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Petrology of the Mount Shields Formation (Belt Supergroup) western Montana northern Idaho

David A. Barlow

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PETROLOGY OF THE
MOUNT SHIELDS FORMATION
(BELT SUPERGROUP) WESTERN MONTANA
NORTHERN IDAHO

By
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B.S., West Virginia University, 1981

Presented in partial fulfillment of the requirements for the degree of

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Date
The detrital mineralogy of the Mount Shields Formation is characterized by a moderately sorted, subangular to subrounded fine-grained population (62 to 250 microns) and a poorly sorted, subrounded to well rounded coarse-grained population (25 to 2000 microns). The aerial distribution of grain types reflect source terranes located south, southwest, northeast and north of the Belt basin. The southern terrane contained predominantly granitic rocks and associated igneous injected terranes. Very fine to medium- and coarse-grained chert-bearing quartz sandstone also existed south of the basin. The southwestern terrane contained coarse, chert-bearing quartz sandstone and metaquartzite. Granitic rocks were subordinate. Granitic rocks and associated igneous injected terranes, and coarse, chert-bearing quartz sandstone were exposed northeast of the basin. A very fine to fine-grained chert-bearing quartz sandstone, perhaps the upper Snowslip and lower Shepard, provided grains and rock fragments from the north. Volcanic rock fragments were reworked from the lower Shepard and/or eroded directly from the Purcell lava exposed north of the basin. The composition of the four source terranes remained relatively constant throughout deposition of the sediments which comprise the Mount Shields Formation. Abrupt increase in sandstone content from the Mount Shields I to the Mount Shields II reflect an episode of rapid basin subsidence relative to the surrounding source terranes.

Inferred weathering products include smectite and perhaps hematite and chlorite. Carbonate cements in the lower and upper Mount Shields Formation were precipitated in a subaqueous environment. Diagenetic hematite formed from oxidation of biotite, magnetite and ilmenite. Smectite was converted to illite and chlorite and eventually to 2M illite (200°C to 350°C) providing silica for quartz cement growth. Degredation of potassium feldspar and perhaps biotite supplied the constituents necessary for potassium feldspar precipitation.
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INTRODUCTION

Sedimentologic Setting

The Mount Shields Formation is comprised of sediments which were deposited on alluvial aprons in the Middle Proterozoic Belt basin of western Montana, northern Idaho, eastern Washington, and British Columbia (Figs. 1 and 2). These sediments are part of an enormously thick package of conglomerate and coarse, crossbedded quartzite, red, green and black argillite, and dolomite which were deposited in braided stream channels, on sheet wash fans, subaerial and subaqueous mudflats, and shallow water carbonate banks respectively. The Mount Shields Formation consists of red argillite and fine, horizontally laminated quartzite with lesser thicknesses of crossbedded quartzite.

Near Alberton, Montana, the Belt Supergroup reaches a thickness over 20 kilometers (Harrison, 1972). The great thickness of the Belt Supergroup sediments has been attributed to their deposition on slowly sinking tectonic blocks, bounded by high-angle faults (Winston et al., 1982; Harrison et al., 1974). The thickness of these sediments, and more specifically of the Mount Shields sediments, varies regionally and is a reflection of differential subsidence of these tectonic blocks.

Slover (1982) analyzed in detail the fining upward sequences in the lower part of the Mount Shields Formation and proposed that they result from cyclic alternation of abrupt rainy periods followed by gradual increased in aridity. Her thesis requires that the Belt basin was internally drained. Slover's findings support a similar conclusion proposed by Grotzinger (1981).
Figure 1. Index map outlining the Belt Basin and locating measured sections (modified after Harrison, 1972).
Figure 2. Block diagram showing the facies and corresponding rock types of Belt alluvial fans (Winston, 1978).
Stratigraphic Setting

Winston et al. (1982) have constructed stratigraphic columns for the different tectonic blocks they have proposed for the Belt basin (Fig. 3). These structural blocks are discussed more fully in the following section. The importance of these stratigraphic relationships and their tectonic implications will become evident to the reader when the results of this study are discussed and interpreted.

The Mount Shields Formation was subdivided into four units in the Jocko Mountains, Montana. Winston and Jacob (1977) have informally named them: 1) Mount Shields I (interbedded fine-grained feldspathic quartzite and red argillite), 2) Mount Shields II (fine- and medium-grained feldspathic quartzite), 3) Mount Shields III (red argillite and abundant salt casts), and 4) Mount Shields IV (green argillite). The Mount Shields Formation is correlative with the Striped Peak Formation of the Coeur d'Alene district in northern Idaho (Fig. 3). At Clark Fork, Idaho (Harrison and Jobin, 1963) the Mount Shields I and II are correlative with the Striped Peak I; the Mount Shields III correlates with part of the Striped Peak II and III (Winston, 1977). In the northern, eastern and western sections of the Mount Shields Formation a stromatolite bed or calcareous beds mark the base of the Mount Shields III, and form an important stratigraphic marker. Extending below the stromatolite bed and the calcareous beds is a coarse-grained interval of the Mount Shields II ranging from a few centimeters thick at the northwestern sections to several meters thick in the south. These coarse grained beds occur in all sections of this
Figure 3. Stratigraphic sections of the Belt Supergroup for each of the proposed tectonic blocks of the Belt basin (Winston et al., 1982).
study except at Clark Fork, Idaho where the grains are medium. The significance of this course interval will be discussed in a following section.

**Structural Setting**

As mentioned above, the Belt Supergroup sediments were deposited in a block faulted basin. Winston et al. (1982) have proposed three zones of high-angle block faults which they call lines. These lines are in addition to the previously described east-west trending Perry line which bounds the south edge of the Belt basin and the north edge of the Dillon block (Fig. 4). The Perry line and the nearly east-west trending Greenhorn and Jocko lines are intersected on the east by the northwest-southeast trending Townsend line which marks the eastern boundary of the Deer Lodge, Ovando, and Charlo blocks, and the western end of the Helena Embayment (Fig. 4). Winston et al. (1982) have proposed that the western boundary of these blocks be marked by a western thrust belt. Harrison et al. (1972) have proposed that the Hope fault (Clark Fork, Idaho) coincides with a Proterozoic fault zone, and McMannis (1963) studied the Willow Creek Precambrian fault which lies along the Perry line.

The tectonic blocks proposed by Winston et al. (1982) not only controlled the structure of the Belt basin but may have acted as buttresses and ramps for Late Cretaceous thrusting. Winston et al. (1982), as well as other geologists (Harrison et al., 1974) speculate that the emplacement of other structures, such as the Idaho and Boulder
Figure 4. Proposed Precambrian tectonic blocks of western Montana and northern Idaho (Winston et al., 1982).
Figure 5. The spatial relationships of the nine measured sections with the major thrust faults of western Montana. The arrows indicate the direction of the original locations of these sections (modified after Winston et al. 1982).
batholiths and Late Cretaceous extensional faults, was controlled by inhomogeneities and faults in the Precambrian basement.

Figure 5 shows the locations of the nine measured sections and their relationships with some of the major thrust faults in the region. The arrows extending west from each section indicate the direction but not necessarily the distance to their original location. The present east-west relationships of the measured sections are the same as the original relationships that is, the Clark Fork section is the furthest west today and was probably the western-most section prior to thrusting. The original north-south relationships are also the same as today. The mineralogical and textural trends presented in this study are therefore valid for interpretation of source terrane locations in their relation to the measured sections.

Purpose of Study

Previous workers (Fenton and Fenton, 1937; Ross, 1963; Harrison, 1972; and others) have proposed several source terranes for the sediments of the Belt Supergroup (including the Mount Shields Formation) on the basis of regional facies relationships. One source area is northeast of the basin, another is south or southwest of the basin. These workers, however, have not systematically analyzed the mineralogy and textures in the Belt rocks for further evidence of source rock locations and compositions. Harrison and Grimes (1970) examined and mineralogy and geochemistry of the Belt Supergroup but only sampled the rocks in the Mission Mountains, Montana and Pend
Oreille, Idaho. This thesis is a systematic study of the mineralogy and textures of the lower part of the Mount Shields Formation throughout most of the Belt basin and will therefore propose solutions to several interesting questions not necessarily answered by previous workers. Some of these questions are:

1. Where were the source terranes for the Mount Shields Formation sediments?

2. Did these source rocks have similar or different compositions and textures?

3. Was there a significant change in source terranes during deposition of the Mount Shields sediments?

4. What do the mineralogical and textural trends in the Mount Shields Formation imply about the tectonic history during deposition of these sediments?

The diagenetic and low grade metamorphic features of the Mount Shields Formation are also examined in this study to understand better the alteration processes which have affected these rocks.

The Mount Shields Formation was chosen for this study because it is well exposed throughout the basin, it is only slightly metamorphosed, and the sand-sized grains lend themselves to examination under the petrographic microscope.
Methods of Study

Stratigraphic sections of the Mount Shields Formation, three measured by Winston (personal communication), one measured by McGill and Sommers (1967), two measured by Slover (1982), and three measured by myself, were representatively sampled every 20 to 50 feet; approximately 130 samples were collected. The nine measured sections are: Rock Creek (includes Flint Creek), Willow Creek, Morrell Mountain, Prickly Pear, Wood Creek, West Glacier, Kootenai Falls, and Clark Fork (Fig. 1).

Thin sections of the samples collected were stained with sodium cobaltinitrite for potassium feldspar indentification, and examined under a petrographic microscope to characterize rock compositions and textures. Sample grain sizes and percentages were visually estimated in thin section, and the histogram in Appendix III is based on grain size range frequencies. Diagenetic features, such as grain overgrowths, were also studied under the petrographic microscope.

X-ray diffraction methods were used to identify the general clay mineralogy, including illite polytypes. The proportion of 2M illite polytype to total illite was estimated using Velde and Hower's (1963) method. The relative intensities of the 3.74A and the 2.58A illite peaks were determined from randomly oriented samples using the method described by Schultz (1964).
Previous and Related Work

There are no previous petrographic studies on the Mount Shields Formation. Winston (personal communication) has examined thin sections of the Mount Shields sandstone but has not systematically analyzed them. Hernden (personal communication) is presently studying the petrology of the Revett Formation which is similar depositionally to the Mount Shields Formation but has undergone greater diagenetic and metamorphic alteration.

Burial metamorphism in the Belt Supergroup has been studied by Maxwell and Hower (1967) using illite polytypes. They collected samples ranging from the lower Belt to the upper Missoula Group from sections in the Little Belt Mountains and Glacier Park, Montana and at Clark Fork, Idaho. Eslinger and Savin (1973) also studied burial metamorphism of Belt rocks at Glacier Park and concluded from their oxygen isotope studies that metamorphic grade increases down section, and confirmed that illite polytypes can be used as a measure of geothermal grade in Belt rocks. Eslinger and Sellars (1981) examined evidence for conversion of illite from smectite during burial metamorphism of the Belt Supergroup at Clark Fork, Idaho. These studies provide important mineralogic and chemical data, and significant diagenetic interpretations which support the results and interpretations given in this paper for the diagenetic and low grade metamorphic processes in the Mount Shields Formation.
MINERALOGY OF DETRITAL GRAINS

The following grain descriptions apply to the entire Mount Shields Formation except where specified. Grain percentages are tabulated in Appendix I, and Appendix II gives statistical support for some of the grain distribution discussed.

Granite Fragments

Description. Granite fragments in the Mount Shields Formation occur in poorly sorted beds of the coarse-grained population (greater than 250 microns; Appendix III) (Fig. 6a). These fragments range from 350 microns (medium sand) to 2000 microns (very coarse sand), and consist of grains 125 to 1000 microns in diameter (fine- to medium-grained granite). A few pebbles as large as 5000 and 9000 microns with 2000 to 4000 micron (medium granite) sized grains occur at Rock Creek. The maximum size and the angularity of the granite clasts at approximately the same stratigraphic level (top of the Mount Shields II) decrease in a general northward direction from Rock Creek (9000 microns; subrounded), Willow Creek (2000 microns; subrounded) and Prickly Pear (2000 microns; rounded) to Morreell Mountain (710 microns; round to well rounded) and Wood Creek (1410 microns; round to well rounded). Although the fine to medium granite fragments at West Glacier are also smaller (710 microns) than those in the south they are equally angular (subrounded to rounded) as the southern granite fragments. Granite fragments are most abundant (more than one percent) at Prickly Pear, Wood Creek and Rock Creek, and less common (less than
Figure 6. Partly sericitized granite fragment from Rock Creek (35X) (K-feldspar stained yellow) (a). Quartz sandstone fragment from the upper Mount Shields II at Prickly Pear (42X) (b).
one percent) at all other sections except Kootenai Falls and Clark Fork where these grains are absent.

Clear quartz occurs in each granite fragment. These quartz grains have straight extinction. Approximately 75 percent of the granite clasts contain orthoclase. At the southern localities (Rock Creek, Willow Creek, Prickly Pear) granite grains containing sericitized orthoclase are commonly mixed with those which have fresh orthoclase; the orthoclase in granite fragments at other sections is mostly sericitized. Five percent or less of the granite clasts contain fresh microcline. About 10 percent of the granite grains in the Mount Shields Formation contain microperthite; they occur primarily at Rock Creek and Willow Creek. Fresh and sericitized antiperthite occur only at Willow Creek. Twinned plagioclase (albite-oligoclase) occurs in some granite clasts at Rock Creek (approximately one percent), and is sericitized. Biotite flakes in the granite casts are fresh and occur in about 3 to 5 percent of the granite fragments (only at Rock Creek and Prickly Pear). One granite grain at Willow Creek contains a clear, brown and green zoned tourmaline crystal. These zones parallel the c-axis of the crystal. Green tourmaline also occurs in other granite fragments at Willow Creek. Two granite clasts at Rock Creek have muscovite flakes and one grain has zircon.

Interpretation. Fine- and medium-grained granite supplied the granite fragments to the Mount Shields Formation. The decrease in size and angularity of the grains to the north from Rock Creek, Willow Creek and Prickly Pear suggests that they were transported from a source
terrane in the south. Another granitic source in the northeast may be implied by the subrounded to rounded, coarse granite fragments at West Glacier.

Antiperthite is common at Willow Creek but absent at West Glacier, thereby implying that a granitic source nearby Willow Creek may have been more sodic than the northeastern granite which supplied detritus to the West Glacier area. Sericitic alteration probably resulted from burial metamorphism.

**Sandstone Rock Fragments**

**Description.** Fine- to very coarse grained (125 to 2000 microns) sandstone rock fragments in the Mount Shields Formation are subrounded to rounded, and contain moderately sorted round grains of very fine to fine-grained (62 to 250 microns) or fine to medium (177 to 350 microns) (only at Rock Creek) quartz sand cemented in clear quartz with straight extinction (Fig. 6b). One fragment contains a recycled quartz grain (doubly overgrown). Chert and polygonized quartz occur in approximately 20 percent of the sandstone clasts and one grain at Rock Creek contains orthoclase.

Sandstone fragments occur in moderately sorted beds of the fine-grained population (less than 250 microns; Appendix III) at Morrell Mountain and Kootenai Falls, and in coarse-grained beds at Prickly Pear, Morrell Mountain, West Glacier and Kootenai Falls. Sandstone clasts are absent at Clark Fork and Wood Creek. Sandstone clasts are most abundant in the coarse-grained population at Kootenai Falls and West Glacier (0.4 percent), and less common at Rock Creek.
(0.2 percent), Willow Creek (less than 0.1 percent), and Prickly Pear and Morrell Mountain (0.1 percent) (Appendix I). Sandstone fragments make up 0.1 percent and less than 0.1 percent of the fine-grained population at Kootenai Falls and Morrell Mountain respectively.

**Interpretation.** The sandstone fragments in the Mount Shields Formation were derived from a very fine to fine-grained and fine- to medium-grained sandstone, probably a unit lower in the Belt Supergroup such as the lower part of the Shepard Formation. In addition to quartz, this sandstone contained small amounts of chert, polygonized quartz, and orthoclase. This sandstone may have been a more important source of sediment to the Kootenai Falls and West Glacier localities than to the other localities. Sediment from sandstone exposed in the northern end of the basin could have been transported southeast to West Glacier and southwest to Kootenai Falls. Sandstone in the southwest probably shed fragments and grains northeastward.

**Quartzite Fragments**

**Description.** Quartzite fragments are distinguished from sandstone fragments by the undulatory extinction and sutured grain boundaries of the quartz grains which comprise these fragments; these quartz grains are very fine to coarse sand (88 to 1410 microns) (Fig. 7a). Quartzite fragments in the Mount Shields Formation are subrounded to rounded, approximately 500 to 2000 microns in diameter, and are only present at Prickly Pear, Willow Creek and Rock Creek. Quartzite grains are most common at Willow Creek (0.8 percent) and less abundant at Prickly Pear.
Figure 7. Quartzite fragment from Willow Creek (55X) (a). Broken round quartz grain from Flint Creek (35X) (b).
(0.6 percent) to the northeast, and Rock Creek (0.4 percent) in the south. Appendix II shows that the abundance of quartzite fragments is statistically higher at Willow Creek.

**Interpretation.** A metamorphic source terrane in the southwest provided the quartzite fragments to the sediments comprising the Mount Shields Formation. The greater abundance of these fragments at Willow Creek might imply that their source rock was closest to this location. Sediment from this source could have therefore been transported southward to Rock Creek and northeast to Prickly Pear.

**Quartz**

**Description.** Thin section examination of the Mount Shields Formation reveals two distinct populations of quartz, a moderately sorted fine-grained population (62 to 250 microns) and a poorly sorted coarse-grained population (250 to 2000 microns). The characteristics of the two modes are discussed below.

Quartz is evenly distributed throughout the fine-grained population. Approximately 53 percent of the detrital grains in the fine-grained population at Kootenai Falls, Prickly Pear, West Glacier, and Wood Creek is quartz; Clark Fork contains a little less quartz (48.6 percent) and Morrell Mountain slightly more (55.6 percent). All quartz grains in this population are subangular to angular, clear, and have straight extinction. Many grains have small overgrowths; some grains appear doubly overgrown. Polygonized quartz occurs at all sections and is included in the percentages given for quartz in Appendix I.
Quartz is not evenly distributed in the coarse-grained population. It is most abundant at Wood Creek (62.2 percent), Willow Creek (57.5 percent), and Rock Creek (58.7 percent). Quartz at other locations is less common and averages 51.4 percent. Appendix II shows that the greater abundance of quartz at Wood Creek, Willow Creek and Rock Creek is statistically significant. Quartz in the coarse-grained population is subrounded to well rounded, clear, and has straight or slightly undulatory extinction. Broken round grains, and large syntaxial overgrowths, some double or abraded, are also common (Figs. 7b, 8a, b). One quartz grain at Clark Fork has numerous bubble trains, and a fragment of composite, vein quartz occurs at Wood Creek.

Interpretation. Because the quartz in the granite fragments is clear and has straight extinction, the quartz in the fine-grained population which has the same characteristics was probably derived from erosion of the same granitic source rocks. The even distribution, and the uniform size and shape of these grains indicate that they were deposited evenly throughout the basin. The uniform abundance of fine-grained quartz also implies that the southern granite and the northeastern granite had similar quartz contents. The fine quartz grains with double overgrowths were clearly eroded from a sandstone, most likely the same sandstone that provided the sandstone fragments. Some polygonized grains may have also been eroded from this sandstone; others were polygonized after deposition, probably during compaction.

The high degree of rounding, and the occurrence of abraded and double overgrowths and broken round grains is convincing evidence that the coarse, common quartz grains were eroded from a sandstone coarser
Figure 8. Double quartz overgrowth from Prickly Pear (55X) (a). Reworked quartz overgrowth from West Glacier (143X) (b).
than the sandstone which provided the fine-grained population. The relatively high percentages of coarse quartz at Wood Creek, and Willow Creek and Rock Creek suggests that the coarse-grained sandstone was exposed nearby these sections (i.e. in the east and the south). Coarse sandstone was probably a particularly important source of coarse quartz at Wood Creek. Less rounded coarse quartz resembles that in the coarse-grained granite fragments and was probably derived from the fine- to medium-grained granitic source rocks south and northeast of the Belt basin. The composite, vein quartz fragment and possibly the quartz grain with bubble trains were eroded from a hydrothermal vein (Krynine, 1946a) most likely in the northeastern granitic terrane.

Orthoclase

Description. There are two populations of orthoclase, a moderately sorted fine-grained population (62 to 250 microns) with a mode at 88 to 125 microns and a poorly sorted coarse-grained population (250 to 2000 microns) with a mode at 710 to 1000 microns (Appendix IV).

In the fine-grained population orthoclase is most abundant at Clark Fork (10.4 percent) and least common at Kootenai Falls (6.8 percent). The abundance of fine-grained orthoclase at the other sections is within one percent of the overall average of 8.6 percent. Specific percentages are given in Appendix I. Very fine and fine orthoclase is subangular to angular and is fresh or altered to sericite. Fresh syntaxial overgrowths surrounding fresh and altered detrital orthoclase occur in many samples. A few orthoclase grains at
Kootenai Falls appear to have double overgrowths. Although the stratigraphic and aerial distribution of the very fine and fine-grained orthoclase is relatively uniform, the percentages of altered (sericitized) and fresh orthoclase vary inversely. Appendix II shows orthoclase is most altered (4.0 percent) at Kootenai Falls, Prickly Pear, and Morrell Mountain and freshest (8.8 percent) at Clark Fork, West Glacier and Wood Creek.

In the coarse-grained population orthoclase is subrounded to well rounded and averages 6.5 percent (Appendix II). The percentage of coarse orthoclase at Wood Creek (4.2 percent) varies farthest from this average. Orthoclase is coarsest at Rock Creek (2000+ microns), Willow Creek (2000 microns), Prickly Pear (2000 microns), Wood Creek (1410 microns), and West Glacier (1000 microns) and finer (710 microns) at Morrell Mountain, Kootenai Falls, and Clark Fork. Coarse orthoclase is fresh at Rock Creek, Wood Creek, West Glacier, and Clark Fork but is more altered at Willow Creek, Prickly Pear, Morrell Mountain and Kootenai Falls (Fig. 9a).

Interpretation. The percentage distribution and texture of the very fine and fine-grained orthoclase does not indicate source terrane locations, however, the granitic source rocks in the south and northeast are likely sources for most of this orthoclase. Doubly overgrown orthoclase at Kootenai Falls is evidence that some orthoclase was eroded from the sandstone source possibly in the north. The distribution of sericitized orthoclase probably is not a reflection of weathering or depositional processes but was probably produced by
Figure 9. Sericitized (left) and fresh, stained orthoclase (right) from Rock Creek (55X) (a). Fresh biotite flake sampled at Clark Fork (570X) (b).
differing diagenetic processes discussed in the chapter entitled Weathering and Diagenesis.

Orthoclase in the coarse-grained population bears evidence of source rocks in the south and northeast. The coarser orthoclase at Rock Creek, Willow Creek and Prickly Pear imply a southern source terrane. Orthoclase is less common in the coarse population than in the fine population because quartz from the coarse-grained sandstone source rock has "diluted" the population of orthoclase. Coarse orthoclase is least abundant at Wood Creek because this is where coarse quartz derived from the sandstone source is most common. Also, some orthoclase in the coarse population is in granite fragments and included in the percentages given for these fragments. The distribution of sericitized coarse orthoclase is similar to that of fine orthoclase. Coarse orthoclase has therefore undergone similar diagenetic alteration.

Microcline

Description. Microcline occurs in beds of all grain sizes (62 to 2000 microns). These grains are subangular to angular in the very fine and fine-grained rocks, and subrounded to rounded in the coarse and very coarse rocks. Appendix II shows that microcline is statistically more abundant (1.4 percent) at Prickly Pear and Rock Creek than at Clark Fork, Kootenai Falls, West Glacier, Wood Creek, Morrell Mountain and Willow Creek where only 0.6 percent of the detrital grains are microcline; specific percentages are tabulated in Appendix I.
Altered (sericitized) microcline occurs at all localities but is less common than altered orthoclase. Overgrowths are not common; they are small, not twinned and some at Prickly Pear are more altered than the grains.

Interpretation. A southeastern source of microcline would account for the relatively high abundance of this mineral at Rock Creek and Prickly Pear, and the smaller amount of microcline at Willow Creek. Granite fragments containing microcline are good evidence that the microcline grains in the Mount Shields Formation were eroded from southern (southeastern?), and probably northeastern granitic source rocks. Most sericitic alteration of the microcline probably resulted from burial metamorphism. Microcline is less altered than orthoclase because microcline is more stable under weathering and diagenetic conditions than orthoclase. Microcline overgrowths are more altered than detrital microcline probably because the overgrowths have monoclinic crystal symmetry and are therefore less stable (Baskin, 1956; Goldsmith, 1953).

Microperthite

Description. The abundance of microperthite is uniform within individual measured sections. These grains are very fine to very coarse sand (62 to 2000 microns), and subangular to rounded. The basin-wide distribution of microperthite is not uniform. Rock Creek, Willow Creek, Prickly Pear and Morrell Mountain contain an average amount of microperthite (1.2 percent) statistically greater than the
average percentage of microperthite (0.8 percent) at Wood Creek, West Glacier, Kootenai Falls and Clark Fork (Appendices I and II). The sodic phases of feldspar occur as "blebs" in orthoclase and less commonly in microcline. Three samples at Willow Creek contain approximately one percent antiperthite. A few grains with symplektitic texture also occur in these rocks. Overgrowths are absent and most grains are sericitized, especially the albite intergrowths.

Interpretation. Microperthite and antiperthite in granite fragments at Rock Creek and Willow Creek, and the greater abundance of these minerals at the southern-most sections suggest that the southern granite may have been more sodic than the other granitic sources. Microperthite and antiperthite were probably replaced by sericite during high grade diagenesis or low grade metamorphism.

Plagioclase

Description. The table in Appendix I shows that plagioclase (albite-oligoclase) is most common at Rock Creek (1.0 percent), comprises less than one percent of the grains at Willow Creek, Prickly Pear, Morrell Mountain, Wood Creek and West Glacier, and less than one tenth of one percent at Clark Fork, and is absent at Kootenai Falls. Harrison and Campbell (1963), however, report 10 percent or more albite-oligoclase in the Striped Peak Formation at Clark Fork, Idaho. The reason for this discrepancy is not certain. Plagioclase grains are equally abundant in the fine-grained and the coarse-grained beds, range from very fine to coarse-grained (approximately 62 to 1000 microns),
and are subangular to subrounded. All grains are twinned, not overgrown, and most are slightly to highly sericitized.

**Interpretation.** Plagioclase-bearing granite fragments at Rock Creek certainly indicate that the southern granitic source provided plagioclase to the Belt basin. Plagioclase at West Glacier and perhaps Wood Creek was eroded from the northeastern granite. The paucity of plagioclase grains at Clark Fork and their absence at Kootenai Falls is the result of prolonged transport and removal of these grains by weathering. Sericitic alteration of plagioclase is the result of burial metamorphism.

**Muscovite**

**Description.** Muscovite is ubiquitous throughout the Mount Shields Formation. The average length of these muscovite flakes ranges from approximately 125 microns in the very fine and fine-grained beds to 1000 microns in the coarse and very coarse beds. Notice from Appendix I that the distribution of this mineral is relatively uniform from section to section. Muscovite comprises 0.9 percent of the detrital grains in these rocks. The muscovite grains are not visibly altered.

**Interpretation.** The even distribution of muscovite does not reflect source terrane directions, however, the occurrence of muscovite in granite fragments at Rock Creek indicates that at least some of the muscovite grains were eroded from the southern granite. The northeastern granite most likely contained muscovite and is another probable source for these grains. The lack of alteration of the musco-
vite is not surprising considering its chemical stability under weathering and diagenetic conditions.

**Biotite**

**Description.** Less than 0.5 percent of the detrital grains in the Mount Shields Formation are biotite. These grains are commonly aligned subparallel to bedding and are approximately 250 to 500 microns long. Many biotite grains are crushed between other detrital grains. Biotite is equally abundant in beds of all grain sizes. Appendix I shows that all sections except Willow Creek contain this mineral. Most biotite flakes are oxidized to hematite but the Rock Creek, Kootenai Falls and Clark Fork sections contain some fresh biotite (Fig. 9b).

**Interpretation.** Biotite flakes oriented subparallel to bedding, and crushed between other grains are definitive evidence that the biotite in the samples collected is detrital. Considering that granite fragments at Rock Creek and Prickly Pear contain biotite, the southern granite is a likely source for the biotite in the southern part of the basin. The northeastern granite probably supplied biotite to the Wood Creek and perhaps the Kootenai Falls and Clark Fork sections. Absence of biotite at Willow Creek may imply that the grains at this section were derived from a source separate from that which shed grains into the Rock Creek area. Biotite oxidation is discussed in the chapter entitled *Weathering and Diagenesis.*
**Chlorite**

**Description.** Detrital chlorite in the Mount Shields Formation is commonly associated with biotite and has a similar distribution (Appendix I). Chlorite comprises less than 0.5 percent of the detrital grains in these rocks and is absent at Willow Creek. Chlorite flakes are approximately the same length as the biotite flakes (250 to 500 microns). They are clean and have light to medium green pleochroism.

**Interpretation.** The association of detrital chlorite with biotite, and their similar distribution and grain size may imply that they came from the same source terranes. Chlorite is a common alteration product of ferromagnesium minerals such as biotite, therefore, some of the biotite in the granitic source rocks may have been altered to chlorite before erosion and transport. Low grade metamorphic rocks are other possible sources of chlorite.

**Chert**

**Description.** Chert is most common at Willow Creek (1.1 percent) and less abundant (0.5 percent) at the other sections (Appendices I and II). These grains are commonly subangular to subrounded and range from approximately 62 to 1000 microns in diameter. A few chert grains at Willow Creek contain chalcedony.

**Interpretation.** Recall that several sandstone fragments in these rocks contain chert. The sandstone which provided these rock fragments probably also supplied most or all of the chert grains. The apparent concentration of chert at Willow Creek suggests that sandstone was a
more important source rock near Willow Creek and/or this sandstone contained more chert than the eastern and northern sandstones.

Magnetite and Leucoxene

Description. Magnetite and leucoxene (an alteration product of ilmenite) grains in the Mount Shields Formation are very fine to fine-grained (62 to 250 microns), subangular to angular, and occur in heavy mineral bands with zircon and tourmaline. Appendices I and II show that magnetite and leucoxene are most abundant (1.5 percent) at Clark Fork and Kootenai Falls and less common (0.3 to 1.0 percent) at the other sections. Magnetite is commonly oxidized to hematite. At Rock Creek, and Kootenai Falls and Clark Fork where the beds are mostly drab white or green, magnetite is not as oxidized as at the other sections where red beds predominate.

Interpretation. Magnetite and ilmenite are common accessory minerals in granite and were most likely eroded from the southern and northeastern granites. The abundance of magnetite and leucoxene at Clark Fork and Kootenai Falls probably reflects a favorable diagenetic environment for the preservation of these minerals. The section entitled Weathering and Diagenesis discusses the conditions under which the magnetite was oxidized and the association of fresh magnetite with drab and green beds, and oxidized magnetite with red beds.

Zircon

Description. Zircon is evenly distributed and comprises approximately 0.4 percent of the detrital grains in the Mount Shields
Formation. These grains are very fine to fine-grained (62 to 250 microns), clear and occur in heavy mineral bands. There are two populations of zircon, a subhedral and euhedral population, and a rounded population which also includes broken round grains. Grains from both populations occur at all sections.

Interpretation. Zircon in a granite fragment at Rock Creek is conclusive evidence that euhedral and subhedral zircon was eroded from the southern granitic source. The northeastern granite is a likely source of zircon. Zircon is a highly durable mineral, therefore, the round and broken round grains could not have attained their degree of rounding in a single sedimentary cycle. These grains were eroded from another sedimentary rock, probably sandstone in the south, east or north.

Tourmaline and Tourmaline Rock Fragments

Description. The table in Appendix I shows that tourmaline is evenly distributed and comprises about 0.5 percent of the detrital grains in the Mount Shields Formation. These grains are very fine to fine sand (62 to 250 microns), subangular or subrounded to rounded, and range from mostly green, blue, brown or pink to pale yellow or black; some grains are colorless, others are zoned brown and green parallel to the c-axis. Bubbles and black inclusions are common in all varieties. Tourmaline overgrowths are ubiquitous; some are tens of microns long.

Brown and green zoned tourmaline predominantly occur as crystal groupings and aggregates or small euhedra in two kinds of rock fragments. In addition to the granite fragment at Willow Creek, this
distinctive variety of tourmaline is commonly contained in very fine grained chert or amorphous-looking material, and mudchips (Fig. 10a). These rock fragments contain as much as 50 percent tourmaline and are medium- to coarse-grained; fine-grained fragments occur at Clark Fork. In Appendix I, tourmaline rock fragments are tabulated separately from tourmaline. They are found only in the middle to upper part of the Mount Shields II and are most abundant at Clark Fork (0.2 percent fine grains; 0.7 percent coarse grains) and less common at West Glacier (0.2 percent), Willow Creek (0.4 percent) and Rock Creek (less than 0.1 percent); these grains are absent at other sections.

Interpretation. Green, brown and pink, and blue tourmaline are typical granite and pegmatite varieties. The other types of tourmaline are diagnostic of pegmatite injected terranes (Krynine, 1946b). The subangular fragments were probably eroded directly from granite and pegmatites. Tourmaline-bearing granite fragments at Willow Creek support this interpretation. The occurrence of zoned tourmaline in a granite fragment at Willow Creek and in rock fragments certainly suggests that they were derived from a granite and its country rock. The southern and northeastern granitic terranes are likely sources. Schofield (1915) reports very fine grained chert bearing tourmaline crystals near Cranbrook, British Columbia (Sullivan mining district). Perhaps some of the tourmaline-bearing chert in the Mount Shields Formation was eroded from a Sullivan type terrane, although this is highly speculative.

Because of its high durability the subround and round tourmaline probably could not have attained its degree of rounding in a single
Figure 10. Tourmaline rock fragments from Willow Creek (plane light) (55X) (a). Volcanic rock fragment from West Glacier (225X) (b).
sedimentary cycle, therefore, these grains were eroded from a sedimentary rock. The southern, eastern and northern sandstones are likely sources.

Volcanic Rock Fragments

Description. Subangular volcanic rock fragments, one at Kootenai Falls (177 microns) and another at West Glacier (710 microns), occur in the upper Mount Shields II. These grains are glass containing gray or white feldspar laths (Fig. 10b).

Interpretation. Basalt, probably the Purcell lava, provided the volcanic rock fragments to the Mount Shields Formation. The Purcell lava extends from the central part of Glacier Park and northwest into British Columbia, therefore, the basalt fragments at West Glacier and Kootenai Falls were transported from the north.
EXPANDED ANALYSIS AND INTERPRETATION

This chapter analyzes the detrital mineralogy of the fine-grained population and the coarse-grained population, and fully develops and relates the interpretations discussed here to previous studies.

Fine-Grained Population

Grains in the fine-grained population range from 62 to 250 microns in diameter (Appendix III), are subangular to subrounded, and moderately sorted. Listed below are the grain types in the fine-grained population.

- quartz (52.9 percent)
- orthoclase (8.6 percent)
- microcline (0.8 percent)
- microperthite (1.0 percent)
- plagioclase (0.4 percent)
- muscovite (0.9 percent)
- biotite (0.3 percent)
- sandstone rock fragments (trace)
- chlorite (0.2 percent)
- chert (0.5 percent)
- magnetite/leucoxene (0.9 percent)
- zircon (0.4 percent)
- tourmaline (0.5 percent)
- tourmaline rock fragments (0.2 percent)
- volcanic rock fragments (trace)

The size and shape of the grains in the fine-grained population is uniform throughout the Mount Shields Formation, however, the detrital mineralogy is not. The uneven distribution of fresh and sericitized orthoclase is the most striking mineralogic inhomogeneity of the fine-grained population. The abundance of microcline, microperthite, plagioclase, biotite, chlorite, chert, and magnetite and leucoxene, as well as tourmaline rock fragments, sandstone rock fragments and volcanic rock fragments, also vary within this population. The fine-grained population occurs alone or mixed with the coarse-grained population.
Coarse-Grained Population

The coarse-grained population contains grains which range from 250 to 2000 microns in diameter (Appendix III). A few grains at Rock Creek are as large as 5000 and 9000 microns. Grains in this population are subrounded to well rounded and poorly sorted. Grain types in the coarse-grained population include:

- **quartz** (54.3 percent)
- **orthoclase** (6.5 percent)
- **microcline** (0.8 percent)
- **microperthite** (1.0 percent)
- **plagioclase** (0.4 percent)
- **muscovite** (0.9 percent)
- **biotite** (0.3 percent)
- **sandstone rock fragments** (0.1 percent)
- **chlorite** (0.2 percent)
- **chert** (0.5 percent)
- **granite fragments** (0.7 percent)
- **tourmaline rock fragments** (0.2 percent)
- **quartzite fragments** (0.2 percent)
- **volcanic rock fragments** (trace)

The texture, as well as the detrital mineralogy, of the coarse-grained population varies. The grains in this population are largest (up to 9000 microns) and most angular (subrounded) in the south and southwest, but smaller (up to 2000 microns) and more rounded (rounded to well rounded) in the other parts of the basin. Quartz in the coarse-grained population is most abundant at Rock Creek, Willow Creek and Wood Creek, whereas the percentage of orthoclase is not only low at these sections but is less common in the coarse-grained population than in the fine population.

Provenance

The mineralogy, texture and distribution of grains in the fine-grained population and the coarse-grained population reflect the com-
position and locations of four source terranes for the Mount Shields Formation. These terranes are located in Figure 11 and discussed below.

**Southern Source Terrane.** A southern source terrane is indicated by both textural and mineralogical evidence in the Mount Shields I and II. The maximum grain size of these rocks decreases north and northwestward from Rock Creek (9000 microns), Willow Creek (2000 microns), and Prickly Pear (2000 microns) to Morrell Mountain (710 microns), Kootenai Falls (710 microns) and Clark Fork (710 microns) certainly suggesting source rocks at the southern end of the basin (Fig. 11). The concentration of granite fragments and microcline at Rock Creek and Prickly Pear, and microperthite at Rock Creek, Willow Creek, Prickly Pear and Morrell Mountain is evidence of granitic source rocks in the south and perhaps southeast. Very fine to medium-grained quartz sandstone and coarse-grained sandstone also shed grains and rock fragments from the south.

A southern source terrane for the Belt Supergroup and therefore the Mount Shields Formation has been proposed by McMannis (1963) who demonstrates that the sediments of the LaHood Formation (lower Belt) were eroded from an uplifted crystalline terrane (Dillon Block) south of the Willow Creek fault (along the Perry line). Ruppel et al. (1981) suggests a southwestern source for the Mount Shields Formation and other Missoula Group Formations. Stratigraphic and sedimentologic evidence in the Bonner Formation cited by Quattlebaum (1980) and his paleocurrent analysis of planar cross-beds in these rocks show that the
sediments comprising the Bonner Formation were derived from the south or southwest.

**Southwestern Source Terrane.** Unlike the southern source rocks, coarse, chert-bearing quartz sandstone and quartzite provided the abundant quartz, chert and quartzite fragments at Willow Creek. The relatively low amount of granite fragments and the absence of biotite and chlorite (possibly a weathering product of biotite) in these rocks suggest that granite was a subordinate source of sediment. Detritus from the southwestern terrane was most likely transported north and northeastward and deposited with sediment derived from the south (Fig. 11).

**Northeastern Source Terrane.** Coarse-grained granite fragments and orthoclase at West Glacier and Wood Creek and abundant coarse round quartz at Wood Creek are evidence of granitic and coarse sandstone source rocks east of these sections (Fig. 11). Eastward thinning and coarsening of the Mount Shields Formation (Harrison, 1972) also implies a source terrane east of the basin. The Canadian Shield is a likely source of granite fragments at West Glacier and possibly Wood Creek. Harrison and Grimes (1970) found that the average composition of Belt rocks closely approximates the average composition of the Canadian Shield (granite-granodiorite) (Shaw et al. 1967). An eastern sandstone source rock is contrary to Harrison's (1972) assertion that sedimentary source rocks for the Belt Supergroup were limited to the southwestern part of the basin. At West Glacier, sediment from the northeastern terrane was deposited with grains eroded from the northern source area.
Northern Source Terrane. Thinning of the Snowslip Formation and the Purcell lava northwest from the Whitefish Range into southeastern British Columbia (Smith, 1963) shows that a low-relief "positive" area lay at the northern end of the basin. Price (1962) found that the Purcell basalt and the Snowslip Formation had been eroded prior to deposition of the upper part of the Shepard Formation. Pebbles of Purcell basalt in the lower part of the Gateway Formation (Shepard equivalent) near Cranbrook, British Columbia (Schofield, 1915) confirm Price's findings. The very fine to fine-grained sandstone rock fragments at West Glacier and Kootenai Falls could have been eroded from the upper most Snowslip or other fine-grained sandstone and probably a little coarse sandstone in the Shepard Formation exposed in the "positive" area at the north end of the Belt basin (Fig. 11). Basalt fragments in these sections may have been reworked from the Shepard and eroded directly from the Purcell lava.

Tectonics

The overall mineralogy of the Mount Shields Formation at a single stratigraphic section is relatively uniform and therefore does not provide evidence of tectonism or changes in source terranes during deposition of these sediments. Slover (1982), however, attributes the abrupt increase in grain size from the Mount Shields I to the Mount Shields II to a major episode of basin subsidence relative to the surrounding source terranes. The uniform texture within the Mount Shields I and within the Mount Shields II reflect gradual and constant subsidence of
Figure 11. Schematic diagram of approximate source terrane locations showing transport directions of selected grain types.
the basin and/or uplift of the source areas. Textural variations within these units were produced by climatic changes (Sloven, 1982).
WEATHERING AND DIAGENESIS

Given a granitic source and long transport, one would deduce that the sediment of the Mount Shields Formation was weathered during transport. Although most weathering products have been diagenetically altered, the climatic conditions during deposition of these sediments (Sloven, 1982) and diagenetic characteristics in these rocks imply the pre-diagenetic mineralogy that includes smectite, magnetite and ilmenite, and biotite.

Weathering Products

Smectite. Although smectite was not detected in the samples collected, Eslinger and Sellars (1981) propose that smectite was originally present in the Belt Supergroup. Smectite is usually the primary weathering product of feldspars in arid environments (James et al. 1981), and salt casts in the Mount Shields III certainly suggest high evaporative conditions during deposition of these sediments. Wilson et al. (1971) report that the formation of smectite is favored by an alkaline environment with minimal leaching. The sediments of the Mount Shields Formation may have been deposited in such an environment.

Hematite. Hematite produced from the oxidation of iron in magnetite, ilmenite and biotite commonly coats detrital grains and grain overgrowths and comprises 20 percent or more of the red pigmented beds but is less common in green and white strata. Evidence that the hematite in the Mount Shields Formation was formed prior to deposition (Van Houten, 1973) is inconclusive. Although some of the hematite in
these rocks may be pre-diagenetic, evidence indicates that most hematite formed by diagenetic oxidation of iron-bearing minerals. Diagenetic hematite is discussed in a subsequent section.

**Chlorite.** The amount of chlorite weathered from detrital biotite and the process of this transformation are uncertain. Some chlorite probably formed by aluminum, iron, or magnesium hydroxyls replacing the interlayer potassium ions in the biotite. Vermiculite or montmorillonite may have been intermediate phases (Birkeland, 1974).

**Diagenetic Products**

**Carbonates.** Calcite and dolomite commonly occur together in the Mount Shields Formation; siderite is not common. Calcite crystals are anhedral and range from 62 to 88 microns in the fine-grained rocks and up to 500 microns in the coarse beds. Dolomite crystals are rhombic, 62 to 88 microns in diameter in fine-grained rocks and 125 to 177 microns in coarse rocks. Calcite and dolomite occur primarily as interstitial cement, and commonly have replaced detrital grains, particularly feldspar. These carbonates show no conclusive evidence of having replaced each other.

Dolomite and calcite occur low in the Mount Shields I, at the top of the Mount Shields II and in the Mount Shields III. The gradational decrease in the amount of carbonate cement from the base of the Mount Shields Formation up into the lower Mount Shields I reflects the transition from the subaqueous depositional environment of the Shepard Formation to the fluvial environment of the Mount Shields I and II. Dolomite and calcite at the top of the Mount Shields II and in the
Mount Shields III also indicate a subaqueous depositional environment. Although there is no evidence that calcite precipitation preceded dolomite, the high evaporative conditions during deposition of these sediments was probably favorable for calcite followed by precipitation of dolomite.

**Hematite.** Hematite is most abundant in the red beds of the Mount Shields Formation and less common in the green and white beds (Rock Creek, Kootenai Falls, and Clark Fork). This mineral coats detrital grains and overgrowths and rarely forms dust rims around quartz grains. These coatings are thin or absent at grain contacts. Hematite coatings are particularly thick around biotite, magnetite, and leucoxene grains as if iron were "bleeding" from these minerals. Walker (1967; 1974) and Walker et al. (1978) also found hematite-lined interstices and coated iron-bearing minerals in desert alluvium and red beds in tropical climates. These workers propose a diagenetic origin for the hematite. Conditions during deposition of the sediments in the Mount Shields Formation were probably ideal for the production of hematite. The cyclic alternation of rainy and dry periods proposed by Slover (1982) would have repeatedly raised and lowered the water table allowing oxidation of the iron-bearing minerals. Conditions at Clark Fork, Kootenai Falls and Rock Creek were apparently unfavorable for the precipitation of ferric oxide. Here there is no evidence of hematite oxidation followed by reduction (McBride, 1974). Instead, most magnetite and biotite grains at these localities are fresh and do not appear etched or eaten away. The sediments comprising the rocks at Clark Fork and Kootenai Falls were deposited on the distal reaches of
alluvial aprons. The water table at these locations may have therefore remained high prohibiting oxygenation of the sediments. The rocks at Rock Creek were probably originally quite permeable and formed relatively high on the depositional slope. Hematite that might have been deposited in these sediments may have been flushed out and deposited farther down the depositional slope.

**Illite and Chlorite.** Illite and chlorite occur at all localities. The green beds owe their color directly to illite and chlorite (Keller, 1953) and indirectly to the absence of other coloring agents such as hematite (McBride, 1974). In addition to illite (sericite) and chlorite replacing feldspars, illite and chlorite occur intergrown and form "furry" coatings on detrital grains, grain overgrowths and less commonly between quartz overgrowths and their detrital nuclei (Fig. 12a). Smectite formed from weathered feldspars was the probable precursor of the illite (Eslinger and Sellars, 1981). Through progressive burial, temperature and pressure increased and brought about the conversion of smectite to mixed layered illite/smectite (50°C to 200°C) and finally to 1Md and 2M illite (200°C to 350°C). Eslinger and Savin (1973) determined from their oxygen isotope studies that the Belt rocks at Glacier Park reached temperatures between 225°C and 310°C. These mineralogic changes were accomplished by substitution of Al³⁺ for Si⁴⁺ in the tetrahedral sites (Hower et al. 1976) and fixation of K⁺ in the interlayer sites of smectite (Hower et al. 1976; Hoffman and Hower, 1979). These workers propose that the aluminum and potassium were derived from potassium feldspar. Silicon released from
decomposed potassium feldspar, and iron and magnesium expelled from the octahedral layer of smectite contributed to the formation of quartz and chlorite respectively. These mineralogic transformations are represented in the equation below.

\[ \text{smectite} + \text{K-feldspar} = \text{illite} + \text{chlorite} + \text{quartz} \]

The penecontemporaneous relationship of illite, chlorite and quartz represented in the equation above agrees with the textural relationships of these minerals in thin section. High proportions of 2M illite do not necessarily accompany large amounts of sericitized feldspar therefore, the higher percentages of altered orthoclase at Willow Creek, Prickly Pear, Morrell Mountain and Kootenai Falls probably did not result from the same diagenetic processes which produced 2M illite. Apparently, local unexplained geochemical conditions controlled feldspar sericitation. Further quantitative clay mineral and geochemical analyses is needed to solve this problem.

Maxwell and Hower (1967) studied burial diagenesis in the Belt Supergroup and documented an increase in the proportion of 2M illite from the east side of the basin at the Little Belt Mountains westward to Glacier Park and Clark Fork, Idaho. They attribute this increase to westward thickening of the supergroup and therefore progressively higher grades of burial diagenesis from the east side of the basin to the west side of the basin. Proportions of 2M illite in the Mount Shields Formation follow a similar trend. Where the Missoula Group is thinnest the percent 2M illite in the Mount Shields Formation is
Figure 12. Sericite coatings on quartz grains and overgrowths from Flint Creek (143X)(a). Euhedral quartz overgrowth sampled at Prickly Pear (55X) (b).
lowest; 2M illite in these rocks is most common at sections where the Missoula Group is thickest. Listed below are the localities sampled with their corresponding proportions of 2M illite and approximate thicknesses of the lower Missoula Group at these locations. The proportions of 2M illite at each section are also listed in Appendix I.

<table>
<thead>
<tr>
<th>SECTION</th>
<th>MISSOULA GROUP THICKNESS</th>
<th>2M/2M + 1Md x 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>WOOD CREEK (MCGILL AND SOMERS, 1967)</td>
<td>1500 FEET</td>
<td>.18 PERCENT</td>
</tr>
<tr>
<td>MORRELL MOUNTAIN</td>
<td>UNKNOWN</td>
<td>19 PERCENT</td>
</tr>
<tr>
<td>PRICKLY PEAR (KNOPF, 1963)</td>
<td>4800+ FEET</td>
<td>22 PERCENT</td>
</tr>
<tr>
<td>WEST GLACIER (ROSS, 1959)</td>
<td>5400+ FEET</td>
<td>24 PERCENT</td>
</tr>
<tr>
<td>ROCK CREEK (CALKINS AND EMMONS, 1915)</td>
<td>5000+ FEET</td>
<td>27 PERCENT</td>
</tr>
<tr>
<td>WILLOW CREEK (CALKINS AND EMMONS, 1915)</td>
<td>5000+ FEET</td>
<td>27 PERCENT</td>
</tr>
<tr>
<td>KOOTENAI FALLS (WINSTON, PERS. COMM.)</td>
<td>7000+ FEET</td>
<td>32 PERCENT</td>
</tr>
<tr>
<td>CLARK FORK (WINSTON, PERS. COMM.)</td>
<td>7000+ FEET</td>
<td>34 PERCENT</td>
</tr>
</tbody>
</table>

Table 1. Table showing correlation of highest proportions of 2M illite in the Mount Shields Formation with the thickest Missoula Group sections.
Maxwell and Hower (1967), as well as this thesis, do not consider additional burial of the Belt Supergroup by stacked thrust sheets. A future study examining the affects of Cretaceous-Tertiary thrusting on the low grade metamorphism of the Belt Supergroup may provide insight to this problem.

Quartz. Quartz overgrowths occur in most of the samples collected. These overgrowths range from tens of microns thick on fine grains to hundreds of microns thick on coarse grains (Fig. 12b). Some coarse-grained samples contain grains which are loosely packed and cemented in quartz. Large volumes of pore water circulating through the sediments are required for precipitation of silica cement (Blatt, 1979). The abundance of quartz cement in the coarse-grained beds is therefore not surprising considering the original permeability of these beds was probably much higher than that of the finer grained beds. Quartz cementation may have occurred over a wide range of temperatures. Detrital grains loosely packed in quartz cement certainly suggest early cementation before deep burial and therefore at near surface temperatures (Blatt, 1979). Quartz overgrowths on illite and chlorite coated grains implies that silica may have also precipitated at temperatures as high as 200°C to 350°C. Silicon released by the conversion of smectite to illite is one likely source of silica for the later quartz cement in the Mount Shields Formation. Evidence of pressure solution was not observed in these rocks and can therefore be discounted as a source of silica.

K-Feldspar. Thin (a few tens of microns) potassium feldspar overgrowths occur on detrital orthoclase and less commonly on detrital
microcline. The source of potassium, aluminum and silicon ions needed for the growth of diagenetic feldspar in the Mount Shields Formation is not certain. Ali and Turner (1982), Stablein and Dapples (1977) and other workers consider interstitially degraded detrital potassium feldspars important sources of potassium, aluminum and silicon ions. Degraded biotite may have also contributed these constituents. Baskin (1956) proposes that diagenetic feldspar forms at low temperatures (less than 100°C). Oxygen isotope studies by Savin and Epstein (1970) confirm a low crystallization temperature for diagenetic feldspar.

Unlike some quartz overgrowths in the Mount Shields Formation, illite and chlorite occur only on the outside surfaces of feldspar overgrowths not between overgrowths and their detrital nuclei. Diagenetic potassium feldspar in these rocks therefore, probably precipitated prior to illite and chlorite growth at temperatures less than 200°C.
CONCLUSIONS

The detrital mineralogy of the Mount Shields Formation is characterized by a fine-grained population and a coarse-grained population. Grains in the fine-grained population are subangular to subrounded, moderately sorted and range from 62 to 250 microns in diameter. Grains in the coarse-grained population are characteristically subrounded to well rounded, poorly sorted, and range from 250 to 2000 microns in diameter. A few pebbles (5000 to 9000 microns) occur at Rock Creek. Four source terranes supplied the detritus in the Mount Shields Formation. These terranes were located south, southwest, northeast and north of the Belt basin. Granite fragments, abundant subrounded quartz and feldspar and muscovite reflect granitic source rocks in the south, southwest and northeast. Tourmaline rock fragments and tourmaline were eroded from igneous injected rocks within these granitic terranes. Coarse, rounded and well rounded quartz grains, some of which are broken, doubly overgrown or have abraded overgrowths, are common at Rock Creek, Willow Creek and Wood Creek, and were eroded from coarse, chert-bearing sandstone exposed nearby these sections. Very fine to medium sandstone also outcropped in the south. Very fine to fine-grained sandstone, perhaps the upper Snowslip and lower Shepard, shed grains and rock fragments south from the northern source terrane. Volcanic rock fragments were reworked from the lower Shepard and/or eroded directly from the Purcell basalt exposed north of the basin.
The detrital mineralogy of the Mount Shields I and II at a single locality is relatively uniform, thus reflecting constant source terrane compositions. The abrupt increase in sandstone content from the Mount Shields I to the Mount Shields II was produced by an episode of rapid basin subsidence. Textural variations within these units were climatically controlled (Slover, 1982).

Some feldspar in the Mount Shields Formation was probably originally weathered to smectite, although this mineral was converted to illite and therefore not detected in any samples. Some hematite in these rocks may have formed from oxidized magnetite, ilmenite and biotite before deposition of these minerals. Some detrital biotite might have altered to chlorite prior to deposition.

Abundant diagenetic hematite is responsible for the red coloration of these rocks. Repeated raising and lowering of the water table brought about by cyclic alternation of rainy and arid periods (Slover, 1982) oxygenated the sediments and allowed formation of iron oxide from biotite, magnetite and ilmenite. Hematite is absent from the distal green beds because a high water table produced reducing conditions. Hematite was flushed through the permeable white coarse beds at Rock Creek. Quartz overgrowths formed at low, near surface temperatures and penecontemporaneously with illite and chlorite at temperatures perhaps as high as 200°C to 350°C. The conversion of smectite to illite is one likely source of silica (quartz). Potassium feldspar overgrowths formed early at relatively low temperatures. Potassium, aluminum and silicon in these overgrowths were probably derived from degraded potassium feldspar and possibly biotite.
REFERENCES


APPENDIX I

TABLE OF DETRITAL MINERALOGY
<table>
<thead>
<tr>
<th>GRAIN TYPES</th>
<th>GRAIN POPULATION</th>
<th>CLARK FORK</th>
<th>KOOTENAI FALLS</th>
<th>PRICKLY PEAR</th>
<th>MORRELL MOUNTAIN</th>
<th>WEST GLACIER</th>
<th>WOOD CREEK</th>
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$2M \times 100$ general: 34 32 22 19 24 18 27 27

$2M+1Md$ general: values given are percent detrital grains

trace—less than 0.1 percent
APPENDIX II

STATISTICAL COMPARISONS (t TEST)

OF DETRITAL GRAIN MEANS
FINE POPULATION

Orthoclase (Fresh)

Clark Fork, West Glacier, vs. Kootenai Falls, Prickly Pear, Wood Creek vs. Morrell Mountain

- mean: 8.8 percent vs. 3.8 percent
- degrees of freedom: 72
- t value: 8.35
- probability of random occurrence: $1 \times 10^{-15}$

Orthoclase (Altered)

Clark Fork, West Glacier, vs. Kootenai Falls, Prickly Pear, Wood Creek vs. Morrell Mountain

- mean: 0.7 percent vs. 4.0 percent
- degrees of freedom: 69
- t value: 7.00
- probability of random occurrence: $1 \times 10^{-12}$

COARSE POPULATION

Quartz
COARSE POPULATION (cont.)

Quartz (cont.)

Rock Creek, Willow Creek, vs. Clark Fork, West Glacier
Wood Creek, Kootenai Falls, Prickly Pear, Morrell Mountain

mean
58.3 percent

mean
51.4 percent

degrees of freedom
46

t value
3.39

probability of random occurrence
$1 \times 10^{-3}$

Quartzite

Willow Creek vs. Rock Creek, Prickly Pear

mean
0.8 percent

mean
0.5 percent

degrees of freedom
29

t value
1.85

probability of random occurrence
$1 \times 10^{-2}$

GENERAL POPULATION

Orthoclase

Fine Population vs. Coarse Population
GENERAL POPULATION (cont.)

Orthoclase (cont.)

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Microcline

Prickly Pear, Rock Creek, vs. Clark Fork, Kootenai Falls, West Glacier, Wood Creek, Morrell Mountain, Willow Creek

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</table>

Microperthite

Rock Creek, Willow Creek, vs. Wood Creek, West Glacier Prickly Pear, Kootenai Falls, Clark Fork Morrell Mountain
GENERAL POPULATION (cont.)

mean
1.2 percent

mean
0.8 percent

degrees of freedom
127

t value
3.70

probability of random occurrence
1 x 10^-4

Plagioclase

Rock Creek, Willow Creek, Morrell Mountain,
Clark Fork, Kootenai Falls vs. Prickly Pear,
Wood Creek, West Glacier

mean
0.03 percent

mean
0.5 percent

degrees of freedom
128

t value
6.03

probability of random occurrence
1 x 10^-9

Chert

Rock Creek, Morrell Mountain
Prickly Pear, Wood Creek
Willow Creek vs. West Glacier, Kootenai Falls
Clark Fork
Magnetite and Leucoxene

<table>
<thead>
<tr>
<th>Mean</th>
<th>Degree of Freedom</th>
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<td>1.5 percent</td>
<td>128</td>
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APPENDIX III

HISTOGRAM OF APPROXIMATE

GRAIN SIZE DISTRIBUTION
FINE POPULATION

COARSE POPULATION

NUMBER OF SAMPLES

GRAIN SIZE CLASSES

μ 62 88 125 177 250 350 500 710 1000 1410 2000

φ 4 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0 0.5 -0.5 -1.0
APPENDIX IV

HISTOGRAM OF APPROXIMATE

GRAIN SIZE DISTRIBUTION

OF ORTHOCLASE
APPENDIX V

THIN SECTION DESCRIPTIONS
CFO CLARK FORK

Grains: 50%
size: ≤ 62.8 μm (silt to very fine sand)
shape: subangular to sub-rounded
sorting: moderate
composition: Qtz - 30%
mica higher, K-feld - 20% (mostly cleavel, some slightly detrital)
minor: feldspar - 30%
tour fine (one grain)
ms - 10%
talc - 30%
chlorite - 20%

Matrix: 50%
(calcite (probably replaced original matrix & some grains), a little dolomite)

CF 45

fair photo of dolomite concretions

Grains: 75%
siz - 62 - 250 μm (medium fne sand) wi - 1% 350 - 500 μm (med. sand)
shape: subangular to sub-rounded (larger grains more rounded)
sorting: moderate to poor (fine grading)
composition: Qtz - 62% (some w/dolomite replacements) w/talc of bubble
maybe 1 - 2% opal - 1% feld - 7% (pettite shens)
by calcite

mica - 3% cleave
pseudotachylite - 7% cleave
more tafoni - 1% tafoni - tafoni

matrix: 25% magnesite - 1% (calcite) & cream like subrounded
Grains: 75%+
  Size: 62-125 μm (very fine to fine sand)
  Shape: Subangular
  Sorting: Moderate
  Composition, %:
    K-feld: 10%
    Plagioclase: 2%
    Mica: 1%
    carbonate: 1%
    other: 6%
  Zircon: trace
  Magnetite: 1% (total)

Grains: ~50% in coarse layers; 70% in fine-grained portion
  Size: 62-710 μm (very fine to coarse); 6 μ-125 μm (very fine sand)
  Shape: rounded to well-rounded; subangular to subrounded
  Sorting: Poor; moderate
  Composition, %:
    K-feld: 8% (same as matrix); K-feld: 12%
  Mica: 1%
  Plagioclase: 1% (clay)
  Particles: 1% (clay)
  Zircon: trace (subrounded)
  Bau: -trace
  Hematite: trace (scattered)

Matrix: 50%; 30%
CIF 200

Grains: 65%
size: 8 - 1724
shape: subangular to angular
sorting: moderate
composition: 93 - 98% (a few amorphous)
may vary up to 6 - 192% (most sp. and glassy)
calk: 5 - 12%
calk: less than 8%
tau: 0.60
more: 5 - 15%
brick: 0.35%
more: 5 - 15%
mud: 0.35%
tau: 0.60
more: 5 - 15%
brick: 0.35%
CIF 200

To - fine - grained (a few grains are very fine sand)
Calcium carbonates 5 - 9.5%
Gypsum composition to calibrate

Tests:
1. brown - green (case)
2. yellow - brown (x), red (x)
3. brown (2), yellow (brown) hues (2), bai (2)
4. red, Ant (x), red, green (2)
5. calcium, lime
6. Hand of the sand in calcite (calcutate) and marlomite, white, fine grains
Grains: 75%

Size: 8.8 - 125 μm (very fine sand)
Shape: subangular to subrounded
Sorting: moderate to well

Composition:

- Feldspar: 70% (72% dark)
- Mica: 5%
- Quartz: trace
- Tourmaline: trace
- Muscovite: 5%
- Plagioclase: trace
- Garnet: trace
- Gneiss: 7%
- Green feldspar: trace (quite small)
- Mica: 3% (scattered)
Grains: 75%

Size: 250-325 µm (med.-sand)
Shape: subrounded to rounded, a few well-rounded
Sorting: moderate
Composition: 65% (double cements)
Nonclay: 12-27 (few)
Chert: 3%
Peat: trace
Other: trace
Zircon: trace (longer and rounded/well-rounded)
Cut-out: 25%
Chlorite: 25% 94 - 18%
Calcite: 5%
CS 545

**Haynes photo of sand:**

Grains: 760%+

- Size: 0.2-0.5 mm (v. fine sand); w/ pebbles-rounded chips, 2 mm-5 mm (med.)
- Shape: subangular; sub-rounded to rounded
- Sorting: poor
- Composition: feld. 39%

- Clay of calcite, red 12. field 5-7% (very fine grained; replaced calcite by clay)
- Mica - 1% - muscovite - trace

- 2% feldspar (ground) - trace (in heavier layers
- Mud-chips: 10% - trace (approximately 1%)

- Matrix: 80% - many are larger and broken

Matrix, 80% (wet)

---

EC 1

**FLINT CREEK**

Grains: 70%

- Size: 0.001-0.1 mm (very fine to very coarse sand)
- Shape: rounded
- Sorting: poor
- Composition: feld. 55%

- 12 field: 10% - (darker, 7% stained; some sericitized
- Muscovite - 1% - (slightly darker)
- Mica - trace - 1% - (clear)
- Granite frag - 18% - (med. grained)
- Phosphate frag - 3% - (fine to med. grained)
- Iron oxide: 2% - trace
- Muscovite: 2%
- Zircon - trace included: magnetite - trace
FC5

Grains: 70%
Size: 250 - 2500 μm (very fine to fine sand)
Shape: subrounded to subangular
Sorting: moderate
Composition: 97.5%
K-feld: 10% (slightly grey, somewhat reddish, alkali poor)
Plagioclase 2%
Muscovite 8%
Plagioclase
Zircons: few (anhedra, subangular), some brown
Tourmaline: 1% (subangular)
Magnetite: trace
Muscovite: trace
Siltite: trace

FC6

Grates fine, granite fines, rounded grains

Grains: 65%
Size: 177 - 1410 μm (fine to very coarse sand)
Shape: subrounded to rounded
Sorting: poor
Composition: 84.4% (some muscovite)
K-feld: 10% (dirty, replaced by detrital)
Muscovite 1%
Plagioclase: trace
Zircons: trace (mostly fine-grained, some coarse-grained)
Garnet: trace (some coarse-grained)
Muscovite: trace

Matrix: 35%
Dolomite and calcite: 35% (replaces detrital felds)
FC 9

photo of ton in rock fuge.

Grains: 70%
Size: 0.8 - 350 μ (very fine to medium)
Shape: subangular to subrounded
Sorting: moderate
Composition: fay - 52%
K-feld - 12% (some is partly dirty, potassium)
Plagioclase - 21% (clean)
Mica - 11% (clean)
Muscovite - trace
A muscovite + quartz + feldspar - 16% (pyroxene)
Magnetite - 11% (scattered)
Fay. - 11% - 11%
Zircon - trace (brown)

FC 14

Grains: 7.5%
Size: 0.8 - 350 μ (very fine sand)
Shape: subangular to subrounded
Sorting: moderate to well sorted
Composition: 47 - 66%
K-feld - 7% (dirty cherry
clean)
Micaceous - trace (clean)
Plagioclase - trace
Musc. - 2/8%
Plag. - trace (dirty)
Chert - trace
Ton. - trace
Opaque (oxidized, gray, red, brown) - 1% (some crude lenses)
Zircon - trace
Grains: 60%

Size: 62-1410μ (very fine to very coarse sand)
Shape: subangular to subrounded
Sorting: very poor
Composition: quartz 44%
12-m field 4% (3% stained, clean)
Mica - trace
Feldspar - 19%
Chert - traces (1 gm)
Ferromagnetics - 17% (fine to coarse, 10 gm)
Mudclasts - trace
Tea, tone in 3 gms. color blue to light green (clear)
Muscite - trace

KE-72 Kootenay Falls

Grains: 60%

Size: 62-850μ (very fine sand), a few (1/24) fine grains
Shape: subrounded
Sorting: moderate 50%
Composition: quartz (some minor overgrowths)
+40% silic., 12-m field 4% (many minor, mostly quartz)
Feldspar - trace
Mica - trace
Ferromagnetics - trace (some in traces)
Mudclasts - % ignored

Matrix: 40%
Stones 30%
Shells 10%
**KF 12s**

Photo of s.s. Aug

Grains: 65%  65%  10%  20%  5%

Size: 62 - 125 μm (very fine sand) and 125 - 250 μm (moderate sand)

Shape: subangular

Sorting: moderate

Composition: 91.5%  48%

+70% saturated  63 - 4%

Pristine (natural)

Magnetic: 2% (loose magnetic)

Clay: 1%

Matrix: 35%

Silt: 20%

Chlorite: 5%

---

**KF 20s**

Grains: 65%

Size: 62 - 125 μm (very fine sand)

Shape: subangular

Sorting: moderate

Composition: 91.5%  48%

+70% saturated  63 - 4% (loose saturated?)

Pristine: none

Pristine: none

Magnetic: none

Clay: none

Matrix: 35%

Silt: 20%

Chlorite: 5%
LF 265

Grains: 60%
- Sizes: 62-35μm (very fine to medium sand)
- Shape: subangular to subrounded
- Sorting: moderate to poor: 53%
- Composition: silt + sand (some overgrown) 10-22%

2+5% replaced by silts - 2% (sensitive)

by calculation:
- pebbles: < 1%
- muscovite: trace
- tourmaline: trace (sub-rounded)
- hornfels: trace

Matrix: 40%

KF 300

Grains: 50% - 60% - 40% - (silt + sand)
- Sizes: 62-35μm (very fine to medium sand): 17-35μm (fine to medium sand)
- Shape: subangular to subrounded, some of these are rounded
- Sorting: moderate to poor
- Composition: < 1% - 39% overgrown

slightly lower content: kaolinite 2-3% - 1% (5% kaolite)
- pebbles: < 1%?
- muscovite: trace
- some feldspar (very fine - fine): < 1%
- muscovite: 2%

Matrix: 50%
KF-3,0

Grains: 65%

- Size: 62-25 my (very fine to fine sand)
- Shape: subangular to subrounded (mostly subrounded)
- Sorting: moderate to poor
- Composition: feldspar 55% (some mica)
- 5% intermediate-fine sand (dark, some quartz)
- 1% quartz (light-colored)
- Mica: trace (light-colored, some clear)
- Muscovite: ≤ 1%
- Tourmaline: tourmaline
- Circumference: subangular-rounded
- Magnetite/microcline: > 1%

Mud: 35%

- Silt: 20%
- Clay: 15%

KF-450

(Take photo of fungus sample) (good clay sample)

Grains: 55%

- Size: 88-350 my (very fine to medium sand)
- Shape: subangular-rounded
- Sorting: moderate to poor
- Composition: feldspar 45% (a few micas)
- 2-3% rounded feldspar 5% (darker, some basaltic)
- Quartz: 1% (dark)
- Chert: trace
- Silt: trace (muscovite)
- Mica: trace (subrounded)
- Tourmaline: tourmaline (brown)
- Iron oxide: trace

Mud: 45%
**KF 463**  
(Tube photo of square-rounded recrystallized grains)

Grains: 50% (original may have been higher)
Size: 62-85µm (very few over 100µm)
Shape: sub-rounded to angular
Sorting: moderate 42%
Composition: 97% (some rem. trace)
Min: 1%

Major trace (mainly trace - norm. - gran.)
Ulexite Zircon (amphibolite)
X = no apparent K-feld. looks as though all replaced by remnants 25% rem. 75%

Notice: 50%

Grains: 70%
Size: 8-17µm (very fine to fine) 250-350µm (med. fine) <1%
Shape: sub-rounded to sub-rounded; sub-rounded to rounded
Sorting: moderate to poor
Composition: 7%
+3% opaque = K-feld. 3% (slightly altered)
Quartz 1% - 1% (clean)
Muscovite 1% (clean)
Mica 1% - trace
Tourmaline 1% (trace)
Zircon 1% (sub-rounded)
Siderite 1% (small)
Magnetsite 1% (clean)

**KF 500**  
(Tube photo of s.s. flag)

Grains: 70%
Size: 8-17µm (very fine to fine) 250-350µm (med. fine) <1%
Shape: sub-rounded to sub-rounded; sub-rounded to rounded
Sorting: moderate to poor
Composition: 7%
+3% opaque = K-feld. 3% (slightly altered)
Quartz 1% - 1% (clean)
Muscovite 1% (clean)
Mica 1% - trace
Tourmaline 1% (trace)
Zircon 1% (sub-rounded)
Siderite 1% (small)
Magnetsite 1% (clean)
KESO

( good clay sample )

Grains: 60%

size: 5.8 - 2.5 (very fine to finest sand)
shape: subangular - subrounded
sorting: moderate
composition: 98% (some small angular grains)
1.2% cemented

mica - 7%

quartz (1%) - meg.

Micas: trace

Nature: 40% silt - 25% (some sand - 15% cement)

KESO

Grains: 70%

size: 38 - 3.5 (very fine to med. sand)
shape: subangular to subrounded w/ a few rounded (med. sand)
sorting: moderate to poor
composition: 98% (some angular, some subangular)
1.2% cemented

mica - 6% (some sand - 2% (very clean)
pyrite - 2% (reddish brown)
macrocryst - trace
trace - trace
zircon - trace (subangular)

magnete - 2% (some in under layers)
chert - trace

1 - 1% (magnetite)
Grains: 60%
size: 80-120 (very fine to fine sand) some 250-350um (med. sand)
shape: sub-rounded & sub-angular
sorting: moderate
composition: quartz - 50%
21% siltized
pale - 5% (clay)
matrix: trace

Matrix: 40%
composition: sericite - 30% calcite - 3%

Grains: 65%
size: 62-250um (very fine to fine sand) w/a few medium grains
shape: sub-rounded & sub-angular
sorting: moderate
composition: quartz - 56% (some small angular)
1-2% siltized
pale - 5% (slightly dirty)
matrix: trace

Matrix: 35%
composition: sericite - 35% clay - 15% calcite - 1%
**KF 745**

Grains: 65%
- Size: 62-250 μm (very fine to fine sand)
- Shape: subangular to subrounded
- Sorting: moderate
- Composition: quartz 45%, feldspar 39% (clean or sericitized)
- Opaque (17%), pyrite 1% (clean)
- Hematite, any indicating in mine - trace (clean)
- Minerals: none
- Carbon: trace
- Vegetation: subangular, embedded
-英特尔: trace (green) subrounded
dent: trace

Nature: 35% compressed, size edges
- Composition: quartz - 32%, calcite 37% (pyrite, opaque sericite)

**KF 800**

Grains: 70%
- Size: 62-125 μm (very fine sand), a few 177-250 μm (fine sand)
- Shape: subangular to subrounded
- Sorting: moderate
- Composition: quartz 55% (some mica
- +1% sericite K-feldspar 10% (clean)
- Pyrite: trace (clean)
- Opaque (3%), magnetite, trace (dark brown) subangular
- Hematite: trace
- Minerals: none
- Carbon: trace

Nature: 30%
- Composition: quartz 27%
- Alteration material (?) 5%
**KF 350**

**Grains:** 70%  
**Size:** 88 - 255 μm, very fine to fine sand  
**Shape:** subangular to subrounded, some rounded  
**Sorting:** moderate  
**Composition:**  
- 21% quartz  
- 14% feldspar - 5% (some well rounded, others clean)  
- muscovite - 11% (clean)  
- paraffin - 11% (clean)  
- magnetite - 2% (some in larger)  
- feldspar - 1%  
- zircon - 1% (subrounded to rounded)  
- chlorite - 1%  
- semiquartz - 2% (fine sand)  
- quartz - 1%  
- feldspar - 1% (clean)  
- muscovite - 1%  
- feldspar - 1% (clean)  
- zircon - 1% (subrounded)  
- magnetite - 1% (scattered)  
- chlorite - 1% (clean)  
- muscovite - 1% (clean)  
- zircon - 1%  

*Volcanic rock from Ragnor glacial bed (left 1.5 m)*

---

**KF 900**

**Grains:** 75%  
**Size:** 88 - 255 μm, very fine to fine sand  
**Shape:** subangular to subrounded, some larger grains are rounded  
**Sorting:** moderate to poor  
**Composition:**  
- 47% quartz  
- 14% feldspar - 5% (some well rounded, others clean)  
- muscovite - 1% (clean)  
- paraffin - 1% (clean)  
- feldspar - 1%  
- zircon - 1% (subrounded)  
- magnetite - 1% (scattered)  
- chlorite - 1% (clean)  
- muscovite - 1% (clean)  
- zircon - 1%  

*Maybe take photo of dome ice formation*
**KF 950**

Grains: 60% -
- Size: 0.2 - 0.5 mm (very fine sand)
- Shape: subangular
- Sorting: moderate to good
- Composition: 40% - 52%

- 2% organic material
- 1% Fe-FeO-Fe2O3 (siderite, magnetite)
- Racine: trace
- Molybdenite: trace
- Muscovite: trace
- Muscovite: trace

**HM 2313a**

Grains: 75% -
- Size: 0.12 - 0.5 mm (very fine sand to silt)
- Shape: subangular
- Sorting: moderate
- Composition: 62% - 75%
  - 12.5% - 15% (some heavy minerals, quartz, feldspar, mica, muscovite, biotite, chlorite)
  - 1% - 2% (trace)

- Remaining: 5% - 10% (magnetite, hematite, titanium, zircon, garnet, tourmaline, chlorite, muscovite, feldspar)
MH 360
Grains: 70%
Size: 62-125 μ (very fine sand)
Shape: subangular
Sorting: modest
Composition: graphite 5.6%
Original sand > K-feldspar 5%
(highly altered, 3-7%; otherwise clean)
Plagioclase: 1% (slightly altered)
Biotite: trace (green)
Silt: trace (indurated)
Zircon: trace (sub-rounded)
Musc: trace
Fauc: trace
Magnetite 1% (scattered)

MH 390
Grains: 70%
Size: 62-125 μ (very fine to fine sand)
Shape: subangular to sub-rounded
Sorting: moderate
Composition: quartz 57% (quartzine stone)
Original sand > K-feldspar 5%
Perthite: 1% (slightly altered)
Plagioclase: 1%
Zircon: trace (sub-rounded)
Musc: trace
Biotite: trace
Magnetite: 1%
**HM 445**

Grains: 65%

- Size: 0.8 - 2.5 mm (very fine to fine sand)
- Shape: sub-rounded, some rounded
- Sorting: moderate
- Composition: feldspar 48% (amphibole)
  - Microlite: 12% (amphibole)
  - Play: 17% (clean, some dirty)
  - Opaque: 1% (dirty)

- Zircon: trace (sub-rounded)
- Tour: trace
- Siltite trace + mud chips 1%
- Detrit: trace
- Detrit: feldspar (brown) 0%
- TOUR: 0%
- Muc: 1%

**HM 484**

Grains: 70%

- Size: 0.2 - 1.25 mm (very fine sand)
- Shape: sub-rounded to angular
- Sorting: moderate 54%
- Composition: feldspar 33% (amphibole)
  - Microlite: 10% (amphibole)
  - Play: 2% (clean)
  - Opaque: 1% (clean, slightly dirty)

- Zircon: trace (clean, some dirty)
- Tour: trace
- Siltite trace + mud chips 1%
- Detrit: trace
- Mic: 1%
- Zircon: trace, several (2%) in layers
MM 533
Grains: 75%
size: 6.2 - 25 \mu (very fine sand)
shape: subangular to subrounded
sorting: moderate 59%
composition: quartz - 2%
marl - 1%
plagioclase - 2% (some altered, some clean)
feldspar - 1%
chlorite - trace 6.4 ± 1% (red stain, weathered?)
cheat - trace
tour - trace
zircon - trace, subangular
magnetite - 1% (scattered)

MM 585
Grains: 70%
size: 8.8 - 172 \mu (very fine to fine sand)
shape: subangular
sorting: moderate
composition: quartz 55% e (o. eumin)
feldspar - 10%
plagioclase - 2% (clean)
marl - 1% (clean)
plagioclase - 1% (dirty)
tour - trace
silt - trace
epidote - 1% (magn./mica, scattered)
zircon - trace (subangular)
apatite - trace (gran)
**HH 637**

Grains: 70%
- Size: 83 - 172 μm (very fine to fine sand); about 9 - 6 grms. of γ (2.0 - 3.5 μm)
- Shape: subangular to subrounded
- Sorting: moderate
- Composition: γ: 92%, Δ: 56%

- 2% opaques, K-feld.: 7%

by weight:
- microlite: 2% (clean)
- plagioclase: 1% (dirty)
- mica: 1%
- fine: 1%
- biotite: trace (brown, some green)
- opaques: may, bve. 51% - some could be tourmaline

**HH 640**

Grains: 75%
- Size: 83 - 172 μm (very fine to fine sand)
- Shape: subangular to subrounded
- Sorting: moderate
- Composition: γ: 92%, Δ: 59% (mean: 61%) (mean: 20%)

6% = opaques
- tourmaline: 7% (greenish, red, not tourmaline)
- plagioclase: 6% (clean)
- mica: 1%
- biotite: trace (red, brown, we think)

mud chips: 3%
- tourmaline: trace
- chlorite: trace (swaniated)
- magnetite: 2% (leucox)
**MM 740**

Grains: 70%

- Size: 62 - 177 μm (very fine to fine sand)
- Shape: subangular
- Sorting: moderate
- Composition: 97% (2% admixed to sericite)

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mica</td>
<td>7%</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>8%</td>
</tr>
<tr>
<td>Porphyrite</td>
<td>1%</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>2%</td>
</tr>
<tr>
<td>Biotite</td>
<td>1%</td>
</tr>
<tr>
<td>Clasts</td>
<td>1%</td>
</tr>
<tr>
<td>Mud chips</td>
<td>3%</td>
</tr>
</tbody>
</table>

**MM 790**

Grains: 70%

- Size: 62 - 125 μm (very fine sand)
- Shape: subangular to subrounded
- Sorting: moderate
- Composition: 97%

<table>
<thead>
<tr>
<th>Grain Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mica</td>
<td>10%</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>5%</td>
</tr>
<tr>
<td>Porphyrite</td>
<td>2%</td>
</tr>
<tr>
<td>Tourmaline</td>
<td>1%</td>
</tr>
<tr>
<td>Clasts</td>
<td>1%</td>
</tr>
<tr>
<td>Mud chips</td>
<td>1%</td>
</tr>
<tr>
<td>Spheres</td>
<td>3%</td>
</tr>
<tr>
<td>Zircon - tourmaline - subangular</td>
<td>1%</td>
</tr>
</tbody>
</table>

Spheres: very rare, base, triad, scattered
MM 840
Grains: 70% 
Size: 88 - 172μ (very fine to fine sand) 
Shape: sub-rounded to subangular 
Sorting: moderate 
Composition: 94% (some mica) 
K-feldspar - 10% 
micelle - 1% 
plagioclase - 1% 
plagioclase - 1% 
muscovite - 1% 
tourmaline - zircon - tourmaline (subangular) 
epoxy was may, tour, muscovite - 1% (scattered) 
biotite (trace)

MM 890 
Grains: 70% 
Size: 88 - 35μ (very fine to fine) 
Shape: sub-rounded - angular (larger grains now rounded) 
Sorting: moderate 
Composition: 97% (some mica) 
K-feldspar - 10% (coarse and elongated) 
Zircon - tourmaline (subangular, subrounded) 
Biotite - tourmaline - muscovite trace 
Diatomite - tourmaline trace 

difficult to see - grains (may) 11 very fine ground, sub-rounded, evenly spaced, imperfectly mixed 

Mica - tourmaline - muscovite - tourmaline - biotite - tourmaline trace 

Magnetic: 30%

separate: 50%
**MM 940**

Grains: 70%

- Size: 88-177 μ (u. fine to fine-sand) w/ a few 250-350 μ (med. sand)
- Shape: subangular
- Sorting moderate, minimum layer of coarse grains
- Composition: 95%, 56% (some intermediate)

12% sand/n... 1K-sand... 7%... (sand/n)

- Mucilag...: 1.2% (clean)
- Particles: 17% (dirty)
- Mucilag...: 2%
- Biotite...:
- Clast...: 1%
  - Magnetite...: 11% (sand clays)
  - Plagioclases...:
  - Mudclips...: 1%
  - Tourmaline...: Zircon...: Trace (subangular)

**MM 990**

Grains: 75%

- Size: 125-250 μ (fine sand) w/ a few medium grains
- Shape: subangular to sub-rounded
- Sorting moderate
- Composition: 95%

This slide next... 1K-sheet... 7% (arrested... semireterminate sheet) = 4% semireterminate

- Particles...: 1%
- Mucilag...: 2%:

- Biotite...: 2% (red stained)
- Plagioclase...: 1% (dirty)
- Mudclips...: 3%
- Magnetite...: 1% (some layers)
MM 1035

Grains: 70%

size: 125 - 250 μm (medium sand)
shape: subrounded
sorting: moderate
composition: quartz - 57% (some micas) (some petrocalcite)
feldspar - 12% (slightly to distinctly sericitized)
mica - 17% (clean)
pyrite - 2% (clean)

may, may (trace)
play - trace (dirty) + (clean)
tour - trace

mica - 1% zinc - trace (undetected)
zinc - trace (subangular)
barite - trace
muscovite - 1% chart - trace

MM 1091

Grains: 70%

size: 63 - 125 μm (very fine sand)
shape: subangular to subrounded
sorting: moderate
composition: quartz - 56%
feldspar - 17% (clean, slightly dirty)
mica - <1%
tour - trace (clean)
pyrite - <1% chart - trace
zinc - trace (subangular)
barite - trace

may, may - <1% as (calcite layers)
play - trace (dirty)
**MM 11/10**

Grains: 65%

- **Size:** 88-77 μm (very fine to fine sand); 1-2% (177-350 μm) (finer to med. sand)
- **Shape:** subangular to subrounded
- **Sorting:** moderate + poor
- **Composition:**
  - Quartz: 51%
  - Feldspar: 6% (feldspars: 5% sanidine, 1% plagioclase)
  - Micas: 1%
  - Detrital: trace
  - Carbonates: 1%
  - Zircon: trace (subangular)
  - Oligocene (magnesium, limestone, andesite) ≤ 1% (scattered)

---

**MM 11/90**

Grains: 65%

- **Size:** 62-125 μm (very fine to fine sand); 125-177 μm (finer to med. sand)
- **Shape:** subangular to angular
- **Sorting:** moderate
- **Composition:**
  - Quartz: 52%
  - Feldspar: 2% (6% sanidine)
  - Micas: 1%
  - Detrital: trace
  - Carbonates: 1%
  - Zircon: trace (subangular)
  - Oligocene (magnesium, limestone, andesite) ≤ 1% (scattered)
MM 13ac

Grains: 65%
Size: 80-125μ (very fine sand); 250-750μ (med. to coarse sand)
Shape: subangular-rounded; sub-rounded to rounded, some well-rounded
Sorting: poor
Composition: 55% matrix, 45% sand

Minerals: 10%
Plagioclase: 10%
Mud clubs: 10%

Chemical: 75%
Silica: Na(K)Al
Granite: None
Zircon: trace
Plagioclase: trace (slightly altered)

MM 13bc

Grains: 65%
Size: 80-175μ (very fine to fine sand); 350-710μ (med. to coarse sand)
Shape: subangular; rounded to well-rounded
Sorting: poor
Composition: 55% matrix, 45% sand

Minerals: 10%
Plagioclase: 10%
Mud clubs: 10%

Chemical: 75%
Silica: Na(K)Al
Granite: None
Zircon: trace
Plagioclase: trace (slightly altered)
PPE Poor Silt  
PRICKLY PEAR

Grains: 60%
- Size: 62-83 μ (very fine sand)
- Sorting: moderate
- Shape: subangular
- Composition: qtz - 46%
  - K-feld - 10%
  - mica - 2%
  - muscovite - 1%
  - Lithics (mudchips) - 1%
  - Perthite - 1%
  - Chlorite - 1% (detrital)

Matrix: 40% (even)

PPS Silt, not sandy

Grains: 75%
- Size: 62-83 μ (very fine sand)
- Sorting: moderate
- Shape: subangular to subrounded
- Composition: qtz - 59% (quartz)
  - K-feld - 7% (dirty - clean even grain size)

Biotite - 49% (predominant to minor), hornblende
- Perthite - 1% (Wustite)
- Mica - 16% (green, brown, rounded)

Secondary minerals: 3%
- Mica - 1% (brown, decayed)

Matrix: 25% (even)

some are

smashed into pseudomatrix.
Grains: 65%

- Size: 38 - 125 μm (very fine sand)
- Shape: subangular to subrounded
- Sorting: moderate
- Composition: qF - 51% (some double muscovite)
- 6% authigenic ilmenite
- K-feldspar - 5% (clean or sericitized)
- replaced by carbonate, perthite - 1% (clean)
- muscovite - ≤ 1% (clean)
- tourmaline - tourmaline -
- mica - 2%
- zircon - tourmaline (subrounded)
- chlorite - 1%

Matrix: 35%

- qF - tourmaline (clean pseudomorph)
- 20% dolomite
- 13% calcite
- 2%

Grains: 70%

- Size: 62 - 125 μm (very fine sand)
- Shape: subangular to angular
- Sorting: moderate
- Composition: qF - 58% (some double muscovite)
- 12% K-feldspar - 5% (clean)
- replaced by carbonate, perthite - 1% (clean)
- muscovite - tourmaline -
- mica - 1%
- tourmaline -
- chlorite -

Matrix: 30%

- qF - tourmaline (clean pseudomorph)
- 15% calcite
- 3% (dolomite)
102

PP 23.2

Too much replacement is still correct original composition.

Grains: 50%  
Size: ~62-125 μm (very fine sand)  
Sorting: moderate to poor  
Shape: subangular  
Composition: 97 - 43% (some enargite)  
musc: 2%  
chlorite: 1%  
k-feld: 1% (tour: tourn: tour)  
Matrix: 50% (enargite)

The percentage of grains is probably more different from the original.

PP 23.9

This rock is ~90% calcite (calcite).  
Minerals identified include: (grains on slide to my right)  
97% calcite

biotite  
tour: blue or green variety  
musc  
may
micaeline (looks clean)

Not practical or worthwhile to estimate grain %
PP 350  
broken crenulums & May be photo of sevance
Grains: 65% bioclastic
Size: 88-500µm (very fine to med. sand) ~ about 3% of coarse grains, crinoid -- subangular to rounded. Some well rounded
Sorting: moderate to poor
Composition: 97% 0.49% (some, very few amorphics)
3% silicified: K-feld - 1%, (clear, or sericitized)
microcline - 3% (clean)
pelite  - 3% (mostly clean)
plagioclase - trace
Micaceous clay - fine 1%
Muscovite - trace, muscovite - trace
clear, muscovite may heucite - 2% (oxidized or altered layers)
(zircons)  - trace (subrounded)
95% - trace (stretched)
clasts: trace

PP 415  
This slide has too much carbonate replacement.
40 - 50% grains, remainder in carbonate (mostly calcite/ dolomite)
Grain composition includes:
95% orth.
3% pelite, clean - 2%
3% pelite, trace - 2%
4% dolomite, traces of some chlorite < 2%
clasts: trace
Dolomite? - trace
Chert? - trace
KP 450

Grains: 6.5%
- Size: 62-32 μm (very fine sand); 1% 250-350 μm (medium sand)
- Shape: subangular to angular
- Sorting: moderate-
- Composition:
  - clay: 52% (poles, some smectite)
  - silt: 6% (little clay) =
  - mica: 1% (clean)
  - feldspar: 1% (clean)
  - quartz:
  - plant:
- Granule size:
  - presence:
  - diatomite:
  - mica:
  - tourmaline:

PP 195

May be good clay sample (enserite)

Grains: 6.5%
- Size: 62-32 μm (very fine sand)
- Sorting: moderate
- Shape: subangular to angular
- Composition:
  - clay: 54% (smectite)
  - silt: 6% (clayey)
  - diatomite:
  - mica:
  - tourmaline:
  - quartz:
  - plant:

Matrix: 35%
- Composition:
  - phosphorus: 10%
  - carbonate: 26%
  - silicon: 5%
PP550

Grains: 70%

Size: 125-172 μm (three to four powders)
Shape: subrounded to subangular
Sorting: moderate
Composition: 91% - 59% (some powders)
4% quartz, 8% feldspar: 70% (silt, sand)
2% mica, 3% (clean)
1% other
Zinc: trace (subangular)
Fur: trace
Mg: trace
Biotite: trace

PP610

Good day sample

Grains: 65%

Size: 62-125 μm (very fine sand)
Sorting: moderate
Shape: subangular to subrounded
Composition: 95% (quartz)
5% feldspar, 5% (some montmorillonite)
Mica: 2%
Muscovite: 1%
Biotite: trace
Precipitate: 1%
Plagioclase: 24%
(Quartz) 1%
Limonite: 1%
Zinc: trace (subrounded)
Chert: trace
3.5%
PP650

May be good clay sample

Grains: 65%
- size - 62-125 µ (very fine sand) also some fine sand
- sorting - moderate
- shape - subangular to subrounded
- composition - qtz - 50% (quartz, muscovite)

7% sand-sized,
- K-feld - 4%
- muscovite - 1%
- biotite - 1% (altered to hornblende)

trace trace
- no oxidized grains (magnetite - 1% (slightly dirty)
- zircon - trace (subrounded) none close - 1% (some muscovite) slightly dirty)

Matrix: 35%
- composition - sericite - 35%
- feldspar - trace
- quartz - 2%
- biotite - trace

PP700

Take photo of "very thin muscovite"

Grains: 65%
- size - 88 to 177 µ (very fine to fine sand)
- sorting - more clastate
- shape - subangular to subrounded
- composition - qtz - 50% (quartz, muscovite)

5% sand-sized,
- K-feld - 10%
- biotite trace
- muscovite trace
- zircon trace (subrounded) perthite - 2%

trace trace
- muscovite - 1% (some muscovite) (some thin muscovite)

Matrix: 35%
- composition - sericite - 35% (some feldspar)
- feldspar - trace
- biotite - trace
PP 202
Take photo of unaliquoted microlite.
(Good sample for clay)
Grains: 65%
size - 88 - 177 µ (very fine to fine sand)
sorting - moderate
shape - subrounded to subangular
composition - 97% (poly, overgrown some)
4% quartered - K-feld - 7% (overgrown)
cheet - trace
tourmaline - 2% (overgrown - more altered than grain)
zircon - trace (round)
barite (in heavy) - 1%
perthite - 1% (clean)
matrix - (nearly loose)
Natri - 35%
composition - sanidine - 35%
quartz - trace
feldspar - trace

PP 210 Slide too thin, not stained
Grains: 65%
size - 88 - 350 µ (very fine to medium)
shape - subangular to subrounded
sorting - moderate to near
composition - qz - 57% (poly, somewhat stretched)
or th - 5% (dirty grains)
tourmaline - 2% (clean)
perthite - 1% (clean)
musc - trace
cheet - trace
tour - trace
Natri - 35%
sanidine - days
PP 969

Grains: 60%
size: 62-125 μm (very fine sand); 250-35 μm (med. sand)
sorting: moderate
shape: subangular, some subrounded
composition: 47% pyg. ( qty)
3% sensitized.
K-feld - 6% (clean)
wt. mus. cl. - 2% (clean); m.pthite - 1% (clean)
trace
in mass: mus. - 1% (smashed into pseudomorphs)
biotite - trace; zircon - trace (subrounded)

Matrix: 40% < sericite
composition: --

PP 950  Slide not stained

Grains: 70%
size: 88-17 μm (very fine to fine sand); a few med. grains
sorting: moderate to poor
shape: subangular
composition: 56.1% pyg. some: muscovite, brown
orth - 61% (highly sericitized)

2% hematite
in mass (poor)
cheat: 2%

biotite - 1% (clean)

mus. - 21%

trace

biotite - trace; hematite (calcined to hematite)

trace

Matrix: 30%
composition: sericite - 30%; hematite - trace
DP 1000

65%

Grains:
size: mainly 90-120µm; less of 250-350µm (medium sand)
sorting: poor
shape: subangular to subrounded
composition: 97% felsic (very few enclaves)
3% hematite: 1% FeO (clean)

muscovite: minor; 2% (clean); plagioclase - 1%+ (clean)
(tour)

Diaginite: trace
tour: trace (approaches 1%)

Ilmenite: trace (rounded)

Matrix 35%

composition: sericite 35

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DP 1150

Grains: 60% F/L = 15
size: 6-25µm (very fine to fine sand) and 350-141µm (med. to coars)
sorting: poor
shape: large grains (rounded to well-rounded), small grains (subangular)
composition: 93% felsic (polygons: some stretched
orthoclase 8% (dirty, weathered) grains)

2% hematite (weathered)
(granite - 2% (course grained), illite 1%)
potash - 1% (clean)

more than about four (med. sand grain)

more than 2% (clean)

tour: more green, more (weathered)

Hematite: 50%
sericite: 37%, calcite: <1%, hematite: 2%
RP 1240

Grains: 65%
- Size: 28 - 100 um (very fine to coarse sand) (bimodal)
- Sorting: poor
- Shape: large grains are rounded, small grains are subangular to subrounded
- Composition: 97% (clean or slightly weathered)
- Some heave... some clay, 2% (clean)
- 97% texture: 2% (clean)
- Granule lag: 1% (F = c)
- Quartz: trace
- Trace chalk: 1%
- Nature: 35%

RP 1250

Grains: 70%
- E/A = 12
- Size: 0.6 - 3.5 cm (very fine to medium sand), 350 - 20 cm (coarse to very coarse)
- Sorting: poor
- Shape: large grains (rounded to well-rounded), small grains (subrounded)
- Composition: 95 - 53% (clean or slightly weathered)
- 93% texture: 1% (clean)
- Some heave... some clay, 2% (clean)
- Granule lag: 1% (clean)
- Granule lag: 1% (clean)
- Surface: 1% (clean)
- Nature: 30%
- Concretion: some 2.7% (clean, medium to coarse)
Grains: 70%

- Size: 62-13μm (very fine sand) -/very fine sand
- Sorting: moderate
- Shape: subangular to angular
- Composition: 94% - 60%
- 2% scattered
- K-feld: 4%
- Perthite: 37% (crescent)
- 1% opaque (mainly mica)
- 1% corundum (mainly muscovite)
- Zircon: trace (sub-rounded) tour - near biotite - ±1% ( altered hematite)

Matrix: 30%

- Composition: 74% - 15% (mainly "silty")
- Hematite: 15% (patchy) (main intergranular w/ siltate)

PP 1345

PP II 71 (1416)

Take photo of "granite" close. Photo of chest?

Grains: 70%

- Size: 177-71μm (mainly coarse sand), 71μm -280μm (mainly very coarse sand)
- Sorting: poor
- Shape: subangular (small grains), rounded to well rounded (large grains)
- Composition: 97% - 55% (a few small anhydrous phases) (feldspar) ± 12 -feld: 6% (structured) (some are stretched)
- Tour - trace: 1% (slightly curved)
- Pyroxene: 2% (slightly stretched)
- Granite flag: 3% (main: e.g., quartz, biot)
- Mica - trace - approx. 1%
- Zircon - trace (sub-rounded) large grains, also interstitial

Matrix: 30%
PP II 82 (1427')

**Grains:** 63%
- **Size:** 588 sqµm (very fine to medium sand), 710-230 µm (coarse to very coarse)
- **Sorting:** poor
- **Shape:** small (subangular to subrounded), large (rounded to well rounded)
- **Composition:** quartz - 97%, 54% (clay of grains), 5% highly degraded, 14% well cemented
- **Mica:** 2%

**Matrix:**
- Composition: quartz - 35%, Feldspar - trace

PP II 84 (1429')

**Grains:** 63%
- **Size:** 588-250 (very fine to fine sand), 50-250 µm (coarse to very coarse)
- **Sorting:** moderate
- **Shape:** small (subangular to subrounded), large (rounded)
- **Composition:** quartz - 97%, 54% (clay of grains), 5% highly degraded, 14% well cemented
- **Mica:** 3%

**Matrix:**
- Composition: quartz - 35%, Feldspar - trace
- Mica - trace

**Variation:**
- No apparent
- No mica
- No silt
- Trace of mica cement (clear)
- Trace of mica in quartz (clear)
- Trace of mica in quartz (partly altered)
PP II 15c (1498)

Grains: 50% (original was light)
- size: 88 - 172μ (very fine to fine), 350 - 200μ (mod. to very coarse sand)
- sorting: poor
- shape: small (subangular), large (rounded to subrounded)
- composition: 93% (some amorphous), pebbles, flakes, chert
- matrix: 2% (clean)
- opaque (1%) may occur
- 17% more time
- w/ matrix grain: K-feldspar 4%
- 4% muscovite, biotite, calcite, clays, fine-grained, w/19.72 and 40%
- Matrix: 50% (original pred. laven)
- composition: calcite, 50% (mod. size)
- matrix: trace quantity (trace)

ROCK CREEK

Grains: 75%
- size: 88 - 250μ (very fine to fine sand)
- shape: subangular to subrounded, some rounded
- sorting: moderate
- composition: 93% (some amorphous), pebbles, flakes, chert
- 24% cemented
- K-feldspar 7% (clasts, segregation)
- muscovite 2% (clean, slightly cloudy)
- quartz, rock fragments 2% (slightly cloudy)
- poikiloblastic 1% (clean, in situ clasts)
- muscovite 1% (biotite)
- chloride 1%
- zircon 1%
- quartz 1%

Matrix: 25%
- cement 1% (mod. quartz, feldspar, calcite)
- matrix 1% (subangular, angular)
RC 26

Haybye try to find s.s. flag for test site.

Grains: 70%
- Size: 172 - 100 um (fine to coarse sand) w/175 grains of very coarse shapes, subrounded to rounded
- Sorting: poor
- Composition: 45% - 62% (polymorphous grain, angular)
- 3.2% silted
  - 14% - 5% (some clay, some silted)
- Petro: - 4% (slightly dirty)
- Matrix: - 1% (clean)
- Plays close - They (dirty)

We found:
  - Granite frags - 1% (clean, highly weathered, fine and medium grade)
  - Muscovite - 1%
  - Zircon - trace

Difficult to define: Chert - none
- Gran. bonded - 55, 75, 11 gm. (fine and medium) has poly. S.

RC 53

Double muscovite, recrystallized grain. &

Grains: 75% +
- Size: 62 - 125 um (very fine sand), 250 - 425 um (medium to coarse sand) (5% silted)
- Shape: subangular - subrounded, subrounded, less rounded
- Sorting: poor

Composition:
- 60% (some polymorphous, double muscovite, omphacite amphibole)
- 95% sericite + biotite - 10% (clean or slightly)
- Muscovite - 5% (clean, slightly)
- Petro: - 5% (clean, slightly)

May be inter more than trace
- Chart: none
- Zirr cone trace (ambedial?)
- Haste: How
  - Biotite: 10% (beta altered may be undetermined)
  - Muscovite frags fine - 1% (med.) w/ zirr, 17th
RC 268

Grains: 75%
Size: 62-155 m (very fine sand) and 500-52100 m (coarse to pebbles)
Shape: subangular to subrounded
Sorting: moderate
Composition: ph - 62% (clean or subclean),
        K-feld - 8% (clean or slightly dirty),
        mica - 1% (clean or slightly dirty),
        plagioclase - 1% (clean or slightly dirty),
        tour - tour,
        musc - 1% (clean or subclean),
        hematite - hematite,
        clay - 2% - 1%,
        mag - magnetite.

RC 316

Grains: 65%
Size: 62-155 m (very fine sand) and 500-52100 m (coarse to pebbles)
Shape: subangular to subrounded
Sorting: very poor
Composition: ph - (subclean to subclean),
        K-feld - 10% (highly rounded or clean),
        mica - 2% (clean or slightly dirty),
        tour - tour,
        plagioclase - 1% (clean or slightly dirty),
        hematite - hematite,
        clay - 2% - 1%,
        musc - musc,
        magnetic iron (subclean),
        mag - magnetite.

RC 348
broken round grain

Grains: 75%
Size: 3.8 - 7.1 mm (very fine to coarse sand)
Shape: subrounded to angular and well rounded
Sorting: moderate to poor
Composition: feldspar - 5% (may be some pale, may be none)
2% muscovite
plagioclase - 1% (dark gray, somewhat)
zoisite - trace (angled or rounded)
biotite - tiny flakes

Glauconite: 1% Na. muscovite: 2% muscovite: 1% (mostly muscovite)
chlorite: 1%
granite felsite: 1% (gneiss and gneiss intersect with)

RC 375
maybe some rounded broken grains

Grains: 75%
Size: 6.2 - 250 m (very fine to fine) and 350 - 710 m (med - coarse)
Shape: subangular-subrounded, rounded to subrounded
Sorting: poor
Composition: feldspar - 55% (very few, a few small overgrowths)
<2% muscovite
12% feldspar: 10% (clean, slightly sodium)
plagioclase: 1% (clean)
muscovite: 2% (partly clean)
plagioclase: 1% (light greenish)
mask: 2%
biotite: trace (attenuated biotite)
pyrite: 2% (reddish-brown)
granite felsite: 1% (gneiss and gneiss)
chlorite: 1%
RC 402

Grains: 75%  
Size: 1.25 - 1006 (RC) of a few 1000 - 1410 (very coarse) sand in the  
Shape: subangular to subrounded; larger grains are rounded  
Sorting: moderate to poor  
Composition: quartz - 63% (euhedral)  
(2%) rounded  
K-feldspar - 7%  
Muscovite - 1% (prettily clean)  
Plagioclase - 5% (pale, clean)  
Plagioclase - two (angular)  
Granite fragments - 2% (angulated, plagioclase, dark biotite)  
Feldspar (clay) chart - fine. (not many grain sizes. fine and coarse)  
Muscovite - 2%  
Biotite - two  
(2%) fine (shattered)

RC 423  
Photo of granite, sandstone, phyllite

Grains: - 0%  
Size: 350 - 1000 mm (met sand to pebbles)  
Shape: subrounded and rounded  
Sorting: very poor  
Composition: granite - 85% (granite, clast)  
K-feldspar - 5%  
Muscovite - 2% (clean)  
Plagioclase - 1% (dirty, ser.)  
Biotite - 1% (sericitized and chalcy)  
Chart - 1%  
Muscovite - two  
Feldspar - two  
(2%) two (18 - 750 mm crimp) (hazy, natural)  
Plagioclase - 5% (500 - 750 mm, partly altered fresh grains)  
Sediment debris - 1-2% (6.8 mm grains)
RC 450  sticks too thin

Grains: 80%
  size: 250 - 700µm (med sand to pebble)
  shape: subrounded and rounded
  sorting: poor
  composition: Fb - 67% (some mica)
  K-feldspar - 8% (clean, very strained)
  plagioclase - 16% (clean)
  olivine - 1% (clean)
  other trace: (granite, basalt)

Matrix: 28% (light, new, partly bleached), semi- to fine cement

RC 499

Grains: 75%
  size: 250 - 710µm (med-sand, 1/2000 - 700µm, very coarse to pebble)
  shape: rounded to subrounded
  sorting: poor
  composition: Fb - 67% (one large amphibole, some mica)
  K-feldspar - 12% - 21% (very strained)
  plagioclase - 1% (clean)
  olivine - 1% (clean)
  other trace: (granite, basalt)

Matrix: 15% (light, new, partly bleached), semi- to fine cement
**Willow Creek**

Grains: 60%

- Size: 88-232 μm (very fine to very coarse sand)
- Shape: sub-rounded to rounded
- Sorting: very poor
- Composition: quartz 55%, feldspar 10%, heavy minerals 5%

- K-feldspar 3%
- One large euhedral grain (small).  
- Microlite, hite (chert) small grain.
- Plagioclase, hite (cleat) small grain.
- Qtz, feld 2% (mostly 50-70 μm, some up to 85 μm).
- Mica laths 5% (red and some small ejected).
- Chert, hite, chert (ammonite, cleat).
- Granite, chert, chert (ammonite).

**Winton**

Grains: 70%

- Size: 177-719 μm (fine to coarse sand)
- Shape: sub-rounded to rounded
- Sorting: poor to moderate
- Composition: quartz 65%, feldspar 3%

- K-feldspar 2%
- One (euhedral) sandstone, quartz.
- Plagioclase, hite (chert), sanidine.
- Qtz, feldspar (coarse grains).  (stretched)
- Rock fragment, sub-angular (too thick), 2%
- Chert, decussate (large, sub-rounded), abundant (1%)
- Tiny quartz grains.
- Granite, feldspar (ammonite), quartz, rare.

Matrix: 30%
Grains: 65% 
Size: 62 - 0.05 μm (very fine sand) to 710 - 100 μm (coarse sand) 
Shape: subangular to angular (rounded & well rounded) 
Sorting: very poor - 54% 
Composition: 9% - (some angular) 
5% dirt: 12% - 5% (mostly dirt or a large % in altered) 

Plagioclase: 3% opaque (trachy - magnetite) 
Silica: felsic - felsic 
Quartz: 1% (some mica filled): granite: felsic 
Plagioclase: felsic (dirty) 
Zircon: trace (subrounded) almost euhedral 

(Totally made of coarse grains - felsic, biotite, and quartz) 

Grains: 65% 
Size: 62 - 0.05 μm (very fine sand) to 710 - 100 μm (coarse sand) 
Shape: subangular to angular (rounded & well rounded) 
Sorting: very poor - 54% 
Composition: 9% - (some angular) 
5% dirt: 12% - 5% (mostly dirt or a large % in altered) 

Plagioclase: 3% opaque (trachy - magnetite) 
Silica: felsic - felsic 
Quartz: 1% (some mica filled): granite: felsic 
Plagioclase: felsic (dirty) 
Zircon: trace (subrounded) almost euhedral 

(Totally made of coarse grains - felsic, biotite, and quartz)
Grains: 80%
size: 125-710μm (fine to coarse sand)

shape: sub-rounded (smaller grains); rounded - well-rounded (larger grains)
sorting: poor

composition: quart - 70% (det eroded, many rounded) (polyangular)
1/2 - 2% (dirty), ≤1% not channel = long grain (round)

most do not stain?!

Zircon - trace
Tour. Tour. Sca. Trace ≤1% (some megagran, granitoids)

may have:
Zircon - trace
Tour. Tour. Sca. Trace ≤1% (some megagran, granitoids)

Grains: 6.5%
size: 62-50μm (some mixed, some in separate layers) (smaller grains, large grains)
shape: sub-rounded

sorting: poor in some layers, moderate in others

composition: ⊕ 58% (some ungrained, some circular)

2% actually so 1/2 - 2% are tour.

peg. trace (partly dirty)

magnetite trace (dirty, slates)

Tour. Tour. Sca. Trace ≤1% (some wet sand grains) (some highly saturated)
magnetite (1%) scattered

some 1%

Zircon - trace

chart. trace (maybe sand?)

Photo of clastic micrite, uncarbonated, Pliocene, basin. No. 1
200

Grains: 75%
size: 62-100µm (very fine to coarse sand)
shape: sub-rounded to rounded (small grains), rounded to well rounded (large grains)
drilling: poor
composition: %
- 12-field ≤ 15% stained, 25% (average)
- pectate ≥ 3% (dirty; dirt doesn't stain)
- reidolite (slightly dirty)
- air-cured (well rounded, brown)

TRF: looks like tour, may - tour, may - tour
in 1/1 chart: ≤ 1%
grains: tour (pure) grains, tour (fine and gravel)
tour
sedimentary rocks?

250

(Tiny pieces of grains/tour!! - average 1mm, 1/100)
Grains: 60%
size: 125 to 500µm (fine to medium sand)
shape: sub-rounded to rounded (well rounded)
drilling, moderate to poor
composition: %
- 12-field 3% (slightly dirty)
- pectate ≥ 1% (slightly dirty)
drain - trace

TRF: 0.3% (gray/white - green tour) tour
tour (green)
photo of photo, numbered pyramids.

Grains, 65%
- size: 0.2 - 1.0 mm (very fine to coarse sand)
- shape: subrounded to rounded
- sorting: poor
- composition: organic 9%
  - kaolinite: 15% (detrital)
  - clay: 10% (detrital)
- foreign material
  - mud chips (organic, silt, clay): 2%
  - nodule: 5%
  - (root) (tree) (shale)

Grains, 75%
- size: 0.2 - 2.0 mm (very fine to medium sand)
- shape: subrounded to rounded
- sorting: moderate
- composition: clay 58%
  - kaolinite: 10%
  - illite: 10%
  - mixed layer (sericite (sericite), chlorite (sericite)
  - opaque (1%) (magnetite)
- impurities
  - (root) (tree) (shale)
  - (root) (tree) (shale)
  - (root) (tree) (shale)
  - (root) (tree) (shale)

T2F, very small (tree)
### W 380

**Photo of 95% grains**

- **Grains:** 65%
- **Size:** 0.2 - 1.00 cm (very fine to coarse sand)
- **Shape:** rounded to well-rounded
- **Sorting:** poor

**Composition:**
- Quartz: 54%
- Felspar: 3%
- Clay: 11%
- Sand: 2%

- Micrite: trace
- Pentrite: trace
- Granite: trace (clean)
- Gneiss: 1% (light green)
- Gypsum: 1% (gray - green)
- Ferrugineous: rounded (trace)
- Plagioclase: trace (clean)

**Total:** 97%

**Lost:** 3%
W 500
Grains: 70%
Size: 62-500μ (v. fine to med. sand mostly non-laminar)
Shape: sub-rounded to subangular
Sorting: medium to poor
Composition: quartz - 57%
K-feldspar - 8% (clean)
Potash feldspar (dirty)
Quartz - trace
Chert - 2%
Pyrite - trace
Muscovite - 1%
Tourmaline - trace
Zircon - trace

W 515
Grains: 75%
Size: 677-710μ (fine to coarse sand)
Shape: rounded to well rounded
Sorting: poor
Composition: quartz - 67% (±10% rounded largely non-laminar)
K-feldspar - 2% (clean)
Potash feldspar (clean) (some slightly dirty)
Muscovite - 1% (clean)
Tourmaline - trace
Pyrite - trace
Zircon - trace (sub-rounded, rounded)
Chert - 1% (some with chalcedony)
Pyrite - trace
Biotite - trace (sub-hedral, hemimorphic)
WC 270

WOOD CREEK

Grains: 65%
size: 62-125µ (very fine sand)
sorting: moderate
Shape: subangular to angular
composition: 92-45%

12-feldspar 10% - pretty fresh (some slightly dirty)
plag. = 1%

some very rounded micro-fossils

opaque (red) clay, under 170 wave: trac
chest (and/or siltite grains) - 1%
perthite: trace

(Hopeful good clay sample)
(take photos of reworked (broken) grains!)

WC 295

Grains: 65%
size: 62-125µ (very fine sand), w/177-56µ layers of sand (fine-med)
Sorting: moderate

shape: subrounded/subangular, subangular, subrounded, afwround.
Composition: 94 - 56%

K-feld: 97% - pretty clean (hard to tell from plagi)
plag. - 5% overgrowth (reworked?)(some loss, some)

trace

perthite: 1% - little dirty

pepl.: trace, mostly very fine grained
siltite: trace; biotite: trace; chlorite:

Matrix: 35%
Composition: 11111 - (aligned) - 35%
WC 310

Grains: 70% (Fine sand)
size = 62-125μ (very fine sand), about 12000 grains/25-177μ
sorting -- moderate to well
shape -- subangular to angular, some large grains subrounded
composition -- quartz - 49%, plagioclase, feldspar, clay, etc.
K-feldspar: 15%
plagioclase: 15%
feldspar, alkali feldspar, etc. (esp. K-feldspar)
microlite: 15%
trace
trace
trace
trace
Zircon: trace, (very small, round)
mud chips (coarse-grained): 5%
(over)

WC 330

Grains: 65%
size = 62-125μ (very fine sand)
sorting -- moderate
shape -- subrounded to angular, some large grains subrounded
composition -- quartz: 54%
K-feldspar: 15% (sericite)
plagioclase: 15%
microlite: 15%
trace
trace
trace
trace
trace
trace
trace
trace
trace
Zircon: trace, (very small, round)
Muscovite?

Nature: 35%
tourmaline (light yellow, green)
(over)
WC 350

Grains: 60%
size: ≤ 62-80 μm (silt + very fine sand)
sorting: moderate
shape: subangular
composition: qfj: 48%
K-feld: 10%+ (quartz altered, sericitised)
plag.: trace
musc.: 2%
musc.: trace
clay: 2%
cement: trace (very fine-grained) 40%

Matrix: 40%
composition: red mud 40%

WC 360

Grains: 65%
size: ≤ 62-80 μm (silt + very fine sand)
shape: subangular to angular
sorting: moderate
composition: qfj: 41.9%
K-feld: Bt+ (3/4 in clean, 1/4 fairly dirty)
plag.: trace
musc.: ≤ 1%
biotite ≤ 1% and chlorite
cement; trace
clay: trace (one large grain of brown or green together) 35%

Matrix: 35%
Grains: 70%
size: ≤ 62, 82 μm (silt to w.c. sand) + 350-1000 μm (m, s.c.) w/ 62-125 μm
shape: subangular to angular
sorting: moderate
composition: Qtz - 58% (amorphous)
musc. - 13% (amorphous)
rialite - 1%
chlorite - 1%
opal - 2%
Musc. - 13% (amorphous)
Musc. - 13% (amorphous)
plag. - 13% (amorphous)
K-feld. - 10% (amorphous)
clay - 1%
matrix: 30%

Claystone?

Wc 390
Grains: 70%
size: 62-125 μm (very fine sand)
shape: subangular, subrounded
sorting: moderate
composition: Qtz - 57% (amorphous)
K-feld. - 13% (amorphous)
Plag. - 13% (amorphous)
musc. - 13% (amorphous)
clay - 13% (amorphous)
matrix: 30%

Wc 370
Grains: 70%
size: ≤ 62, 82 μm (silt to w.c. sand) + 350-1000 μm (m, s.c.) w/ 62-125 μm
shape: subangular to angular
sorting: moderate
composition: Qtz - 66% (amorphous)
K-feld. - 2% (amorphous)
musc. - 13% (amorphous)
calci. - 13% (amorphous)
talc - 13% (amorphous)
matrix: 30%
Grains: 70%
Size: 6.1 - 8.8 μm (very fine sand)
Shape: Subangular, subrounded
Sorting: Moderate (layer along edge is very poor - see comments)
Composition: Quartz = 55% (average)
+2% detrital K-feldspar - 12°
Mica = 1% (average) - Fairly clean
Opaque = 1%, magnetite, in partite - 2% (average) - dirty
Crude layers
Chert = 1%
Zircon = trace, biotite - trace, chlorite
Silicate = 1% - trace
Plagioclase - trace
Diagenesis
Matrix: 30% calcite, 2%, hematite - 20%, feldspar - 3%, pyrite - 5%
WC 4180

Grains: 60.65%  
size: $\leq 6.2 \cdot 10^{-3}$ m (silt to very fine sand)  
shape: subangular to angular  
sorting: moderate  
composition:  
- $qf$: $\sim 50\%$ (small angularite)  
- $k$-feld $10\%$ (slightly cloudy)  
- plagioclase - trace  
- mica $2\%$  
- biotite $1\%$  
- chlorite $1\%$  
- chl $2\%$  

Glauconite $? \%$  
- mica $2\%$  
- chlorite $2\%$  
- tour. - trace

WC 4191

Grains: 70%  
size: $\leq 6.2 \cdot 10^{-3}$ m (silt to very fine sand)  
shape: subangular to angular  
sorting: moderate  
composition:  
- $qf$: $\sim 60\%$ (angularite)  
- $k$-feld $7\%$  
- biotite: trace (very small grains)  
- opaque: trace  
- mica: trace  
- chlorite $2\%$  
- plagioclase: trace (afters)  
- mica + tour. + (highly altered)  
- tour. + tour. + (quartz)  

(color)
WC 515

Grains: 75%
- Size: ≤ 0.05 mm (silt to very fine sand)
- Shape: subangular to subrounded
- Sorting: moderate

Composition: 67% (clayey silt) - 4% (plastic clay)
- Micas - free
- Opaque - free
- Quartz - free (clean)
- Feldspar - free (clean)
- Chert - free - 1%

(continued)

WC 520

Grains: 70%
- Size: ≤ 0.2-0.5 mm (silt to very fine sand) - 350 - 50um (mod. s. mud)
- Shape: subangular to angular
- Sorting: moderate

Composition: 57% (clayey silt) - 4% (organic matter, very coarse, thin)
- Micas - free (plastic clay)
- Opaque - free
- Quartz - free (light gray, clean)
- Feldspar - free (clean)
- Chert - 1%; mud-chips - 37%
Grains: 70%
- Size: 62-78 μm (slightly fine sand)
- Shape: subangular, subrounded (maybe some rounded)
- Sorting: medium
- Composition: quartz - 58%
  - K-feldspar - 10% (gritty clinopyroxenes, some altered)
  - Plagioclase (clay)
  - Muscovite - trace
- Tourmaline (grain boundaries outlined in section)

Glaucophane - trace
- Biotite - 10% and chlorite
- Chlortite - 14%
- Pseudomorph - trace zircon - trace

 WC 530

(Take photo of granite)

Grains: 75%
- Size: 88-125 μm (very fine sand) 1000-1400 μm (very coarse sand)
- Sorting: very poor
- Shape: subrounded to subangular
- Composition: quartz - 60%, some feldspar
  - K-feldspar - 10%
  - Granite fragments - 3% (med grained)
  - Muscovite - 7%
  - Biotite - 1%
- Zircon - trace (rounded) K-feldspar

Matrix: 25%
- Composition: quartz - 20%, K-feldspar 5%
- Difficult to tell if because so well compacted and cemented
**West Glacier**

Grains: 65%
- Size: 62-125 μm (very fine sand)
- Shape: subangular to angular, some are subrounded
- Sorting: moderate to poor
- Composition: quartz - 53% ( alot of amorphous)
- 2% sericitized feldspar-7% ( alot of thin amorphous, part of quartz)
- mica - 1% ( not too dirty)
- opaque (13%) - magnetite, plagioclase - trace ( pretty dirty)
- heavy minerals (16% - perthite - 19% (dirt) very dirty)
- Zircon - trace ( subrounded), rounded
- tourmaline - trace ( brown to green grain), bluish green
- biotite - trace, chlorite - trace

**WG 19**

Grains: 75%
- Size: 85 - 250 μm (fine to medium sand)
- Shape: subangular to subrounded (some rounded)
- Sorting: moderate to poor
- Composition: quartz - 60%
- 3% hematite-coated K-feldspar - 6% dirty (amorphous)
- mica - 19% + dirty (aragonite)
- opaque (trace) - magnetite - trace, pretty dirty
- heavy minerals - trace, pretty dirty
- tourmaline - trace
- Zircon - trace (rounded, subrounded)
Grains: 70%
Size: 88 - 710 μm (very fine to coarse s.s.)
Shape: rounded to sub-rounded
sorting: poor
composition:
- 60% (spheres)
- 12 - 15% (may be aggregates due to weathering or rounded by eddy)
- 10 - 15% (rounded grays & browns, subangular)
Valc. Silt:
   - 10% (rounded s.s. to subangular)
   - 5% (sub-rounded)
Zircon: trace (sub-rounded)

Grains: 75%
Size: 88 - 770 μm (s.s. < f.s.) layers: 250 - 50 μm (med. f.s.) layers
Shape: sub-rounded to rounded (fine grains a little more angular)
sorting: moderate to poor
composition:
- 95% 67% (spheres)
+5% altered
   - 12 - 15% (sub-rounded, pretty clean)
   - 10 - 15% (sub-rounded, pretty clean)
   - 10 - 15% (sub-rounded, pretty clean)
   - 10 - 15% (sub-rounded, pretty clean)
   - 10 - 15% (sub-rounded, pretty clean)
Mattice: 25%
Grains: 55%
size -- 62 to 710 µm (0.6 to 7.1 mm) -- mixed layers in mud
shape -- subrounded to rounded, smaller grains more angular
sorting -- very poor
composition:
opaque (1%) -- magnetite
in crude layers:
feldspar -- 17% -- (a little cloudy)
chert -- trace
muscovite -- trace -- chlorite -- (trace) -- green
circum -- trace -- (subrounded)
clay -- 17%
1% == granite (98% mud) (fine)

Grains: 70%
size -- ≤ 62-325 µm (slightly to very fine sand), ±-feldspar 177-250 µm grains (s. sand)
shape -- subangular
sorting -- moderate
composition:
feldspar -- 47% -- 55%
magnesite -- 10% (clean)
opal -- 1% (slightly cloudy)
opaque (trace) -- magnetite
limonite -- trace
zircon -- trace -- (slightly green, subangular, subrounded)
muscovite -- 15%
silicate -- 1% -- chlorite -- 1%

Note: No macronline found
WG 120

Grains: 70% T.R.F.; 30% granite.
Size: 62.5-710μ (very fine to coarse sand).
Shape: subangular to subrounded (some rounded).
Sorting: moderate.
Composition: 97% T.R.F.; 3% granite.

Granite: 2%. Fine (some angular).
Zircon: 1%.

WG 121

Grains: 50%
Size: 62.5-710μ (very fine to coarse s.s.)
Shape: subangular to subrounded (some rounded).
Sorting: poor.
Composition: 97% T.R.F.; 3% granite.

Granite: 2%. Fine (some angular).
Zircon: trace.
Chert: trace.
Mudchips: 1% (910μ).
Granite: 2%. Chlorite (trace).

Grains: 65%

- Size: 0.2 - 0.03mm (very fine sand), 0.02 - 0.002mm (fine sand)
- Shape: Subangular, Angular
- Sorting: Moderate
- Composition: 48% - 50% K-feld., 10% (pretty fresh)
- Pumice: 1% (clean)
- Magnetite, scattered: 1%
- Red mud chips: 1%
- Zircon: Trace (subangular, subrounded)
- Mica: Trace (clean) (subangular)

Unit: 160

Grains: 68%

- Size: 0.02 - 0.03mm (very fine sand)
- Shape: Subangular, Angular
- Sorting: Moderate
- Composition: 48% (amphibole)
- K-feld.: 5% (pretty clean)
- Pumice: 1% (clean)
- Magnetite, scattered: 1%
- Red mud chips: 1%
- Zircon: Trace (subangular, subrounded)
- Mica: Trace (clean) (subangular)
**Grains: 70%**
- Size: ≤ 0.2-3.0 μm (very fine sand)
- Shape: subangular to angular
- Sorting: moderate
- Composition: 75% (some small angular)
- K-feld.: 15% (angular feldspar)
- Quartz: trace (subrounded)
- Tour.: trace (green, subrounded, irregular)

**Opaque Minerals**
- Muscovite, scattered

**Grains: 75%**
- Size: 0.2-0.8 μm (very fine sand) ≤ 0.2-3.0 μm (medium sand) mud chips
- Shape: subangular to angular
- Sorting: moderate
- Composition: 55% (muscovite)
- K-feld.: 15% (muscovite, pretty clean)
- Quartz: trace (very clean, muscovite)
- Tour.: trace (green, subrounded, irregular)
- Mud chips: 1%
- Opaque (1%) molybdenite, scattered
- Muscovite, scattered
We 228

Grains: 85-70%  
size: < 0.2 mm  
shape: subangular to angular 
sorting: medium 
composition: 96.9% (muscovite)  
plagioclase 5% (diopside, anorthite) 
pyroclastics 1% (glass, crystal) 
cyanite, feldspar 
magnetite 
more 1% 
chlorite  1%  
red muscovite  5%