite and argillite.

The medium to very fine grained quartzites and siltites consist largely of quartz, feldspar, muscovite, minor chlorite with a varying amount of matrix and cement (Part B in Appendix). Cementing minerals include quartz and minor calcite and iron-magnesium carbonates. Carbonate cement is irregularly distributed within the quartzites and siltites but is locally abundant in the argillites. Quartzites containing iron-magnesium carbonate minerals have reddish-brown specks, the residue from the altered carbonate minerals. Trace amounts of idiomorphic magnetite and pyrite crystals are ubiquitous, and manganese dioxide and specular hematite are commonly smeared along joint and fracture surfaces. The color of the rocks may be white, red to pink, black, medium-gray to light gray, green-gray to purple-gray or green reflecting varying concentrations of the minerals hematite, limonite, geothite, magnetite or chlorite.

Piegan Group

The Piegan Group (Fenton and Fenton, 1937) in Idaho and westernmost Montana consists of the Wallace formation, which shows an increase in thickness west, east, and north from the Coeur d'Alene district; Belt stratigraphy south of the district is complicated by metamorphism (Hietanen, 1963-68). In the Coeur d'Alene district the Wallace is reportedly 5000 feet thick (Ransome and Calkins, 1908) and increases to 8000 feet in western Idaho (Griggs, in press). East and north from the district it thickens to 10,500 feet near Superior, Montana (Campbell, 1960), and 14,500 feet near Libby, Montana (Johns, 1959).

The Wallace has been subdivided into five mappable members that range from 400 to 3500 feet in thickness. (Harrison and Jobin, 1963; Harrison and Jobin, 1965). These rock-stratigraphic units contain varying proportions of (1) interlaminated black or green argillite and siltite, (2) thinly interbedded carbonatic siltite and argillaceous siltite, (3) laminated dolomitic limestone, (4) laminated dolomitic quartzite, and (5) dense carbonatic argillite.

The most diagnostic feature of the Wallace is the relatively large amounts of calcite and dolomite, and when these carbonate-rich rocks weather, solution pits and ocher-yellow colors become conspicuous (Plate 1). Aside from the carbonate content, parts of the Wallace are lithologically indistinguishable from parts of the Burke and St. Regis formations (Ransome and Calkins, 1908, p. 43). This is especially true of the lowermost member of the Wallace, which was examined in conjunction with the study of the St. Regis.

Plate 1. Sedimentary features of the lowest member of the Wallace formation (Wl) in the study area.

(A). Ribbon - and pit-shaped solution cavities formed by the selective removal of calcite from "molar-tooth" and "birds-eye" structures. Photograph taken near Graves Creek Falls.

(B). Lens and pod-shaped cavities formed by the selective removal of calcite. Photograph taken near Graves Creek Falls.

(C). Massive weathering carbonate mudstones (U) and thin carbonatic quartzite lenses (Q) define the Wallace-St. Regis contact. Photograph taken of exposure on U.S. Highway 10A west of Clark Fork, Idaho.


A
B
C

The boundaries of the Wallace with the underlying Ravalli and with overlying Missoula groups are transitional (Figure 3). The upper member of the Wallace consists of thin interbedded carbonatic, black argillite and white siltite; and the contact with the Missoula group is generally placed at the top of uppermost interbedded black argillite and white siltite unit. The basal member of the Wallace is characteristically a mixture of the lithologic types given above that ranges between 2,000 and 3,000 feet thick and it interfingers with the St. Regis for about 200 to 600 feet. The contact between the St. Regis and Wallace formations is generally placed where carbonatic rocks become a consistent part of the transition zone, however, the lithologic similarity and transitional contact indicates that the St. Regis and basal Wallace are genetically related. Because of this relationship,the units are treated as a single depositional phase.

Organic Activity. The only conspicuous evidence of organic activity in the lowermost Wallace is "molar-tooth" structure. "Molar-tooth" is a field term that has been applied to describe differentially weathered surfaces of an intricately crinkled system of calcite sheets (Bauerman, 1885). These structures are believed to be algae in origin, although examples of similar structures that are tectonic in origin are also known (Smith, 1968). Molar tooth limestone beds in the Wallace are restricted to the lower (Wallace (1) member) and upper calcareous members.

The recent work by Pflug (1965a, 1965b) provides additional information regarding the presence of organic activity during the time these rocks were deposited. Pflug examined and described the microflora (microscopic algae and Problematica) in samples collected from calcareous horizons in the Wallace, Libby and Striped Peak formations in the Clark Fork quadrangle in northern Idaho (Harrison and Jobin, 1963). Schopf (1968) compares this microflora described by Pflug with those described in other Precambrian rocks, i.e., the Fig Tree Series, Gunflint Iron Formation and Bitter Springs Formation. He concludes that although the Belt flora (1100 m.y.) is not similar to the Bitter Springs flora (1000 m.y.), it most probably contains the oldest eucaryotic microfossils. The eucaryotic cell, the fundamental unit of all higher plants and animals, is characterized by (1) the presence of a well defined nucleus, (2) the occurrence of membrane-bound plastids, (3) true mitosis and (4) the presence of sterols and the absence of mucopeptides as wall constitutents; the more primitive procaryotic cell does not have these characteristics. The time of origin of the eucaryotic cell is significant because emergence of higher organisms and biological evolution based on sexuality could not have occurred until eucaryotic microorganisms had evolved from their non-nucleated, asexual, procaryotic ancestors (Schopf, 1968, pp. 661-662).

Origin. Ransome and Calkins (1908) proposed that the Ravalli and Piegan groups represent shallow marine, beach and mud flat, environments. They hypothesized that the fine-grained sediments were brought to the coastal plain by large meandering rivers and became part of a great delta(s) as the rivers debouched into the sea. This interpretation was based on (1) the fine grain size, (2) presence of mud cracks, ripple marks and cross-stratification, (3) the conformable relations in the sequences, and (4) the gradual transitions between formation (p. 70). More recently Hobbs and others (1965) elaborate on the marked alternation of thin beds of quartzite and argillite, gradational bedding, and probable sole markings, but no alternative origin is proposed. This shallow water interpretation is based largely on the earlier classical idea that crossbedded and ripple marked sands occur in agitated (shallow) water, i.e., above wave base, and mud cracks are produced only during subaerial exposure, whereas, uncracked, horizontally laminated, finer grained sediments are suggestive of quiet (deep) water sedimentation, i.e., below wave base (Pettijohn, 1957, p. 593). Modern studies in sedimentology demonstrate that these features are not necessarily depth dependent (Allen, 1967; Jüngst (1934), White (1961), and Burst (1965) have shown that mud cracks can form subaqueously and with little or no overburden; thick sand bodies occur below "wave-base" (Stride, 1959; Houbolt, 1968; Stride and Kenyon, 1970) and ripple marked sands have been observed in hundreds and thousands of feet of water (Bouma, 1965). In addition, acceptance of the Ransome and Calkins shallow-water hypothesis requires an almost unique steady state condition between sedimentation and subsidence for very long periods of time, which even Ransome and Calkins found difficult to accept (1908, p. 71).

A NEW APPROACH TO AN OLD PROBLEM

A study of the bedding features and sedimentary structures of the Ravalli Group provides a key to understanding how thick clastic sequences can accumulate without requiring a unique relationship between sedimentation and subsidence. The Ravalli Group exhibits the following sedimentary features: (1) the thin bedded quartzites have sharp bases, but vertically are gradational into argillaceous siltites and silty argillites: (2) single sedimentation units show systematic vertical arrangements in sedimentary structures markedly similar to that described by Bouma (1962) for individual turbidites; (3) sole markings and convolute laminae are very common among the individual sedimentation units; and (4) that the combination of the above points recurs for hundreds and in some places thousands of feet. These features strongly suggest that the alternating sequence of quartzites and argillites are turbidite in origin. The salient features of ancient turbidites have been reviewed by Kuenen (1964) and Walker (1970) and these features compare very closely to those found in recent deep-sea studies (Shepard and others, 1969). The following summary of the conspicuous features of modern and ancient turbidites is a composite drawn from Kuenen (1964), Dzulynski and Walton (1965) and many of these features are observed in the Ravalli Group.

(1) Repetitive Bouma cycles through a thick sequence of sediments.

(2) Beds tend to become thinner, finer grained, more gradational, and better sorted away from the point source.

(3) Sands are not distributed arbritarily but the amount and composition of the sand will vary with the source area(s).

(4) Slopes on the present ocean floors are generally free of deposits or have a thin veneer. Nearly all deep-sea sands are formed on bottom slopes of one degree or less.

(5) Current directions are normally subparallel over wide areas and through thick sequences.

(6) Individual turbidites have limited lateral extent and generally cannot be traced beyond a single exposure.

(7) Deposition of turbidites is very rapid because only the upper part of the previous bed is reworked by burrowing.

(8) Lower bed margin is sharp; upper margin may be sharp or grade upward into a normal pelagic layer.

(9) Current ripples are quite common and frequently lie on and are covered by horizontal laminations.

(10) Bed thickness varies from a few millimeters to 10 meters.

(11) Convolute lamination associated with current ripple lamination.

(12) Sole marks, especially flutes, grooves and tool markings are common.

(13) Early deformational features such as flame structure and pull apart structures are common.

(14) Shales (marl or hemipelagic clays) that are poor in fossils overlie the turbidite and may become burrowed.

The general nature and origin of some of the sedimentary features given above and the internal organization of structures within a turbidite are discussed below in order to relate them to the same or similar features observed in the Ravalli Group.

Graded bedding and the Bouma cycle. As originally defined by Kuenen (1953), graded bedding describes a sandstone bed that contains a moderately high percent of matrix and shows a definite decrease in median grain size vertically. This change in size is determined by a gradual decrease in mean velocity from the front to the rear of the turbidity current as demonstrated from flume experiments (Kuenen and Migliorini, 1950; Simons and others, 1965),(Figure 6). Of greater interest than the vertical change in grain size is the organization of sedimentary structures within a graded bed as discussed first by Pearl Shelden (1928) for upper Devonian rocks of New York State that have been accepted turbidites by Kuenen (1956) and Walker and Sutton (1967). Bouma (1962), however, was first to devise a model that characterized the vertical sequence of sedimentary

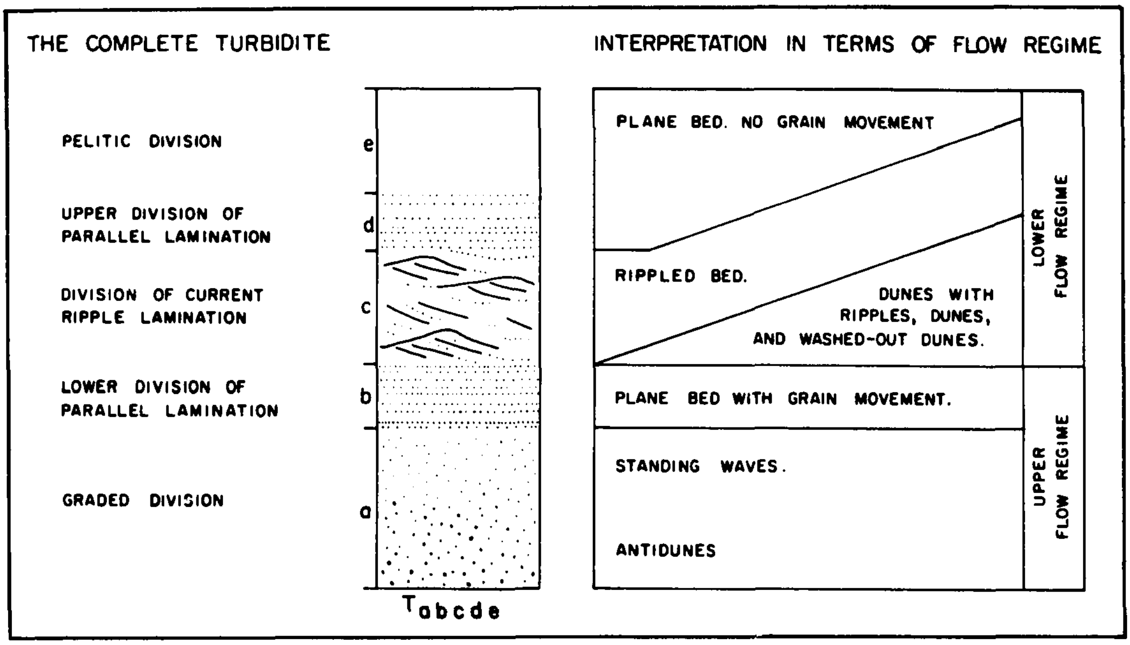
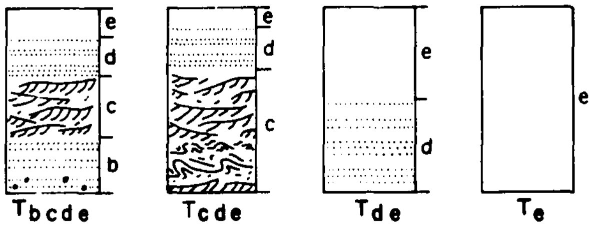


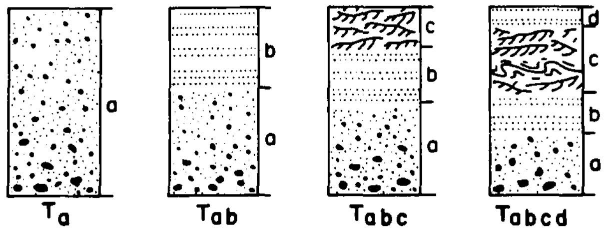
Figure 6. The vertical sequence of sedimentary structures in Bouma's complete turbidite (1962) and corresponding inferred flow regimes (simons and others, 1965). Modified from Walker (1965).

structures in a single turbidite and propose a simple shorthand useful for describing these beds. In so doing, he successfully integrated several different ideas and observations into a compact concept. Bouma (1962) proposed that a complete turbidite sequence consists of a systematic vertical arrangement of five elements and that this sequence is repeated vertically within a turbidite-bearing formation. This sequence has since been referred to as the Bouma Cycle. Walker (1970) reviews the developments and studies in graded bedding and the Bouma cycle and their impact on basin analysis in greater detail.

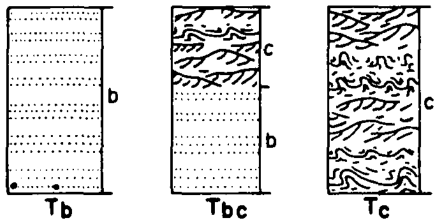
The vertical arrangement of the five divisions in a complete Bouma cycle and the relationship between each division and respective flow regimes as first proposed by Walker (1965) are given in Figure 6. From base to top these divisions are: a - a lower massive or graded layer, b - a lower zone of parallel lamination, c - a zone of ripple bedding, d - an upper zone of parallel lamination in silty sediment, and e - an uppermost clay layer. Cross-bedding or convolute laminations may occur in the c member of the sequence. This complete sequence is relatively rare in nature and variations of the sequence are the rule. Possible variations of the sequence that may result from truncation of the underlying beds, non-deposition, or a combination of these are given in Figure 7. A modification of the ideal sequence of Bouma has been proposed by Hubert (1966) who argues for the inclusion of a "dune" phase below the b division in the ideal sequence. Thomson and Thomasson (1969),



A. Base cut out sequences, lower intervals of complete sequence missing, probably result of non-deposition.



B. Truncated sequences, upper intervals of complete sequence missing, possibly result of erosion.



C. Truncated and base cut out sequences. Tops and bottom of complete turbidite missing.

Figure 7. Modifications of Bouma's complete sequence due to nondeposition and/or erosion (after Bouma, 1962).

however, suggest that the dune phase be restricted to an idealized sequence for proximal turbidites, as it was never observed in the distal sequences in their study. Walker and Sutton (1967) describe another type of bed that occurs in turbidite sequences that grade from a to e without lamination or cross-lamination and is generally only 3 cm thick. They suggest that the fine sand or silt bed may have been deposited either by a current so fast that no structure formed or by a current so slow that ripples were not developed. Experimental evidence is not available to evaluate either alternative.

Convoluted laminations. Convoluted laminations and related penecontemporaneous deformational features are nearly ubiquitous in the graded bedded sequences that consist of very fine grained sand and/or coarse silt. These deformational features are typically in the c zone within the graded bed and are bound above and below by flat-lying (undeformed) beds (Plate 2). A striking feature of the undeformed layer is its uniformity in character and thickness when traced laterally. Ten Haaf (1956) and Sanders (1960) discuss the characteristics, possible origins, and the significance of convoluted lamination. Ten Haaf concludes that the deformed bedding is an internal syngenetic structure frequently associated with fine grained sediments (silty sands) deposited by turbidity currents and is common in repetitively bedded sediments of the flysch-type.

Plate 2. Convoluted laminations in the *c* division of a truncated Bouma sequence (T_c) overlying a cracked, dark colored argillite lamination.

The turbidite at the position of the knife, Tabcd sequence, has truncated the underlying convoluted sequence.

Mud Cracks. Although it has been popular to attribute all mud cracks to subaerial dessication, Jüngst (1934), White (1951) and Burst (1965) have demonstrated experimentally that "mud cracks can form under water. The developments of cracks or fissures that resemble mud cracks in sediments as well as other structures, such as "pit and mound" that resemble rain drop impressions and "cone and crater" that resemble hail impressions, depends on the electrolytic character of the solution and the clay mineralogy within the depositional environment. Clay particles generally do not settle as individual particles but flocculate with the degree of flocculation depending on electrolyte concentration, Van der Waals' charges, charge differences on particle faces and edges, and turbulence. Turbulence enhances flocculation by inducing a high rate of collision between floccules (Hahn and Stumm, 1970) and of formation and size of floccules increases with turbulence (Krone, 1962 and 1963). The floccules are almost spherical, of low density and have a high water content (Sherman, 1953).

In a concentrated chemical environment flocs of clay settle randomly, and cracks develop as interstitial water is lost during compaction; this process is called synaeresis. These cracks temporarily close with continued sedimentation of the clay flocs because of the internal shifting of particles during compaction. Salts that are left behind cause the compacted clays to be structurally out of equilibrium with their chemical environment. Because the clay is exposed to an aqueous solution, water is absorbed by the chemical system causing swelling and cracking; these cracks are called synaeresis cracks.

According to this theory, mud cracks and other structures, commonly inferred to be indicative of subaerial exposure, have been produced subaqueously with little or no overburden and are considered to be indicative only of the chemical environment during sedimentation and are not indicative of depth of water.

Another type of crack or fissure, that is locally common but not ubiquitous within argillite laminations in Ravalli rocks, appears bulbous and almost subcircular in cross section. These cracks are inferred to be burrows but the nature of the organism that produced the structures is problematical. Burrows generally extend midway to three-fourths into the argillite and rarely penetrate even the very thin laminae, and locally has disturbed sediments several centimeters thick (Plate 7A). Modern studies by Bouma (1965) and Stanley and Kelling (1969) have demonstrated that burrowing organisms exist in deep water (greater than 600 feet). Extrapolation of depth of water based on the presence of burrows is unwarranted unless more can be determined about what creature produced the burrows. The presence of eucaryotic cells in the overlying Wallace tends to support the possible burrow structures.

Having this general conceptual framework of the characteristics of turbidites and the origin of some related sedimentary structures in mind, the following details of the case study of the upper part of the Ravalli Group will now be considered.

SEDIMENTARY FACIES

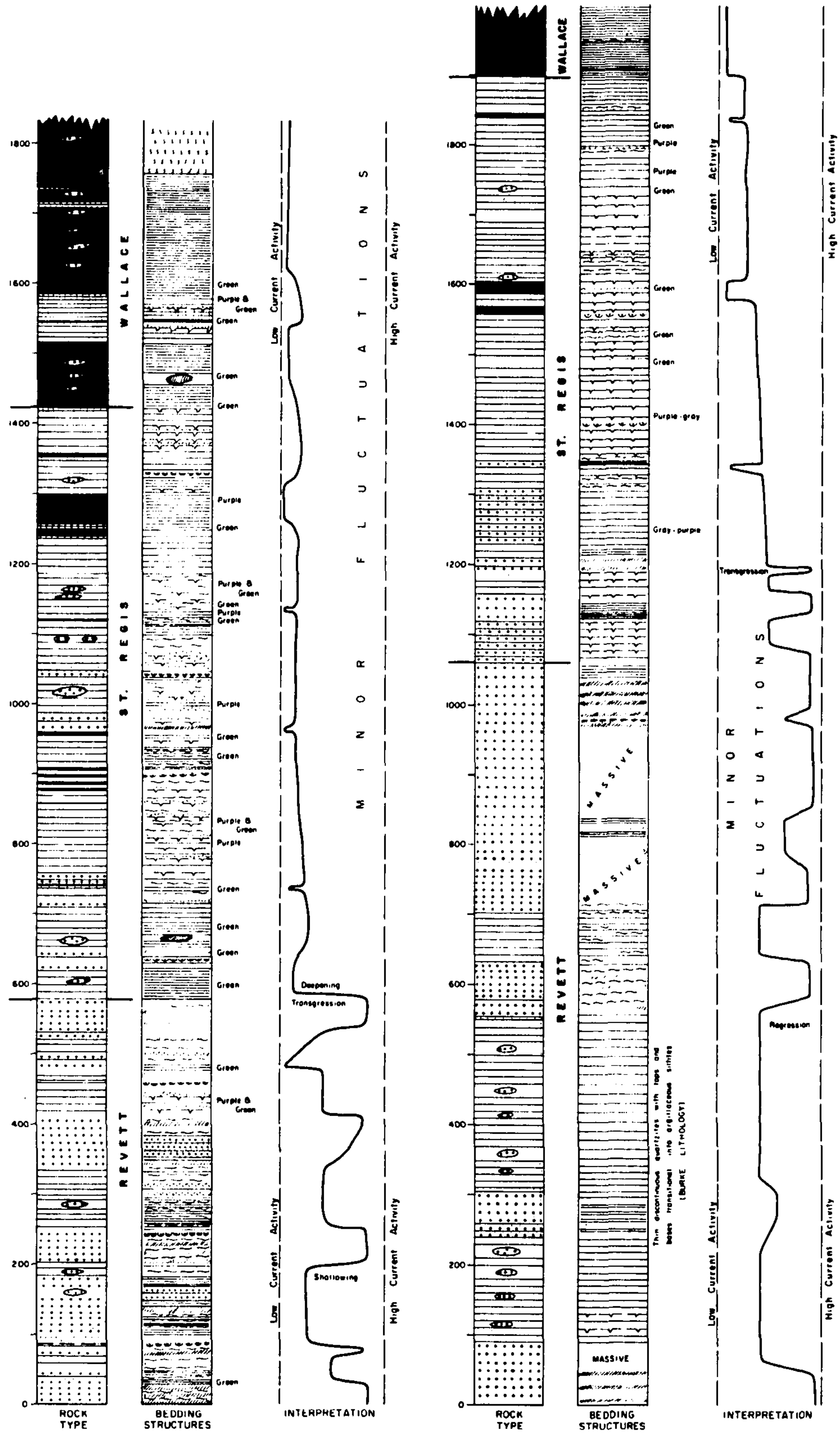
The Ravalli and Piegan groups contain only a few recurring lithologic types, hence bed by bed descriptions of each formation are repetitious (Figure 8). To minimize repetition the following discussion is subdivided into two major lithofacies: laminated to cross-bedded quartzite, the base-of- slope facies; thin interbedded quartzite, siltite and argillite and massive to very finely laminated carbonatic argillite, the basin facies. This subdivision is approximately equivalent to the Revett and the combined St. Regis and lower Wallace respectively.

Base-of-Slope Facies

Thickness and Distribution. The total thickness of all the bundles of quartzite in the Revett Formation increases north and east of the Coeur d'Alene district. The Revett is reported to be 800 feet thick just south of the Coeur d'Alene district (Wagner, 1949). It increases to 1000 feet in the Coeur d'Alene district (Ransome and Calkins, 1908) and to 3000 to 10,000 feet in adjacent parts of Montana (Gibson and others, 1941; Wallace and Hosterman, 1956; Campbell, 1960) but is absent north of Libby, Montana (Johns, 1959) and probably east of Superior, Montana. This increase in the total thickness of the Revett Formation is accompanied by a general decrease in thickness of the individual quartzite bodies within it. For example, individual quartzite bodies in the Coeur d'Alene district and southwestern part of the study area are 100 to 200 feet thick with a major lithologic break, whereas, they are generally only 30 to 100 feet in thickness near Clark Fork, Idaho; northeast of Trout Creek and east of Thompson Falls, Montana.

Lithology. These quartzites are dominantly fine- to very fine-grained subortho-quartzites and arkoses (Plate 3). Bedding ranges from 4 to 175 cm but averages about 30 cm in thickness. Graded bedding is poorly developed or absent in part due to the limited grain sizes available and truncation of bedding sequences by scouring.

Figure 8. Generalized stratigraphic and sedimentologic columns for the St. Regis formation in the eastern (right side) and western (left) parts of the study area. Note vertical changes in lithologies and inferred changes in current activity. Green carbonate mustones associated with argillaceous intervals.



KEY

BEDDING AND STRUCTURES

∵∵ Graded bedding
⌣⌣⌣ Deformed bedding
∴∴ Mud chips
⌄⌄ Cracks & burrows
sss Molar tooth structure
⬭ Quartz lenses
///// Cross-bedding
~~ Ripple bedding
▤ Laminated

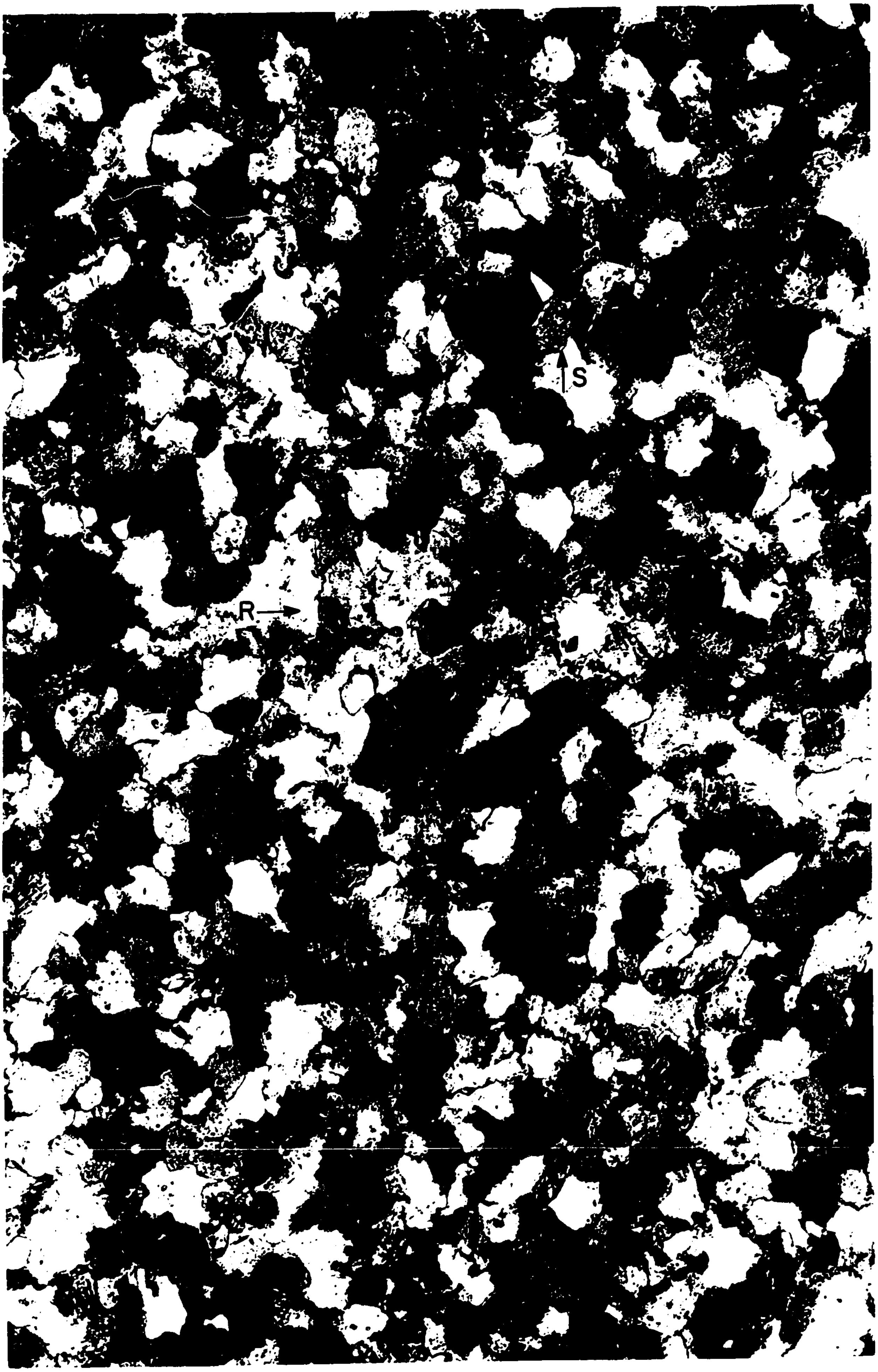
ROCK TYPE

:::::: Quartzite
∙∙ Siltite
═ Argillite

SCALE

1 inch = 100 feet

Plate 3. Subarkosic quartzite from Revett formation. (Clark Fork measured section). Note serititization of a feldspar grain (S) and rounded quartz grain (R). Nicols crossed. Magnification X 80.


S
R

Scour channels less than 8 meters deep, that have been observed only in extensive cirque exposures, are filled with thick cross-bedded and laminated quartzites (Plate 4B). Smaller scours with a few centimeters to a meter of relief are frequently observable in smaller exposures. Quartzites, that fill these scours or occur in thick sequences with no major scour or channel discernible, do not appear to have graded bedding. However, commonly observed bedding sequences are in decreasing order of abundance Tbc, Tac, Tbcd, Tcd and Tcde. Convolute lamination is not a common feature of the c portion of the units. The c division in these sequences may be ripple cross-laminated or contain a tangential cross-bed. The average thickness of 108 cross-beds is 37 cm. Tangential cross-bedding that is not part of the c division also occurs. These cross-beds are commonly 30 to 60 cm in thickness and rarely greater than 100 cm (Plate 5). The base of the cross-bed may be sharp or grade into a few centimeters of massive quartzite, but the top is gradational into a massive to laminated quartzite which in turn grades into a zone of ripple lamination. Although cross-bedded sandstones have been considered rare in turbidite sequences (Kuenen, 1953; Dzulynski and Walton, 1965; Walker, 1966), more recent investigations have provided contrary evidence that argues for a modification of Bouma's ideal sequence (Hubert, 1966a, 1966b and Walker, 1967) to include cross-bedding as an important part of the b portion of the cycle in the proximal facies, the facies nearest the point source. A modification only for the ideal proximal turbidite sequence, rather than

Plate 4. Sedimentary features of the Revett formation in eastern part of the study area. Photographs A and B taken in cirque near Chicago Peak measured section.

(A) Siltite zone (turbidite zone). - Interbedded, very fine-grained quartzite, siltite, and argillite. Bouma cycles well developed: *abcde* and *bcde* sequences common.

(B) Scour channels in quartzite interval near Revett-St. Regis contact. Quartzites weather massive and blocky, but consist of amalgamated beds.

(C) Aerial view of the Ravalli group in fault contact with the Pritchard formation. Dashed line indicates approximate position of Snowshoe fault. Ravalli group (left) consists of alternating sequence of quartzites and turbidites. Argillite is a minor constituent. Photograph taken of north-northwest view of the area immediately north of Rock Lake.

A

B

C

Plate 5. - Sedimentary features of the Revett formation in the northern part of the study area. Photographs are taken at the Clark Fork measured section.

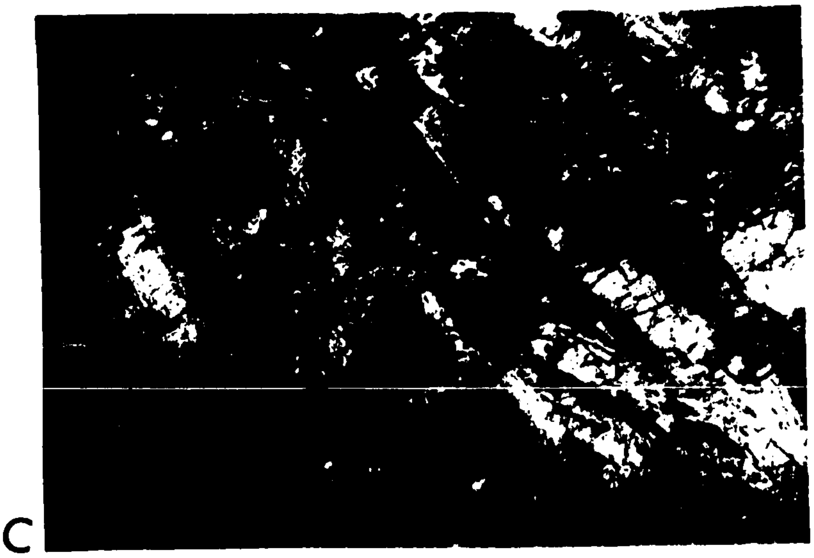
(A) Thin bedded quartzites with gradational tops and bases that occur between the laminated, cross-bedded quartzite intervals. Bedding is flat or rippled. Scale in centimeters.

(B) Cross-bedded quartzites with transitional tops occur in intervals rarely greater than 50 feet in thickness.

(C) Tangential cross-bedding with sharp base and top. Photograph near base of measured section.

A

B



C

Bouma's sequence for the distal turbidite, is suggested by Thomson and Thomasson (1969). Their revision is based on the development of large scale cross-bedding below the b or lower lamined division in the Bouma cycle that is otherwise similar to the cross-bedding described by Hubert (1966) and Walker (1967) in proximal turbidite facies. The dune phase in the Revett quartzites has some features that are similar to that described by Walker (1967) and Thomson and Thomasson (1970) as cited above. It is dissimilar, however, in that it is not associated with coarse conglomeratic beds or large scale slump features that are considered criteria for proximal turbidites. There are several possible explanations to account for this discrepancy (1) the grain-size available during sedimentation, (2) the limited sampling of the Revett quartzites, and (3) the areas that were sampled are representative of the down-dip limits of the proximal facies. The first and last reasons are probably most correct. Assuming, however, that these are base-of-slope deposits, the location of the adjacent shelf deposits remains unknown.

Sedimentary Structures and Paleocurrents. Sedimentary structures that occur in the quartzites are, in decreasing order of abundance, parallel lamination, ripple marks, cross-bedding, flutes and other sole markings, and soft sediment deformational features. An accurate estimate of the abundance of bedding surface and sole markings is difficult to obtain because of weathering, lichen cover and precipitous exposures. Sole markings (flutes) that were observed at the Clark Fork section (22) had the same paleocurrent directions as the cross-bedding. Parallel lamination or

A

B

C

current lineation essentially paralleled the dip direction of cross-beds, but these measurements were not plotted because of uncertainties that arose when tectonic features similar to parting lineation were observed. Soft sediment deformation is exemplified by ball and pillow structures and convoluted bedding that measure from 15 to 60 cm across the longest observed dimension; these features are relatively scarce.

Cross-bedding dip directions and strikes of ripple marks were the most reliable, abundant, and accessible sedimentary structures from which paleocurrent directions and paleoslope could be inferred. Two hundred and sixty-two cross-bed measurements collected from the Revett formation show that the sands were transported down paleoslope to the northeast (Figure 9). Inspection of the cross-bedding pattern of the respective stations shows a moderate amount of variability giving a fan-like pattern with a spread of about 120 degrees. The vector mean of the limited cross-bedding data collected from the Burke, St. Regis and Wallace formations compare closely with that in the Revett formation(Table 4)

Strikes of 162 ripple marks collected from the graded bedding lithology within the Revett formation are oriented north-south almost perpendicular to the azimuth of the cross-bedding (Figure 10), but locally show two modes, one nearly perpendicular, the other parallel to the dip direction of cross-bedding. Sampling bias, as suggested by the number of observations per station, probably

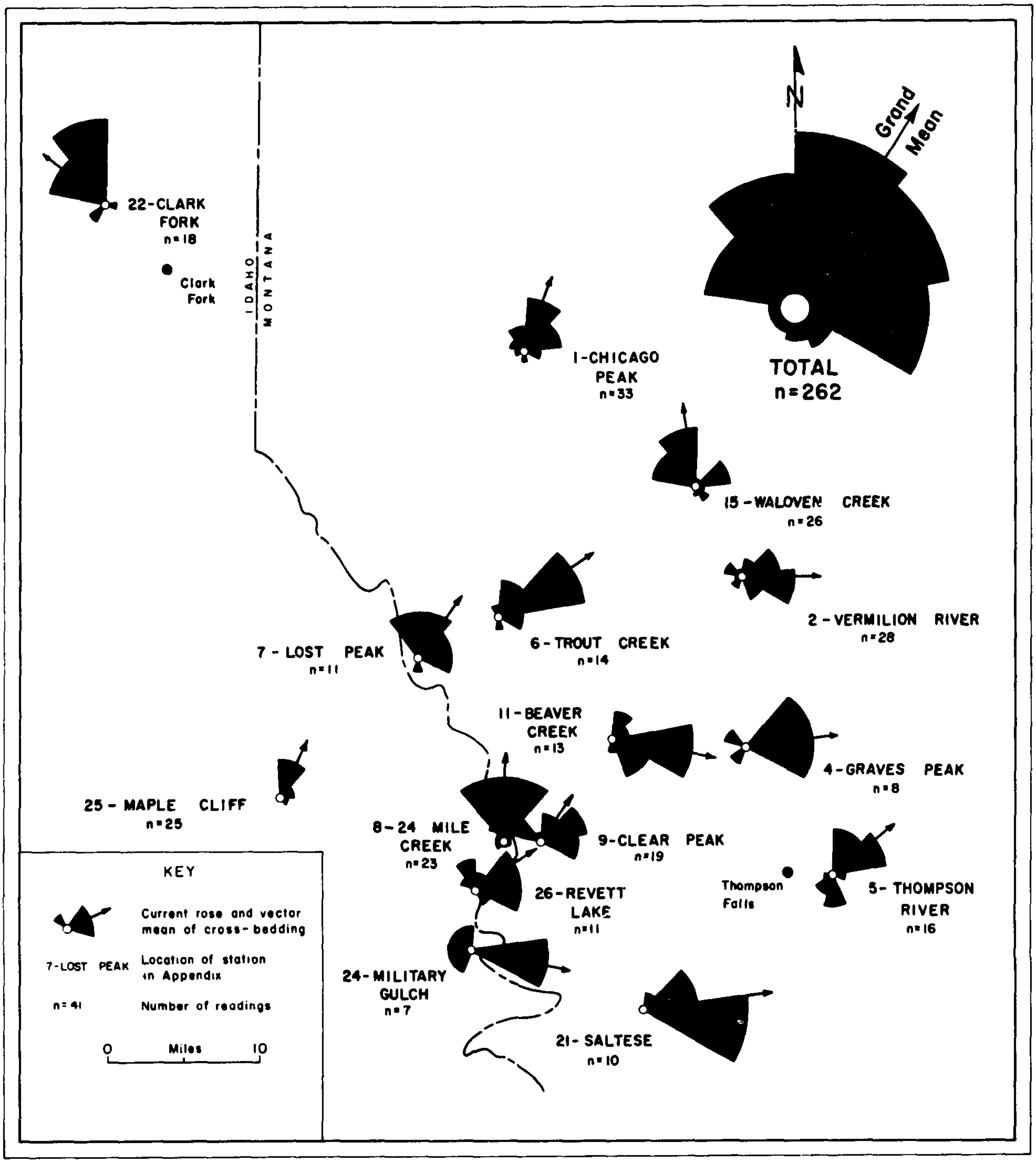


Figure 9. Current rose and vector mean of cross-bedding from the Revett formation. Note the general divergent (radial) paleocurrent pattern.

No. and Name of section and Formation		Number of Readings (n)	Vector mean (θ)°	Vector Length (R)	Length in percent (L)	Standard deviation (±)°
(1) Chicago Peak	-R	33	24	16.89	51.19	68.55
	-S	17	30	5.49	32.29	83.72
(2) Vermilion River	-R	28	80	11.65	41.61	79.57
(4) Graves Peak	-R	8	80	4.11	51.33	77.09
(5) Thompson River	-B	4	10	3.82	95.51	20.00
	-R	16	50	5.03	31.43	87.33
(6) Trout Creek	-R	14	56	10.53	75.22	47.26
(7) Lost Peak	-R	11	35	6.46	58.70	63.62
(8) 24-Mile	-R	23	358	16.81	73.10	49.31
(9) Clear Peak	-R	19	31	12.51	65.84	51.37
	-S	3	100	3.00	100.00	0.00
(11) Beaver Creek	-R	13	102	9.59	73.77	46.23
(15) Waloven Creek	-R	26	350	12.88	49.54	72.04
	-W	2	320	1.88	93.97	28.28
(20) Deborgia	-R	10	81	8.96	89.59	28.30
(22) Clark Fork	-R	18	307	13.10	72.75	54.18
	-W	8	52	2.85	35.65	89.71
(24) Military Gulch	-R	7	100	0.12	1.72	115.47
(25) Maple Cliff	-R	25	28	21.1	84.3	34.6
(26) Revett Lake	-R	11	55	6.11	55.56	62.48

Table 4. Summary of cross-bedding data for Burke (B), Revett (R), St. Regis (S), and Wallace (W) formations. Location of sections are shown in Figure 5.

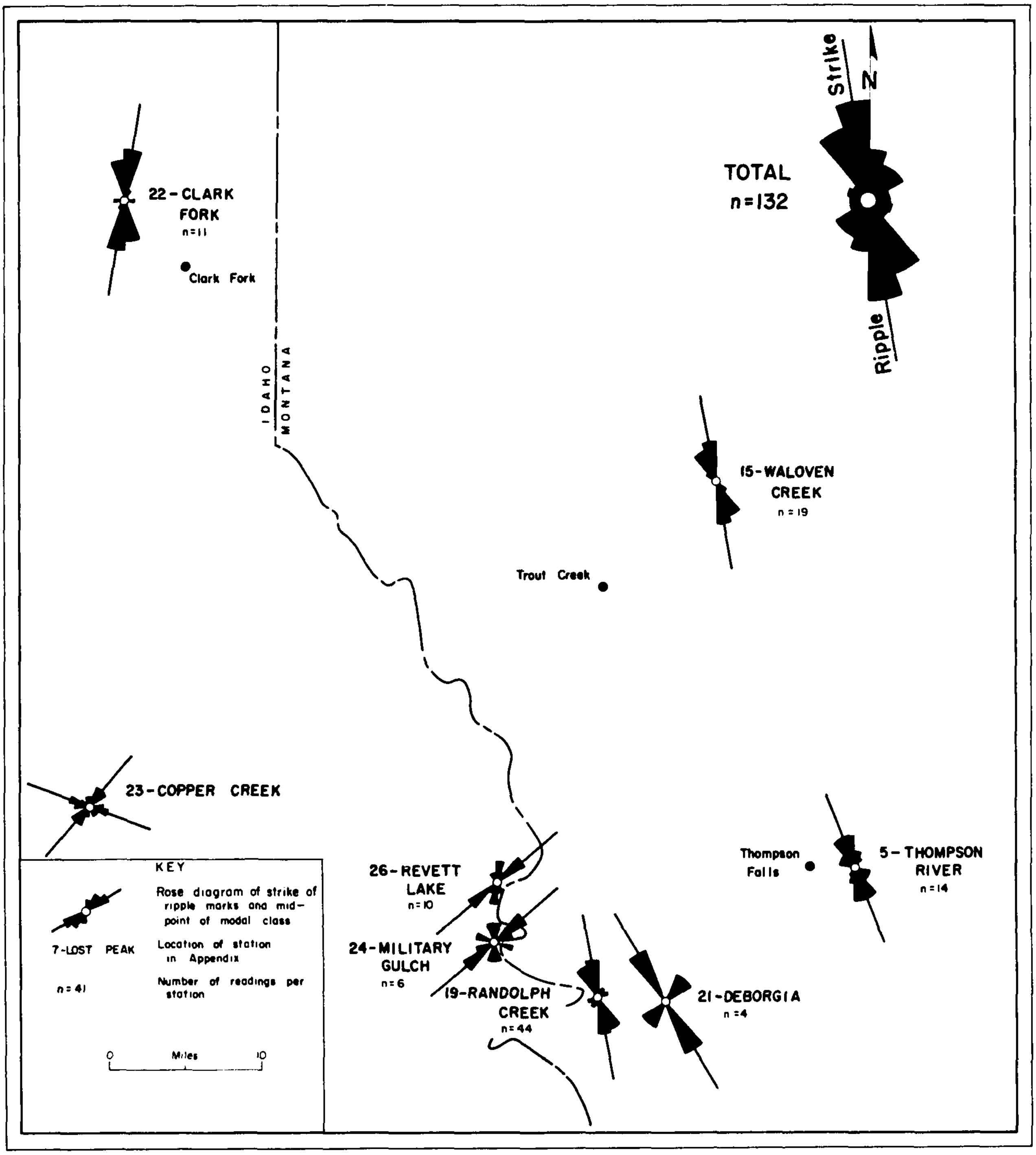


Figure 10. Orientation of the strikes of 132 ripple marks in the Revett Formation. Show a dominant north-south mode. At the respective stations the mode may be either parallel or nearly perpendicular to the dip direction of the cross-bedding.

accounts for the weakly developed orthozonal relationship using the combined cross-bedding and ripple mark data. These data do suggest, however, that a northeastward dipping slope was persistent throughout the time that the Ravalli Group was deposited .

Basin Facies

The basin facies is exemplified by the St. Regis formation, although as stated earlier this facies does occur in the adjacent formations. The following discussion of the intermediate facies is essentially the results of a detailed study of the St. Regis formation in western Sanders County, Montana.

Thickness and Distribution. The estimated thickness of 1000 feet in the Coeur d'Alene district and along the Idaho-Montana line (Figure 11) is based on cliff outcrops at Maple Cliff and Castle Rock along the north fork of the Coeur d'Alene River, and at Military Gulch. West from the Coeur d'Alene district, in western Idaho and eastern Washington, its thickness increases to about 1500 (±) feet. (Griggs, in press and Miller, 1969), but eastward, in the valley of the St. Regis River, the St. Regis reportedly thickens to several thousand feet (Wallace and Hosterman, 1956) but the stratigraphy is complicated by faulting and metamorphism (Plate 6), especially in central Idaho (Hietanen, 1963, 1968). Northeast from the Coeur d'Alene district the formation thins rapidly as the stratigraphic range of the (Revett) quartzites increases. The basin facies is still recognizable where it broadly interfingers with the quartzites in the eastern and northern parts of the study area (Plate 4c) and where it completely replaces the quartzites north and east of the study area.

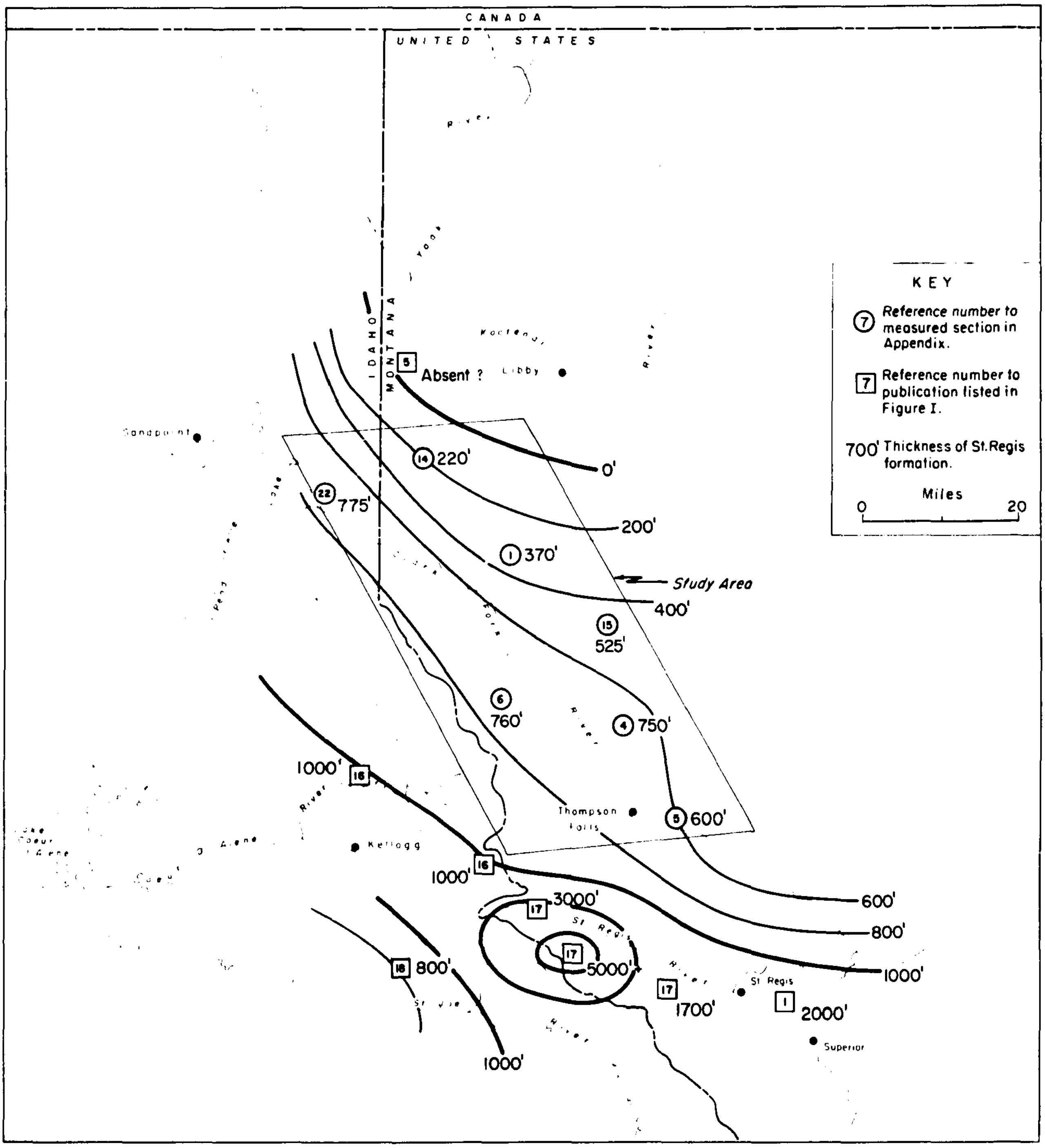


Figure 11. Thickness of St. Regis formation based on published data, and measurements collected in this study. Note abrupt changes in thickness north and south of study area.

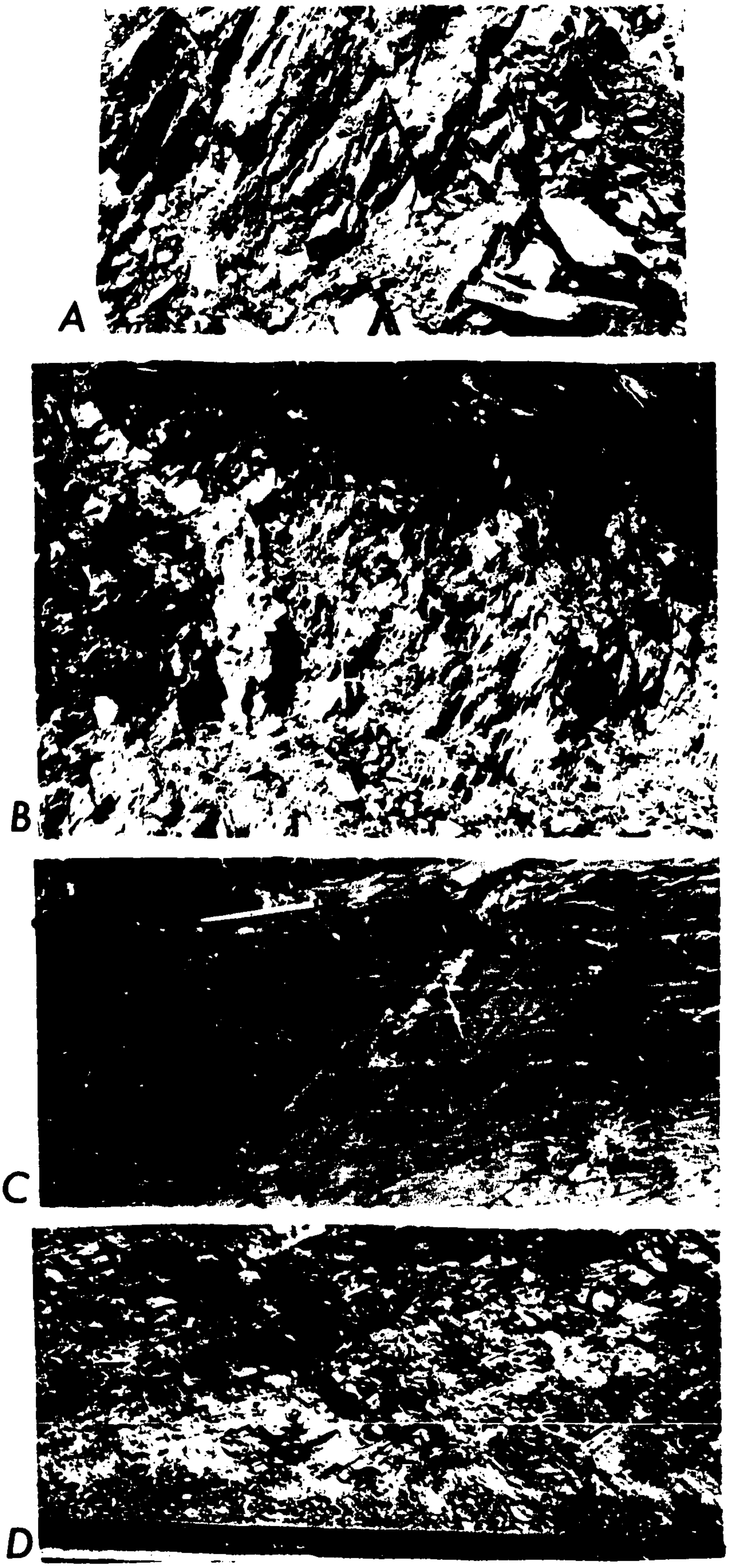
Plate 6. - St. Regis lithology in the St. Regis river valley. Photographs A and B taken of road cuts along Randolph Creek: C and D taken of exposures immediately east of Lookout Pass on U. S. 10.

(A) Sedimentary structures in argillaceous units are obliterated by shearing. Photograph taken near Revett-St. Regis contact.

(B) Thin-bedded quartzites and siltites stand out as massive, blocky units.

(C) Closeup of argillaceous interval (dark) in photo D. Flat to ripple bedded argillaceous siltites and silty argillites.

(D) Quartzite and siltite zones (Q) alternate with argillite zones (dark). Lithology very similar to Burke formation (Ransome and Calkins, 1908).


A
B
C
D

Lithology. Ransome (1905, pp. 281-282) describes the lithology of the St. Regis formation as:

> "...siliceous shales or argillites, shaley sandstones and impure, fine-grained quartzites, characterized throughout by features indicative of shallow water deposition and by rather bright green and purplish-gray tints...The formation is far from uniform in aspect, however, and shows considerable lithological variation in different parts of the field. It contains beds not ordinarily distinguishable from certain beds in the Burke and Wallace formations..."

For example, thin, green ocherous weathering carbonate beds that are very common in the lower part of the Wallace are present, but constitute a very small part of the formation (Plate 7). This description is generally correct and has since been used in published geological reports. However, in the light of recent studies in sedimentology, the lithology can be described more explicitly in many places using the "microstratigraphy" of the turbidite model proposed by Bouma (1962)

The basin facies can be subdivided into three distinct and recurring lithologic units (1) turbidites, beds that contain the Bouma cycle, (2) interlaminated siltite and argillite, and (3) carbonate-rich argillites or mudstones. Within the study area the turbidite units are locally conspicuous, but generally make up less than 50 percent of this facies. North of the area, however, turbidite units predominate (No. 17 in Appendix). Changes in the proportions of the different lithologies that occur within this facies probably account for the variation in the St. Regis formation in the Coeur d'Alene and adjacent areas (Ransome and Calkins, 1908; Wallace and Hostermann, 1956 and Gibson and others, 1941).

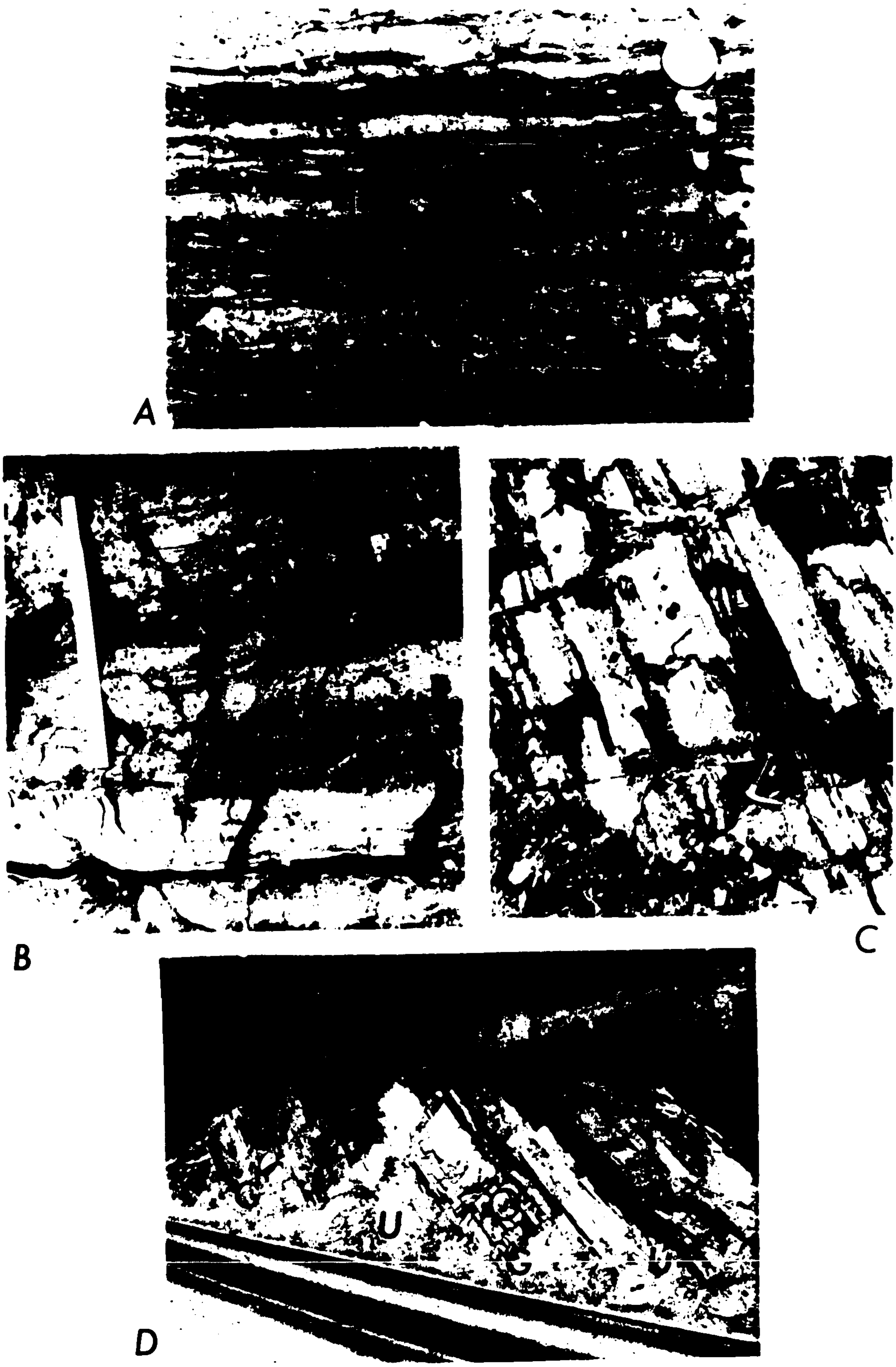
Plate 7. - Sedimentary features of the St. Regis. Photographs taken at Clark Fork measured section.

(A) Ungraded Zone (U): Interlaminated siltite (light gray) and argillite (dark gray). Cde and e (a-e) graded sequences. Argillite laminations cracked and/or burrowed. Angularity of mud chips indicate little or no transport. Scale is 25-cent coin.

(B) Graded Bedding Zone (G): Thin bedded quartzite, siltite and laminations of argillite, showing cde and bcde graded sequences. Banded stains cut bedding below scale. Scale is 21 centimeters long.

(C) Green carbonate mudstone bed(W1B in photo). These beds occur within the St. Regis, but are thicker and more abundant in the lowest member of the Wallace (W1)

(D) Graded (G) and ungraded (U) bedding zones occur throughout the St. Regis. The graded zones are transitional into the ungraded zones which become thicker higher in the section. Photograph of base of St. Regis formation.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Turbidites. Turbidites are well developed in what has been previously described as thin bedded quartzite and argillite or thin interbedded quartzite, siltite and argillite (Plate 7 and 8). Individual turbidites range from 223 cm to 7 cm in thickness, although the more frequently observed thicknesses range from 8 to 25 cm. It is difficult to determine whether the quartzite and siltite beds are graded. Field observation and examination of thin sections indicate that the maximum grain size can occur in quartzite, siltite and argillaceous siltite layers and, hence, are not necessarily restricted to the basal quartzite bed. The grading observed in the field is largely due to an increase in the argillaceous matrix vertically.

Individual beds are lenticular (60 to 120 cm long) in cross section (Plate 8). Pull-apart structure is relatively common in good exposures and in part accounts for the apparent lateral discontinuity in bedding. The quartzite unit in an "average" Bouma cycle is about 10 cm thick and frequently has an erosional base, but the depth of scouring is only a few centimeters. Rounded to angular mud chips - or shale pebbles - and more rarely rounded quartz pebbles occur as a lag deposit in the base of these scours. Most commonly however the mud chips float in a massive sandy matrix that fills broad, very shallow scours. Although flutes (Plate 9) and other small scale scour features seem to be sparse, this is due largely to the inaccessibility of the lower bedding surfaces. Numerous small scours (1 to 6 cm wide and less than 1 to 4 cm deep)

Plate 8. - Sedimentary features of the St. Regis in the eastern part of the study area.

(A) Incomplete Bouma sequence (Tabce) showing convoluted bedding and flame structure. Note sole marks at base of <u>a</u> division. Argillite layer below. Photograph of sample from Burke Formation Thompson River section.

(B) Turbidite with soft sediment deformation and flame structure. Small-scale scour at knife and pull-apart structure in upper right. St. Regis formation at Chicago Peak.

(C) Rock face oblique to transport direction. Turbidites are discontinuous and frequently scour underlying beds. St. Regis formation at Chicago Peak.

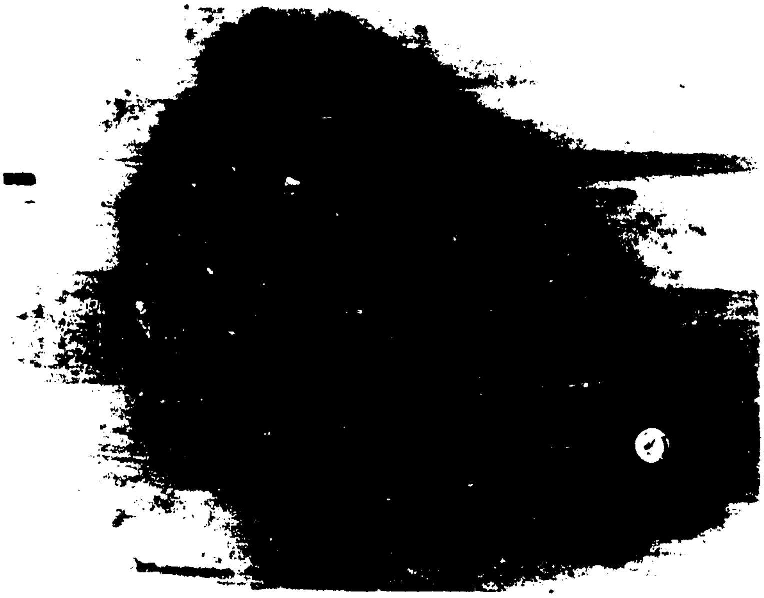

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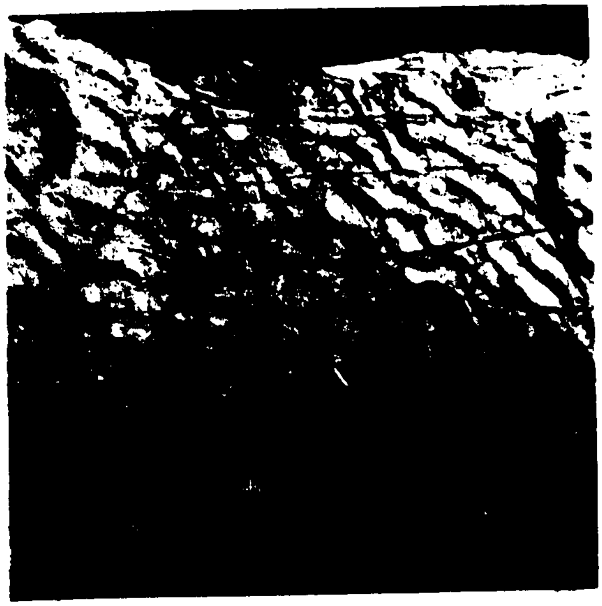
Plate 9 . - Sedimentary structures that occur in the St. Regis.

(A) Asymetric ripple mark. Photo taken near Revett Lake, Idaho.

(B) Low-angle cross-bedding. Photo taken at Clear Peak, Montana.

(C) Flutes. Arrow indicates current direction. Sample collected from Missoula Group along Willow Creek road, Montana.



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are believed to be the cross sectional view of flutes and grooves. These grooves are filled with massive or very finely laminated sand. Current ripple laminations are conspicuous in most outcrops and appear to have the same or similar dip direction as the cross-bedding at the respective outcrops, but are rarely measureable. The quartzite bed passes gradually into siltite beds that average 3 cm and range from 0.1 to 18 cm in thickness. Very fine lamination or ripple laminations that occur in the siltites and are frequently deformed producing ball and pillow structures, one to five cm in diameter, or layers of convoluted lamination (Plate 8) that commonly extend the length of the outcrop without showing any apparent variation.

A pelitic or argillite layer lies at the top of the turbidite. These layers are 0.2 to 6.0 cm thick, gray to green-gray or purple-gray, and appear to be laterally continuous. These beds often appear flat-bedded and show little lateral variation, but cracks and burrows are very common. In the thicker clay layers the cracks generally are V-shaped, whereas, the width is uniform in cross section in beds less than one cm thick. In plane view the cracks appear as simple gash structures, incomplete polygons, and complete polygons (Plate 10). These cracks are filled with very fine sand or silt from the overlying bed. The origin of these mud cracks is related to the process of synaeresis, which as discussed earlier is essentially a dewatering process that is not related to depth of water or current velocity. The

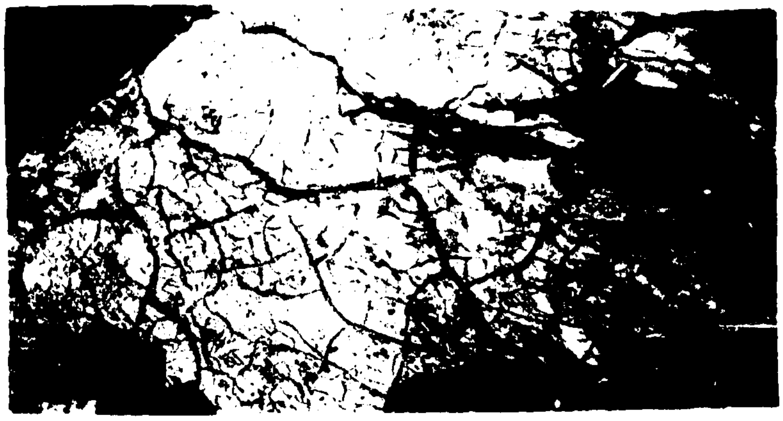
Plate 10.- Sedimentary structures in the St. Regis.

(A) Two sets of polygonal mud cracks filled with siltite. Photo taken at Chicago Peak.

(B) Mud cracks forming incomplete polygons. Photo taken at Clear Peak.

(C) Parting lineation. Current direction parallel to scale (pen). Photo taken at Chicago Peak.

(D) Gash structure showing preferential orientation. Sample collected from Wallace Formation along highway 10A west of Clark Fork.



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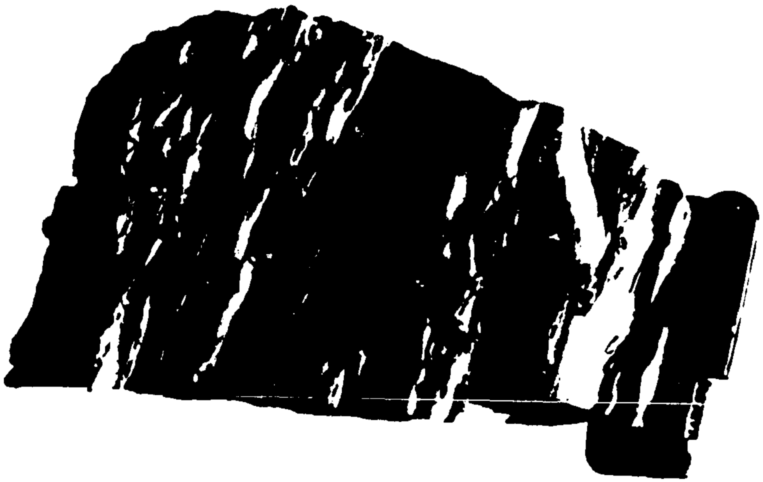

D

association of the mud cracked pelitic layers with turbidites strongly suggests that the cracks formed subaqueously. Similar features have been described by Sheldon (1928) in rocks presently accepted as turbidites.

Structures believed to be burrows are frequently somewhat bulbous in cross section, and occur within the clay layer but do not penetrate into the underlying silt beds. Frequently the burrows are deformed and lie parallel or subparallel to the slaty cleavage that is conspicuously developed in argillites and very argillaceous siltites. A detailed study of burrow structures and discovery of other trace fossils would be valuable especially since the discovery of the eucaryotic flora by Pflug strongly suggests that metazoans could have existed.

Interlaminated siltite and argillite. This lithology is typified by interlaminated siltite and argillite, and thin interbedded sandy siltite and silty argillite that occurs in zones 25 to 200 cm thick. This lithology overlies a bundle of turbidites 25 to 300 cm thick and forms fining upward cycles 50 to 500 cm thick that recur within the basin facies (Plate 7ABD). The interlaminated siltites and argillites may have sharp contacts, grade into one another or, less commonly, form Tcde and Tbcde Bouma sequences. The basal silt unit may rest conformably or on a slightly scoured surface. Most of these small scours are probably flutes and grooves that have been filled by the overlying sands and silts. The sediments that fill the scours are generally massive, but horizontal lamination and ripple lamination are the most frequently occurring sedimentary structures. Syndeformational structures such as small scale ball and pillow structures, convoluted bedding and flame structures are common and can still be observed in beds one to two centimeters thick. Mud cracks and burrows that are conspicuous features in argillite laminations in the turbidite sequences also occur.

Carbonate-rich argillites or mudstones. Carbonate-rich, green argillite beds (Plate 7 C) range from 5 to 90 cm in thickness, and although the bedding is very finely laminated, the rock tends to be dense, massive looking, and breaks with a conchoidal fracture. Weathered surfaces, however, are ocherous-yellow in color and appear to consist of an alternating sequence of light and dark bands 1 to 2 cm thick. Deeper weathering brings out the inhomogentics of the rock and ripple lamination (about 1 cm high and 2 to 3 cm long), very fine quartzose laminae, scours (1 to 3 cm across and 1 to 3 cm deep), and mud cracks are discontinuously distributed along bedding plains. Burrows have never been observed in these argillites, although "molar-tooth" does exist.

Green, carbonate-rich argillite beds generally 8 to 30 cm thick are irregularly distributed within the St. Regis formation. These beds are associated with the interlaminated siltites and argillites and tend to increase in thickness and abundance up section becoming conspicuous in the transition between the St. Regis and Wallace. In the lower Wallace these argillites are thick and occur with thin (15 to 60 cm), white, carbonate-rich quartzite lenses and beds. The discontinuous quartzite lenses appear massive but occasionally contain abundant rounded and subrounded mud chips, especially when occurring as a scour filling.

Sedimentary structures and paleocurrents. Sedimentary structures of this facies are nearly identical with those in the quartzites, but the relative abundance changes. The most abundant sedimentary structures include parting lineation, ripple marks, shallow scours, penecontemporaneous deformational features, sole marks, mud cracks and cross-bedding. Detailed examination of ripple parameters (ripple index, length and shape) was not undertaken because of limited exposures, and to a lesser extent because of structural deformation and truncation of structures by ice during Pleistocene glaciation. Well exposed ripple marked surfaces at Clear Peak and the unnamed pass between Chicago and St. Paul peaks show both symmetrical and asymmetrical shapes with wave lengths between 1 and 6 cm. Climbing ripples are occasionally observed in the graded bedding sequences, but rare occurrences of 3 and 5 foot beds of climbing ripples can be observed at the Waloven Creek measured section near the Revett-St. Regis boundary.

Orientation of the strikes of 345 ripple marks in the St. Regis (Figure 12) and 75 in lower Wallace (Figure 13) show a dominant north-south mode as in the Revett, and the limited cross-bedding data shows an eastward to northeastward transport direction as in the Revett quartzites.

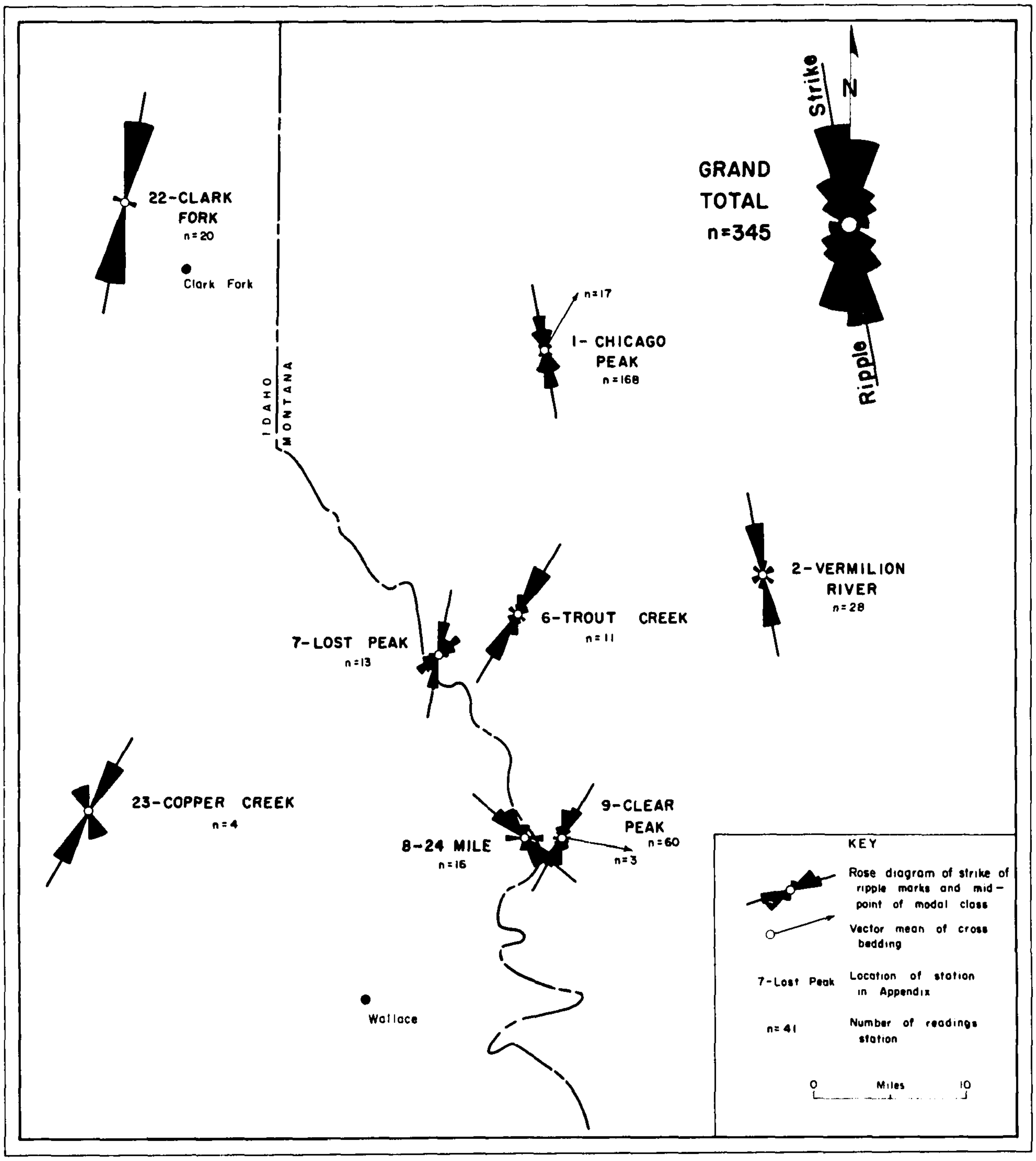

Figure 12. Orientation of the strikes of the ripple marks and the dip direction of cross-bedding in the St. Regis. Trends are similar to those in the Revett. Ripple marks grouped in 20-degree intervals. Vector mean of the cross-bedding is shown.

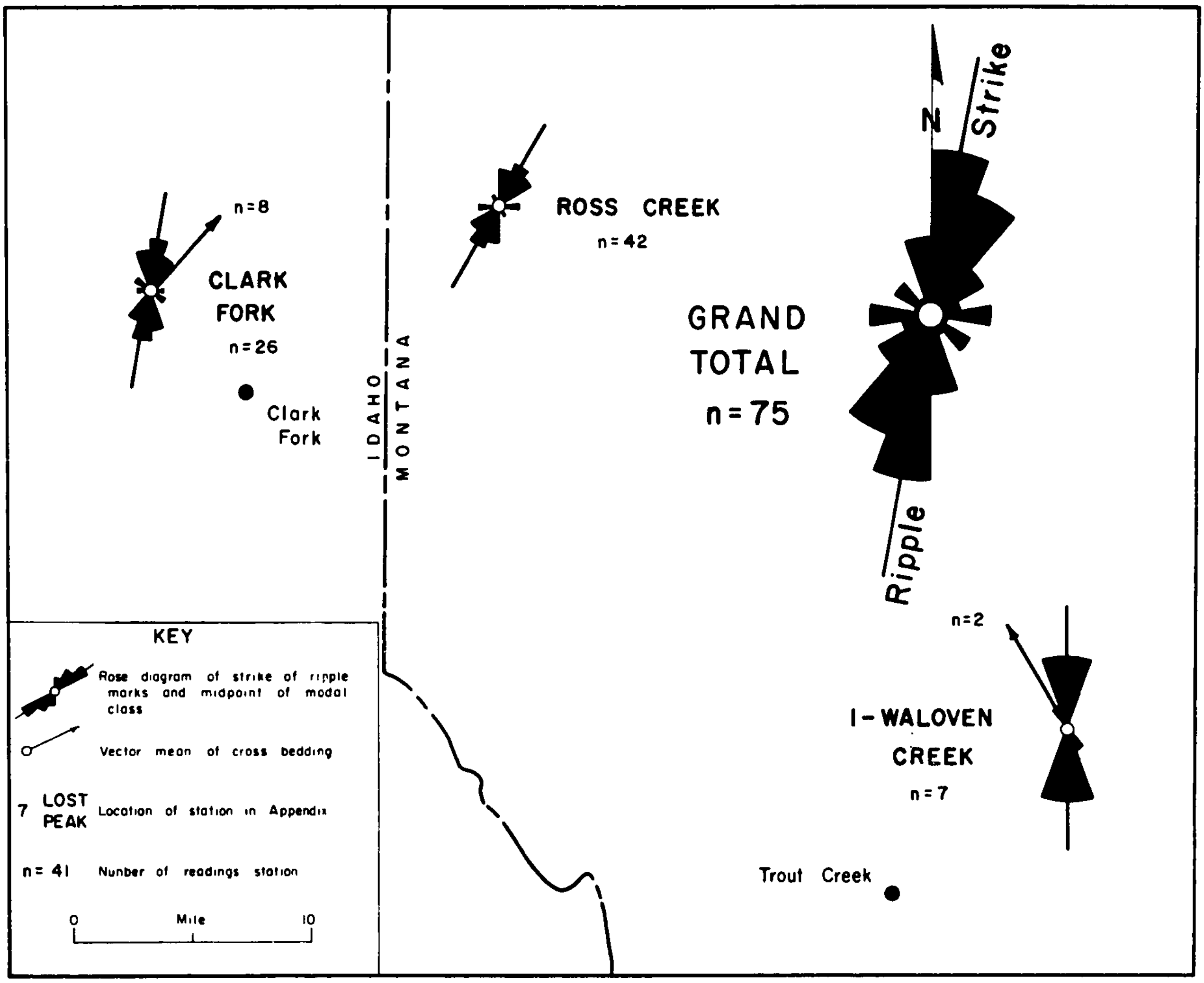

Figure 13. Orientation of the strikes of ripple marks and dip direction of cross-bedding in the lower Wallace. Trends are similar to those in the Ravalli group.

Bedding study. The thickness of bedding units and types and sequences of sedimentary structures were recorded during a bed-by-bed measurement of about 20 meters of the lower part of the St. Regis formation at two sections, Clark Fork (22) and Chicago Peak (1) using the technique described by Walker and Sutton (1967). This method involves recording the successive types of sedimentary structures and measuring the thicknesses of the respective divisions within a single turbidite to the nearest centimeter. Beds that grade from *a* to *e* without lamination or cross-lamination were recorded as *e (a-e)* beds and included under the *c* beds for calculations. Turbidites are numbered successively from *1* through *n* across continuous outcrops; covered intervals of less than two feet are disregarded. Successive turbidites were subjectively grouped into "natural groups" of beds that are identified in the field by abrupt changes in bed thickness and the presence of thin argillite breaks (3 to 18 cm thick). Finally, an abc index (P_1 value) was calculated for each group. The P_1 value (Walker and Sutton, 1967) is calculated using the equation $P_1 = [a - e\,(a\text{-}e)] + 1/2b$ where (a) and (b) are the percentages of beds in a group beginning with divisions of *a* and *b* and *e(a-e)* is the percentage of beds that grade from *a* to *e* without evidence of parallel or cross-lamination. High P_1 values (100%) are indicative of high flow regime for currents depositing the beds and low values (zero percent) indicates a low average flow regime for the currents.

Details regarding the derivation of the above equation are discussed in Walker and Sutton (1967).

Exposures at the Clark Fork (western sequence) and Chicago Peak (eastern sequence) measured sections were used for this bedding study because there the outcrops are lichen-free and clean continuous exposures are a prerequisite for this type of study. Altogether 275 bedding sequences were measured at Clark Fork totaling 17.02 meters; and 215 bedding sequences were measured at Chicago Peak totaling 16.86 meters. The results of the study are summarized in Table 5. The most common bedding sequences based on the measurement of 174 turbidites from this sampling include T_{cd} , Tbd, T_{bcd}, T_c, T_{bc} (Table 6).

Turbidites from near the base of the sequences contain the thickest Bouma sequences, which average 21 cm in thickness and range from 8 to 30 cm. Successive groups generally contain a 30 cm thick graded sequence but the modal size ranges from 3 to 8 cm, and the percentage of *e(a-e)* beds and *cde* beds sharply increases and then remains uniformly high. These intervals that contain the relatively high percentages of *e(a-e)* beds characterize the very thinly interbedded to interlaminated siltite and argillite. The graded beds within these zones range from 1 to 7 cm in thickness, with the *e(a-e)* beds measuring from less than 1 cm to 4 cm.

In contrast to this facies, a sample of the base-of-slope facies was recorded at Chicago Peak (group 1-14), which contains thick zones of quartzite that consist of truncated *a*, *ab*, *abc*, *bcd*

Group	Number of Beds Per Group	Percent Beds Containing				Percent a - e Beds	Average Thickness of Divisions (cm)				Percent Beds Beginning With			P_I
		a	b	c	c plus e (a - e)		a	b	c	c plus e (a - e)	a	b	c plus e (a - e)	
St. Regis - Chicago Peak Section														
1- 14	13	61	69	38	38	0	10	45	12	--	61	31	8	77
15- 38	24	29	25	29	70	41	6	8	4	4	37	17	46	46
39- 67	29	14	7	10	93	83	4	3	5	3	17	0	83	17
68-106	39	5	7	15	85	74	6	4	5	3	5	5	90	8
107-129	23	8	8	26	87	61	2	6	4	3	9	9	82	14
130-139	10	10	20	50	90	40	4*	1	6	3	10	20	70	15
140-215	76	12	12	30	87	57	5	6	6	3	13	7	80	12
St. Regis - Clark Fork Section														
1- 15	15	20	47	40	80	49	4	7	12	4	20	40	40	40
1- 21	21	24	19	48	95	48	4	7	8	3	24	10	66	29
22- 25	4	25	25	--	50	50	7*	2*	--	3	25	25	50	38
26-111	86	1	3	9	92	83	1*	3	3	3	1	2	97	2
112-131	20	--	10	30	90	65	--	6	6	3	--	10	90	10
1- 44	44	14	16	16	82	73	9	9	4	4	13	9	77	18
45-106	62	5	32	39	84	50	4	7	4	3	5	27	69	19
107-129	23	--	4	13	96	83	--	3*	7	3	--	4	96	2

* Single measurement

Table 5. Thickness and occurrence of sedimentary structures in groups of turbidites from the St. Regis Formation at the Clark Fork and Chicago Peak measured section.

Complete	abcd (5)		
Base cut out	bcd (15)	cd (52)	
Top cut out	abc (6)	ab (4)	a (4)
Base and top cut out	bc (14)	b (4)	c (15)
Internal cut out	ad (8) abd (4)	bd (21)	acd (12)
Top and internal cut out	ac (10)		

Table 6. Variations of the Bouma cycle that occur in 174 turbidites sampled from data in Table 5.

sequences. These sequences, that range from 12 to 206 cm in thickness and average 55 cm, are associated with scours 5 to 20 feet deep. The very thick beds are the result of the amalgamation of several smaller beds that can occasionally be traced laterally into a conformable sequence. Irregularly distributed between the major quartzite intervals at this measured section is a graded bedding sequence that contains a dune phase that is not part of the <u>c</u> division, but is similar to that described by Hubert (1966). This graded bedded sequence consists of a cross-bed (15-45 cm) that is generally transitional downward into massive to laminated quartzite a maximum of 4 cm thick and grades upward into a laminated division (1-3 cm thick) which in turn is overlain by a ripple bedded (c division) 3 cm to 18 cm in thickness. Calculation of the P_1 values calculated for the two sections sampled (Table 5) show little difference between the two sets of data except for the group (1-14) relatively high values in the quartzite intervals of the slope facies. This indicates, according to Walker and Sutton, (1967), that the thicker quartzites were deposited by faster currents than the interbedded and interlaminated lithogies.

INTERPRETATIVE SUMMARY

Questions concerning the origin of the St. Regis Formation fall into three major categories: local depositional environments, the relationship of these local environments to a regional framework, and the ultimate sources of the sediments.

The St. Regis Formation represents turbidites that were deposited by currents that moved northeastward down a gentle slope. Short periods of moderately high current activity followed by longer periods of quiescence are inferred from the frequency of scouring, mud chips and internal sequence of sedimentary structures of the sand layers and lenses that are invariably overlain by a pelitic lamination that is commonly cracked and burrowed.

These turbidites accumulated as part of one or more subaqueous fans, located along a slope break and onto the basin floor, and broadly interfinger upslope with thick sand bodies of the Revett quartzites (Figure 14). In the study area these sand bodies represent channel deposits of the subaqueous fans as indicated by scours and channels, radial paleocurrent pattern, and association with the turbidite facies. Cross-bedded sand bodies in the Coeur d'Alene area and westward may have been part of a shelf facies, but the evidence is too sparse to verify this interpretation. The general sequence of events is summarized in Table 7.

In fan or base-of-slope deposits, lithologic changes occur away from the point source with lithologic continuity being greater

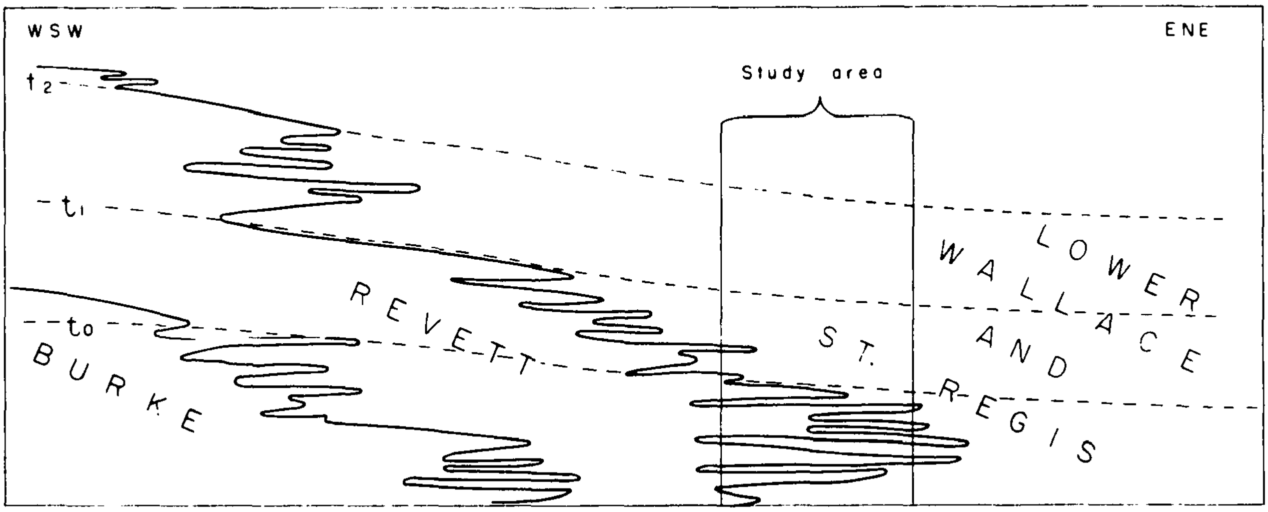

Figure 14. Schematic WSW - ENE cross section of the Ravalli group showing (1) the relationship of the respective lithostratigraphic formations at single interval of time (t_o); and (2) the development of the general stratigraphic sequence in the study area where the St. Regis transgresses the Revett as the basin subsided during intervals t_1 and t_2 .

1. Transport of silts and muds down a very gentle north-northeastward dipping slope and concentrated in broad shallow valleys by turbidity currents and related phenomena.

2. Accumulation of sand and muds on subsea fans at break in slope and onto adjacent basin floor. Sand concentrates in channels but finer grained sediments are transported down dip, across the fan and onto the basin floor by waning turbidity currents.

3. Minor fine grained basin carbonates transported from eastern source and deposited between periods of low current activity.

4. Local faulting or other mechanism causes shifting of up-dip channel position which results in a corresponding shift in the depositional site down-dip.

5. Subaqueous fan system coalesce and prograde basinward as sedimentation continues.

6. Subsidence. Basin facies (St. Regis Formation) transgresses base-of-slope facies (Revett Formation).

Table 7. Sequence of events for the deposition of the Ravalli group and basal Wallace in the study area.

in the down slope direction, roughly parallel to the current direction (Bouma, 1965). Modern studies (Haner, in press), (Shepard and others, 1969) show that the sand bodies are largely restricted to the channels, which are arranged in a distributary or radial pattern on the fan. Turbidity currents are confined to channels only in the upper part of the fan but in the lower reaches may continue to flow longitudinally within channel confines or spread laterally over the fan surface (Haner, in press, Shepard and others, 1971). Differing deceleration rates, as these currents spread over the fan and basinward, results in various assemblages of sedimentary structures (Figure 15). Over a period of time channel positions shift across the fan and the fan may prograde basinward and coalesce with one another, and in so doing produce a sequence of sediments that is generally homogeneous looking, but does contain subtle lithologic variations laterally and vertically even over short distances. In western Montana where outcrops are discontinuous and widely spaced, the details of geometry and arrangement of sand bodies are nearly impossible to reconstruct. However, one would suspect that the lithologic continuity of individual units would be greatest in a northeast-southwest direction, which is roughly parallel to the paleocurrent direction.

Because of the widespread distribution and interfingering of this slope and basin facies the paleoslope was probably very

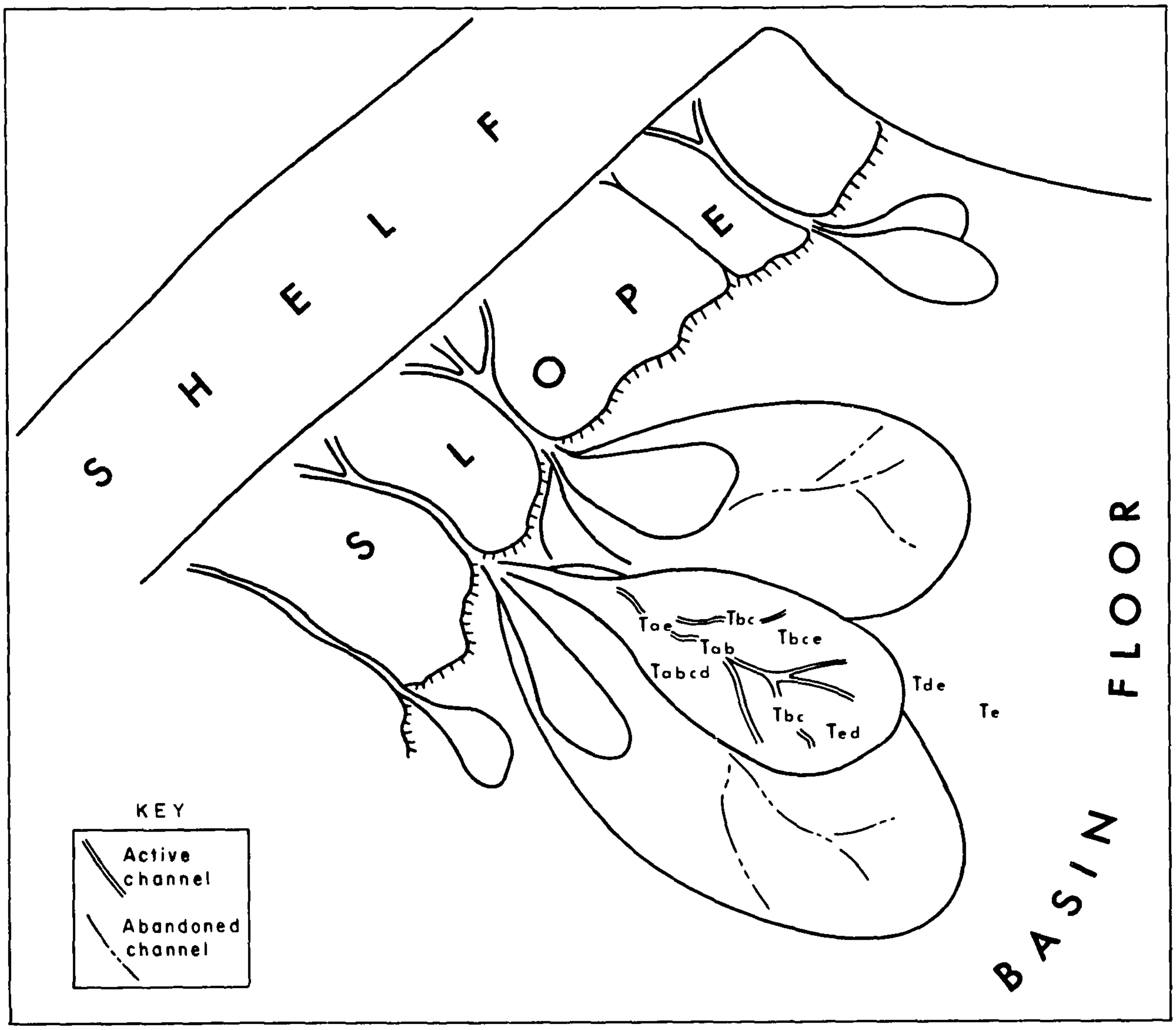

Figure 15. Hypothetical plan view of successive turbidite lobes infilling the basin (modified from Bouma, 1962). Note: (1) overlapping of successive lobes (2) general tendency for greater continuity of sediment type parallel to current direction and (3) general trend of truncated Bouma sequences away from the point source reflecting a general deceleration of currents away from the channels.

gentle, but the change in thickness and number of sand bodies in the Ravalli north and east of the present Clark Fork fault zone suggests that a Precambrian structure may have been weak but active.

The depth of water in which these sediments were deposited cannot be answered precisely because faunal data is absent and primary sedimentary structures alone are not depth indicators. Four possibilities will be considered using an indirect approach and based on the fact that the Ravalli Group is about 10,000 feet thick. First, we could assume that the water depth was about 10,000 feet at the beginning of Ravalli sedimentation and the sediments simply filled in the basin. This implies that the lower part of the Ravalli contains deep water sediments and the upper part contains shallow water sediments. Although this is possible, it cannot be verified. Secondly, following the idea of Ransome and Calkins, we could assume that the water was very shallow (less than 50 feet) and sedimentation kept pace with subsidence for the time necessary to deposit the Ravalli Sequence. This alternative requires a delicacy of balance that must also be extended for other groups that are thicker than the Ravalli, if we accept it. Thirdly, the water depth would have been greater than 10,000 feet deep which would produce little problem with regard to the deposition of a thick sequence. Fourthly, the Ravalli sequence could have been deposited in water that was between 300 to 5000 feet deep with some subsidence during sedimentation, but without requiring a unique balance between sedimentation and subsidence or extremely deep water. I believe that case four is the most reasonable of the alternatives, and although the range of depth given above was arbitrarily selected and may be revised with additional study, it provides a workable hypothesis that does not demand a unique relationship between sedimentation and subsidence, or extremely deep water.

Mineralogic and petrographic data are inconclusive about the ultimate source(s) of the terrigeneous sediments in the Ravalli Group. The subangular to rounded very fine quartz grains and the dominantly subrounded to round heavy mineral suite indicate that the ultimate source area contained fine-grained sedimentary rocks and less crystalline rocks. These crystalline rocks may have been in part granitic and metamorphic as evidenced by low percentage of idiomorphic zircon crystals and twinned plagioclase and potassium feldspars. Trace amounts of carbonate mineral in the Revett, St. Regis and Lower Wallace suggest the carbonated sedimentation prevailed during Ravalli time. The carbonates are more abundant where not diluted by terrigeneous clastics. Hence the general decrease in mean grain size up section is accompanied by an increase in carbonate content. The homogeneity of the terrigeneous fraction of the Ravalli and lower Piegan rocks could have originated from reworking of marine sediments on the shelf that were funneled down canyons to the basin floor. A more likely possibility is that the sediments are a mixture of both fluvial-deltaic sources and marine sediments that were mixed and transported across a shelf and down the basin slope with smaller amounts of carbonate coming in from the east (Figure 16). The volume of sediments certainly suggests that the westward landmass that ultimately provided the clastic debris was subcontinental in size. Determination of proximity to the westward margin of the basin has not been determined because of the higher degree of metamorphism and thick Tertiary lava sequences in eastern Washington and Idaho. Based on these data, plus the fact that the Belt rocks are at least 25,000 feet thick in eastern Washington (Miller, 1969) does not support the idea the present outcrop distribution closely approximates the size of the basin in which the sediments were deposited (Ross, 1963, p. 91). The hypothesis I prefer is one suggested by Walcott (1916). In essence Walcott suggests that the Belt rocks in the Rocky Mountain region were deposited in an inland mediterranean. His idea is even more appealing in the light of the recent sedimentological studies of the present Mediterranean Sea by Stanley (1970). Using this area as a possible model it is easy to envision multiple sub-basins each with a different mode of filling - radial, longitudinal, lateral or a combination of these - and the amount and variations in sediment type would depend on the number, size and load of the streams supplying the respective basins. Additional studies of the sedimentology and paleocurrent analysis of Belt rocks are needed to develop or reject this hypothesis.

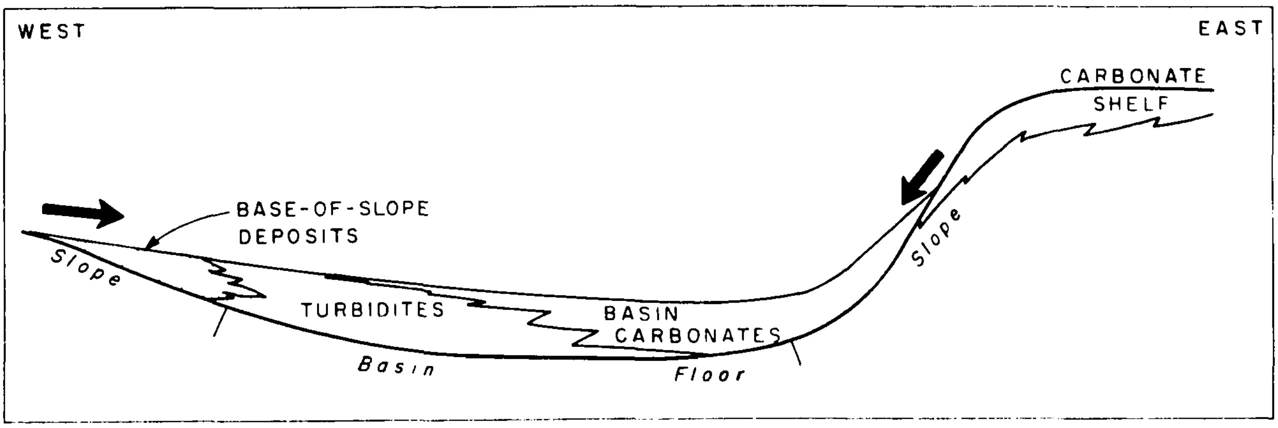

Figure 16. Hypothetical east-west cross section of the Belt basin during Ravalli sedimentation. Dominantly flysch-like sedimentation in western part of basin with minor carbonate being supplied from an eastern source.

In comparison with the interpretation of modern sedimentological studies of thick sedimentary sequence, the St. Regis Formation and Ravalli Group - represents a flysch phase during the filling of the geosyncline. Hsu (1970), who carried out a historical investigation in search of an acceptable lexicographical definition of Flysch, proposes:

> "Flysch be used as a term for a recurrent facies that included alternation of sandstone and marine shales or some impure limestones which constitutes a well-bedded sequence in an alpine-type mountain chain with a tectonic setting and sedimentological features similar to the Alpine Flysch in its more typical development."

The sedimentological similarity of the St. Regis to what has been called flysch in other areas was given earlier. For those who believe that the term is inappropriate because no alpine type mountain chain existed during the Late Precambrian in this area, the term flyschoid might be preferable (Stanley, 1970).

OLD PROBLEMS AND FUTURE WORK

The St. Regis formation and the Belt Megagroup as a whole contain a number of unanswered geologic problems; these include:

(1) Will the interpretation of the St. Regis Formation as a turbidite sequence serve as a model elsewhere in the western thick clastic sequence?

(2) How is the more carbonate-rich eastern belt sequence related to the thick terrigeneous clastic sequence of the western belt? Do the carbonates grade laterally into non-carbonate units, do they interfinger with non-carbonate units, or do they grade laterally into the slightly carbonatic units?

(3) What is the source(s) of the more than 250,000 cubic miles of fine-grained sediment?

(4) Was the Belt Megagroup deposited in a single basin?

(5) Were the Late Precambrian sediments in southern Idaho deposited in the same basin?

(6) Did the axis of the Belt basin change during the Late Precambrian? How does one test such an idea?

(7) To what extent can provenance of these rocks be extrapolated from petrographic studies?

(8) To what extent has diagenesis and low grade metamorphism limited petrographic inferences?

The interpretation of the Ravalli Group as a turbidite sequence during a flysch phase of sedimentation adds a new perspective to both the local and regional picture of Ravalli and Belt sedimentation. More stratigraphic and sedimentologic studies are needed to test whether this hypothesis can serve as a model elsewhere in the non-carbonate sequence in the western belt and to relate this sequence to the more calcareous sequence in the eastern part of the outcrop belt.

Although the Belt rocks consist predominantly of silt and mud, little attention has been given to the study of muds, their sedimentation, texture, diagenetic fabrics and relation to coarser sediments. Perhaps one would begin to answer such a question with a bibliography of studies of mud. X-radiography has proven to be a successful technique for determining internal structures in what appeared to be massive sandstones (Hamblin, 1965) and modern muds collected in cores from the recent off-shore drilling projects (Stanley, 1970) and a systematic radiographic study of the siltstones and mudstones of Belt rocks might also prove to be useful. Why study mud? The study of the geometry of sand and sandstone has been relatively successful in determining certain depositional environments (Allen, 1965). But what if geometry cannot be determined? Sand and sandstone bodies are now known to exist in deep water (Houbolt, 1968; Kenyon and Stride, 1968;). If the geometry and internal characteristics of the sand body cannot be determined in the outcrop or core, the adjacent "muds" or argillite may offer vital clues to the environment because of its faunal and/or floral content and microstratigraphy.

One of the most simple but useful field techniques for both stratigraphic and sedimentologic studies is the vertical profile. This technique includes the systematic collection of bedding data, sedimentary structures and paleocurrent measurements, petrographic samples, grain size - sand-shale ratio - and any other measurable property at one or more stratigraphic sections. A single profile could be made for the complete stratigraphic section in a small area like Glacier National Park or a series of profiles could be made of a particular formation over a larger area. East-west, and north-south cross-sections of the entire Belt sequence with complimentary paleocurrent data are the goal. The collection of field data must be at a smaller scale than in previous published investigations, if we are to elaborate on the early reconnaissance work rather than try and reproduce it.

The correlation of Late Precambrian rock in southern Idaho or south of the Lewis and Clark lineament is complicated by faulting and metamorphism. Possibly these rocks were deposited in different basins that were supplied by different streams and sediment types.

Extrapolation of provenance from petrographic and heavy mineral studies seems doubtful. When trying to put together the petrographic data which I had collected over a period of months, the homogeneity of the composition of the Ravalli rocks was not easily rationalized. If my sampling (233 thin sections) reflects the uniformity of composition of Belt rocks in northern Idaho, and western Montana, as it seems to (Harrison and Campbell, 1963), several possibilities may account for this. The simplest case is that the mineralogy of the sediment truly reflects the source area from which it was derived and that area had a very uniform composition. But do the sediments reflect the nature of the landmass at the time they were being deposited in their final resting place? How much had the landmass changed since the original sediments had been transported from the highlands, across alluvial plains, along and across the shelf? How much mixing took place between the sediments coming from streams and off deltas with those already on the shelf which may not have been derived from the same source area? Similar questions have been raised by Garner (1959) in his study "Stratigraphic and sedimentary significance of contemporary climate and relief in four regions of the Andes Mountains". Even if dissimilar sediment types were dumped onto a shelf, selective sorting by current action could homogenize the sediments to the extent that recognition of the original suites would be difficult, if not impossible. The length of time the sediments move along and on the shelf seems to be a factor that could determine the degree of homogenization of recent and relict sediments. Once the sediments have been deposited diagenetic changes through time could also influence the bulk mineralogy. The Ravalli rocks all show some evidence of recrystallization, and until the amount and date of origin of secondary minerals can be accurately determined, it seems totally unreasonable to assume that significant mineralogic changes have not occurred in rocks that have been exposed to changing pore water solutions for 900 million years. Detailed geochemical data is necessary if these problems are to be resolved.

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APPENDIX A

Location of the Study

The Trout Creek-Thompson Falls study area is located in northwestern Montana and northern Idaho. The area encompasses approximately 300 square miles of the Betteroot and Cabinet Mountain ranges and lies within parallels 47°30' and 48°15' north latitude and meridians 115°15 and 116° west longitude in Sanders and Lincoln counties, Montana and in southeastern Bonner and Shoshone counties, Idaho. This study area was selected because of the accessibility of exposures, availability of geologic maps in and adjacent to the area and a reported lithologic change in the Ravalli Group north and east of the Clark Fork River (Calkins and MacDonald, 1909; Gibson and others, 1941 and Gibson, 1948).

Field Work

Approximately 5 1/2 months were spent doing field work during the summers of 1968 and 1969. Field work during 1968 consisted of locating and measuring sections, collecting vertical profiles for petrographic study, and collecting paleocurrent data in the study area. During July and August 1969 the field work in the study area was completed and a reconnaissance study was made of the Ravalli group in the surrounding area.

The climate in northern Idaho and northwestern Montana is hot and dry during July, August and early September. The weather is less predictable from late September to June.

Access

Access to the study area is good because U.S. Highway 10 lies immediately south of the area, and U.S. Highway 10A (Montana State Highway 200) cuts diagonally across the study area; both are all-weather highways. Improved dirt and gravel forest roads make most of the area off the main highways readily accessible and marked trails provide additional access into the more remote areas. Forest roads and trails labeled on Forest Service maps (1:125,000) are available from the Forest Service or local ranger stations.

Methods

Stratigraphic sections were measured with a five-foot Jacobs staff. The descriptions of the metasedimentary rocks are based on a threefold division of the rocks into quartzite, siltite and argillite as proposed by Harrison and Jobin (1963). These terms represent the slightly metamorphosed equivalents of quartzose sandstone, siltstone and claystone. The quantitative bedding terms proposed by McKee and Weir (1953) are used in this thesis; bed thickness is measured in centimeters. Grain size was estimated in the field and later measured in thin section utilizing the Wentworth scale.

MEASURED SECTIONS

The following descriptions and locations of outcrops include those measured in and adjacent to the study area and a few reference sections from published reports. They are listed according to county. An appendix map shows by number and symbol the location of sections and outcrops visited in the field. Photographs show the traverse along which the sections were measured.

The description of the measured section is presented in the following order: name, thickness of section, location and access are followed by the body of the description of the measured section and a summary chart of the sedimentary structures for the respective formations.

Thickness

Thicknesses listed represent those measured in the field, and do not always reflect the total thickness of a formation. To determine the thickness of the St. Regis and the nature of its boundaries with adjacent formations, the base of the sections was chosen in the Revett and the top was extended into the Wallace. The amount of Revett and Wallace measured per section was arbitrarily determined by using the rule of thumb that the appropriate thickness should at least include the transitional boundaries; this is somewhat limited by the amount of exposure available.

Description

The description is subdivided into two parts: the general stratigraphic sequence beginning from the base of the section and a chart listing the paleocurrent data and sedimentary features. For convenience in reading the body of the description is written in sentence form rather than listed vertically in stratigraphic form. The description of the stratigraphic sequence is kept very brief in order to eliminate excessive repetition in describing similar lithologies that grade into one another. More complete descriptions of the details and variations in the different rock types is given in the text.

Average paleocurrent directions are recorded at their respective sections. The azimuth of the vector mean for dip direction of cross-bedding is followed by the number of measurements on which the mean was calculated. For example: "184°(6)" indicates that the vector mean of the dip direction is 184° or S. 4° W., and this is based on six field measurements. Ripple marks are grouped in 20-degree intervals and the strike of the ripple marks is represented by the midpoint of the modal class and is given in a similar style; for example, "10°(15)" indicates that the midpoint of the modal class is 10° or N. 10° E., and this is based on a 20-degree grouping of 15 measurements. The summary chart provides a listing of the variety of sedimentary structures and their relative abundance. Scarce, common and abundant are the terms used to indicate relative abundance. The abbreviation N.C. means a feature was not observed.

SANDERS COUNTY, MONTANA

1. Chicago Peak section. Thickness 840 feet. Plate A-1

Cirque exposure. Section measured on northeast side of Chicago Peak along unnamed pass (26, 27 N., 32 W.)

Follow U.S. Highway 10A about 10 miles north of Trout Creek to Rock Creek turnoff, Forest Service route 150. Continue on dirt and gravel road about 5 miles to "T" junction in road. Turn left (north) and continue on 150 to sign marking road to Chicago Peak. This spur road is passable to within a few hundred feet of the saddle into the Rock Creek drainage.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	280'	370'	190'
Cross-Bedding	23°(33)	30°(17)	
Ripple marks		170°(168)	

Excellent display of Bouma cycles, scour channels, and small-scale bedding features in cirque.

Measured section: Base of section; 75-foot thin interbedded siltite and argillite with a thin quartzite bed near top; 80-foot massive to cross-bedded quartzites with sharp bases and transitional tops, 10-foot thin-bedded siltite; 40-foot massive cross-bedded quartzites with transitional tops and sharp bases; 290-foot thin interbedded siltite and argillite and lenses of quartzite - Bouma cycles, 55-foot cover, 75-foot thin interbedded to interlaminated siltite and argillite with minor quartzite lenses, 15-foot cover, 190-foot, thin interbedded to interlaminated calcareous argillaceous, siltite and argillite with a few discontinuous cross-bedded quartzite lenses. Upper 190 feet has indistinct graded bedding.

2. Vermilion River-Bear Creek section. Thickness 590 feet (section overturned, 36° to 54° west).

Flatirons along west-facing slope on Bear Creek (18, 24 N., 29 W.), Plate A-1.

Take Vermilion River Road, which is about one-half mile north of Trout Creek on highway 200. Continue on Vermilion Road for about 18 miles to marked Y-road junction, Willow Creek and Vermilion Road. Spur road just before Miners Gulch goes into Bear Creek drainage.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	420'	105'	
Cross-bedding	80°(23)		
Ripple marks		170°(51)	

Measured section: Base of section covered: 160 feet of continuous quartzite; 100 feet of very homogenous siltite (bedding indistinct); 5-foot cross-bed traceable 150 feet uphill; 20-foot cover; 40-foot homogenous siltite; 30-foot cross-bedded quartzite; 10-foot massive to ripple-bedded quartzite break; 95-foot thinly interbedded siltite and argillite; cover zone with quartzite talus; discontinuous siltite exposures to nose of hill.

3. Vermilion River-Miners Gulch section. Thickness 640 feet.

Road cuts and hillside exposures (12, 24 N., 30 W.). Section overturned.

Same as Vermilion River-Bear Creek, but road exposures are near head of Miners Gulch just past turn-off spur road to Vermilion River-Bear Creek section.

Remarks:	Revett	St. Regis	Wallace
Measured thickness		600'	240'

Good exposures of bedding features.

Measured section: Base of section covered, 400 feet of thinly interbedded siltite and argillite, 240 feet poorly exposed beds of Wallace interfingering with interbedded to interlaminated siltite and argillite lithology of St. Regis. Graded bedding indistinct in very fine-grained intervals; cde, bcde graded sequences occur in the more arenaceous intervals.

4. Graves Peak section. Thickness 1,170 feet.

Cirque exposure at Graves Peak (18, 23 W., 19 N.). Section overturned. Plate A-2.

Turn off to the Blue Slide road is approximately 2-1/2 miles north of Thompson Falls. Drive north on the Blue Slide road to the Graves Creek turnoff and continue up Graves Creek to Vermilion Pass. At Vermilion Pass a logging road leads off to the west and goes along the head of the valley in section '. From the spur logging road it is a short walk to trail 541 that runs along the ridge to Cougar Peak. The trail is clear and well marked. Revett-St. Regis contact on northwest flank of Graves Peak.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	350'	750'	170'
Cross-bedding	80°(8)		

Cross-bedding measured along road one-quarter mile below Graves Creek Falls (25, 23 N., 30 W.).

Measured section: Revett quartzite talus along ridge top (no thickness), base of section; 355-foot thin bedded siltite and quartzite (appears bleached and seriticized), 10-foot thin, interbedded siltite and argillite, 35-foot cover, 170-foot thin, interbedded siltite and argillite, 80-foot cover, 170-foot thin, interbedded to interlaminated siltite and argillite, 80-foot thin, flatbedded argillaceous siltite and argillite interval containing few discontinuous cross-bedded quartzite lenses 6 inches to 12 inches thick, 210-foot thin interbedded siltite and argillite-slaty cleavage developed in argillite laminations; 15-foot thin, flatbedded argillaceous siltite and silty argillite, contains massive to cross-bedded quartzite lenses 6 inches to 12 inches thick, indistinct, graded bedding; 25-foot cover; 20-foot lithology as below.

Argillite laminations cracked and burrowed. Siltites commonly show positive graded bedding.

5. Thompson River section. Thickness 2,200 feet.

Hillside exposures on mountain due west of Koo-Koo-Sint ridge. Section measured from Thompson River road to north-northwestward along hillside (7 and 12, 21 N., 28 W.). Plate A-2.

Access is southwest from Thompson Falls on U.S. Highway 10A to Thompson River junction and up Thompson River about one-half mile.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	740'	600'	125'
Cross bedding	50°(16)		
Ripple marks	340°(14)		

Measured section includes part of Burke: Cross-bedding 10° (4). Whole section calcareous. Fracturing and jointing intense up section. Some small-scale open folds.

Measured section: Base of section; 245-foot massive to cross-bedded quartzites (tangential cross-bedding); 5-foot argillaceous siltite; 5-foot massive quartzite; 20-foot cover, 135-foot massive argillaceous siltite and silty argillite interval containing thin quartzite beds with gradational tops and sharp or gradational bases; 90-foot massive to laminated, thin-bedded quartzites with gradational tops; 250-foot massive argillaceous siltite and silty argillite interval containing discontinuous quartzite lenses. Float indicates very small-scale bedding features (i.e., mud chips and gradational bedding) are present, although not discernible in the outcrop; 50-foot cross-bedded quartzites with ripple bedded tops transitional into 110 feet of thin interbedded siltite and argillite (graded bedding; bcde, cde); 30-foot massive, jointed quartzite 50-foot cover; 40-foot massive, jointed quartzite; 10-foot interbedded siltite and argillite; 100-foot massive, jointed quartzite transitional into 45-foot argillaceous siltite containing discontinuous massive to cross-laminated quartzite lenses; 40-foot massive to jointed quartzite; 68-foot interbedded siltite and argillite; 45-foot massive to laminated quartzites about 2 to 3 feet thick with transitional tops and sharp bases; 30-foot interbedded siltite and argillite; 20-foot cross-bedded quartzite, 30-foot thin interbedded siltite and argillite; 70-foot thin-bedded, massive quartzites with transitional tops; 30-foot interbedded siltite and argillite; 10-foot massive quartzite; 125-foot thin interbedded to interlaminated siltite and argillite; 10-foot cover; 80-foot thin interbedded to interlaminated argillaceous siltite and argillite; 50-foot thin interbedded siltite and argillite containing discontinuous cross-bedded quartzite lenses, increase up section; 5-foot massive quartzite; 20-foot argillaceous siltite and silty argillite containing isolated quartzitic lenses; 40-foot cover; 70-foot thin interbedded siltite and argillite; 5-foot green, flat, thin-bedded argillite; 80-foot interbedded siltite and argillite; 20-foot massive siltite; 5-foot green, flat-bedded argillite; 10-foot cover; 55-foot thin interbedded argillaceous siltite and silty argillite; 30-foot indistinctly graded, bedded sequences of argillaceous siltite and silty argillite containing few thin quartzite lenses about 12 inches thick.

6. Trout Creek section. Thickness 850 feet.

Hillside exposures on south-facing slope of Trout Creek (29, 24 N., 32 W.). Plate A-2.

Take back road through town of Trout Creek and drive north to junction for Trout Creek. Gravel road is passable to junction of East Fork of Trout Creek and Trout Creek.

Remarks	Revett	St. Regis	Wallace
Measured thickness	70'	760'	20'
Cross-bedding	56°(14)		
Ripple-marks		30°(11)	

Measured section: Base of section; 100-foot massive, cross-bedded quartzite, sharp transition into 190-foot thin, interbedded siltite and argillite; 10-foot cover; 20-feet same as below; 45-foot cover; 75 feet same as below; 15-foot cover; 140-foot thin, interbedded, interlaminated siltite and argillite; 10-foot cover; 115 feet as below; 30-foot cover; thin to very thin flat-bedded argillaceous siltite and silty argillite indistinctly graded bedded. Slightly calcareous quartzites up section.

7. Lost Peak section. Thickness 430 feet; top faulted.

Mountain top and cirque exposures from Lost Peak northward along ridge (9 and 4, 23 N., 33 W.).

Take back road through town of Trout Creek and head north on gravel road along west side of Noxon Reservoir to the "T" in the road (section 4). Turn south and drive on forest route 322 past Minton Peak to the Idaho-Montana line. Continue along the state boundary to junction for Lost and Bloom peaks, route 430. Take route 430 for about 1-1/2 to 2 miles, then climb hillside to top. Best exposures occur along ridge top and northeast-facing cirques.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	100'	330'	faulted
Cross-bedding	35°(11)		
Ripple marks		10°(13)	

Measured section: Base of section covered; covered 30-foot cross-bedded quartzite; 30-foot ripple bedded siltite; 10-foot cross-bedded quartzite; 10-foot ripple bedded siltite with some deformed bedding; 85-foot massive to cross-bedded quartzite transitional into 100-foot thin, interbedded to interlaminated siltite and argillite; 35-foot cover; 20-foot lithology as below; 10-foot cover; 2-1/2-foot lithology as below; 2-1/2 foot cover; 20-foot lithology as below; 5-foot cover; 70-foot lithology as below; 5-foot cover; 20-foot lithology as below, some deformed bedding; 15-foot cover; 5-foot lithology as below; cover, possible fault.

Argillites cracked and burrowed. Flute casts in St. Regis float.

8. Twenty-four Mile Section. Thickness 360 feet; top eroded.

Cirque exposures along east-facing slope on Idaho-Montana line (3, 21 N., 32 W.). Section measured near head of Twenty-four Mile Creek.

Access is west out of Thompson Falls on the Prospect Creek road to Cox Gulch (route 876). Continue to turnoff road to Clear Peak. Follow ridgetop trail 635 at Clear Peak to the state line. All roads are dirt or gravel and maintained.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	100'	260'	
Cross-bedding	358°(23)		
Ripple marks		130°(18)	

Measured section: (Base) 100-foot cross-bedded quartzites, 20-foot massive siltite; 30-foot thin interbedded to interlaminated siltite and argillite; 13-foot massive quartzite; 50-foot thin interbedded siltite and argillite; 7-1/2-foot siltite transitional into massive quartzite; 115-foot thin interbedded to interlaminated siltite and argillite; 10-foot cover; 55-foot thin interbedded to interlaminated siltite and argillite.

Argillites cracked and burrowed. Siltite and argillite commonly ripple marked.

9. Clear Peak section. Thickness 420 feet, top eroded.

Cirque exposure in east-facing valley (2, 21 N., 32 W.). Plate A-3.

Access - same as Twentyfour Mile (No. 8 in appendix).

Remarks:	Revett	St. Regis	Wallace
Measured thickness	130'	290'	
Cross-bedding	31°(19)	100°(3)	
Ripple Marks	90°(1)	30°(60)	

Measured section: Base of section; 150-foot massive, cross-bedded quartzite, minor argillaceous breaks; 50-foot thin interbedded to interlaminated siltite and argillite; 15-foot cover; 205-foot lithology as below; top of hill.

10. Little Trout Creek section. (36, 24 N., 32 W.)

Exposures of Revett and St.Regis in woods on west-facing slope. No section measured.

St. Regis lithology, similar to Trout Creek section.

11. Beaver Creek section (32 and 24, 23 N., 31 W.).

Roadcuts and hillsides exposures of Burke, Revett, St. Regis, and Wallace along Beaver Creek. Upper portion of section faulted and partly silicified, probably emplacement of dikes of Haines Pt. intrusive. No section measured.

St. Regis lithology similar to that at Trout Creek section. Bedding features well exposed. Revett cross-bedding 102° and ripple mark 10° (1).

12. Little Beaver Creek (14, 22 N., 31 W.).

Roadcuts and hillside exposures of Revett, St. Regis, and lower Wallace. Rocks badly fractured, intruded, and partly silicified.

Remarks: 921-foot total interval measured. Mostly covered and possibly faulted and/or is intruded. St. Regis lithology similar to Trout Creek section; occurs in discontinuous exposures totaling 190 feet.

13. Little Thompson River (9, 22 N., 26 W.)

Hillside exposures along creek. Stratigraphic position unknown; no top or bottom on section and dominantly siltite and argillaceous siltite, probably Ravalli interval.

Remarks: 310-foot total section measured up hillside. Thinly bedded homogenous argillaceous siltite with small-scale bedded features. Few small scour channels with mud chip sandy fill. Ripple mark common. Probably graded bedded sequence.

LINCOLN COUNTY, MONTANA

14. Mount Vernon section. Thickness 560 feet (33, 29 N., 34 W.)

Remarks:	Revett	St. Regis	Wallace
Measured thickness	40'	220'	300'
Ripple Marks			30°(42)

St. Regis thin. Ripple marks in Wallace measured along ridge top.

Measured section: (Base) 40-foot massive, cross-bedded quartzite; 220-foot thin interbedded to interlaminated siltite and argillite; 300-foot thin indistinctly graded sequences of argillaceous siltite and silty argillite, contains small-scale quartzite lenses (starved sand waves).

Revett lithology very similar to Chicago Peak section (1).

15. Waloven Creek section. Thickness 2,100 feet.

Hillside exposures on west-facing slope on Waloven Creek (11, 25 N., 30 W.) Plate A-3.

Access to the section from either the Kootenai or Clark Fork drainage is possible. Directions given from Trout Creek. North on highway 10A about 1 mile to the Vermilion River road. Take the Vermilion river road to Sims Creek, turn north up Sims Creek. This unimproved road, following trail 882, is drivable (about 3-1/2 miles) to a meadow below the head of the creek. From the meadow continue on trail 882 into the Waloven Creek drainage.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	715'	525'	225'
Cross-bedding	350°(26)		320°(2)
Ripple marks	350°(19)		0°(7)

Good exposures, but lichen and oxidation film mask bedding features in siltite intervals.

Measured section: (Base of section at first exposures above creek level) 35-foot cross-bedded quartzite; 10-foot siltite; 50-foot cover; 20-foot cross-bedded quartzite; 165-foot thin-bedded quartzite-siltite and laminations of argillite-bedding indistinct; 5-foot cover; 10-foot massive quartzite with 1-foot argillite break at top (slaty cleavage); 45-foot, thin interbedded quartzite-siltite and laminations of argillite; 20-foot ripple bedded quartzite; 85-foot cover; 5-foot climbing ripples in quartzite; 15-foot massive quartzite; 40-foot thin, interbedded quartzites and siltite; 90-foot massive quartzite-siltite, some ripple mark and small scours near top; 55-foot cover; 50-foot cross-bedded quartzites with ripple-marked tops and thin, ripple-bedded siltites; 50-foot cover; 5-foot quartzite, lower 2 feet continuous climbing ripples; 10-foot thin interbedded siltite and argillite; 85-foot massive (possibly cross-bedded) quartzite abruptly transitional into 150-foot thin interbedded siltite and argillite interval containing quartzites (1-1/2 feet thick) every 5 to 10 feet up section; 10-foot cover; 5-foot massive quartzites; 65-foot thin, interbedded siltite and argillite; 10-foot carbonate mudstone or argillite; 150-foot thin interbedded siltite and argillite; 50-foot lithology as below but contains few carbonate mudstones 6 inches to 12 inches thick; 210-foot thin, interbedded siltite (and argillaceous siltite) and argillite interval containing occasional quartzite lenses and small scour channels; 100-foot cover; 100-foot thin, interbedded argillaceous siltite and argillite, indistinct graded, bedded, weathered outcrop has banded appearance; 100-foot thin interbedded siltite and argillite; 100-foot thin alternating sequences of (1) thin interbedded siltite and argillite and (2) thin interbedded argillaceous siltite and argillite that has a banded appearance, (3) thin quartzite lenses, and (4) carbonate mudstones.

16. Pete Creek reconnaissance (32, 28, and 29, 36 N., 32 W.).

Remarks: Small, discontinuous exposures of Ravalli along Pete Creek and Hensley Creek road. Thickness 420 feet. Lithology dominantly clean, ripple-laminated siltite with minor quartzite. No thick cross-bedded quartzite units typical of Revett in Coeur d'Alene area. Glacial debris covers bedrock along lower reaches of streams.

17. Garver Mountain reconnaissance. West slope of Garver Mountain (32, 37 N., 32 W.).

Remarks: No section measured. Excellent exposures. Ice-sculpted hillside with minor lichen cover. Formational contacts of Ravalli uncertain because of transitional homogenous lithologies and absence of criteria used in Coeur d'Alene area. Lithology: very fine-grained quartzite to coarse siltite, thin-bedded, white to light gray, dominantly graded bedding (Bouma cycles) with some scours up to 5 feet thick filled with laminated cross-bedded quartzite. Sedimentary characteristics same as Chicago Peak measured section (1).

18. Lost Horse Mountain (14 and 10, 35 N., 31 W.).

Remarks: No section measured. Hilltop mostly talus. Small outcrops fractured and jointed. Lithology similar to Garver Mountain. Few thin cross-beds (less than 15 cm) of medium to coarse sand in float along ridge north of lookout tower.

19. Randolph Creek reconnaissance section. Thickness 2,456 feet. Discontinuous exposures along hillsides and road cuts in Randolph Creek (20 and 21, 31 N., 32 W.).

Remarks: Exposures widely spaced, changes in bedding attitude downstream, shearing and fractures common. Ripple marks in Revett 170° (44).

Description: The limited exposures permit only a general description of the formation as mapped (Wallace and Hosterman, 1956). Burke-Revett: Thickness 1,716 feet; base covered. Thin, massive quartzite and siltite intervals and thin, interbedded siltite and argillite intervals. Thickness of respective intervals unknown. Dominant sedimentary structure is ripple marks. Slaty cleavage in argillaceous rocks commonly obliterates bedding features. Most outcrops were the thin, interbedded lithology that is not different from the St. Regis except for color. Faults may not be recognizable because of lack of exposures.

St. Regis-Wallace: Undistinguishable as described by Wallace and Hosterman (1956). The thin interbedded siltites and argillites (740 feet) sequence becomes more argillaceous up section (toward mouth of valley). Shearing and slaty cleavage pervasive.

20. Deborgia (26, 19 N., 30 W.).

Remarks: Road cut. Location within Revett unknown (Wallace and Hosterman, 1956). Revett crossbedding: 81° (10). Outcrop badly fractured; bedding near vertical.

21. Saltese (14, 19 N., 31 W.).

Remarks: Road cut. Location in Burke-Revett unknown (Wallace and Hosterman, 1956). Ripple mark 150° (4).

BONNER COUNTY, IDAHO

22. Clark Fork section. Thickness 2,100 feet.

Road cut along highway 200 at west end of Howe Mountain (20 and 56 N., 2 E., Clark Fork 15' quadrangle). Base of measured section along road cut (at lowest end of) exposure just east of mine adit and covered interval.

Easy access along highway 200 (also 10A). Traffic may produce some problems because cuts abut road. New highway under construction along margin of Lake Pend Oreille.

Remarks:	Revett	St. Regis	Wallace
Measured thickness	715'	775'	610'
Cross-bedding	307°(54)		52°(8)
Ripple marks	10°(11)	10°(20)	10°(26)

Accessible, very well exposed section to examine vertical variations in lithologies. Section not faulted.

Measured section: (Base) 20-foot cross-bedded quartzites; 45-foot thin-bedded quartzites with transitional tops (graded bedded); 20-ft thin graded beds of argillaceous siltites and silty argillites; 5-foot cross-bedded quartzite; 5-foot quartzite to siltite, deformed bedding; 10-foot cover; 35-foot massive quartzites (from 1 to 2 feet thick) with transitional tops; 55-foot cross-bedded quartzites (from 1 to 2-1/2 feet thick) with transitional tops; 15-foot quartzites lenses (from 1 to 3 feet thick) with transitional tops and bases (from 1 to 2 feet thick); 35-foot cross-bedded quartzites; 5-foot siltites with ball and pillow structure, 60 thin massive quartzites with transitional tops; 30-foot thin interbedded argillaceous siltite and argillite; 20-foot cover; 50-foot massive to ripple bedded quartzite; 20-foot massive to cross-bedded quartzites with transitional tops grades upward into 5-foot thin ripple-bedded siltites; 45-foot thin, interbedded siltite and argillite; 25-foot thin, massive, cross-bedded quartzites with transitional tops; 15-foot thin ripple-bedded siltites; 70-foot cross-bedded quartzites; 7-foot thin flat to ripple bedded siltites and argillites; 38-foot thin, indistinctly graded beds of argillaceous siltite and silty argillite containing a few quartzite lenses; 65-foot massive to cross-bedded quartzites (2 feet thick) with transitional tops that grade in thin flat-bedded siltites and argillites; 30-foot thin interbedded siltite and argillite containing thin quartzite lenses; 5-foot massive quartzite; 30-foot thin interbedded quartzite to siltite and argillite; 8-inch green carbonate mudstone; 30-foot thin interbedded quartzite-siltite and argillite; 25-foot thin interbedded quartzite and siltite; 125-foot thin interbedded quartzite to siltite and argillite; 1-foot argillite; 25-foot thin interbedded quartzite to siltite and argillite; 125-foot thin interbedded quartzite to siltite and argillite; 1-foot thin interbedded quartzite to siltite and argillite; 2-foot green carbonate mudstone; 225-foot thin, interbedded siltite and argillite containing few quartzite lenses; 55-foot cover; 20-foot thin interbedded siltite and argillite; 35-foot massive, green, carbonate, mudstone weather surface shows indistinct, graded bedding; 135-foot thin interbedded siltite and argillite containing occasional quartzite lenses; 120-foot thin interbedded carbonatic argillaceous siltite and silty argillite; green carbonate mudstones and thin massive quartzite lenses; 10-foot cover; 20-foot thin interbedded carbonatic siltite and argillite; 515-foot thin to very thin interbedded carbonatic argillaceous siltite, siltites and silty argillites. Quartzite lenses, molar-tooth and carbonate pods and balls increase in abundance up section (top of measured section).

23. Copper Creek section. Thickness 610 feet.

Conspicuous exposure on west-facing slope on North Fork of Coeur d'Alene River (32, 50 N., 1 E.) just southeast of Copper Creek. Plate A-3.

Interstate 90 to Kingston exit (7 miles west of Kellogg, Idaho), head north past Enaville to the North Fork of the Coeur d'Alene River. Turn onto forest route 209. Road exposure of Ravalli west of Bumblebee campground in sections 3, 4, and 5. Section measured in small gully about 200 feet above road.

Remarks:	Revett	St. Regis
Measured thickness	75'	535'
Ripple marks	40°&110°(22)	30°(4)

Bedding features well exposed.

Measured section: (Base) 5-foot massive quartzite; 35-foot thin interbedded siltite and argillite; 5-foot cover; 15-foot massive quartzite to siltite; 15-foot cover; 15-foot massive to cross-bedded quartzite; 35-foot thin-bedded ripple-marked siltite, some deformed bedding; 80-foot thin interbedded to interlaminated siltite and argillite; 50-foot cover; 5-foot green carbonate mudstone; 35-foot very thin interbedded to interlaminated siltite and argillite; 10-foot cover; 260-foot very thin, interbedded argillaceous siltite and silty argillite; top covered.

24. Military Gulch section. Thickness 864 feet. (13 and 18, 49 N., 6 E.).

Remarks: Crossbedding measured in Revett in cirque at Glidden Lake (18, 48 N., 6 E.). Cross-bedding 100° (7). Ripple mark: 50° (6).

Measured and described by Ransome and Calkins (1908, p. 37). St. Regis, 716 feet. Top and bottom of section present.

25. Maple Cliff - Castle Rock (28, 29 and 30, 50 N., 3 E.). Road cuts and hillside cliff exposure along Coeur d'Alene River.

Remarks: Section at Castle Rock similar to Copper Creek. St. Regis lower at Maple Cliff transition zone well exposed. Siltite to very fine-grained quartzite, gray-green, massive, some crossbedding, and thin, green argillaceous carbonate beds. Top and bottom to section present (Ransome and Calkins, 1908, p. 37).

Revett crossbedding measured along road near Maple Cliff section: 28° (25).

26. Revett Lake (25, 49 N., 5 E.)

Remarks: Exposures badly fractured and joined. Revett exposures fair; somewhat crossbedded; 50° (11), ripple marks 50°(10).

Plate A-1. Traverse of measured sections. Black line approximates line of traverse used in measuring section.

(A) Chicago Peak section. View of east flank of Chicago (flat top) and St. Paul (snow cap) peaks.

(B) Vermilion River - Bear Creek. View looking southwest toward Graves Peak.

A

B

Plate A-2. Traverse of measured sections. Black line approximates line of traverse used in measuring section.

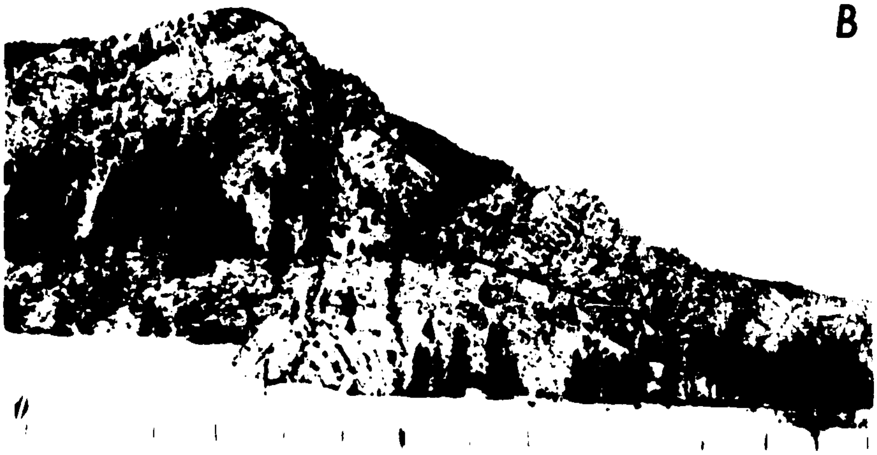
(A) Graves Peak section. View of northeast flank of Graves Peak.

(B) Thompson River section. Photograph taken along U.S. Highway 10A about 5 miles east of Thompson Falls.

(C) Trout Creek section. View of south-facing slope about one mile southwest of Minton Pass.

A

B



C

Plate A-3. Traverse of measured sections. Black line approximates line of traverse used in measuring section.

(A) Clear Peak section. Section measured on east-facing slope.

(B) Waloven Creek section. View of exposures on west-facing slope of Waloven Creek.

(C) Copper Creek section. View of west-facing slope southeast of Copper Creek, along which section was measured.

A

B

C

APPENDIX B

PETROGRAPHY

INTRODUCTION

Several formats have been considered for the presentation of the petrographic data:

(1) The vertical profile, in which the petrography is discussed for the rocks arranged in stratigraphic order,

(2) Discussion by stratigraphic unit and

(3) Discussion according to lithology regardless of stratigraphic unit

The value of the vertical profile is that several parameters can easily be compared and contrasted with ease. This technique is commonly used with satisfactory results; however, the repeated occurrence of a few litholigic types throughout the Ravalli group results in monotonous repetition of nearly identical petrographic descriptions. To circumvent this problem the petrography is discussed by predominant lithology, quartzite, siltite and argillite.

Two hundred and thirty-three thin-sections were prepared from rock chip samples collected at 10 to 25-foot intervals from three of the most completely exposed sections: Clark Fork, Chicago Peak and Waloven Creek. The Vermilion River-Bear Creek section was studied for supplementary data on the quartzites. Rock chips selected for thin-section were cut perpendicular to bedding, and each thin section was labeled with the footage at which the sample was collected in the measured section. Only 112 thin-sections were suitable for the petrography of the quartzites and siltites; the remaining samples were too fine-grained for the grain size and textural studies. A cursory examination was made of most of the finer-grained samples, and peculiarities were noted; only a few samples were examined petrographically in detail. Bulk mineralogy of 50samples was determined by X-ray analysis.

Identification of potash feldspar is based on a yellow coating of sodium cobaltinitrite that forms on the potassium feldspars when treated with a concentrated sodium cobaltinitrite solution. One-half of each thin section was stained using the method described by Müller (1967, pp. 165-167). Each sample was exposed to hydrofluoric acid fumes for 15 seconds and then treated with the sodium cobaltinitrite solution for 30 seconds. The modes determined from stained and unstained parts of a thin-section were compared in several test cases. The unstained part of the thin-sections was consistently very low in K-feldspars, less than 5 percent; content on the stained half varied between 5 and 15 percent with occasional values of greater than 20 percent.

The petrography is used, in part, to test for vertical variation of textural parameters in the measured sections. To minimize operator bias, the thin sections were grouped into a pile, mixed, selected one at a time, given a new number and placed in a second pile. Slides were selected one at a time from the second pile and examined for a particular parameter; i.e., composition or grain size. The results of the point count were recorded in a notebook along with the code number, and the code numbers were later related to the original field sample number. Sample numbers were arranged in stratigraphic order, and the different parameters were compared within and between measured sections.

A 300-grain point count was made on the stained half of each thin-section for the compositional analyses. Two-hundred grain-to-grain contacts of the framework fraction were counted per thin-section for the textural study. Contacts between the framework and authigenic clay minerals and matrix were not counted. Recounts were periodically made on samples to check for internal consistency. After the petrography was completed, another recount and re-examination was made on some of the samples that were examined during the early stages of the study.

X-ray diffraction (Cu-radiation) was utilized to determine the bulk composition of argillaceous siltites and argillites. Unoriented bulk samples were prepared by grinding pea-size rock chips to a very fine powder. A slurry was made from the powder, smeared on a clean glass slide and air dried. The samples were run at two degrees per minute to 40 to 50 degrees 2θ. A smooth, saw-cut face (perpendicular to bedding) of the same set of samples was also irradiated using the same settings. The X-ray diffraction patterns are very similar to those of the unoriented slurry samples, both having sharp and distinct peaks even for the clay minerals.

Sedimentary rock classifications are based on the percentages of different detrital minerals and a major problem with the meta-sedimentary rocks is distinguishing authigenic and detrital minerals, in particular the feldspar minerals and clay minerals. Replacement recrystallization and alteration are common in the very fine-grained quartzites, but are extensive in the argillaceous siltites, and the total percent of detrital clay is difficult to determine accurately. For the purpose of a general rock name, Folk's (Folk, 1961) sandstones classification is used, but textural maturity and genesis are not directly applicable.

QUARTZITES

The average composition of sixty-six quartzite samples is 71 percent quartz, 8 percent potassium feldspar, 5 percent soda-lime feldspars, 9 percent clay minerals and traces of carbonate minerals, heavy minerals, opaques and rock fragments. Grain size of the framework fraction ranges from medium to very fine sand, but fine to very fine sand is predominant. These rocks have average compositions of arkosic sandstone (Folk, 1961) and range from a subarkosic sandstone to graywacke in composition (Plate B-1).

The composition of the quartzites and siltites is similar, but modal analyses data differ in the percent of clay and carbonate minerals with the percent of clay and carbonate increasing, the percent of quartz and feldspars decreasing in the finer-grained rocks. The similarity in the composition of quartzites and siltites in the different formations (Table B-1) is shown graphically in Figure B-1.

Quartz and its varieties composite and semicomposite quartz grains, make up the more than 60 percent of the framework fraction, and all quartz grains have undulose extinction. Grain boundaries are predominantly sutured and most thin-sections show evidence of granulation.

Rounded to subangular detrital grains are outlined by minute dust specks that distinguish the optically continuous quartz overgrowths from quartz grains. Detrital polycrystalline grains are scarce. These grains range in size from 248 to 64 microns and are common in samples where recrystallization is not extensive. Quartz grains in the very clean quartzites tend to be clear or contain vacuoles, needle-like inclusions, microlites or have traces of micaceous specks. Vacuoles may be randomly distributed within a grain or arranged in bubble-trains. Crystalline rutile and tourmaline are the identifiable included minerals, although rare. Occurrences of subrounded to rounded detrital heavy minerals included in quartz grains were noted.

Clay minerals occur in trace amounts in the fine grained quartzites and are generally less than 20 microns in size. (Plate B-1). Elongated shreds of muscovite and chlorite may be concentrated along grain boundaries with larger sericitic particles randomly distributed across the grain or they are arranged in straight lines that cross several grains. Progressive stages of the replacement of quartz by sericite can be observed within any given thin-section. Occasional authigenic shreds of muscovite (> 100 microns) oriented subparallel or parallel to bedding cut across several grains in the framework.

Plate B-1. Disseminated magnetite (euhedral crystals) and trace of leucoxene and pyrite in fine to very fine grained quartzite. Sample from Revett formation (Clark Fork measured section). Plane light with green filter; magnification X 80.

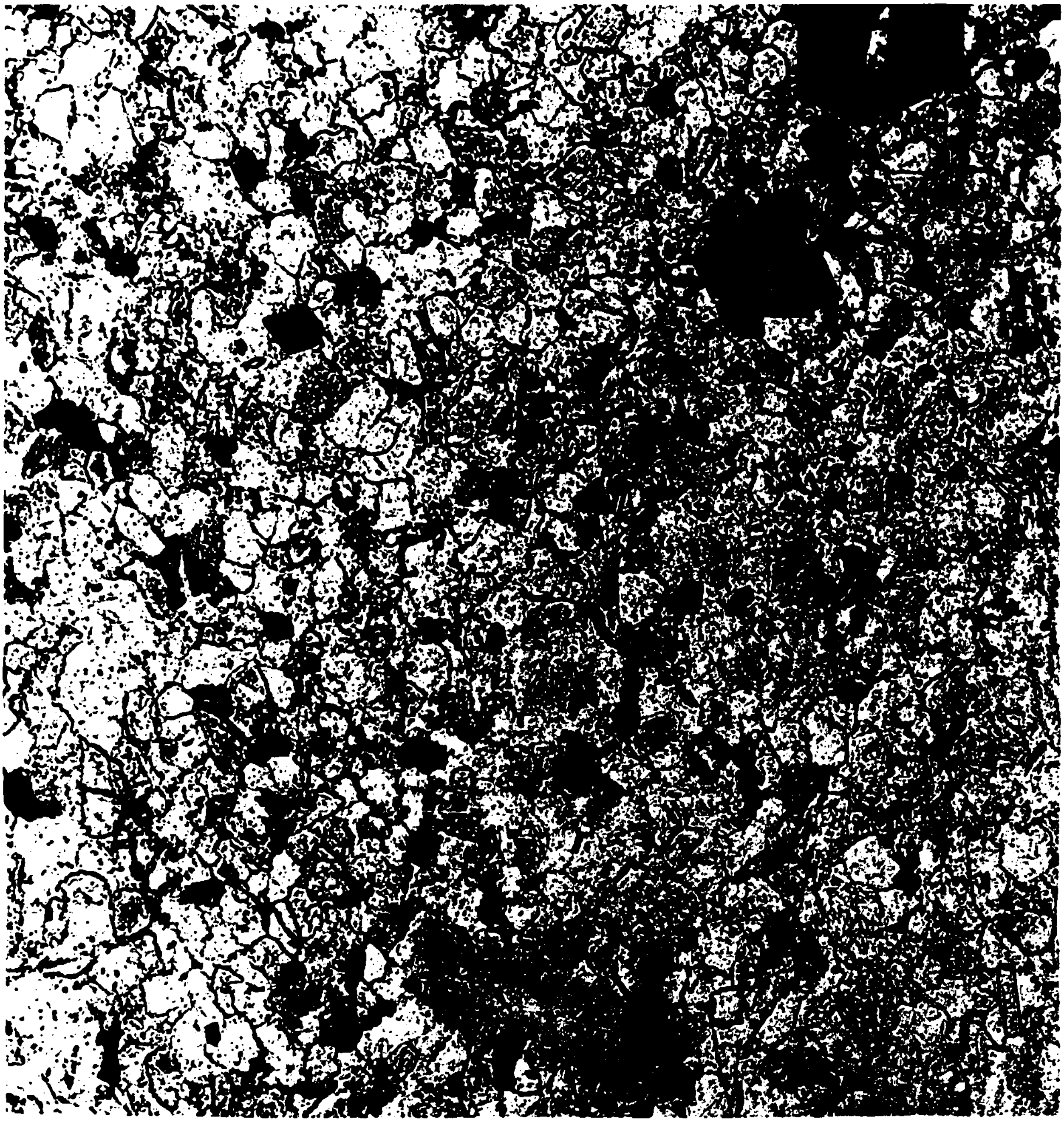
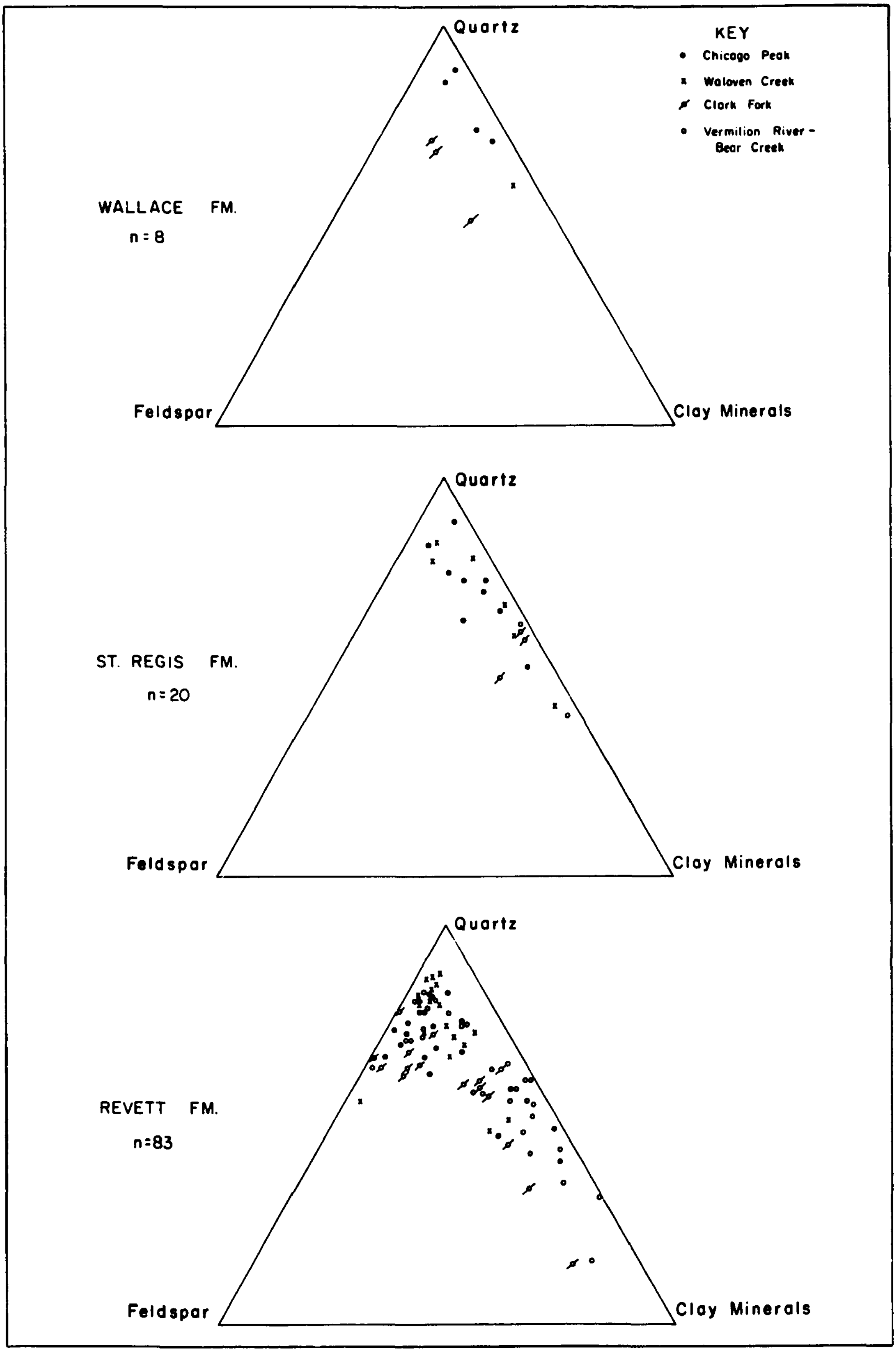


Figure B-1. Plot of the modes of quartzites and siltites from the Revett, St. Regis, and lower Wallace formations on triangular diagrams. Following Folk's sandstone classification, the clean quartzites and siltites are subarkoses: whereas the more argillaceous samples are graywackes.


Quartz
KEY
• Chicago Peak
x Waloven Creek
ø Clark Fork
o Vermilion River - Bear Creek
WALLACE FM.
n=8
Feldspar
Clay Minerals
Quartz
ST. REGIS FM.
n=20
Feldspar
Clay Minerals
Quartz
REVETT FM.
n=83
Feldspar
Clay Minerals

Formation	Rock type	Mineralogy							
		Number of samples	Quartz and varieties	Potassium feldspar	Albite oligoclase	Clay minerals	Carbonate minerals	Rock fragments	Heavy minerals
Wallace	Quartzite	4	66	7	4	12	10	-	t
	Siltite	4	50	5	2	21	21	-	t
St. Regis	Quartzite	9	74	7	8	8	t*	t	t
	Siltite	11	54	5	3	34	t	t	t
Revett	Quartzite	53	43	10	5	8	t	2	t
	Siltite	30	47	7	3	41	t	-	t
Average	Quartzite	66	71	8	5	9	3	t	t
	Siltite	45	50	4	3	32	7	t	t

Table B-1. Average modes in volume percent for siltite and quartzite samples collected from Clark Fork, Chicago Peak, Waloven Creek, and Vermilion River-Bear Creek sections.
Note general uniformity of composition in different formations. Percent clay minerals and carbonate minerals show most variation between rock types, and formations.
Mode based on 300 grain point count.

* Present in two thin sections in about 6 percent by volume.

Total feldspar content averages about 13 percent of the rock and ranges from 4 to 31 percent with rare values greater than 30 percent. Potassium feldspars are generally more abundant than plagioclase feldspars in most samples. Orthoclase and microcline are the principle potassium feldspars, averaging 8 percent of the rock and ranging from about 4 to 18 percent. Polysynthetic twinning according to the Carlsbad, albite and pericline laws is common and useful in identifying feldspars, but untwinned potassium feldspar is predominant and largely authigenic (Kastner, in press).

Plagioclase feldspars average five percent of the rock, and range from about three to 14 percent. Simple polysynthetic twinning is common and many grains show two and three twinning patterns. Perthitic intergrowths of potash and plagioclase feldspars are scarce.

Feldspars show varying degrees of alteration within a sample and between samples and generally the alteration of feldspars increases as the amount of clay in the rock increases. Corresponding decreases in the percentages of plagioclase and potassium feldspars in the finer grained samples suggest that there is little if any preferential replacement between the types of feldspars. Within a given thin-section feldspar grains may be very fresh to nearly completely altered with the alteration products around the edges of the grains and along twinning planes. Alteration products consist largely of muscovite, sericite and minor kaolinite and mixed-layer clays. The existence of kaolinite and mixed-layer clays is based largely on X-ray diffraction.

Original size and shapes of detrital feldspars cannot be determined because of recrystallization. Only one example of a grain of plagioclase with a quartz overgrowth was recorded and its outline was only partly discernible, but appeared to be subrounded. There seems to be little reason to believe that the detrital feldspar differed in range of size or shape from the detrital quartz.

Clay minerals average eight percent of the rock and range from trace amounts to about 20 percent. In order of decreasing abundance these are muscovite (sericite), chlorite, biotite and traces of kaolinite and mixed-layer clays. Only muscovite, chlorite, and biotite are identifiable in thin-section. Clays occur as a part of the matrix, shale pebbles or mud chips (Plate B-2) authigenic products replacing the framework or associated with quartz veinlets.

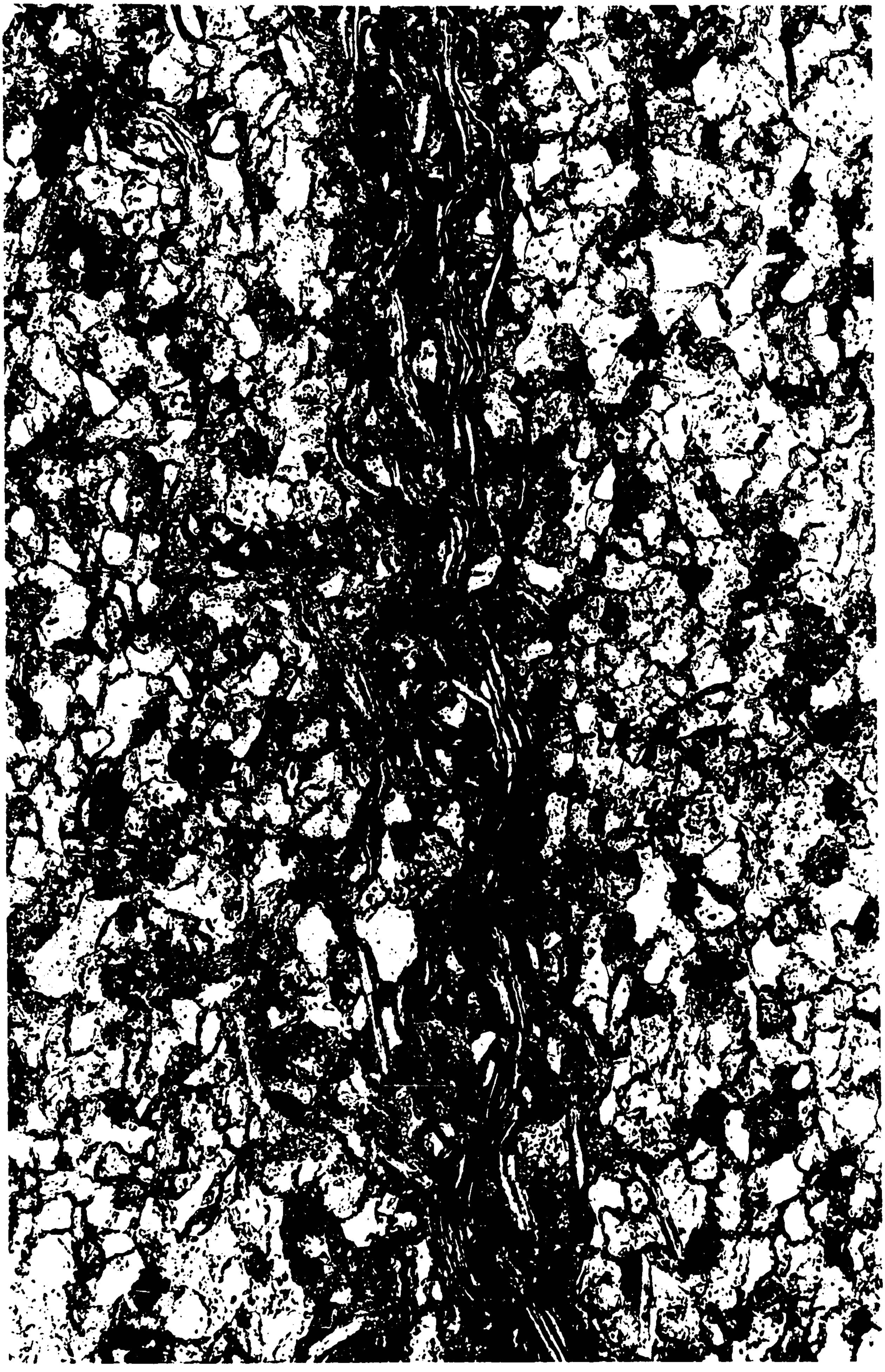
Muscovite, the most abundant clay mineral, is predominantly authigenic. Grain size varies from 8 to 320 microns (very fine to medium sand); its form varies from elongated shreds to subequant grains. A detrital origin is inferred for some grains from elongated shreds that lie parallel to bedding and are deformed about the grains of the framework (Plate B-2), although most of the muscovite commonly occurs as authigenic shreds (> 125 microns) that lie parallel or subparallel to the bedding and cut straight across the framework. A second set of finer grained muscovite and sericite usually lies at some oblique angle, sometimes almost perpendicular to the set of larger clay particles. Sericite is also associated with the matrix of argillaceous rocks and with the alteration of feldspar and quartz grains. The fine-grained authigenic clay very commonly rims quartz and feldspar grains thus obscuring the boundaries.

Chlorite, identified by its greenish pleochroism, anomalous birefringence and micaceous habit, is exclusively authigenic and only locally is it the dominant clay mineral. Grain size ranges from less than 63 to 500 microns. The longer shreds of authigenic chlorite occur within argillaceous laminations and within the framework fraction of the quartzite. This variety varies from green to brown-green and is invariably associated with very fine-grained anhedral magnetite. Habit varies from elongated to subequant shreds or hour-glass shaped. A second variety is subequant to equant in shape and disseminated in and around veinlets or is associated with fractures and faults in the rock and is seldom associated with magnetite. Biotite was observed in trace amounts in a few samples of the Revett quartzite at Chicago Peak and Vermilion River-Bear Creek measured sections. It occurs as elongated shreds and festoon-shaped laths oriented parallel to bedding.

Calcite, dolomite and possibly siderite are irregularly distributed in the quartzites (and siltites) of the Revett, St. Regis and lower Wallace formations ranging from less than one percent in the Revett to about 10 percent in the Wallace; the increase in carbonate content is generally accompanied by a decrease in quartz and feldspar. Ferro-magnesium carbonates are more abundant in the very argillaceous rocks; whereas, calcite is more abundant in the clean siltites and quartzites.

The carbonate minerals occur both as anhedral polycrystalline aggregates and as idiomorphic crystals. Polycrystalline mosaics of calcite are up to several hundred microns across and, in part, replace the framework. Ghosts, the undigested residue of the framework, impart a dusty appearance to the carbonate. Single idiomorphic crystals of the iron magnesium carbonates are about 80 microns in size but the grain size decreases markedly in the direction of the sand-clay or silt-clay boundary. Some of these crystals appear fresh but frequently show some alteration as evidenced by the inner core

Plate B-2. Shreds of chlorite deformed around quartz grains in very fine argillite lamination. Note very fine-grained authigenic chlorite that is replacing the framework. Authigenic magnetite (opaque) is closely associated with the authigenic chlorite. Samples from Revett formation (Clark Fork measured section). Plane light with green filter; magnification X 80.



of highly birefringent carbonate being surrounded by reddish-brown iron oxide. Idiomorphic shapes and replacement of the framework by the carbonate minerals indicate secondary growth and the general lack of interconnecting veinlets and fractures between carbonate-rich units and the low permeability of the carbonate-rich mudstones further support the diagenetic origin.

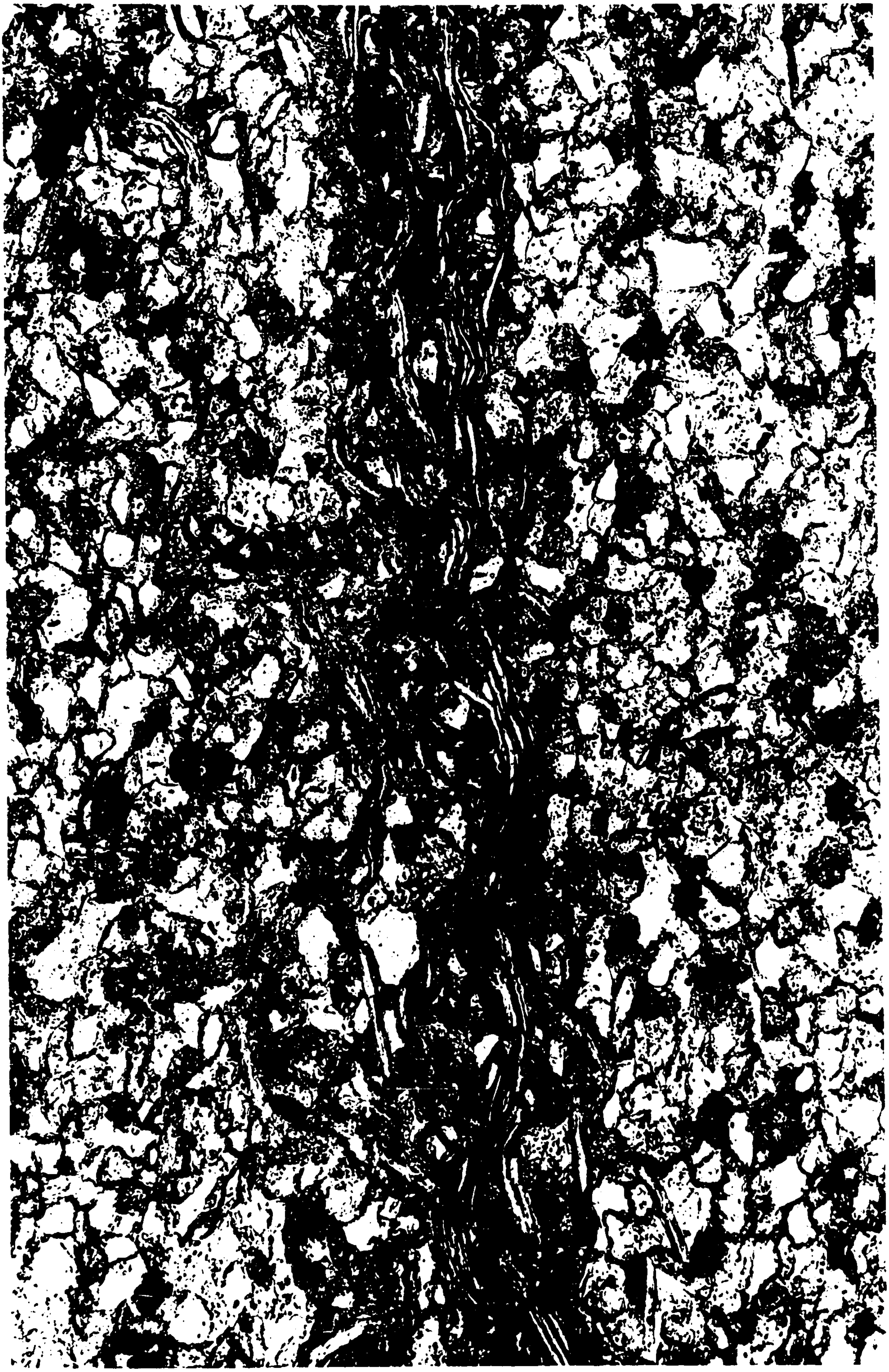
Rounded to subangular zircon, tourmaline, sphene, rutile and possibly garnet make up the heavy mineral suite. Grain size ranges from fine sand to silt (136 to 24 microns). The small grain size and degree of rounding preclude identification of many grains. Larger detrital grains in part retain their crystalline habit which is useful for identification; for example, slightly rounded, diamond-shaped sphene and subangular terminated prismatic tourmaline were observed. A few fine-grained idiomorphic zircon crystals were noted. Heavy minerals are concentrated along bedding planes but sometimes appear to float in the framework of samples where very few heavies were observed.

Rock fragments range from less than a centimeter to several centimeters in diameter and consist exclusively of mud or shale chips (Plate B-3) that are often observed in the outcrop. Mud chips observed in thin-section make up to 20 percent of the rock. Particle shapes may be elongated, rounded or angular chips that generally lie parallel or subparallel to bedding, but in some instances are haphazardly oriented. These fragments occur as a lag at the base of a scour or "float" in the sand and/or silt bed and are probably derived locally from burrowed, and cracked laminae that were torn loose from the substrata by currents. The absence of igneous or metamorphic rock fragments is noteworthy, although one might argue whether rock fragments would occur in such fine-grained sediments or that they may have existed but have been subsequently masked or obliterated by diagenetic processes.

Trace amounts of opaque minerals occur in almost all samples and in rare examples constitute up to five percent of the rock. The common opaque minerals are, in decreasing order of abundance, magnetite, pyrite and illmenite. Grain size range is very fine sand to silt. Shape varies from idiomorphic crystals about 80 microns to small anhedral grains about 35 microns in size. Opaques are found concentrated along bedding planes and disseminated throughout the framework. Very fine-grained anhedral magnetite is usually associated with authigenic chlorite along bedding planes, but the larger idiomorphic grains of magnetite and pyrite are disseminated in the framework. The pyrite is seldom altered, but the magnetite usually exhibits a reddish-brown oxidized rim.

Plate B-3. Sub-angular mud chip elongated parallel to bedding. Sample from St. Regis formation. (Clark Fork measured section). Plane light with green filter; magnification X 40.

Plate B-4. Argillaceous siltite. Sample from St. Regis formation (Clark Fork measured section). Plane light with green filter; magnification X 80.



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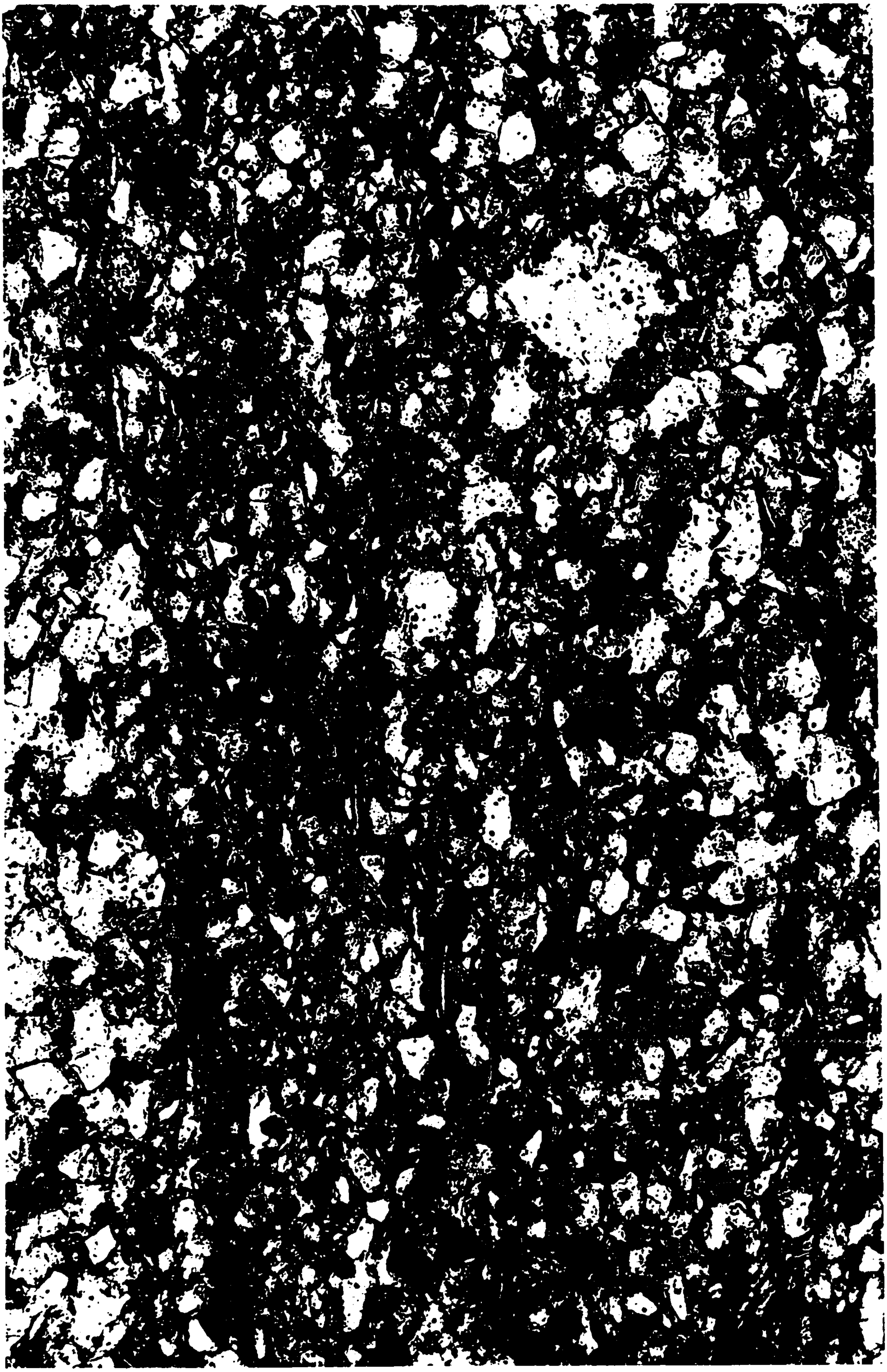


Siltites

The average composition of siltite samples is similar to the average of the quartzites, and it consists of 50 percent quartz, 4 percent potassium feldspar, 3 percent plagioclase feldspar, 32 percent clay minerals, 7 percent carbonate cement and traces of rock fragments and heavy minerals (Table 6). Siltites generally show a higher percentage of clay and carbonate and lower percentages of quartz and feldspar than the quartzites (Plate B-4) The respective minerals of the framework and cement have essentially the same characteristics as described for the quartzites, but generally show a slight decrease in grain size. Grain size of the framework ranges from very fine sand to very fine silt, but is predominantly in the silt range. Granulation, veinlets and fracturing are less conspicuous than in the quartzites, but this may in part be due to the increase in clay which tends to obscure the framework in most samples. These siltites have an average composition of a subgraywacke (Folk, 1961).

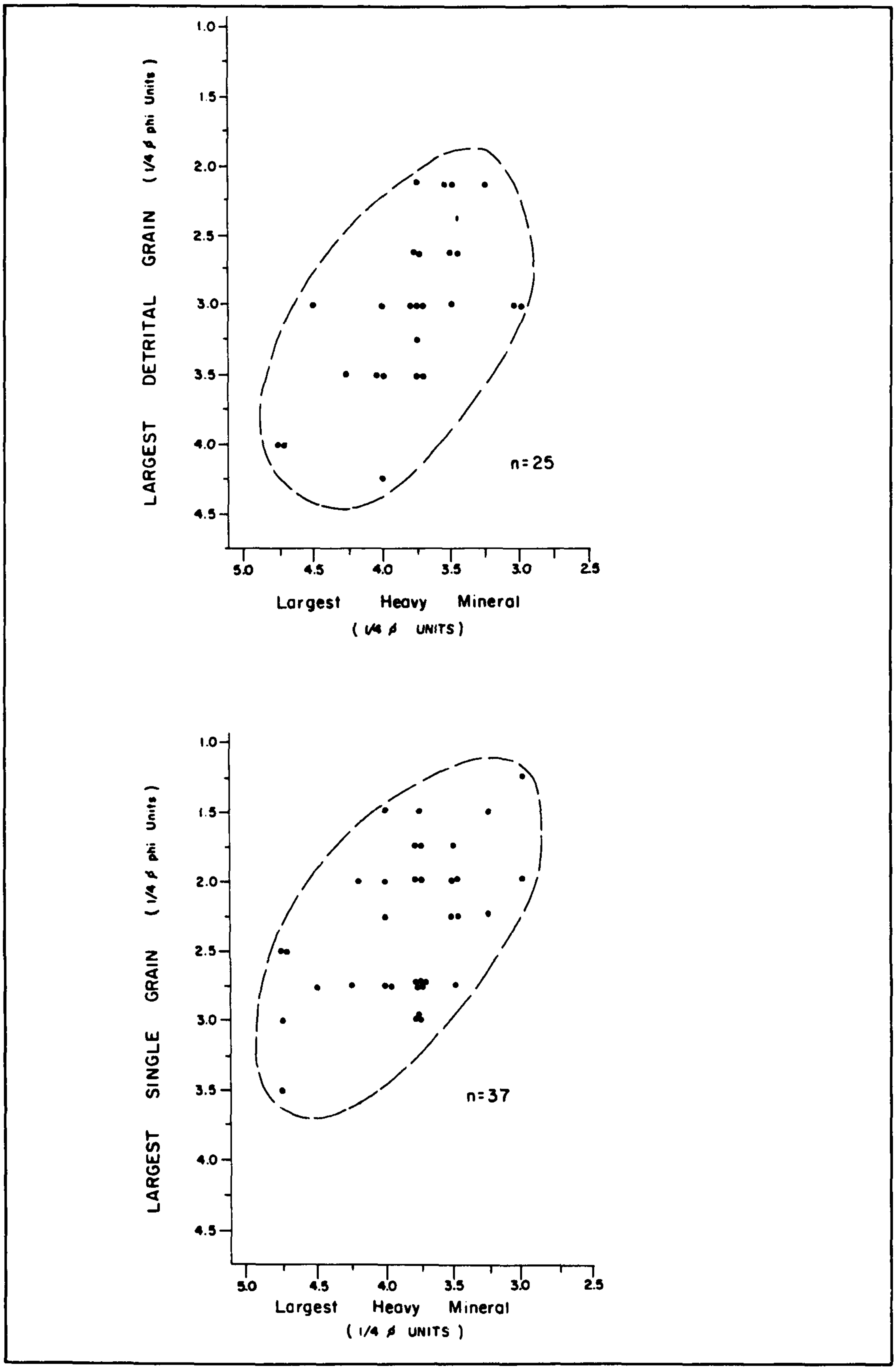
Grain Size

A simple test was devised to determine significant grain size change in the recrystallized samples. The longest axis of the largest heavy mineral, detrital grain, and single sutured grain was measured for each thin-section and grouped in 1/4 phi classes. Separate plots are shown for the largest detrital grain vs largest heavy mineral and largest single sutured grain vs largest heavy mineral (Figure B-2). Similarity in the scatter diagrams suggests that the grain enlargement due to recrystallization is not significant. An initial uniform small grain size, paucity of early cement, and low degree of metamorphism are probably the major reasons for the relatively small increase in grain size.

Type of Grain Contacts

A 200-grain point count of the types of grain contacts (Taylor, 1950) was made on the framework fraction of 112 thin-sections to determine whether the quartzites and siltites show any systematic variation in grain to grain arrangement. Five types of grain boundaries were recognized in the framework fraction; in decreasing order of abundance, these are sutured, curvo-concave, straight, floating and point contacts (Table B-2). Quartzites and siltites show little variation in the percentages of the types of grain contacts. An average quartzite sample shows 69 percent sutured contacts, 23 percent concave, three percent straight, four percent floating grains but rarely has point contacts. A typical siltite has nearly the same proportior

Figure B-2. Estimation of original grain size. Largest heavy mineral grain is plotted against largest single grain (bottom) and largest detrital grain (top) for each thin section. Paucity of overgrowths and similarity in above scatter diagrams suggests minor grain enlargement.


LARGEST DETRITAL GRAIN (1/4 ϕ phi Units)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
n=25
5.0
4.5
4.0
3.5
3.0
2.5
Largest Heavy Mineral
(1/4 ϕ UNITS)
LARGEST SINGLE GRAIN (1/4 ϕ phi Units)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
n=37
5.0
4.5
4.0
3.5
3.0
2.5
Largest Heavy Mineral
(1/4 ϕ UNITS)

Measured Section	Rock Type	Samples	Types of Grain Contacts (Percent)				
			Sutured	Concave	Straight	Point	Floating
Waloven Creek	Quartzite	18	65	25	3	t	7
	Siltite	5	56	36	3	t	5
Clark Fork	Quartzite	9	71	22	2	t	4
	Siltite	6	70	23	1	t	6
Chicago Peak	Quartzite	15	72	23	5	-	-
	Siltite	3	69	27	3	-	-
Average	Quartzite	42	69	23	3	t	4
	Siltite	14	65	28	3	t	4

Table B-2. Types of grain-to-grain boundaries in quartzites and siltites given in percent. Percentages bases on 200 point count.

of the various types of contacts. Comparison of the thin-sections within the respective sections revealed no marked change in types or percentages of types of grain boundaries up section. Thus the increase in carbonate content in the quartzites up section has not influenced changes in the types of grain boundaries. Point counts made parallel and perpendicular to bedding within a thin-section were almost identical and suggest that either the variability within a thin-section is negligible or the technique is not sensitive to subtle changes.

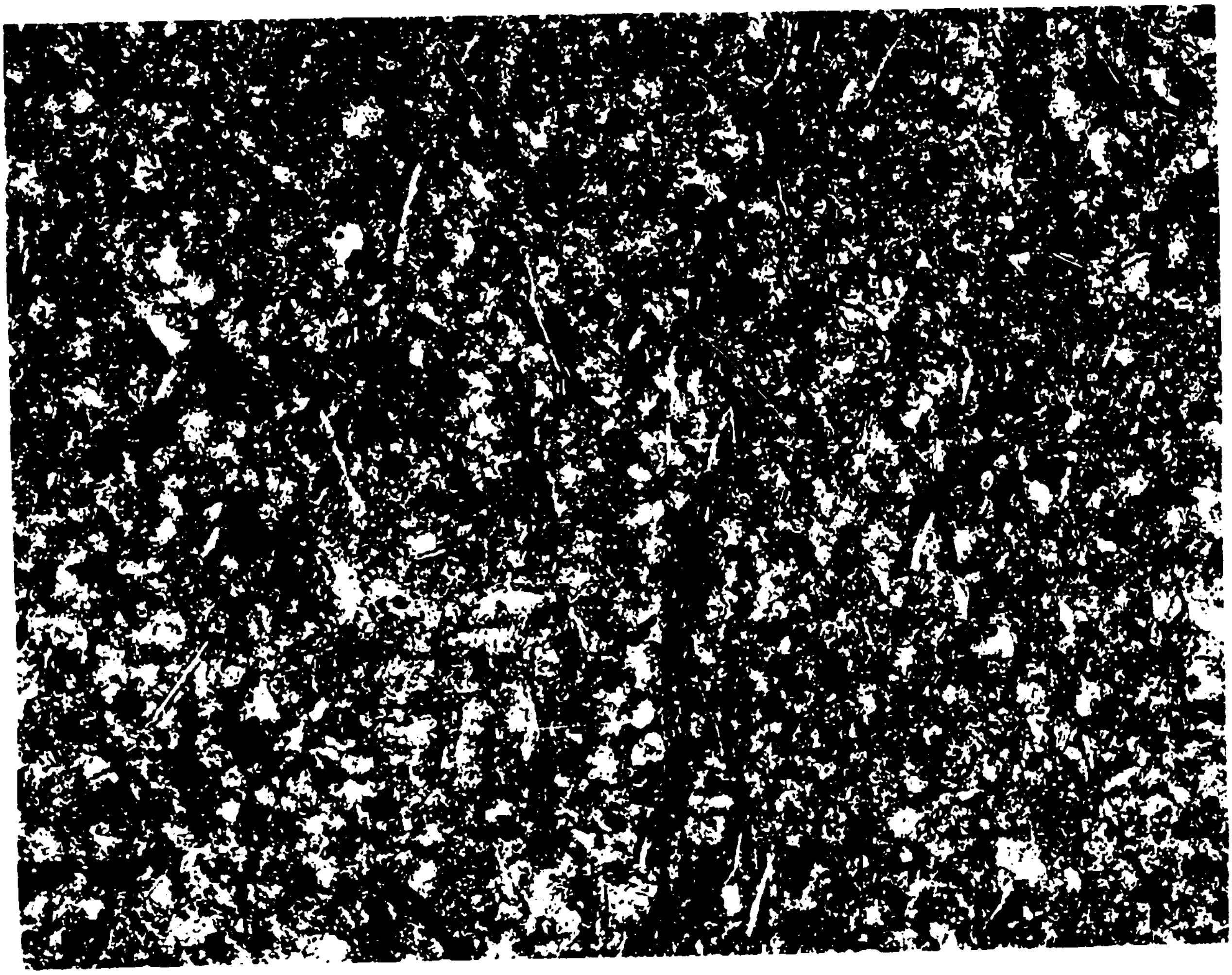
Conspicuous variation in grain arrangements only occurs in rocks from areas of intense deformation where a schistose texture is developed in which the grains of the framework show a distinct preferential elongation. Samples from Chicago Peak, that were collected near a small fault, show more elongated and nearly polygonal grains than the samples from other measured sections. Granulation, micro-fractures, faults and veinlets also increase in abundance in quartzite samples proximal to faults.

Argillites

One hundred and twenty-one thin-sections of the very argillaceous siltites, silty argillites and argillites were examined, although less intensively than the coarser-grained samples. Modal point counts were made on about 12 samples and demonstrates that the composition of the detrital grains is the same as in the siltites and quartzites, but the framework fraction constitutes less than 50 percent of the rock. Quartz, potassium and plagioclase feldspars make up the framework fraction that occurs in discontinuous lenses, very thin laminations or as individual grains floating in clay matrix. Suturing of grain boundaries predominates whenever the detrital grains are concentrated in laminae or lenses. Authigenic mosaics of calcite and individual idiomorphic crystals of carbonate minerals are irregularly distributed within the framework fraction.

The fine matrix of the silty argillites ranges from approximately 50 percent to greater than 80 percent of the total rock (Plate B-5). X-ray diffraction of 35 bulk argillite samples, selected from the vertical suite of rock chips collected at the Clark Fork and Waloven Creek measured sections, demonstrates that the mineralogy of the /matrix of the/ argillites is comparable to that of quartzites and siltites. Green argillites, that occur within the St. Regis and characterize the lower part of the Wallace formation, consist almost exclusively of dolomite and chlorite.

Plate B-5. Argillite. Note fine shreds of muscovite oriented subparallel to bedding. Sample from St. Regis formation. (Clark Fork measured section). Plane light with green filter; magnification X 80.



Replacement of some of the detrital grains by the matrix minerals is evident in most samples. However, determination of the ratio of primary to secondary matrix is impossible. Examination of the textures of approximately 50 silty argillite samples with plane and polarized light indicates that the matrix may be massive, very thinly laminated, or massive with varying amounts of discrete clots of clay. These clots appear rounded to elongated and are randomly distributed within the matrix as single particles or small clusters of particles. The origin of these particles may be one or some combination of the following: (1) sericitization of the quartz and feldspar grains of the framework as suggested by the presence of similar structures that is observable in siltites that are definitely sericitized but less intensely so (2) slightly metamorphozed lithic rock fragments, (3) fecal pellets, as suggested by the burrows in many argillite laminae, and (4) clay floccules that were deposited as the sediment and have been partially recrystallized, and (5) small rip-up mud chips.

The following list briefly summarizes the salient points of the petrography:

1) The mineralogy of the rocks is relatively simple and shows no systematic variation vertically within the stratigraphic section or laterally between measured sections within the study area.

2) The texture of the very fine grained quartzites and siltites shows no systematic variation within the stratigraphic section or between measured sections.

3) Internal redistribution of the original components can partly or wholly explain the dolomitization, sericitization, feldspathization and silicification of the rocks.

4) The roundness of fine to very fine grained quartz grains, heavy mineral grains, and the rare occurrence of well rounded detrital heavy mineral grains within in quartz grains, suggests that the sediments had a very complex (multicyclic) history.

Memo

To: Future workers Date: June 1971

From: S. V. Hrabar

Re: Sedimentology and stratigraphy of the Belt series.

The scoffers said it couldn't be done,

The odds were so great, who wouldn't,

But I tackeled the job that couldn't be done,

But what do you think?

I did it.

VITA

Name: Stephanie Vladimira Hrabar

Date of Birth: March 1, 1943

Place of Birth: Detroit, Michigan

Academic record: Frank Cody High School, Detroit, 1960
B.S., Wayne State University, Detroit, 1964
M.A., Indiana University, Bloomington, 1967.

Societies:
American Association for Advancement of Science
Sigma Xi
Society of Economic Paleontologists and Mineralogists

PUBLICATIONS

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