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Petrology and stratigraphy of Swift and Morrison formations near Drummond Montana U.S.A.

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PETROLOGY AND STRATIGRAPHY OF SWIFT AND MORRISON FORMATIONS, NEAR DRUMMOND, MONTANA, U. S. A.

By

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ABSTRACT

The Jurassic rocks near Drummond, Montana, consist of the Ellis Group and Morrison Formation. In this area the Swift Formation of Ellis Group can be divided into four vertical units which can be traced from place to place. They are (1) basal unit consisting of basal conglomerate, laminated sandstone with abundant pelecypods and shales; (2) cross-bedded sandstone; (3) laminated sandstone and shale and (4) glauconitic sandstone. The grain-size decreases from 0.22 mm at the base to 0.09 mm at the top. Common structures include: interference small scale ripples in basal unit, one set of asymmetrical ripples in glauconitic sandstone unit, small scale straight cross-beds in cross-bedded sandstone unit and laminations in the laminated sandstone. The constituent minerals are common quartz, 'pure' chert, clayey chert, silt-bearing chert, chalcedony, plagioclase, sedimentary rock fragments of fine-grained sandstone and claystone, occasional volcanic rock fragments, glauconite, heavy minerals - tourmaline, rutile and zircon, and quartz and calcite cement. Chert pebbles contain sponge-spicules and phosphorite inclusions.

Claystone grains, different types of chert and phosphorite inclusions in chert suggest that the source rocks of the Swift were claystone, cherty mudstone, siltstone, fine-grained sandstone, limestone and bedded chert probably of Phosphoria Formation of Permian age and Madison limestone of Mississippian age which underlie the Jurassic in this area. The source area might have been local and of low relief as indicated by sharp edged half spherical reworked quartz grains. Calcite cement and replacement of quartz by calcite suggest deep burial of sediments during diagenesis.

The Morrison beds are discontinuous, lenticular beds and can be vertically divided into five units, which are (1) basal unit of sandstone and shale, (2) massive sandstone, laminated sandstone and siltstone unit, (3) covered interval, (4) slabby sandstone and (5) finer-grained unit of fine-grained sandstone and several shales. At the top of Morrison is very coarse grained basal Kootenai conglomerate. The grain-size of Morrison sand grades from 0.20 mm at the base to 0.08 mm at the top.

The constituent minerals are similar to those in the Swift except that glauconite is absent and there are relatively more limestone rock-fragments, which suggest same source rocks as of the Swift. Sharp edged, half spherical quartz grains indicate little transport and local source area. Lenticular shape of the beds, gray shales and fresh water limestone in upper part of Morrison indicate non-marine deposits, probably in a low level basin. On filling of the basin, swampy conditions might have formed the carbonaceous shale. The iron-platings in yellowish gray shale overlying carbonaceous shale suggest oxidising conditions. Abundant illite (90%) in mixed layered illite-montmorillonite of Morrison shales suggests warm and arid climate at the end of Morrison which might have prevailed during the deposition of basal Kootenai conglomerate. Replacement of quartz by calcite indicate deep burial of Morrison sediments during diagenesis.

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INTRODUCTION

Jurassic rocks occur across much of Montana mostly in the subsurface, however, they are absent in the western part of the state. The westernmost exposures of Jurassic rocks are near Drummond, Granite County, Montana, where the Swift and the Morrison Formations overlie the Rierdon Formation. These rocks have been studied very little although the Jurassic rocks of central and eastern Montana and neighboring regions have been studied extensively. Among the previous workers on the Jurassic rocks near Drummond, the recent one is Kauffman (1962), who mapped the Garnet-Bearmouth area, measured one section of the Ellis Group and examined some specimens in thin sections.

The Swift and the Morrison which belong to the Upper Jurassic were studied during Spring, Summer and Fall of 1966. As this area is the westernmost exposures of the Swift and the Morrison in Montana, the petrographic study, aided by stratigraphy and clay mineralogy, might be helpful in understanding the distribution of sea during the Swift and geologic conditions existing at the time of deposition and possible source rocks for the Swift and the Morrison sediments in this region.

ACKNOWLEDGEMENTS

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REGIONAL GEOLOGIC SETTING

The Jurassic rocks studied in this thesis consist of two facies, a lower marine facies and upper non-marine facies of Upper Jurassic age.

The Jurassic rocks rest unconformably on the eroded surface of the Mississippian, Pennsylvania, Permian or Triassic rocks in western Montana.

A branch of Arctic or Boreal sea transgressed from the north across the Fernie basin ofCanada and covered a wide region of the Western Interior part of U.S.A. beginning during late Middle Jurassic. The paleozoic sea from the west had retreated and there was a major break in deposition from probably late Paleozoic to late Middle Jurassic and during that time older rocks of Mississippian, Pennsylvanian, Permian or Triassic were partly eroded. The positive element 'Belt Island' (Fig. I) controlled the distribution of the sea and restricted water circulation during the deposition of the Ellis Group. The effect of Belt Island decreased after the deposition of the Rierdon sediments due to widespread marine transgression. During the deposition of the Swift sediments, the effect of Belt Island barrier decreased south and south-east of this area. Peterson (1957, Fig. 17, P. 432) suggests that the northern and southern seaways may have been connected west of Belt Island and that currents may have flowed northward through the narrow passageway during Swift deposition.

PROBABLE CURRENTS in the SWIFT SEA

TABLE I

PERIOD	SERIES	DRUMMOND AREA	LOCAL LITHOSTRATIGRAPHIC UNITS
JURASSIC	Lower Cretaceous	Kootenai Formation	
	Upper Jurassic	Morrison Formation	5. Finer grained unit. 4. Slabby sandstone unit. 3. Covered interval. 2. Massive sandstone, laminated sandstone and siltstone unit. 1. Basal unit.
		Swift Formation	4. Glauconitic sandstone. 3. Laminated sandstone and shale. 2. Cross-bedded sandstone. 1. Basal unit.
		Rierdon Formation	
	Middle Jurassic	Sawtooth Formation	
	Upper Permian	Phosphoria Formation	

LOCATION OF MEASURED SECTIONS

Jurassic rocks of the area near Drummond, T 11N, R13 and 14W, of Granite County, western Montana are of Middle and Upper Jurassic age and are approximately 550 ft. thick. The stratigraphic column in Table I summarizes the divisions of the Jurassic rocks and their age in this area.

The Jurassic rocks of the Swift Formation, of the Ellis Group and of the Morrison Formation in this area, were measured and sampled in seven outcrop sections. The following five of the seven sections have been the most useful in studying the stratigraphy and petrography of these rocks.

Sr. No.	Name and Location	Section	Township	Range
1	'Bradman' Railroad section	21	10N	13W.
2	West Rattler Gulch section	9	11N	13W.
3	Southwest Rattler Gulch section	16	11N	13W.
4	Van Guran Gulch section	18	11N	14W.
5	William Gulch section	12	11N	14W.

The location of the sections is shown in Fig. 2.

SWIFT FORMATION

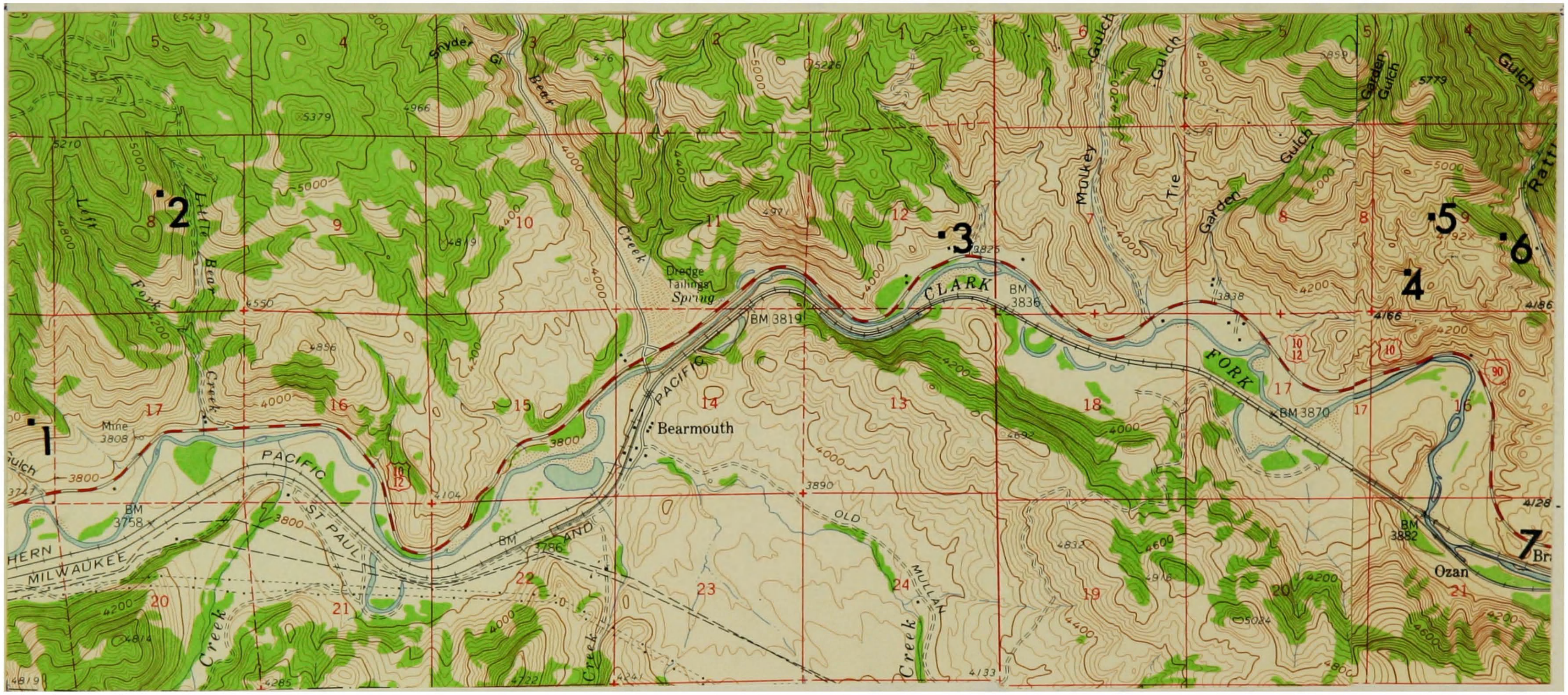
The rocks of the Swift Formation are continuous, uniform, fine-grained, sheet like sandbeds with shale interbeds in some places.

In the field it is possible to divide the rocks of the Swift into four units.

Basal Unit

The basal unit is relatively coarse grained and consists of basal conglomerate one foot thick and overlain by fine-grained sandstone with

Location of Measured Sections



Explanation

Number	Name of Section
1.	Van Curan Gulch Section
2.	Little Bear Creek Section.
3.	William Gulch Section.
4.	Southwest Rattler Gulch Section
5.	West Rattler Gulch Section.
6.	Rattler Gulch Section.
7.	Bradman Railroad Section.

Scale - 1:62500

Figure 2.

abundant pelecypods and wood-fragments. The sandstone which includes thin shale beds ranges in thickness up to 28 ft.

GEOMETRY

A thin, but uniform and continuous one foot thick conglomerate forms the base of the Swift. The conglomerate lies disconformably on the Rierdon Formation in this area. The contact between the underlying Rierdon limestone and overlying conglomerate at Railroad section is sharp and erosional though not angular, suggesting a break in deposition at least for a short time. The conglomerate contains rounded black chert pebbles, quartz sand, clayballs and calcite cement. Scattered chert pebbles also occur in the overlying bed up to four feet above the basal conglomerate. In the Railroad section and southwest Rattler Gulch section, there is still a higher conglomerate lense, from 3 ft. to 4 ft. above the base of the Swift.

Overlying the basal conglomerate is poorly laminated sandstone of varying thickness. The maximum thickness is 28 ft., which includes two shale layers at different levels in different sections. The sandstone contains abundant pelecypods, wood-fragments, clayballs and chert pebbles. The broken and scattered wood-fragements in the sand bed, might have been drifted and deposited along with the sand. There are two shale lenses in the William Gulch section and Bradman Railroad section. At William Gulch section, the shale lenses occur from 17 ft. to 19 ft. and from 24 ft. to 29 ft. above the base of the Swift while at Railroad section they occur from 7 ft. to 15 ft. and from 17 ft. 6 inches to 19 ft. 6 inches above the base. (Plate 1).

SEDIMENTARY STRUCTURES

The beds of the basal unit are internally conformable, continuous and of nearly uniform thickness except for the shale layers at William Gulch, and Railroad sections. The bedding planes are either planar surfaces or are ripple-marked.

Ripple Marks

Small scale asymmetrical interference ripples occur on the bedding plane of the laminated sandstone of this unit at 7 ft. from the base at Railroad section. The interference ripples trend N35°E and N20°W. The amplitude of the ripples is 2 inches to 2.5 inches and wave length is 4 inches to 5.5 inches (Fig. 3). Probably these were locally formed ripple marks and are not necessarily indicative of the regional current directions.

Laminations

Poorly visible laminations occur in laminated sandstone of this unit. The laminations might have been formed due to change in carrying capacity of the currents resulting into poor sorting, due to intermittant supply of material which resulted into frequent breaks in deposition, or due to deposition in the upper flow regime. The supply of material is not likely to change within a very short period of time. There are small scale, straight cross-beds in the sandstone beds of the overlying unit which suggest lower flow regime. Hence, probably, the laminations might have formed due to change in the carrying capacity of the currents.

MINERALOGY

The types and percentages of the minerals of the basal unit as determined from point counts of about 300 grains in each of fifteen thin sections are described below.

Figure 3. Interference asymmetrical ripples on the Swift sandstones at 7 feet from 'Bradman' Railroad section.

Quartz

Quartz is the most abundant mineral of the rocks of this unit and ranges from 17% to 34%. The grains are fine, subequant to subelongate rounded and submature. Some of the rounded quartz grains are sharply broken in half, the sharp edges of which are not rounded off, (Fig. 5).

There are very few inclusions in the quartz grains. Occasional vacuoles filled with gas are scattered or form short lines. The quartz extinction is straight. In some quartz grains, reworked overgrowths can be identified by curved lines of clay included in the quartz grains. Rutile needles and small, round or prismatic crystals of tourmaline also form inclusions in the quartz.

According to genetic classification of quartz, (Folk, 1965, p. 70) these quartz grains are of common quartz. On the basis of secondary overgrowths developed in optical continuity, the quartz grains can be divided into four groups:

(1) Well-rounded grains with no overgrowths, (Fig. 4).

(2) Well-rounded but sharply broken grains having no overgrowths. (fig. 5).

(3) Rounded and broken grains with reworked overgrowths.

(4) Angular and subangular grains due to euhedral or subhedral overgrowths of quartz cement in which the original grain boundaries cannot be identified, (fig. 6A and 6B.)

Chert

Chert really consists of the small granules of crystalline quartz but is described separately as it is considered here to be a monomineralic rock-fragment. It forms one of the major constituents of the Swift

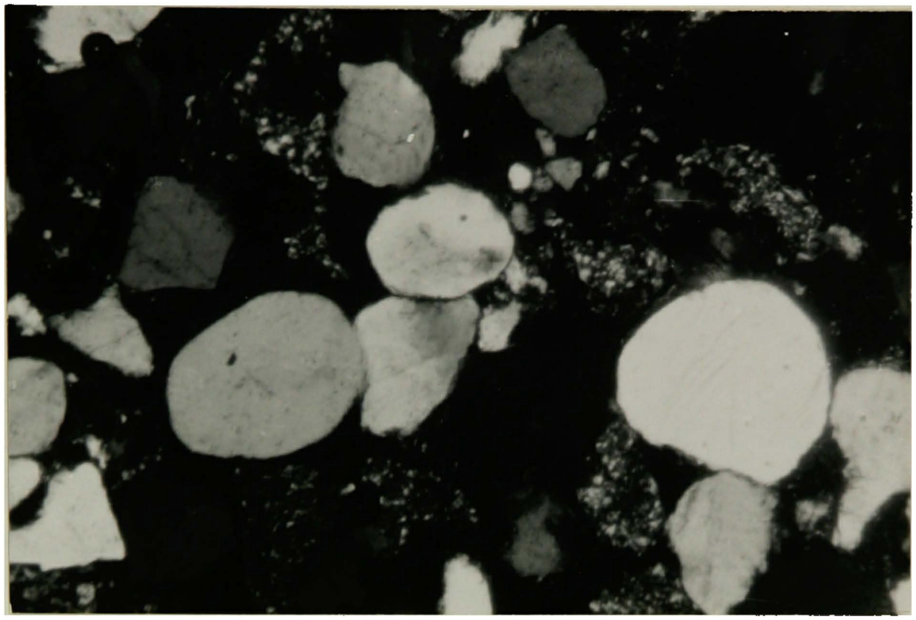


Figure 4. Well-rounded quartz grains mixed with angular chert grains of the Swift sandstone. Sample from Bradman Railroad section at 70 feet from base. X 50.

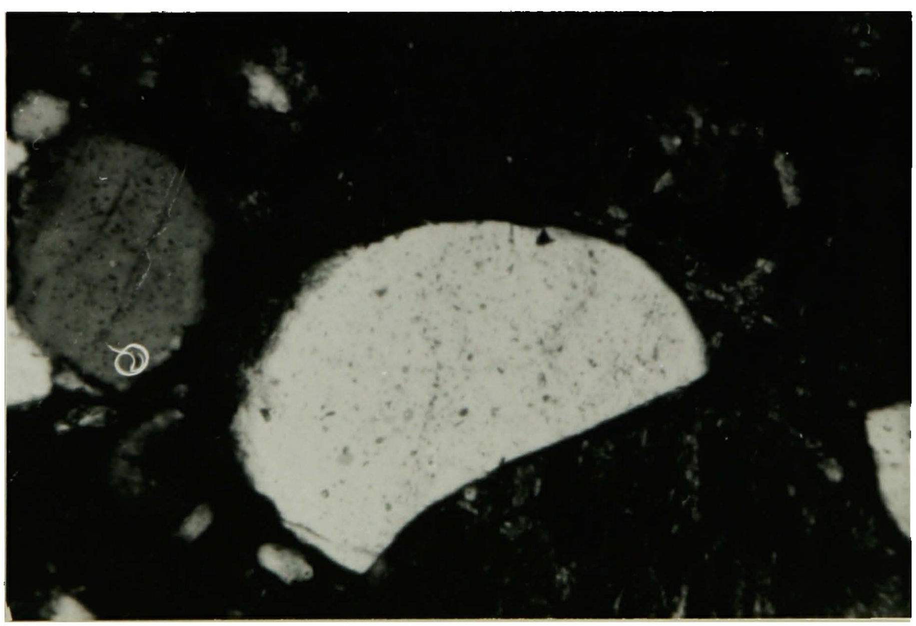


Figure 5. Well rounded but sharply broken quartz grain of the Swift sandstone. Sample from southwest Rattler Gulch section at 68 feet from base. X 60.

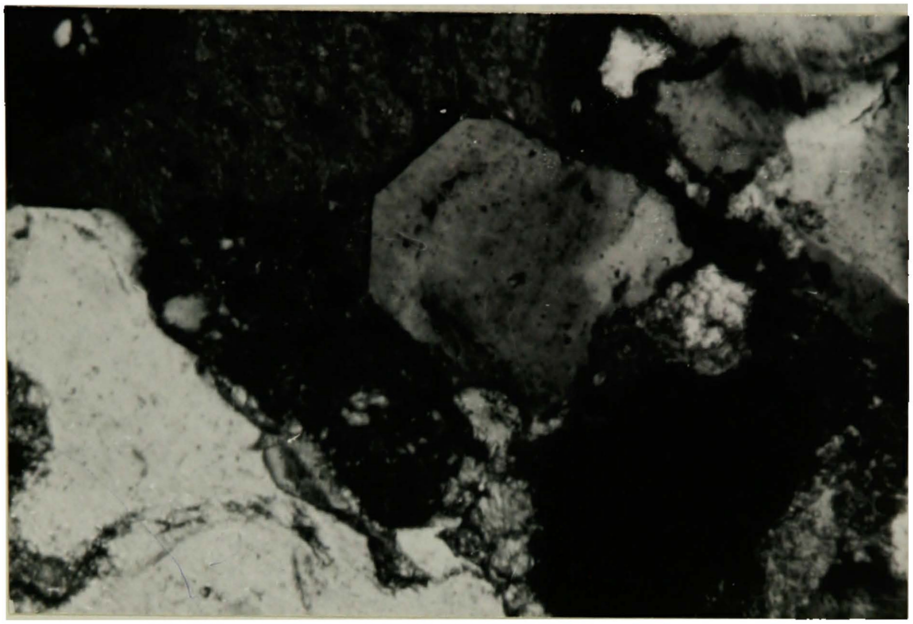


Figure 6A. Well rounded detrital quartz grain encircled by euhedral quartz overgrowth. Sample from Bradman Railroad section at 68 feet. X 60.

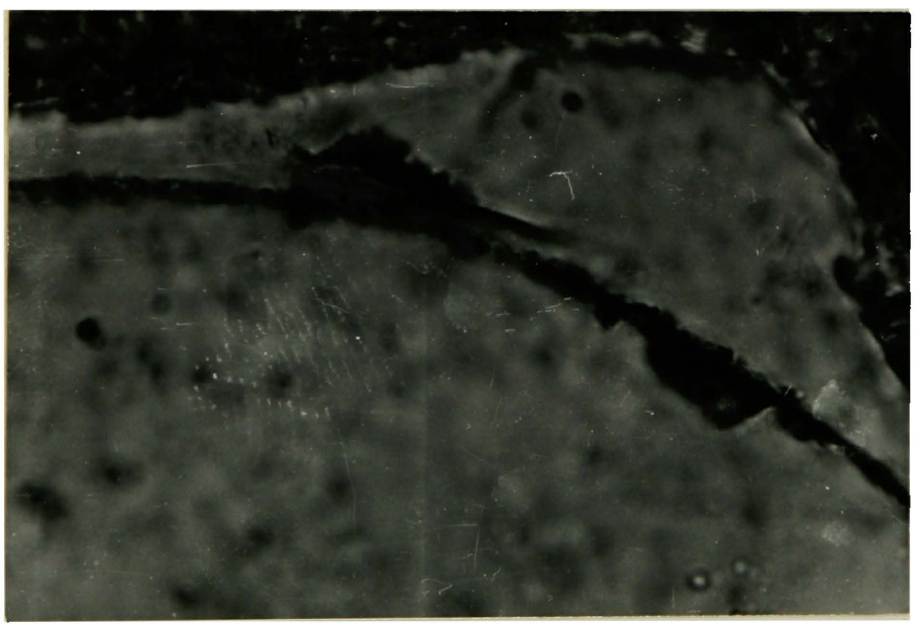


Figure 6B. Part of the quartz grain of figure 6A magnified X400 showing detail of original detrital grain boundary and overgrowth.

ranging from 12.76% to 34.3%. Relatively larger chert grains are more angular than smaller chert grains which are well-rounded having the roundness 3 to 3.5

On the basis of the size of the quartz granules and impurities or inclusions, the chert grains can be divided into three groups as follows:

(1) 'Pure' or 'clean-chert' grains consist of small granules of quartz only. The clay-impurities are absent. The borders of the granules are sharp and the granules can be distinguished from each other easily. This type of chert grains are here called 'Pure' chert, (fig. 7).

(2) Some chert grains consist of small granules of quartz and clayey layers or small clay-patches. Possibly the clay was progressively replaced by chert and upon completion resulted into 'Pure' chert, described above. The clay-bearing impure chert is here called 'clayey' - chert, (fig. 8).

(3) Third type of chert grains consist of silt-sized quartz granules which are here called 'silt-bearing' chert.

'Pure' chert and 'clayey' chert also contain mineral inclusions and fossil - impressions which are distinctly visible in medium grained sand and in chert pebbles of the basal conglomerate bed. The mineral inclusions are (1) rounded brown phosphate grains, probably of impure collophane, (2) small grains of calcite, probably replacing clay in chert, and (3) black opaque grains of magnetite. The fossil inclusions are (1) Sponge-spicules which occur as tubular bodies of quartz granules or chalcedony (fig. 9) and (2) fusulinids in the large chert grains of basal conglomerate at Railroad section.

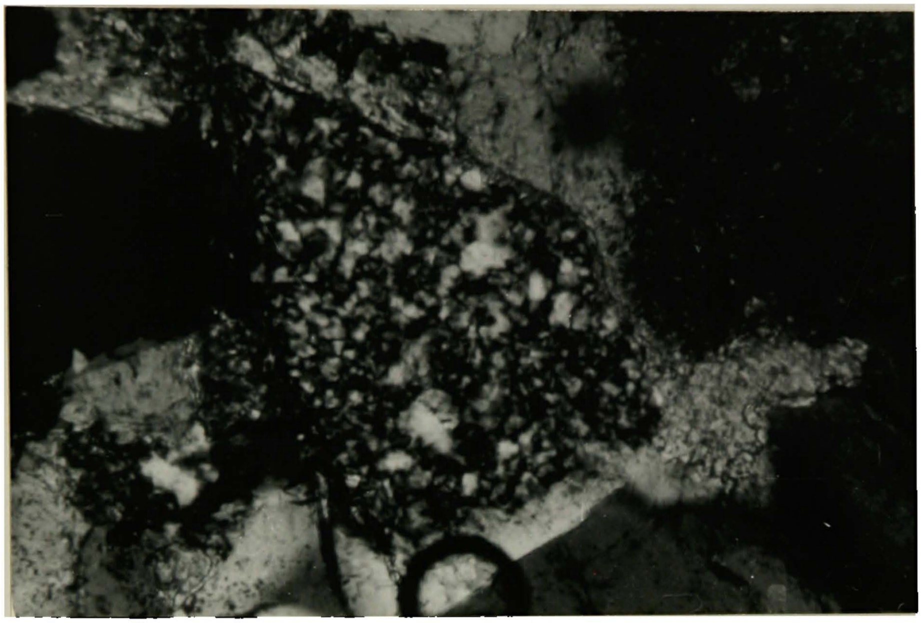


Figure 7. 'Pure' or 'clean' chert having the quartz granules with sharp and distinct borders, from the Swift sandstone. Sample from Bradman Railroad section at 1 foot above base. X 70.

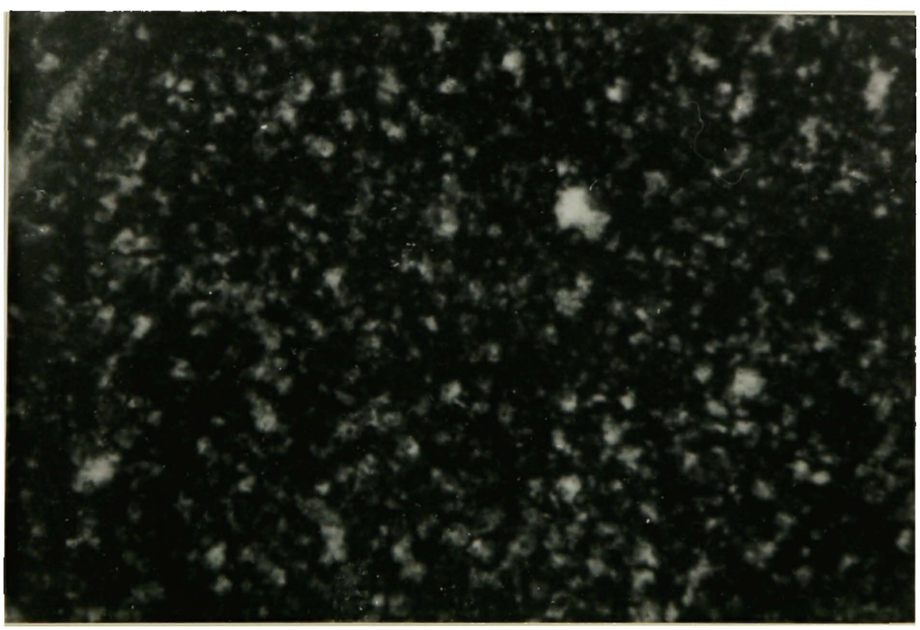


Figure 8. 'Clayey' chert having clay particles from the Swift sandstone. Sample from Bradman Railroad section at 1 foot from the base. X 80.

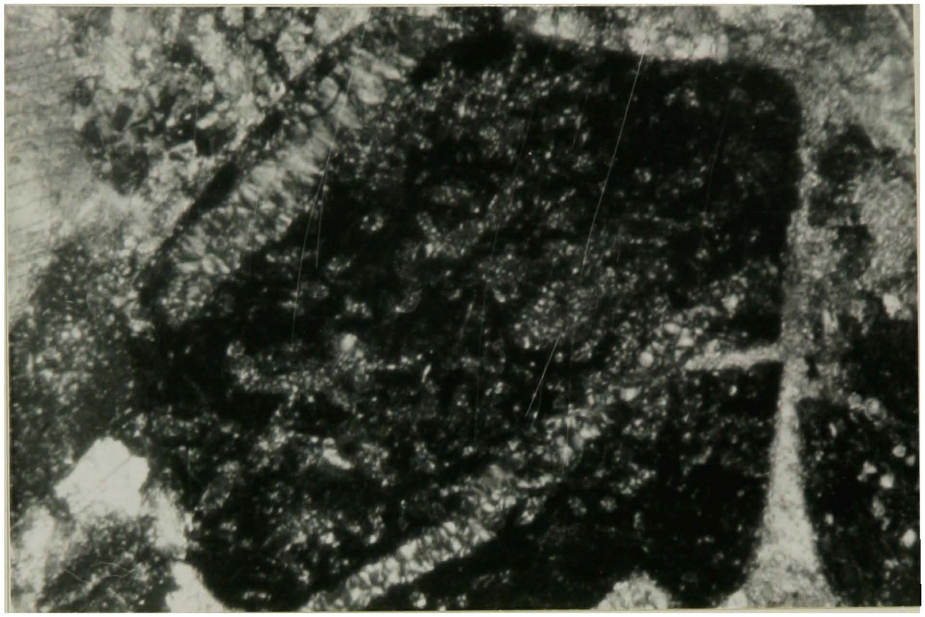


Figure 9. Spicular chert having the sponge spicules, occuring as tubular bodies of quartz granules or chalcedony, from the Swift sandstone. Sample from Bradman Railroad section at 1 foot from base. X 80.

Chalcedony

Chalcedony can be identified easily by its fibrous nature. It occurs as detrital, sub-rounded grains and ranges from 0.87% to 2.17% of the total grains.

Feldspar

Feldspar occurs as scattered small plagioclase grains (fig. 10). Due to the small size of the grains, the type of plagioclase cannot be identified. It is absent in southwest Rattle Gulch - and Van Curan Gulch - sections and varies from 0.14% at Railroad section to 0.30% at William Gulch section.

Rock-fragments

Sedimentary rock fragments are more abundant than either volcanic- or metamorphic-rock fragments. The sedimentary rock fragments consist of fine-grained sandstone, claystone, limestone and chert. The chert grains are described above.

Fine sandstone grains consist of cemented very fine aggregates of quartz grains. Each of the quartz grains within the fine sandstone rock-fragment is larger than the quartz granules in chert and hence can be distinguished easily from them. The sandstone rock-fragments are well rounded and range from 1.22% to 5.6% of the total grains. Claystone grains are internally laminated and rounded. Claystone rock-fragments range from 7.4% to 11.9% of the total grains. Limestone rock fragments are rare, probably, due to softness and solubility. Limestone percentage is very small and could not be calculated, but even a small percentage is important in interpreting the source rocks.

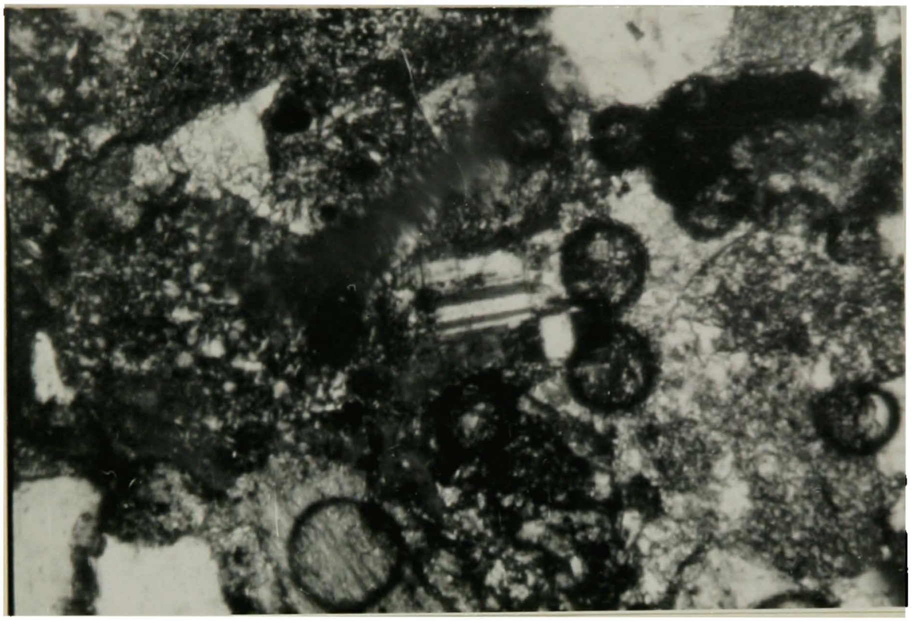


Figure 10. Fresh plagioclase feldspar grain from the Swift sandstone. Sample from Bradman Railroad section at 33 feet from base. X 90.

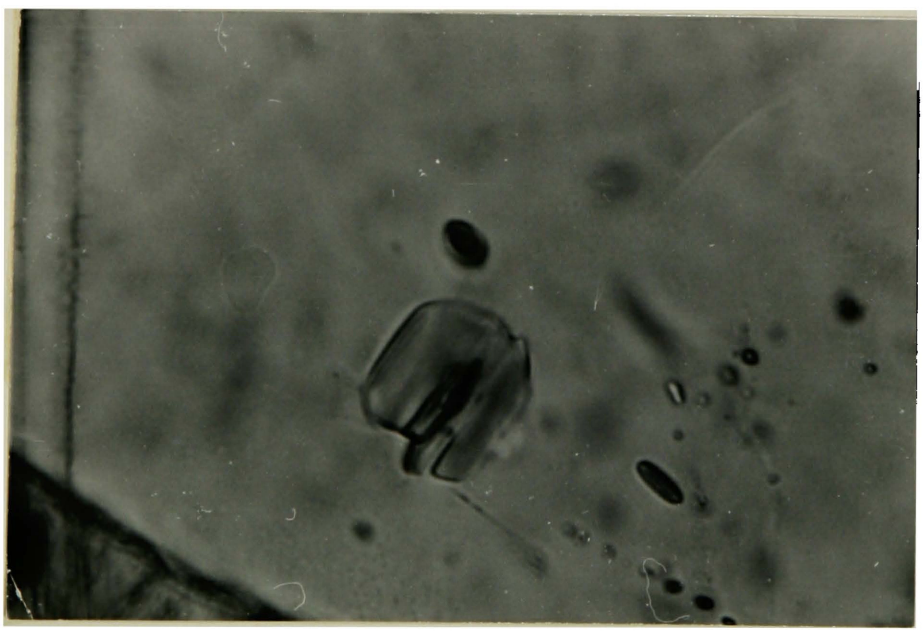


Figure 11. Tourmaline grain occuring as an inclusion in quartz from the Swift sandstone. Sample from Bradman Railroad section at 52 feet from base. X 200.

Volcanic rock fragments are also present. Due to the fact that plagioclase laths of the VRFs are fine-grained, it is possible to identify VRFs only if they are medium grained or larger. Although they occur in trace amounts, the presence of VRFs might be diagnostic of the source rocks.

Heavy minerals

Heavy minerals in the rocks of the basal unit consist of tourmaline, rutile and zircon of which tourmaline and rutile occur as inclusions in the quartz grains. Zircon occurs as subequant and well-rounded grains, approximately 0.06 mm. in diameter. Tourmaline occurs as prismatic and rounded brown grains, and rutile as needles included in quartz grains (figs. 11, 12, 13).

Each type of heavy mineral occurs in only trace amounts. The proprotion of total heavy minerals varies from 0.5% to 0.8% in Railroad section and less than 0.5% in other sections of the Swift Formation as a whole.

Dolomite crystals

There are few scattered rhmbohedral crystals of dolomite also (fig. 14).

Glauconite

Glauconite occurs as well-rounded green to yellowish green, pleochroic, sand sized grains (fig. 15). The proportion of glauconite is 0.05% in this unit which is less than in the upper part of the Swift.

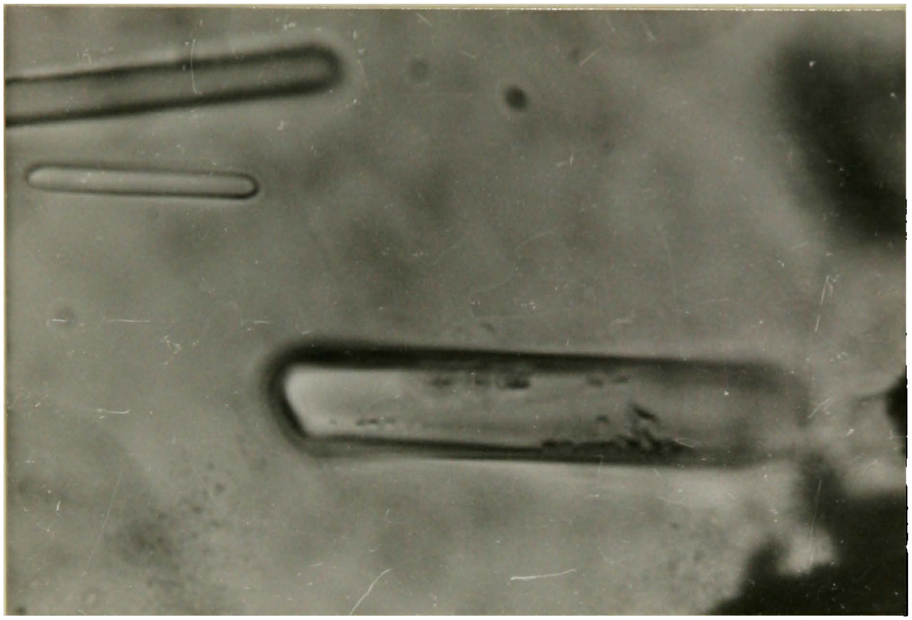


Figure 12. Rutile needles occuring as inclusions in the quartz grains from the Swift sandstone. Sample from Bradman Railroad section at 52 feet. X 200.

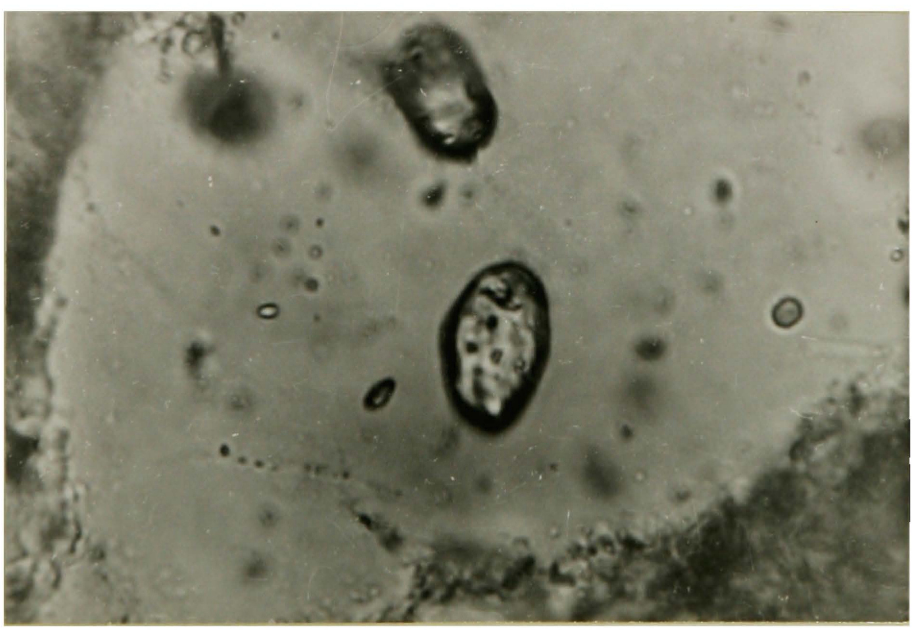


Figure 13. Well rounded zircon grain from the Swift sandstone. Sample from Bradman Railroad section at 52 feet from base. X 200.

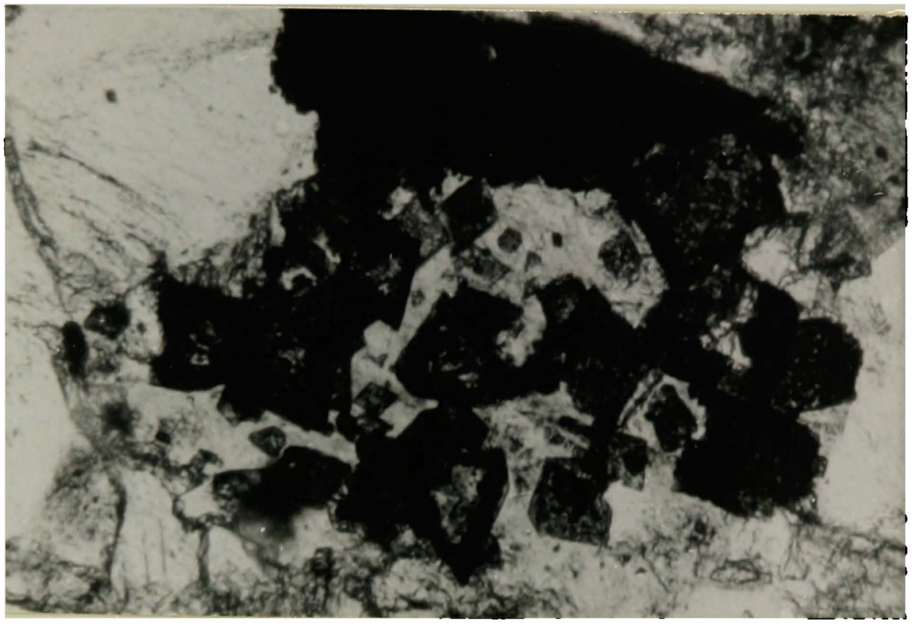


Figure 14. Rhombohedral dolomite crystals in the Swift sandstone. Sample from southwest Rattler Gulch section at 55 feet. X 40.

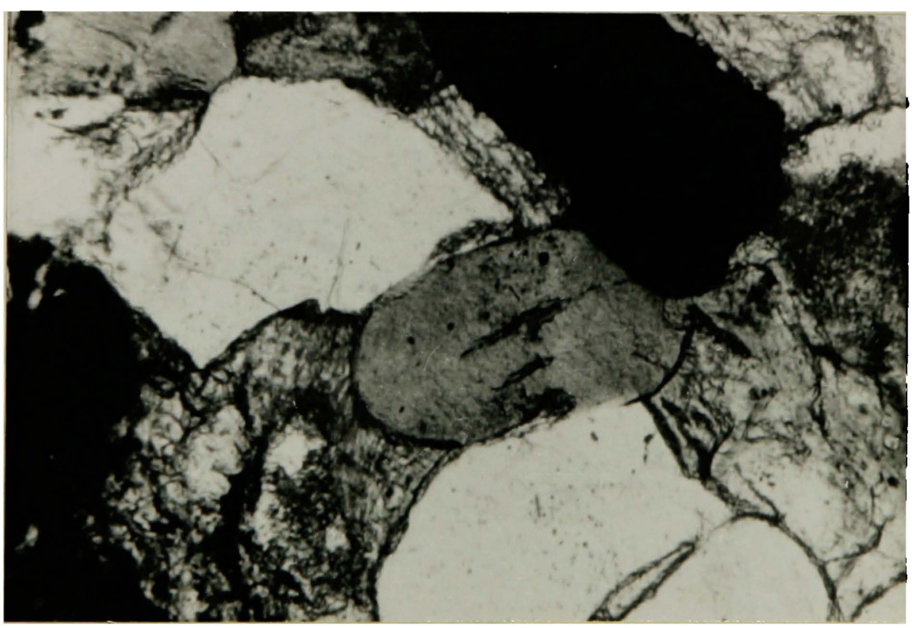


Figure 15. Yellowish green rounded glauconite in the Swift sandstone. Sample from Brádman Railroad section at 56 feet from base. X 80.

Cement-minerals

The cementing minerals, which form a significant part of these rocks are secondary quartz overgrowths on detrital quartz grains and calcite which fills in the remaining pore-spaces. In these rocks calcite is relatively more abundant than quartz-cement.

Altered product

Sericite, which is a large crystal form of illite (Folk, 1965, P. 98), occurs in claystone grains and 'clayey' chert and is very little in amount.

Clay-minerals

The clay mineralogy of the shale beds of the Swift and Morrison was studied by standard X-ray diffraction method. Details of the method of study, various treatments given to clay samples for identification of clay minerals and the results are given in Appendix- II. The clay minerals identified in this study from shale samples of this unit at Railroad section, are as follows (fig. 17).

1. Mixed layered illite-montmorillonite.
2. Septa chlorite.
3. 14 A^{o} - chlorite.
4. Kaolinite (?):

Proportion of montmorillonite in the mixed layered illite - montmorillonite phase varies from 20% to 25%.

FOSSIL FRAGMENTS

The following is a list of fossils observed in thin sections. Some of them namely pelecypods, Belemnites and wood-fragments are observed in

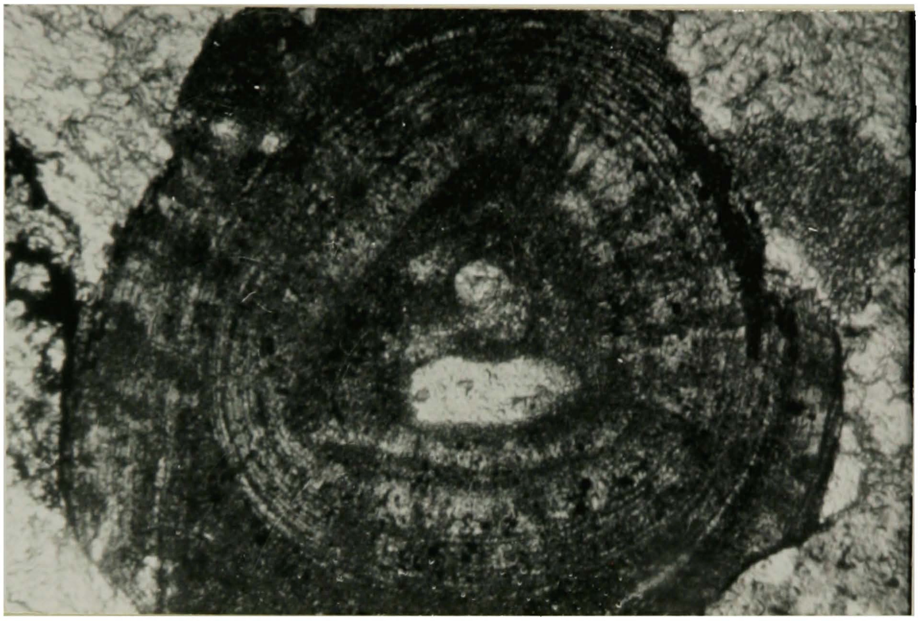


Figure 16. Oolite grain from the Swift sandstone. Sample from Bradman Railroad section at 1 foot from base. X 100.

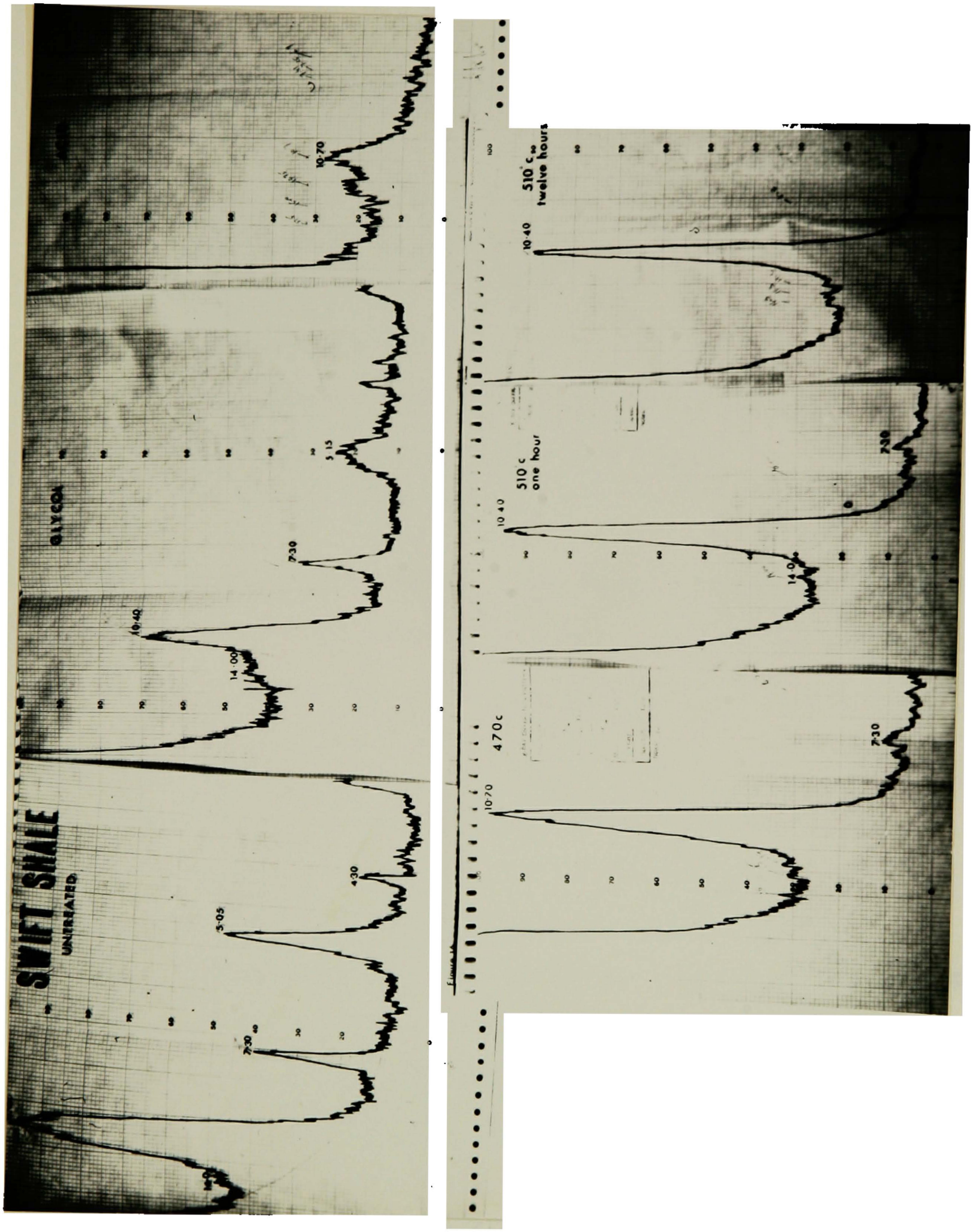


Figure 17. X-ray pattern of the clay minerals of the Swift shale. Sample from Bradman Railroad section at 7 feet from base.

hand-specimens also.

(1) Pelecypod shell-fragments. (Fig. 18)

(2) Crinoids. (Fig. 19)

(3) Crinoids in chert pebbles.

(4) Spicules in chert pebbles. (Fig. 9)

(5) Belemnites.

(6) Wood and bark fragments.

The fossil fragments are abundant from 4 ft. 6 inches to 7 ft. in the Swift at Railroad section.

TEXTURE

The textural elements namely shape, size, sorting, maturity and packing of the rocks of the basal unit were studied in slab surface and in thin section.

Sphericity

The method of study and classification of sphericity proposed by Folk (1965 p. 9) are used for describing sphericity. Seven classes or groups on the basis of the ratio of width to length are as follows:

(1) Very elongate; (2) elongate; (3) subelongate; (4) Intermediate; (5) subequant; (6) equant; (7) very equant.

Quartz grains of the basal unit are intermediate and subequant having the ratio $\frac{\text{width}}{\text{length}}$ $\frac{w}{l}$, 0.69 to 0.72 and 0.72 to 0.75, respectively. Occasional few equant grains having the ratio of more than 0.75, are also present. There are two populations of the quartz grains - very fine-grained subelongate and fine-grained subequant grains.

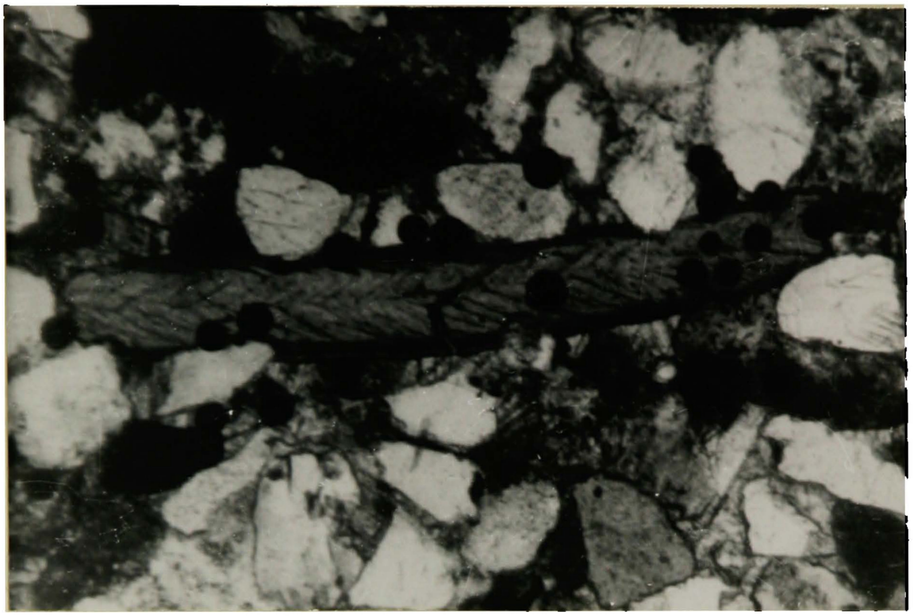


Figure 18. Pelecypod shell fragments in the Swift sandstone. Sample from Bradman Railroad section at 50 feet from base. X 100.

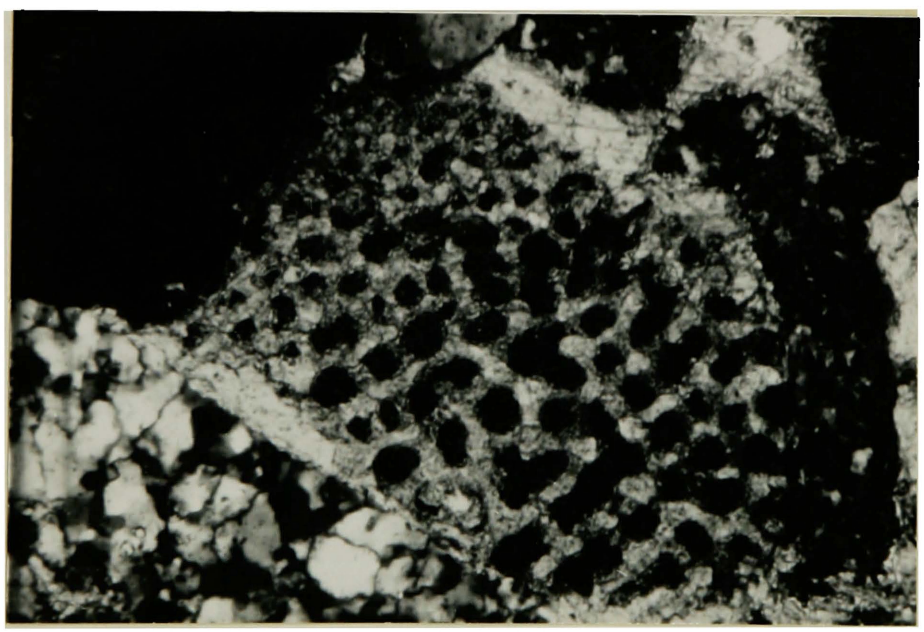


Figure 19. Crinoid fragment in the Swift Sandstone. Sample from Bradman Railroad section at 55 feet from base. X 150.

Chert grains of all types - 'Pure' chert, 'clayey' chert or 'silt-bearing' chert - are subelongate to subequant. Not only are the chert grains less equant but they are also comparatively more angular than quartz grains.

Claystones are mostly subelongate while others are subequant.

Rounding

Power's (1953, P. 117-119) visual scale of roundness was used in estimating roundness.

Quartz grains are rounded to well-rounded having roundness value of 2.5 to 3. Original detrital grain boundaries are visible in some of the quartz grains which have been overgrown by quartz cement. Some of the well rounded quartz grains are broken in half leaving half-moon shaped grains. Though sphericity is not definitely related to roundness, it appears that subequant to equant grains are well-rounded.

Apparent roundness of some of the quartz grains is decreased by two other factors, (1) Quartz overgrowths and (2) replacement of quartz by calcite. Euhedral to subhedral overgrowth boundaries are developed on some of the quartz grains. The degree of overgrowth depends on packing of the grains, amount of secondary silica and suitable conditions for cementation. Some of the quartz grains are replaced by calcite along their borders, which decreases the apparent roundness. In some quartz grains only one side is replaced completely or to a large extent developing sharp angular boundary while in others irregular sutured or comb-shaped boundaries are developed due to varying replacement.

Chert grains also show two values of rounding. The pebbles and medium sand-size particles of chert are well rounded, having a roundness value of about 3, while the smaller fine - and very fine-grained sand sized grains are angular having a roundness value 2 to 3. The chert grains are neither overgrown nor replaced as the quartz grains are.

Size

The grain size of the sandstone of the basal unit ranges from 0.15 mm at William Gulch and southwest Rattler Gulch sections to 0.25 mm at Van Curan section. Quartz grains range in size from 0.25mm to 0.15 mm. Relatively coarser quartz grains are found at Van Curan Gulch section, while finer quartz grains are found at William Gulch-, and southwest Rattler Gulch-sections. Chert grains are mostly from 0.20mm to 0.25mm in size but few chert pebbles are also present. Claystone grains are generally smaller averaging 0.17mm in the sandstone of this unit.

Packing

The sand grains are neither very closely packed nor interlocked. The contacts of the borders of the grains are straight and tangential. However the sand grains are well cemented by quartz and calcite cements of which calcite is more abundant.

Cross bedded compact Sandstone unit

The unit, conformably overlying the laminated sandstone and shale of the relatively coarse basal unit, consists of compact, cross-bedded resistant sandstone that is laterally continuous throughout the area. (plate 1). As it is very compact and resistant, it forms a ridge and is well-exposed. Average thickness is 11 ft. but it varies from 7 ft.

at Railroad section to 20 ft. at the southwest Rattler Gulch section. Here the cross-beds stand out and the total Swift section is more sandy and better exposed.

SEDIMENTARY STRUCTURES

Cross bedding

The cross-bedding is distinct at Van Curan Gulch section and the southwest Rattler Gulch section while it is poorly visible at Railroad, William Gulch and west Rattler Gulch sections. The cross-beds are small scale, straight and dip northeast. Two types of cross-beds are found in this sandstone: Small-scale ripple cross-beds less than 5 cm thick which are straight, are separated by straight bounding planes and lithologically homogenous. They are composed of fine-sand, silt and clay. Second type of small scale cross-beds is lithologically heterogenous. This type consists of coarse laminae containing black chert little matrix and cement that alternate with fine-grained laminae containing quartz sand, more clayey matrix and cement. Heterogenous composition of these cross-beds suggest (1) varying capacity of currents, (2) intermittant supply of chert or both together. As it is unlikely that supply of material may change within the same bed of small thickness, probably this was due to changing capacity of the currents.

MINERALOGY and TEXTURE

Mineralogy and texture of this sandstone are similar to those of the basal unit except for the percentages of the minerals and sizes of the grains.

The mineral percentages of the cross-bedded sandstone unit are as follows:

Mineral	Percentage	
Common quartz	39.93%	Average
Chert	18.49%	"
Chalcedony	1.01%	"
Feldspar	0.31%	"
Rock fragments	13.05%	"
Glauconite	0.14%	"
Cement and fossils	Rest	-

The grain size is very fine and varies from 0.09mm at William Gulch section to 0.20mm at Railroad section. It is much finer than that of the basal unit.

Laminated Sandstone and Shale Unit.

The cross-bedded well-exposed sandstone is overlain by a less resistant unit consisting of laminated sandstone and intermittant shale beds which are well-exposed at Railroad section (Plate 1). A 6 foot shale interval at the base of this unit, is overlain by the laminated sandstone varying in thickness from 8 ft. at Railroad section to 20 ft. at William Gulch section. The upper part of this unit contains shale which is well-exposed at Railroad section where two lenses of shale, about 6 inches and 1 ft.thick are present. At other sections, except William Gulch section, the shale apparently forms a covered interval. Probably the shale is absent at William Gulch section and is replaced by the laminated sandstone. Average total thickness of this unit is 15 ft., but maximum thickness including covered interval at the southwest Rattler Gulch section is 45 ft.

This unit has relatively more shale beds than have other units of the Swift.

SEDIMENTARY STRUCTURES

Laminations

Laminations similar to those in the basal unit occur in the sandstone beds of this unit as well, which might have been formed in upper flow regime or due to change in the carrying capacity of currents.

Ripple-marks

Small scale asymmetrical ripple marks occur on a laminated sandstone bed 40 ft. above the base, in Railroad section. They are small scale ripples having the amplitude of about one inch and wavelength of three inches. These ripples are smaller than those exposed on laminated sandstone of basal unit. The dip direction of the ripples is northeast.

MINERALOGY AND TEXTURE

The mineralogy and texture of the sandstone are similar to those of lower two Swift units, except small change in the percentages of the minerals and grain-sizes.

The mineral percentages of the laminated sandstones of this unit are as follows:

Mineral	Percentage	
Common quartz	42.08%	Average
Chert	15.01%	"
Chalcedony	1.49%	"
Feldspar	0.60%	"
Rock fragments	11.39%	"
Glauconite	0.20%	"
Cement	Rest	-

The grain size varies from 0.07 mm at William Gulch section to 0.20 mm at Van Curan Gulch section. There is very little difference in the grain size from that of the cross-bedded compact sandstone unit.

Clay minerals

The shales of this unit in Railroad section contain the same clay minerals as the shales of the basal unit, namely mixed - layered illite - montmorillonite, septachlorite, 14A° chlorite, and kaolinite (?). The percentage of montmorillonite in mixed layered illite-montmorillonite phase is between 20% and 25%.

Massive Glauconitic Sandstone Unit

The massive glauconitic sandstone unit forms the top of the Swift Formation. It is a compact, massive and ridge-forming, yellowish sandstone. It is overlain by gray shale which is assigned to the Morrison Formation, (Plate 1).

SEDIMENTARY STRUCTURES

Ripple Marks

Small scale asymmetrical ripple marks occur in this unit of the Swift, at 56 ft. in the Railroad section. These ripples are of one set and are similar to those of the 'laminated sandstone and shale' unit below. The trend of the ripples is N35°E.

MINERALOGY and TEXTURE

Mineralogy and texture of this sandstone are the same as those of lower three units except that the percentages of the minerals and grain-sizes differ.

Minerals	Percentages	
Common quartz	45.53%	Average
Chert	15.33%	"
Chalcedony	0.58%	"
Feldspar	0.09%	"
Rock fragments	14.59%	"
Glauconite	0.41%	"
Cement	Rest	-

Glauconite is relatively more abundant in this sandstone and indicates marine deposition. Brachiopod fragments also occur in this sandstone.

Average grain-size of the sandstone is 0.09mm which is of very fine-grained sand, but varies up to 0.15mm at Railroad section.

CUMULATIVE CURVES

By using the average grain size of the samples and thickness of the sandstone beds from which the samples are collected, percentages of the total thickness of different size ranges are estimated and a cumulative percentage curve may be constructed (fig. 20). The difference between the standard method of preparing a cumulative weight percentage curve and the type of the curve constructed here are as follows:

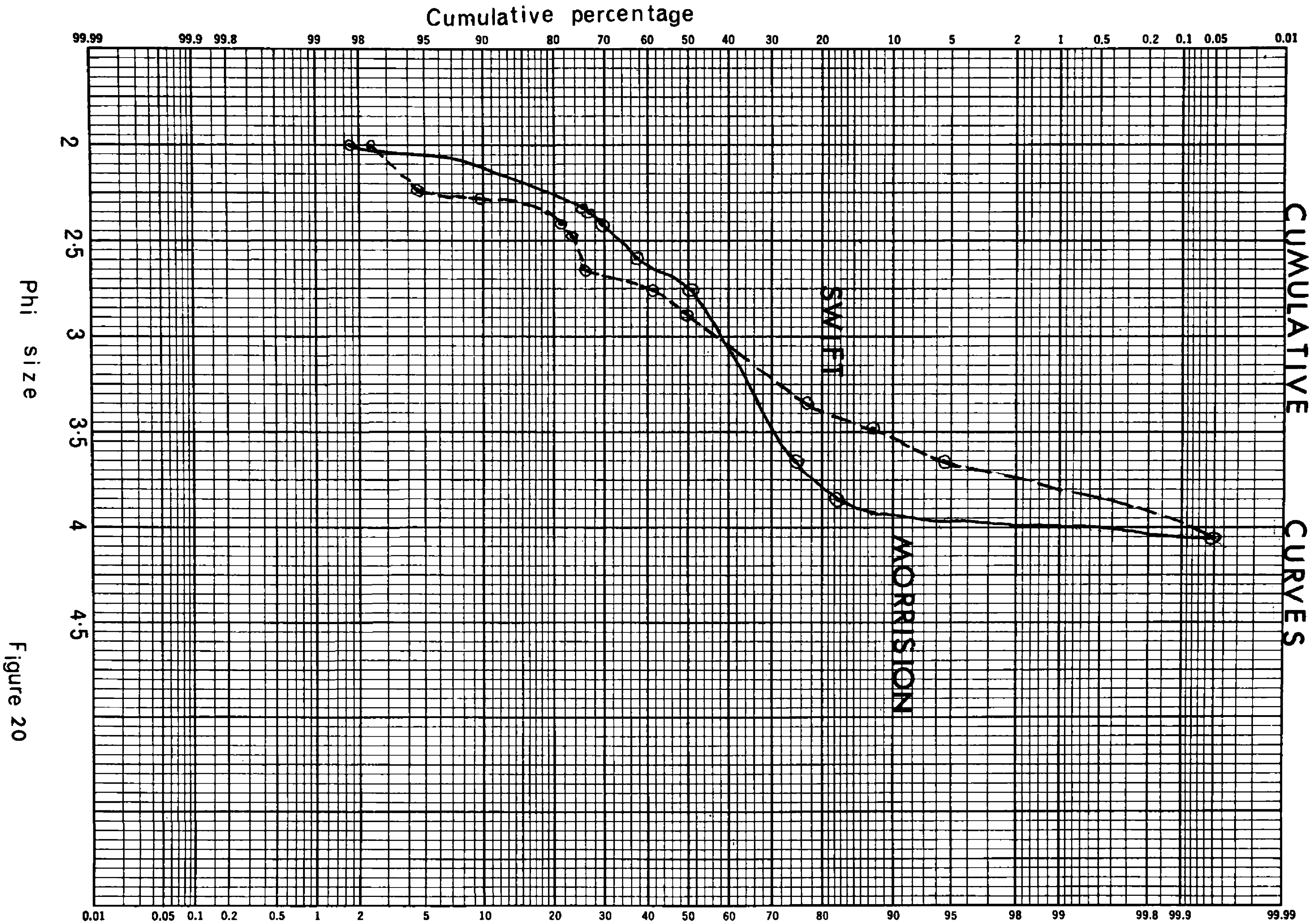

Cumulative percentage
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
Phi size
2
2·5
3
3·5
4
4·5
SWIFT
MORRISION
CUMULATIVE CURVES
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99

Figure 20

(1) Instead by seive analysis, grain size and sorting are measured in thin section.

(2) Instead of weight percentage of each of the sample, thickness of each of the beds from which the sample was collected was measured, and from the cumulative thickness of the whole formation, thickness percentages of each of the beds having different grain-size were estimated and used for constructing the cumulative curve. The cumulative percentage curves constructed here, though not as accurate as standard cumulative weight percentage curve, appear to be very informative. Graphic mean and Inclusive graphic standard deviation are plotted following the definitions of Folk (1965, p. 46). The formulae used and the values determined are as follows:

$$\text{Graphic mean} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$= \frac{2.32 + 2.88 + 3.94}{3} = 2.873\,\phi$$

$$= 0.15 \text{ mm.}$$

$$\text{Inclusive graphic standard deviation} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$= \frac{3.43 - 2.32}{4} + \frac{3.67 - 2.25}{6.6}$$

$$= 0.492\,\phi$$

SORTING AND MATURITY

Sand grains of these rocks are well-sorted as observed from both, the visual chart of Folk (1965, P. 104) and inclusive graphic standard deviation, σI, which is 0.492ϕ.

Though claystone grains are present, clay matrix is minor, less than 5%. Again sorting index, σI, is 0.492ϕ, i.e. nearly 0.5 which indicates that the rock is sub-mature to mature.

The Swift rocks are divided into four units on the basis of lithology, grain-size and ease of tracing in the field. All the four units can be traced from place to place. The grain size changes from fine-grained sandstone and pebbly sandstone at the base to very fine-grained sandstone at the top. The basal conglomerate might have been formed due to reworking of lag material by the transgressing sea.

COMPOSITION DIAGRAMS and CLASSIFICATION

Major constituent minerals and rock-fragments of the Swift are quartz, chert grains of three types, laminated claystone, very fine-grained cemented sandstone rock fragments, occasional volcanic and low grade metamorphic-rock fragments, traces of feldspar and heavy minerals.

McBride's (1963, P. 664-669) classification of the sandstones appears to be the most reasonable, logical and easily used to classify the sandstones. McBride used a triangular composition diagram. The three poles are, (1) Quartz & Chert, (2) Rock fragments except chert, and (3) Feldspar. Though chert is a rock-fragment, McBride includes it with quartz because it is harder than other rock fragments and is monomineralic, consisting of quartz only.

A significant number of the Swift chert grains contain clay. Because there is a continuum between claystone grains and clayey chert grains, it becomes difficult to separate them in point-count. Because chert is a rock-fragment it is placed along with other rock-fragments at the RF pole of the triangular composition diagram. Thus inconsistancies in distinguishing clayey chert grains from claystone grains are not reflected in the mineral composition diagram. Therefore, McBride's composition diagrams are slightly modified by transferring chert from quartz pole to RF pole. Three poles of composition diagram used here are as follows:

(1) Quartz pole including chalcedony.

(2) RF pole including chert.

(3) Feldspar pole.

SWIFT SANDSTONES

The triangular composition diagrams of the Swift sandstone from each section reveal the following points: (figs. 21, 22, 23, 24).

(1) Feldspar is a very minor constituent in all of the sections. Maximum amount is 2% in the Railroad section, while it is less than 1% in the remaining sections.

(2) The rock-fragments including chert are the most abundant at Railroad section. Maximum amount of chert at railroad section is 80.0%. It decreases in general northward; maximum amount in the southwest Rattler Gulch section is 54.0%.

(3) Quartz is the most abundant in the southwest Rattler Gulch section where it reaches 85.5%. It decreases in general southward, so that at Railroad section, quartz is only 49.00%.

DIAGENESIS

After the deposition of the Swift sediments under shallow water marine conditions, the diagenetic changes compacted and cemented the

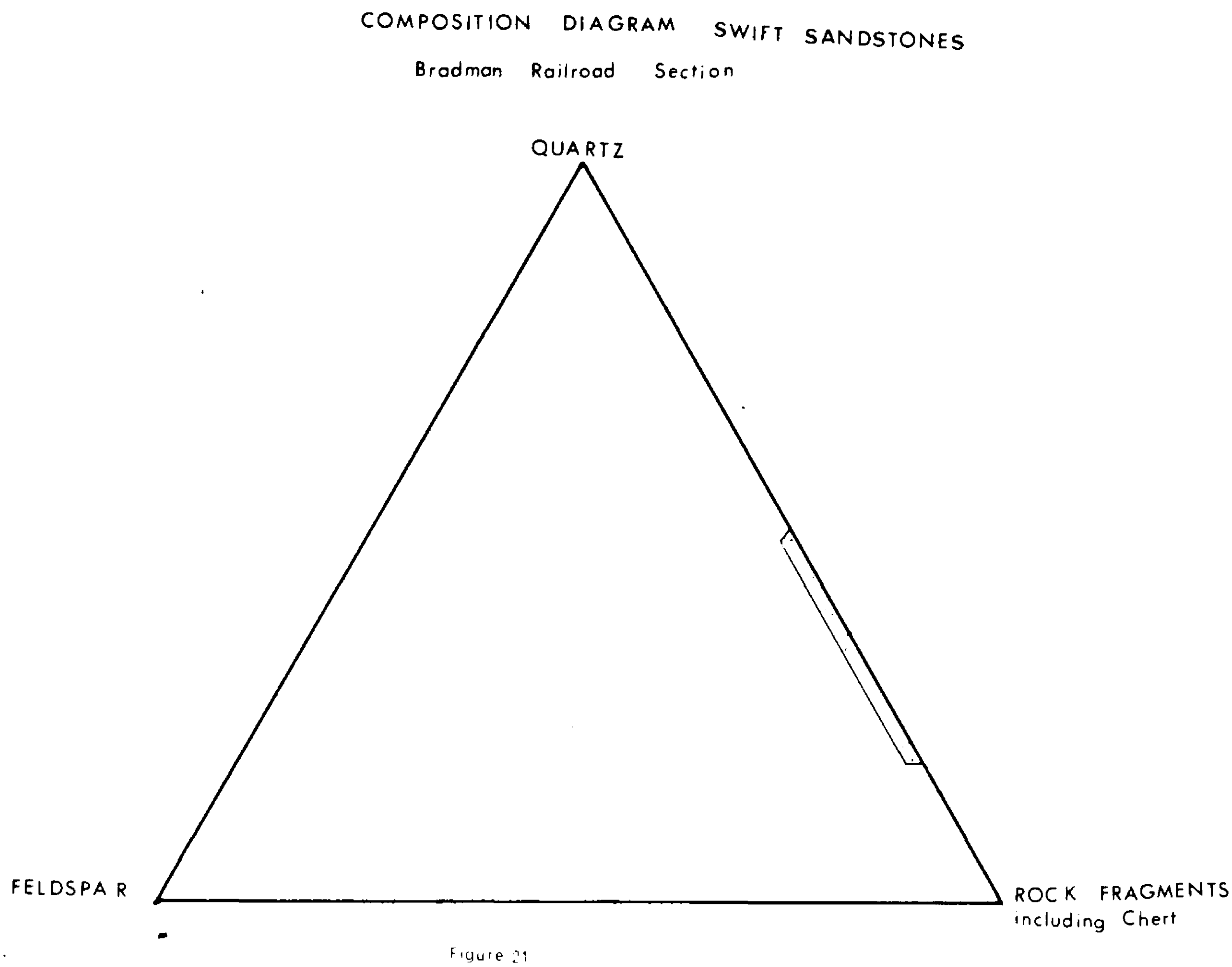


Figure 21. Composition diagram of the Swift sandstone. Bradman Railroad Section.

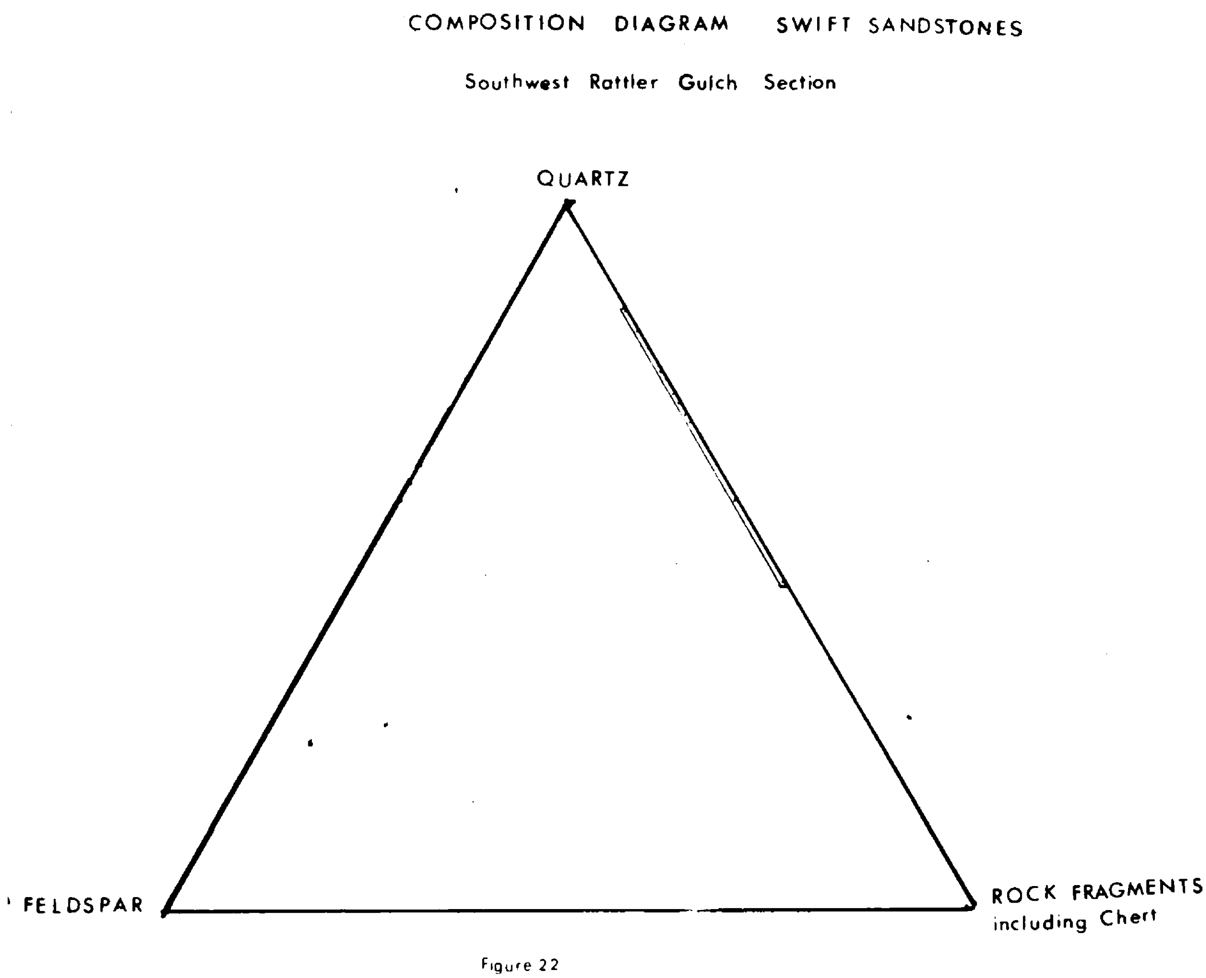


Figure 22. Composition diagram of the Swift Sandstone Southwest Rattler Gulch section.

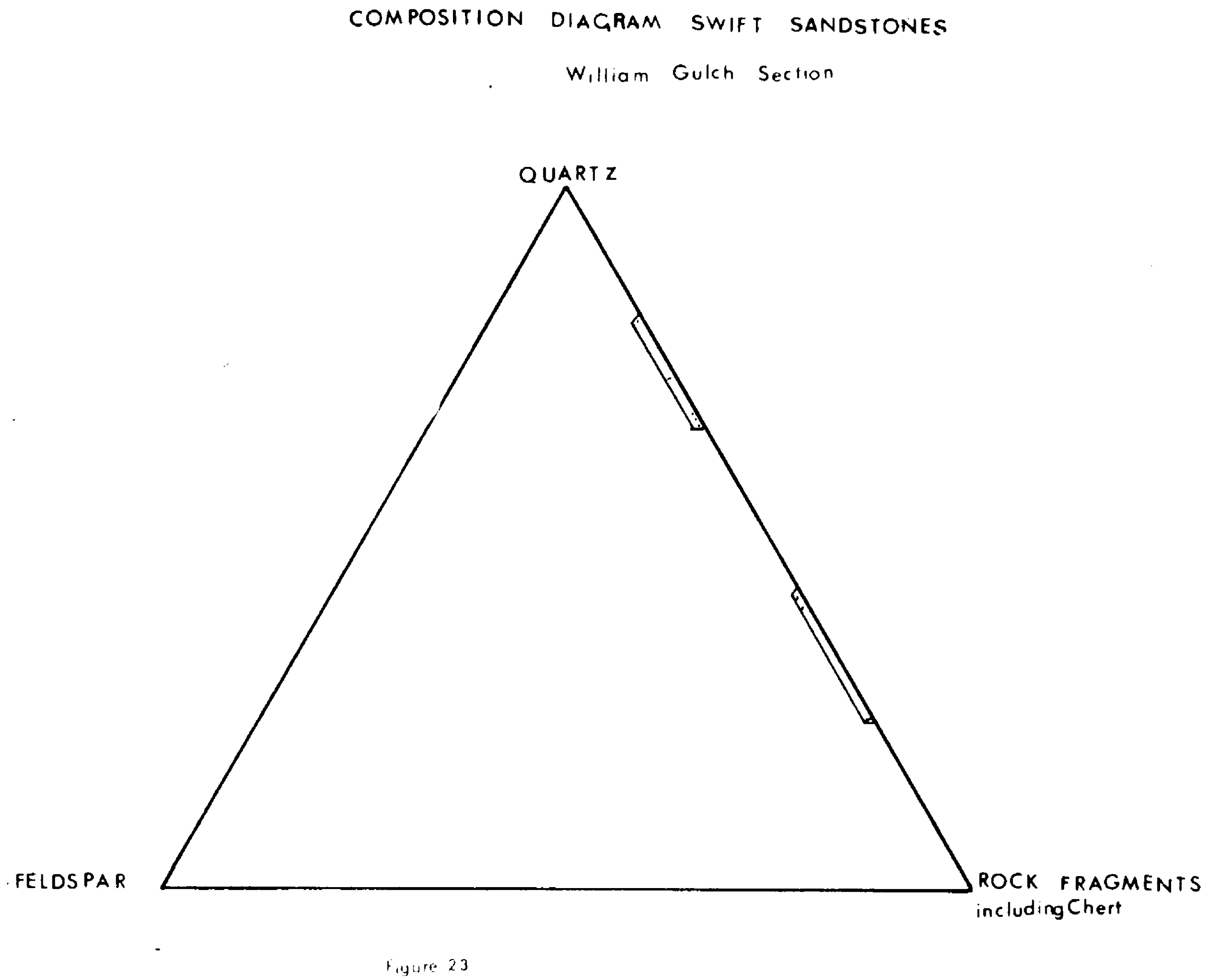


Figure 23. Composition diagram of the Swift Sandstone William Gulch section.

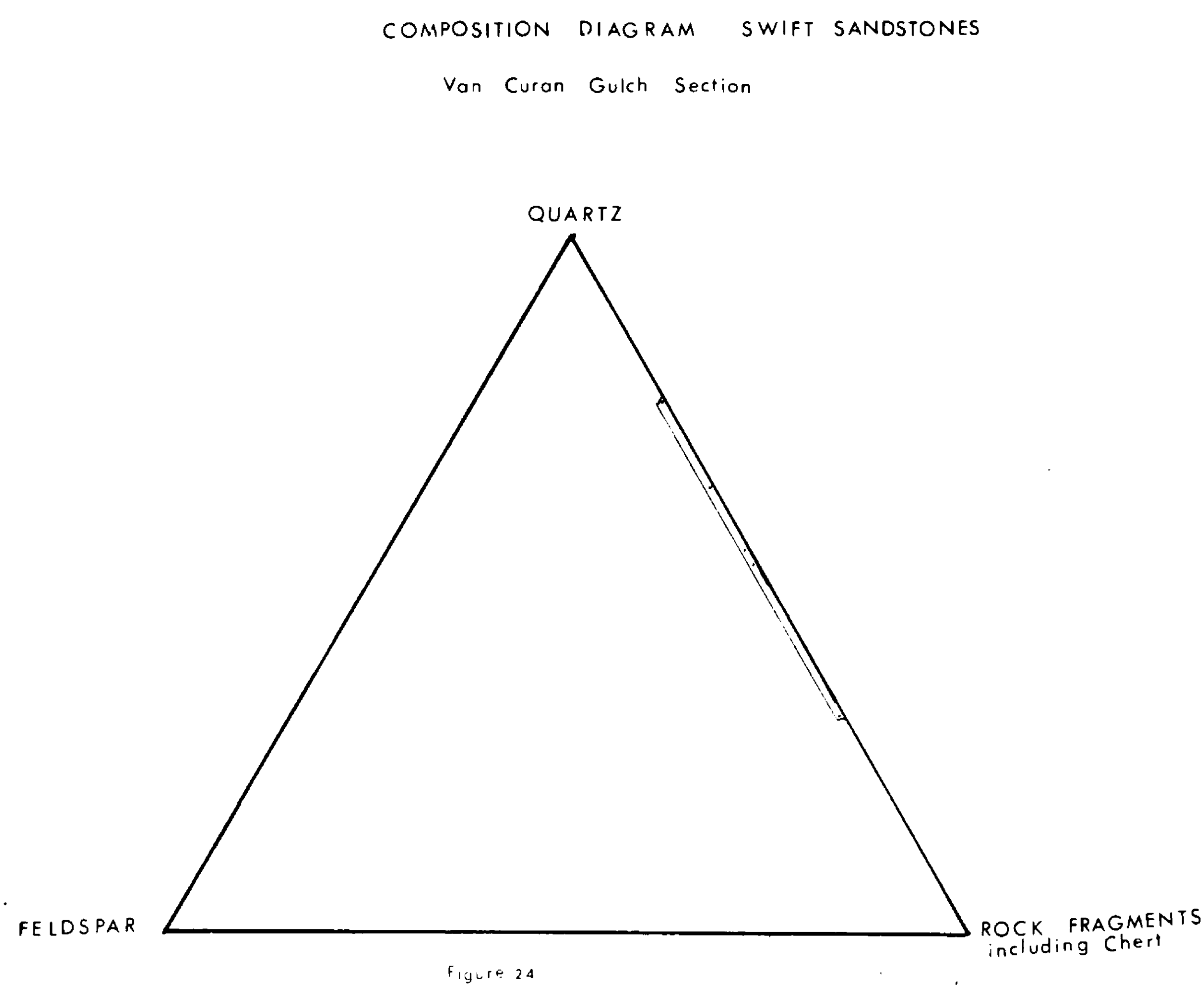


Figure 24. Composition diagram of the Swift Sandstone. Van Curan Gulch section.

loose-grained sediments of the Swift to form the sandstones. The changes that might have occured in the original sediments can be deduced from the study of grain-contacts, filled up pore-spaces, types of cement, replacement of mineral grains and the extent of replacement.

DETRITAL GRAIN-CONTACTS

Straight contacts between grains are most common. Two other types of contacts are present in a few grains namely concavo-convex- and penetrating contacts. Interpenetration of the grains is limited to the overgrowths. These two types of contacts are proportionately more in west Rattler Gulch and Van Curan Gulch sections.

TYPES OF CEMENTS

Quartz and calcite are two major cements in the Swift rocks. Quartz cement can be distinguished easily from the original quartz grains, because it is separated from them by a thin layer of clay along the detrital grain boundary. Presence of original detrital grain-boundary also helps to estimate very broadly the amount of quartz cement. It appears from visual estimation that the quartz cement fills less than 10% of the pore-spaces in the rock-samples from all sections except in those of Van Curan Gulch section in which the quartz cement fills more than 10% of the pore-spaces. Calcite cement is about 26% by volume of the rock and occurs as irregularly crystalline material. Calcite has replaced quartz cement and quartz grains except in the samples of Van Curan Gulch section where quartz cement is more than calcite, (fig. 25).

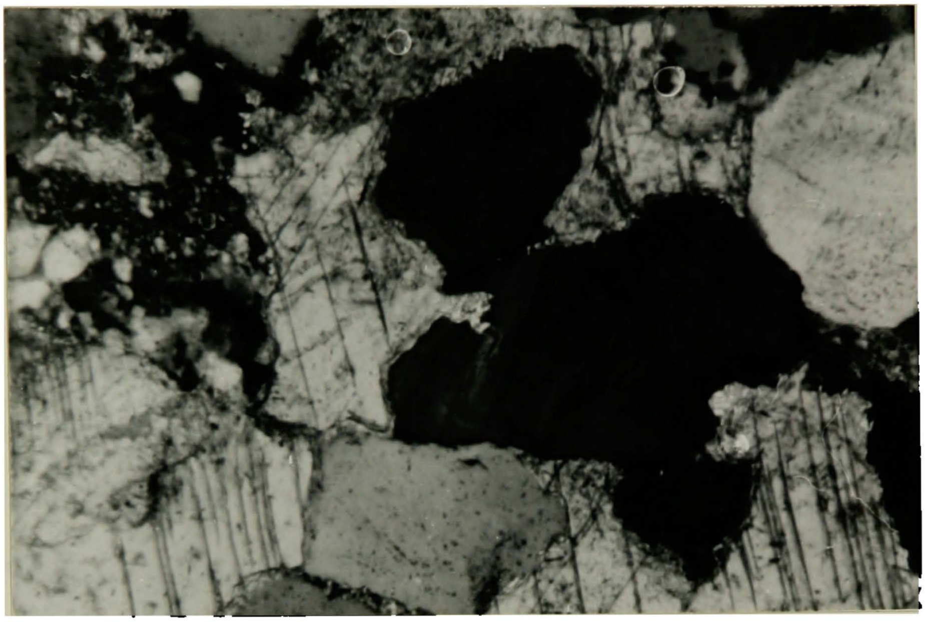


Figure 25. Replacement of quartz by calcite which occurs as cement in the Swift sandstone. Sample from Southwest Rattler Gulch section at 40 feet from base. X 120.

INTERPRETATION - SWIFT FORMATION

The field - and laboratory - studies of the Swift yield the following genetic interpretations regarding source material, source area, transport medium and environments.

Source Material

QUARTZ

Reworked overgrowths on the detrital, reworked, submature, common quartz grains indicate that they have passed through more than one cycle of sedimentation. Those quartz grains which are rounded but sharply broken in half and which do not contain the overgrowths are probably the second cycle grains in which the overgrowths have been broken off along the weak clayey surface of the original detrital grains.

Rounded quartz grains suggest that either the grains came from a source rock containing well-rounded grains, e.g. older sedimentary rocks, or that the grains have undergone much abrasion which might have been due to long transport from a distant place or less transport but much reworking as on a beach. However, the sharply broken, half-circle shaped grains suggest that during the last cycle of erosion and transport, there was very little abrasion. Hence it is more likely that the rounded quartz grains are derived from older sedimentary rocks.

The graphic mean of the sand grains of the Swift as a whole is 2.873 which is fine-grained sand. The fine grain-size might have been inherited from the older sedimentary source rocks. Thus the quartz grains might have been derived from older fine-grained sandstones.

CHERT

The significant amount of chert in the Swift is very helpful in interpreting the source rocks.

'Clayey' chert suggests that either the clay was included in a limestone as an impurity before silicification or that nearly pure clay was partly replaced by chert. There are some claystone chert beds in the Phosphoria Formation of Permian age which underlie the rocks of the Ellis Group in this region. The claystone chert beds contain clayey chert of this type.

'Pure' chert might have been derived from completely silicified claystone or from the chert nodules and beds in limestone.

The fossils such as sponge spicules and crinoids can be identified in coarse chert sand-grains and in pebbles of chert in the basal Swift conglomerate. They confirm that chert grains were derived from older sedimentary rocks.

Some phosphorite grains are also included in chert pebbles which might have been derived from phosphate bearing sedimentary rocks. The rocks of the Phosphoria Formation of Permian age underlie the Ellis Group rocks in this area (Cressman, U.S.G.S., 1964, Paper 313 C). The Phosphoria Formation consists of the following rocks in this area: (1) Phosphatic shales containing phosphate nodules, pellets and oolite fragments of Retort Member, (2) Spicular bedded chert, cherty mudstone, cherty sandstone and sandy chert of Tosi Member of Phosphoria Formation and fine-grained well-sorted sandstone containing chert nodules with spicules and phosphorite grains of Upper Shedhorn Member of Shedhorn Formation. Thus it is very likely that 'clayey' chert, 'pure' chert containing spicules and 'silt-bearing' chert were derived from areas where the rocks of Phosphoria were being eroded. The Madison limestone of Mississippian age and Pennsylvanian rocks also contain chert and underlie the Jurassic rocks in this area. Hence these rocks also might have been the source rocks of chert.

FELDSPAR

The absence or near absence of the feldspar could have been due to one of the following reasons: (1) there was very little feldspar in the source rocks, (2) there was a great deal of mechanical energy input during transport, (3) the feldspar weathered and decomposed in the warm and humid climate.

As emphasized in the description of the quartz grains, there was very little transport or input of mechanical energy during the last cycle of sedimentation. Again the few feldspar grains that are present in the Swift, are nearly fresh. Hence the small amount of feldspar is probably due to a very small amount of feldspar in the source rocks. The Phosphoria Formation and Madison Group which might have furnished chert are poor in feldspar also.

ROCK-FRAGMENTS

The laminated, rounded claystone grains suggest that the source rocks contained mudstone and shale. These soft rocks were eroded by the slow currents which were not strong enough to disintegrate the claystone grains. Some of the claystone grains are cherty suggesting that the source rocks might have been cherty claystones. There are phosphatic shales and cherty mudstone in the Retort and Tosi Members of the

Phosphoria Formation underlying the Ellis Group, which might have formed the source rocks for the claystone fragments.

The rock-fragments of fine-grained sandstone suggest fine-grained sandstone as one of the source rocks. The Upper Shedhorn Member of the Shedhorn Formation contains fine-grained, well-sorted sandstone with chert nodules which also might have formed one of the source rocks.

Trace amounts of fragmented limestone grains indicate that limestone also formed one of the source rocks which might have contained chert nodules, and that the source area was close to the site of deposition.

There are a few volcanic rock fragments in the basal Swift conglomerate suggesting a possible volcanic source. It is also possible that they were reworked from older sedimentary rocks.

HEAVY MINERALS

All the three heavy minerals - zircon, rutile and tourmaline are relatively stable minerals. Absence of less stable heavy minerals than these, suggest that either the sediments were worked upon chemically and mechanically for a prolonged time, or are derived from the old sedimentary rocks having a stable heavy mineral assemblage. Again the absence of characteristic metamorphic heavy minerals suggest that there were no metamorphic rocks in the source area. The Swift sediments were worked upon for a short duration as indicated by sharply broken sharp edged quartz grains. Hence probably the source rocks consisted of old sedimentary rocks containing stable heavy minerals.

GLAUCONITE

Glauconite is a characteristic mineral of the Swift even though it occurs in small amounts. The glauconite might have been formed by organic activity after the deposition of the sediments in the off-shore shallow waters and before the diagenetic changes occured. The presence of glauconite suggests marine origin of even the uppermost part of the Swift Formation.

FOSSIL - FRAGMENTS

The presence of fossil fragments of pelecypods, Belemnites, brachiopods, etc., confirm the shallow water marine origin of the Swift sediments.

SUMMARY OF SOURCE MATERIAL

To summarize, the source rocks were, probably, claystone, cherty mudstone, siltstone, fine-grained sandstone, bedded chert, limestone and volcanic rocks (?). Of these, claystone, cherty mudstone and fine-grained sandstone were predominant. Siltstone might have been the source of 'Silt-bearing' chert.

The possible source rocks are the Retort and Tosi Members of the Phosphoria Formation and Upper Shedhorn Member of Shedhorn Formation, which underlie the Ellis Group in this area. Chert is present in the Madison limestone of the Mississippian also. The source material was probably not very far from the place of deposition.

Source Area

The sharply broken, half spherical quartz-grains suggest that there was very little input of mechanical energy during the last cycle of transport and deposition. Thus, if the sand-grains were transported, the amount of transport was relatively little. The source area must have been local.

Though the larger chert grains are more angular than the coarser quartz, the smaller chert grains are more rounded than finer quartz grains which might be due to softness of the chert (Sneed 1955, Folk, 1965, P. 81).

The presence of claystone grains and clayballs in the Swift sandstones indicate little transport and input of mechanical energy; probably a local source area, not very far from the site of deposition.

The Swift sandstones are moderately to well-sorted and submature. The presence of marine fossils such as pelecypods, crinoids, echinoids and brachiopod fragments indicate marine conditions. Submature sand-grains might be due to relatively small amount of transport by the slow marine currents.

Small scale, straight and short cross-beds at an angle of about 25° to 30° with the planar bounding planes, indicate slow currents, strong enough to carry fine-grained sand, silt and clay-size material only. According to Allen's (1963, P. 83-114) classification these are the 'Beta' type cross-beds. The source area might have been of gentle gradient and low relief. It could not supply more sediments as reflected in the relatively thin deposits of the Swift Formation as a whole.

The dip-direction of the cross-beds in the cross-bedded sandstone is to the northeast suggesting that the general current direction was from the southwest to the northeast.

Gradual decrease of the sand-size material corresponding with increase in silt and clay-size material in the Swift rocks towards the northeast also suggest that, probably, the material was transported from the south in general or that the area in the southwest was of greater turbulance.

From the study of the regional published maps, it appears that the Belt Island decreased in significance as a barrier during the deposition of the Swift sediments, south of this area. Shallow water marine currents were flowing in general northwards, on the west side of the Belt Island (Peterson, 1957, P. 432). The Belt Island might have supplied some sediments. The currents coming from the south eroded the coasts of the narrow sea and probably brought the sediments partly from the Belt Island and partly from the western coast of the narrow sea.

Transport Medium

Continuous, nearly uniformly thick beds of the Swift containing pelecypods, crinoids, brachiopod fragments etc., indicate shallow marine waters as the medium of transport and deposition. Glauconite in the upper part of the Swift rocks, indicates that marine conditions existed throughout the deposition of the Swift.

Small scale asymmetrical ripples on the bedding planes of the sandstone of the basal unit as well as of the massive glauconitic sandstone of the upper part of the Swift, indicate slow and weak currents and lower flow regime. Small scale, straight, cross-beds at an angle of about 25° to 30° also indicate slow currents, strong enough to transport sand, silt and clay-size material. The pebbles in the basal conglomerate might be due to local reworking of the eroded lag material by the transgressing sea.

Presence of claystone rock-fragments also suggest the weak currents and relatively less duration of transport.

As indicated by regional overstepping (Lovely, 1948; P. 2295) of the older rocks by the Swift rocks, the sea transgressed and covered a wide area. This suggests widespread regional subsidence. Mechanical energy played an important role in the deposition of these sediments.

The size of the grains decreases from 0.22 mm. excluding the pebbles in the basal unit to 0.09 mm. at the top. The third unit underlying the glauconitic sandstone contains shale-layers indicating that the current velocities were least and the depth of water might have been the greatest during the deposition of the shales. The basal conglomerate might have been formed during the initial transgression of the sea which continued upto the deposition of the shales of the third unit. Regression of the Swift sea started after this as indicated by fine-grained glauconitic sandstone overlying the shales. Thus, probably, there was one major cycle of transgression and regression of the sea during which the Swift sediments were deposited.

Environments

The important factors of the environments during the deposition of the Swift might have been as follows:

(1) Stable slowly sinking shelf within the infralittoral zone as suggested by the transgressing sea.

(2) Slow currents of low capacity as suggested by small scale straight cross-beds, ripple marks, less sorting and presence of clayballs, claystone grains etc.

(3) Transgression of the sea starting with the deposition of the basal unit which might have been maximum during the deposition of shales of the third unit, after which regression started during the deposition of glauconitic standstone.

(4) The amount of sediments was not much as indicated by relatively thin Swift sediments.

(5) Mechanical energy was important for the deposition of the Swift sediments. Chemical energy played relatively small role during the precipitation of cements after deposition.

Thus the Swift sediments were derived from the older sedimentary rocks exposed south of this area and were deposited under widespread shallow water infralittoral conditions.

Diagenesis

Dapples (1959, P. 36-51) divides the diagenetic changes into three major stages: (1) Initial depositional stage, (2) early burial stage, (3) deep burial stage. It is probable that the changes are transitional from one stage to another.

INITIAL DEPOSITIONAL STAGE

During this stage, the sediments settle from suspension. The water-sediment interface becomes distinct and initial compaction due to weight of new sediments occurs. However, the quartz sand grains could not be compacted much during this stage to decrease pore-spaces. There remained still an open-system relation between the open sea-water and interstitial waters.

EARLY BURIAL STAGE

With increase of burial and compaction of the sediments the interstitial water was completely enclosed in the interstices and isolated from the open water body. The concentration of dissolved salts and silica might have increased due to percolating water moving through pore-spaces. Amount of silica might have increased also due to supply of abraded silica which dissolves easily (Siever, 1962, pp. 139). Increase in concentration of silica might have resulted into precipitation of quartz and hence development of overgrowth on detrital quartz grains. It also suggests that if pH value increased with increasing depth of burial of sediments, the increase in pH must not have been above 8.5, because solubility of silica increases significantly above 8.5 pH (Krauskopf 1959, fig. 4 p.10.) Thus precipitation of secondary silica could occur even at relatively low concentration below 8.5 pH.

As the Swift sediments were deposited in the shallow water marine conditions, the initial interstitial water must have been the marine water containing dissolved salts. The ionic strength of the pore waters might have increased after the isolation of the interstitial waters. Siever(1959, p. 75), suggests that the solubility of silica decreases with increase in the ionic strength of the dissolved salts. This increase in the ionic strength might have helped in the developments of the overgrowths of the quartz grains. Thus the secondary quartz might have precipitated due to (1) addition of abraded quartz and movement of conate waters, and (2) increase in ionic strength of dissolved salts in interstitial waters.

The fact that there are only rare concavo-convex and interpenetrating grain contacts among the sand grains suggests that the development of the overgrowth of the quartz grains due to compaction, dissolution of silica at the points of contacts of more pressure, and reprecipitation of the silica in the pore-spaces was probably an important process.

LATE BURIAL STAGE

Abundance of calcite cement (about 26%) and replacement of quartz cement as well as quartz grains in a few cases by calcite cement, suggest that the pH conditions might have been basic and probably the sediments might have been buried to relatively greater depths where conditions were suitable for precipitation of calcite. Probably the calcareous material was abundant in interstitial waters. The solubility of calcite is more at low, and less at high pH values (Siever 1959, p.76). Hence calcite might have precipitated with increased depth of burial of sediments which is normally accompanied by increase in pH conditions.

The temperature increases with increase in depth from the surface. Solubility of calcite decreases with increasing temperature up to 120°C, (Siever, 1959, p. 76).

Thus the combined increase in pH and temperature, corresponding with increase in depth of burial of the Swift sediments, might have decreased the solubility of calcite. The calcite precipitated and formed secondary cement filling in all the pore spaces, left open after introduction of quartz cement. Since there is more calcite than quartz cement, the amount of dissolved carbonate probably exceeded the amount of dissolved silica in the interstitial waters.

REPLACEMENT OF QUARTZ

Increase in temperature increases the solubility of quartz below 120 (Siever 1959, p. 76). Hence with increase in depth of burial, quartz might have become slightly unstable and might have dissolved at some points. Krauskopf (1959, p. 10, fig. 4) suggests that the solubility of silica increases significantly above a pH of 8.3 to 8.5; a value which frequently exists in natural interstitial waters at great depth.

Thus possibly the solubility of quartz increased due to combined effect of increased temperature and increased pH. Quartz cement and even parts of some quartz grains were dissolved. Due to simultaneous decrease in solubility and hence precipitation of calcite, quartz was replaced by calcite (fig. 22). Sutered boundaries developed between the overgrown quartz grains and calcite cement.

GLAUCONITE

Some glauconite grains are decolorised in the upper part of the Swift, which might be due to deep burial of the Swift sediments (Dapples 1959, p. 44-45).

MORRISON FORMATION

Unlike the Swift Formation, the beds of the Morrison Formation are discontinuous, intertonguing lenses of varying thickness. Laterally the facies change within short distances. However some resistant beds are well exposed and their dip and strike are concordant with beds of the Swift below.

For the most part, the Morrison is nonresistant and parts of all the measured sections were covered. Of the five sections where the Swift was measured, three sections also provide good exposures of the Morrison. They are Bradman Railroad section, Southwest Rattler Gulch section and West Rattler Gulch section. Nearly complete sections of the Morrison are exposed at these three sections. The Morrison can be subdivided into following five vertical units: (1) basal unit, (2) massive sandstone, laminated sandstone and siltstone unit, (3) covered interval, (4) slabby sandstone unit, (5) finer grained unit (plate 1). Individual beds of Morrison do not continue laterally throughout the cross section due to facies change within short distances.

Basal Unit

GEOMETRY

The basal unit is exposed between 61 ft. and 120 ft. above the base at Railroad section, between 90 ft. and 140 ft. in the southwest Rattler Gulch section and between 70 ft. and 147 ft. in the west Rattler Gulch section. The basal unit is poorly exposed and contains gray shale, cross bedded sandstone and laminated sandstone.

Gray Shale

At the Railroad section, the gray shale is 14 ft. thick and overlies glauconitic sandstone of Swift. It forms a covered interval in the west Rattler Gulch section and is absent in the southwest Rattler Gulch section. Its gray color and thin parting planes are similar to those of the overlying shale of the Morrison. Hence it is included in the Morrison Formation and the boundary between the Swift and the Morrison is placed at the top of the glauconitic sandstone.

Cross Bedded Sandstone

The basal gray shale is overlain by compact cross-bedded sandstone. It is 45 ft. thick at the Railroad section. In the west Rattler Gulch section, there are two intervals of cross-bedded sandstone, a lower 10 ft. thick interval and an upper 11 ft. thick interval separated by laminated sandstone. In the southwest Rattler Gulch section, cross-bedded sandstone is 10 ft. thick and passes upwards into laminated sandstone.

Laminated Sandstone and Upper Part of Basal Unit

The thickly laminated sandstone interval occurs between the two layers of cross-bedded sandstone in the west Rattler Gulch section and is 10 ft. thick. There is a covered interval 37 ft. thick overlying the laminated sandstone at this section. In the southwest Rattler Gulch section, the laminated sandstone is 20 ft. thick and overlies the cross-bedded sandstone. There is a siltstone, 20 ft. thick, overlying the laminated sandstone at this section. It is followed by a covered interval of 10 ft. Neither the laminated sandstone nor the cross-bedded sandstone were observed at William Gulch or Van Curan Gulch sections, where the interval is covered.

SEDIMENTARY STRUCTURES

Lenticular beds

Discontinuous lenticular beds of this unit are characteristic and suggest non-marine, probably channel, deposition.

Cross-bedding

The cross-bedding is more distinct in the thick cross-bedded sandstone of this basal unit of the Morrison than in the cross-bedded sandstone of the Swift. There are planar straight cross-beds bounded by planar bounding planes at an angle of about 25° to 30° and dipping northeast, which suggest that the current direction was from the southwest towards the northeast (fig. 26).

Laminations

Alternating relatively coarser dark-coloured laminae containing abundant chert grains and finer-grained light coloured laminae containing more quartz grains and clay matrix, form the laminations in the laminated sandstone interval.

MINERALOGY

The mineral composition and mineral percentages of these sandstones were studied by point counting thin sections. The major constituents are the same as those in the Swift, namely common quartz, three types of chert, claystone and fine-grained sandstone rock-fragments, plagioclase, heavy minerals - tourmaline, rutile, and zircon, and quartz and calcite cements.

Figure 26. Planar cross-beds in the Morrison sandstone sample from Southwest Rattler Gulch section at 99 feet from base.

Quartz

Quartz grains are common, clear, quartz with straight extinction. The percentage of quartz in the sandstone of this unit varies from 45% to 49%. There are very few inclusions in the quartz grains. The gas-bubbles occur as scattered vacuoles, or form lines. Rutile needles and brown pleochroic round and prismatic crystals of tourmaline also occur as inclusions in the quartz.

The quartz grains of these sandstones are more rounded than those of the Swift sandstones. Some of them are sharply broken in half as in the Swift and the sharp edges are not rounded off.

Detrital quartz grains with reworked overgrowths are more abundant than in Swift sandstone. The quartz grains can be divided into four groups: (1) well rounded grains with reworked overgrowths in which original detrital grain boundary can be distinguished by a clayey layer; (2) well rounded grains which inherited their shape from a previous sediment; (3) rounded but sharply broken grains with sharp edges; (4) well rounded detrital quartz grains encircled by euhedral quartz overgrowth (fig. 27).

Chert

As in the Swift there are three types of chert grains- 'clayey' chert, 'pure' chert, and 'silt bearing' chert. The percentage of the chert in the rocks of the basal unit varies from 11% to 32%. Silicified fossils could not be identified as in the chert grains of the basal conglomerate of the Swift. The mineral inclusions in the chert grains are calcite probably replacing clay in the clayey chert and magnetite grains.

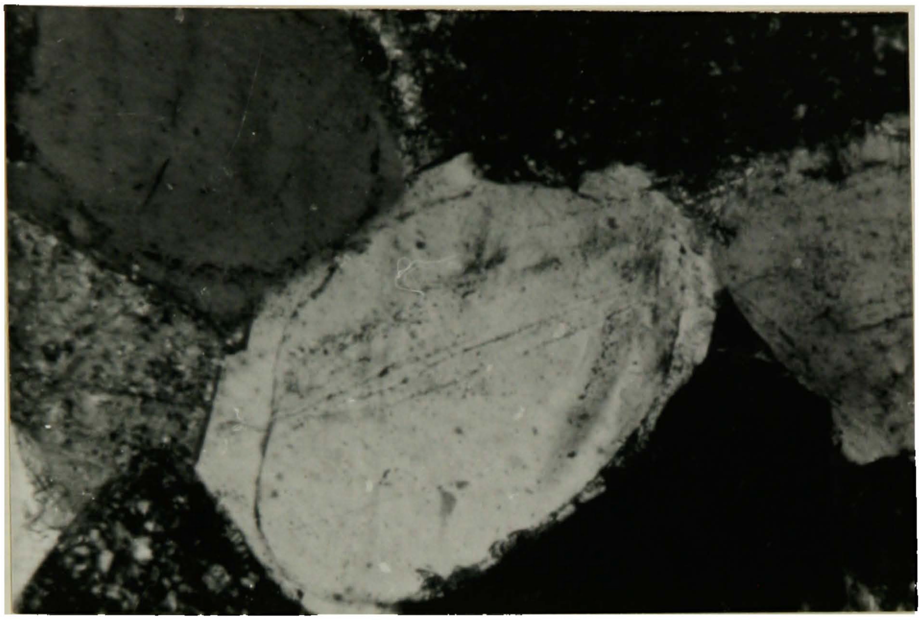


Figure 27. Well rounded quartz grain encircled by euhedral quartz overgrowth in Morrison sandstone. Sample from Southwest Rattler Gulch section at 120 feet from base. X 120.

Chalcedony

Chalcedonic grains are a minor constituent. The proportion of chalcedony varies from 0.67% to 1.12%.

Rock-fragments

Most of the rock-fragments are of the sedimentary rocks - fine-grained sandstone, claystone and limestone. There are few doubtful metamorphic rock fragments and no volcanic rock fragments. MRFs might be of slate which cannot be distinguished easily from laminated shale, in thin section. The proportion of fine-grained sandstone rock-fragments in these rocks varies from 1.76% to 4.45% while that of laminated claystones varies from 5.50% to 9.00%. There are some limestone grains also, but they average less than 1% in these rocks.

Feldspar

There are small, fresh grains of plagioclase. Some of them are replaced along their borders by calcite. Due to their small size, the types of plagioclase could not be determined. The percentage of plagioclase feldspar ranges up to 0.30%.

Mica

Small detrital flakes of muscovite are also present. The proportion of muscovite varies from 0.20% to 1.6%. In addition to muscovite sericite, appears to have replaced clay in the chert grains and feldspar borders of the feldspar grains.

Heavy Minerals

As in the Swift sandstone, the heavy minerals are zircon, rutile and tourmaline of which tourmaline and rutile occur as inclusions in the

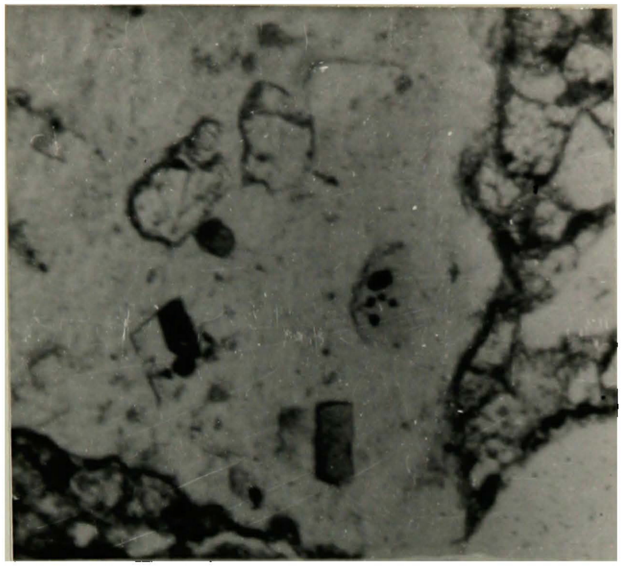


Figure 28. Tourmaline grain occuring as inclusion in quartz grain of the Morrison sandstone. Sample from Bradman Railroad section at 90 feet from base.

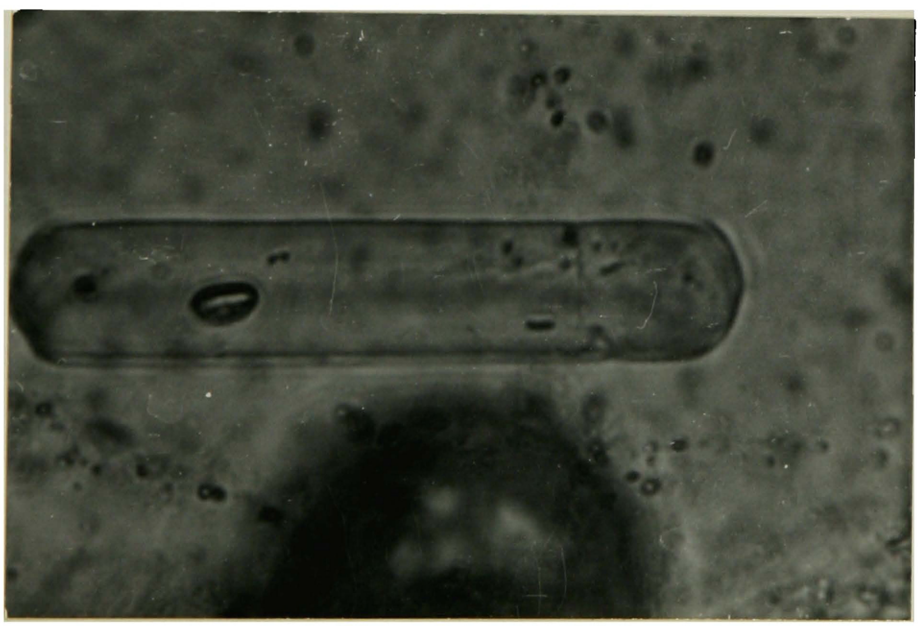


Figure 29. Rutile needle occuring as inclusion in quartz grain of the Morrison sandstone. Sample from Bradman Railroad section at 90 feet from base X 200.

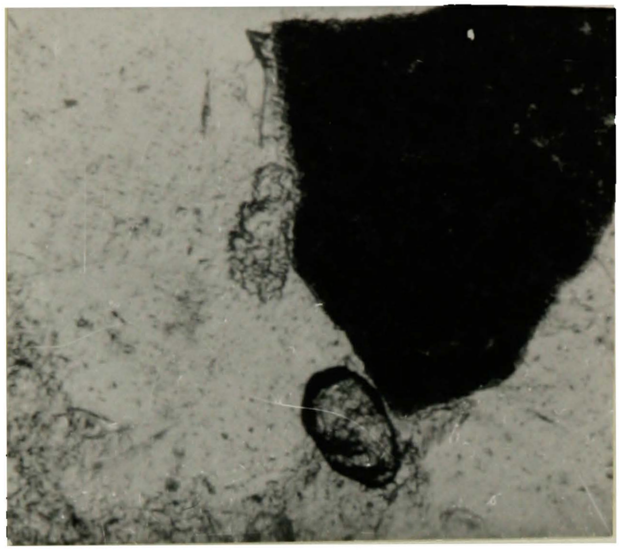


Figure 30. Rounded zircon grain in Morrison sandstone. Sample from Bradman Railroad section at 130 feet from base. X 200.

quartz grains (figs. 28, 29). Zircon occurs as very small rounded grains (fig. 30), rutile as needles and tourmaline occurs as prismatic and rounded grains. The proportion of the heavy minerals is less in the Morrison than in the Swift and averages 0.25%.

Cement minerals

The minerals cementing these sandstones are quartz overgrowths on the detrital quartz grains and calcite, which fills in all the remaining available pore-spaces. In the cross-bedded sandstone of this unit at Railroad section, the cement is mostly quartz together with a minor amount of sidrite. Calcite is absent here. The cement in the sandstones of this unit at William Gulch Section is calcite, while that in the southwest Rattler Gulch section consists of both, calcite and secondary quartz.

Clay Minerals

The clay minerals identified in the gray shales of this unit at Railroad section, are (1) mixed layered illite-montmorillonite, (2) Septachlorite, (3) 14A^{o} chlorite and (4) Kaolinite (?). The montmorillonite in mixed layered illite-montmorillonite phase is 10% which is similar to that in the shales of the overlying units of the Morrison. (Fig. 31).

TEXTURE

Sphericity

The sphericity of the grains of the rocks of the basal unit range from subelongate to subequant which is a greater range than that of the Swift.

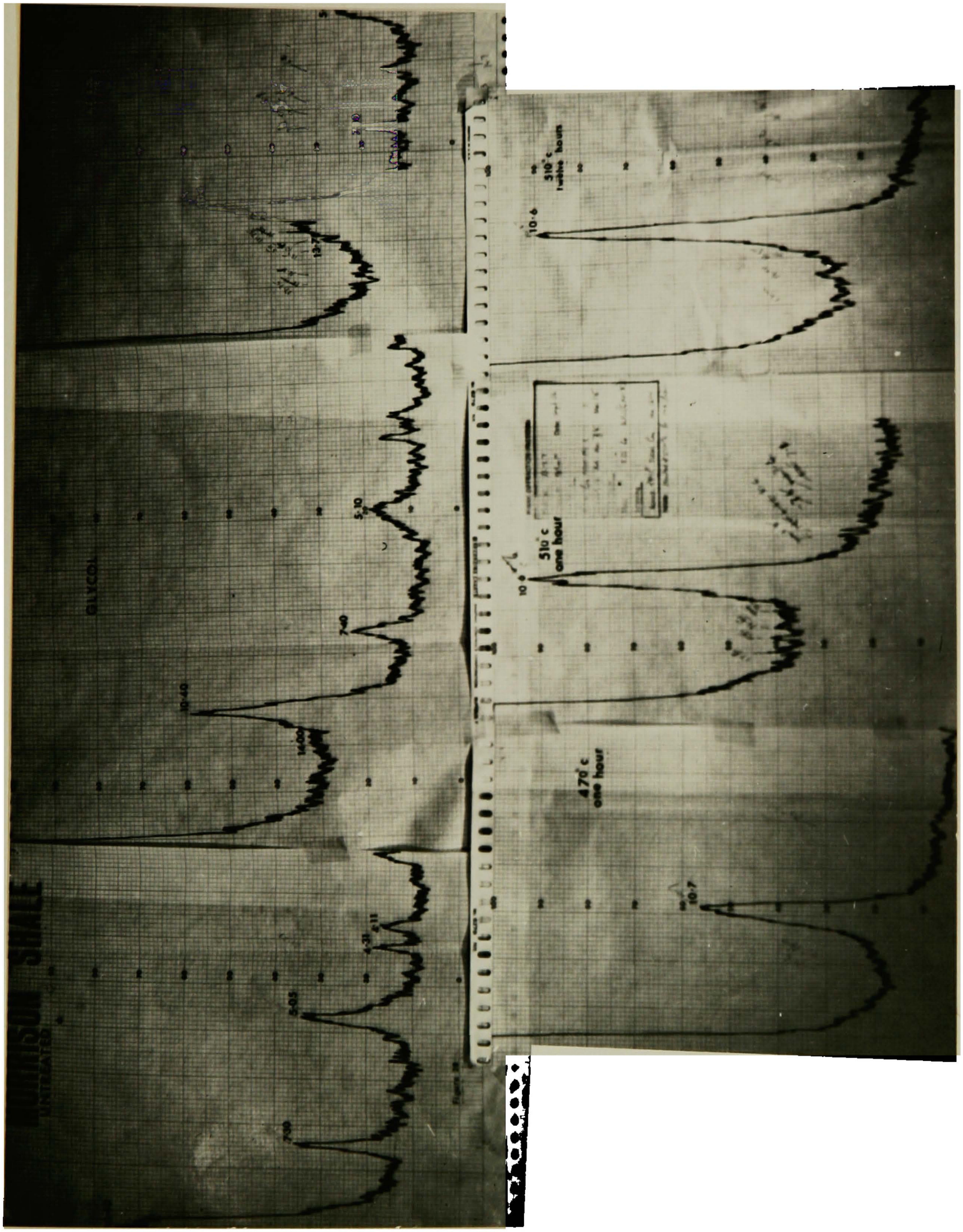


Figure 31. X-ray pattern of the clay minerals of the gray Morrison shale overlying glauconitic Swift sandstone. Sample from Bradman Railroad section at 70 feet from base.

At the Railroad section, it is 20 ft. thick and is exposed from 120 ft. to 140 ft. in the section. The lower part of the unit consists of massive sandstone, 10 ft. thick, which is relatively less resistant than the ridge forming sandstone of the basal unit. The upper part of the unit is siltstone, 10 ft. thick.

In the west Rattler Gulch section, it is 13 ft. thick and is exposed from 147 ft. to 160 ft. in the section. It consists of a 5 ft. thick massive sandstone overlain by siltstone, 8 ft. thick.

In the southwest Rattler Gulch section, it is 30 ft. thick and is exposed from 150 ft. to 180 ft. in the section. Its lower part consists of 20 ft. of slabby sandstone instead of massive sandstone. The slabby sandstone is overlain by laminated sandstone, 10 ft. thick.

At William Gulch section, this unit is also 30 ft. thick and is exposed between 125 ft. and 155 ft. in the section. It consists of laminated sandstone, 10 ft. thick, followed by massive sandstone, 20 ft. thick.

At Van Curan Gulch section, the unit becomes very thin and is exposed from 180 ft. to 190 ft. in the section. It is poorly exposed and consists of siltstone.

SEDIMENTARY STRUCTURES

Laminations

Relatively coarse grained dark colored chert and quartz rich horizontal laminae alternate with finer grained light colored quartz and clay-rich laminae. The laminations might have been formed in the upper flow regime, or by migrating ripples. As there are small scale, straight, cross-beds in overlying sandstones suggesting lower flow regime

Quartz grains are elongate to equant. Most of them are sub-elongate, intermediate and subequant. The larger quartz grains are subelongate. Chert grains are mostly subelongate, intermediate and subequant. Claystone grains are elongate and subequant in general.

Rounding

The sand grains of the Morrison rocks as a whole, are more rounded than those of the Swift. Quartz grains have the roundness values of about 3. In the Morrison also, some of the quartz grains are sharply broken in half and the sharp edges are not rounded off. Relatively larger chert grains are subangular and have the roundness values of about 2 to 2.5 but the smaller ones are well-rounded having roundness value of about 3. Subelongate and elongate claystone grains are well-rounded.

Size

The grain size of the sediments of this unit is nearly uniform. It averages 0.20 mm., which is much larger than that of the top glauconitic sandstone of the Swift and hence can be distinguished easily from the Swift sandstone. The smaller grains are angular and might have been formed by shattering of the larger ones during the last cycle. Average size of these smaller grains is 0.12 mm.

Massive Sandstone, Laminated Sandstone and Siltstone Unit

This unit is better exposed than the basal unit but is discontinuous. It consists of several facies and is exposed at different levels from place to place (plate 1).

At the Railroad section, it is 20 ft. thick and is exposed from 120 ft. to 140 ft. in the section. The lower part of the unit consists of massive sandstone, 10 ft. thick, which is relatively less resistant than the ridge forming sandstone of the basal unit. The upper part of the unit is siltstone, 10 ft. thick.

In the west Rattler Gulch section, it is 13 ft. thick and is exposed from 147 ft. to 160 ft. in the section. It consists of a 5 ft. thick massive sandstone overlain by siltstone, 8 ft. thick.

In the southwest Rattler Gulch section, it is 30 ft. thick and is exposed from 150 ft. to 180 ft. in the section. Its lower part consists of 20 ft. of slabby sandstone instead of massive sandstone. The slabby sandstone is overlain by laminated sandstone, 10 ft. thick.

At William Gulch section, this unit is also 30 ft. thick and is exposed between 125 ft. and 155 ft. in the section. It consists of laminated sandstone, 10 ft. thick, followed by massive sandstone, 20 ft. thick.

At Van Curan Gulch section, the unit becomes very thin and is exposed from 180 ft. to 190 ft. in the section. It is poorly exposed and consists of siltstone.

SEDIMENTARY STRUCTURES

Laminations

Relatively coarse grained dark colored chert and quartz rich horizontal laminae alternate with finer grained light colored quartz and clay-rich laminae. The laminations might have been formed in the upper flow regime, or by migrating ripples. As there are small scale, straight, cross-beds in overlying sandstones suggesting lower flow regime it is likely that laminations did not form in upper flow regime.

MINERALOGY AND TEXTURE

Mineralogy and texture of the rocks of this unit are the same as in the basal unit except the percentages of the minerals and the sizes of the grains which are as follows:

Minerals	Percentage
Common quartz	49.38% Average
Chert	14.16% "
Chalcedony	0.85% "
Feldspar	-
Mica	0.16% "
Rock fragments	
Fine grained sandstone	1.42% "
Laminated claystone	5.10% "
Limestone	3.90% "
Cement	Rest

Grain-size of the sandstones of this unit is not uniform. It ranges from 0.11 mm. at the west Rattler Gulch section to 0.20 mm. at Railroad section. Average size is 0.15 mm., which is less than that in the lower unit.

Covered Interval

Above the relatively well exposed unit of massive sandstone, laminated sandstone and siltstone, there is a major covered interval of varying thickness at all the sections except for a 10 ft. thick gray shale interval which is exposed in the lower part of this unit in the west Rattler Gulch section.

The covered interval is 10 ft. thick at the Railroad and Van Curan Gulch sections and occurs from 140 ft. to 150 ft. and from 190 ft. to 200 ft. respectively. It is 30 ft. thick, from 155 ft. to 185 ft. in the William Gulch section. The covered interval is thickest in the west and southwest Rattler Gulch sections where it is 50 ft. thick and is from 160 ft. to 210 ft. and from 185 ft. to 235 ft. respectively.

Gray shale exposed in the west Rattler Gulch section contains mixed layered illite-montmorillonite, septachlorite, 14A° chlorite and kaolnite (?). The percentage of montmorillonite phase is about 10%.

Slabby Sandstone Unit

Above the major covered interval is a discontinuous sandstone unit (Plate 1). It is referred to as 'Float sandstone' by Kauffman (1963, p. 13) as this is the only sand unit in the finer grained upper part of the Morrison in this area. The sandstone breaks into 3 to 4 inches thick slabs, but is not thinly laminated as the laminated sandstone. It is well-exposed at William Gulch section and in the southwest Rattler Gulch section, where it is 30 ft. and 20 ft. thick respectively. It is exposed from 185 ft. to 215 ft. at William Gulch section and from 235 ft. in the southwest Rattler Gulch section. In the west Rattler Gulch section it consists of 24 ft. of green shale and siltstone from 210 ft. to 234 ft. In the Railroad section it consists of a 40 ft. thick green shale exposed from 150 ft. to 190 ft. which is partly covered.

MINERALOGY AND TEXTURE

Mineralogy and texture of the slabby sandstone are the same as those of the basal unit except for the percentages of the minerals and size of the grains, which are as follows:

Minerals	Percentage	
Common quartz	49.20%	Average
Chert	10.50%	"
Chalcedony	0.40%	"
Feldspar	1.25%	"
Mica	0.20%	"
Rock fragments		
Fine-grained sandstone	8.40%	"
Laminated claystone	6.00%	"
Limestone	-	
Cement	Rest	

Sandstone samples from the 'float' sandstone in this interval are very fine grained averaging 0.08 mm. In Railroad section and in the west Rattler Gulch section, shale replaces the sandstone while at Van Curan Gulch section, the unit consists of siltstone.

Finer-grained rocks unit

The uppermost unit consists of different types of fine-grained rocks; several shale-beds, siltstone and concretionary limestone beds in the west and southwest Rattler Gulch sections; shale and siltstone in the Railroad section; and fine-grained sandstone at William Gulch and Van Curan Gulch sections (Plate 1).

Mineralogy of the fine-grained sandstones at the William Gulch section differ from that of the sandstones exposed at lower level in lacking calcite cement. Except for this, the minerals are the same as those of the units below. The percentages of the minerals are as follows:

Minerals	Percentage
Common quartz	45.5% Average
Chert	13.7% "
Chalcedony	0.75% "
Feldspar	-
Mica	0.35% "
Rock fragments:	
Fine-grained sandstone	1.8% "
Laminated claystone	10.9% "
Limestone	6.6% "
Cement	Rest

Varicoloured shales are poorly exposed in Railroad and in the southwest Rattler Gulch sections. The shales are well-exposed in the west Rattler Gulch section where they are gray, yellowish-gray, black carbonaceous and yellowish platy iron inclusions. The clay minerals are nearly the same in all these shales, and are mixed layered illite-montmorillonite, septa chlorite, 14A^{o} chlorite and kaolinite (?). The percentage of montmorillonite in mixed layered illite-montmorillonite phase is 10% (fig. 32).

There are also three lenses of concretionary fresh water, yellowish, argillaceous limestone in the east Rattler Gulch section.

Basal Kootenai Conglomerate

At all the sections except the Railroad section, a ridge-forming, very coarse grained conglomerate in the basal part of Kootenai Formation overlies the Morrison. It contains quartz, quartzite and chert pebbles

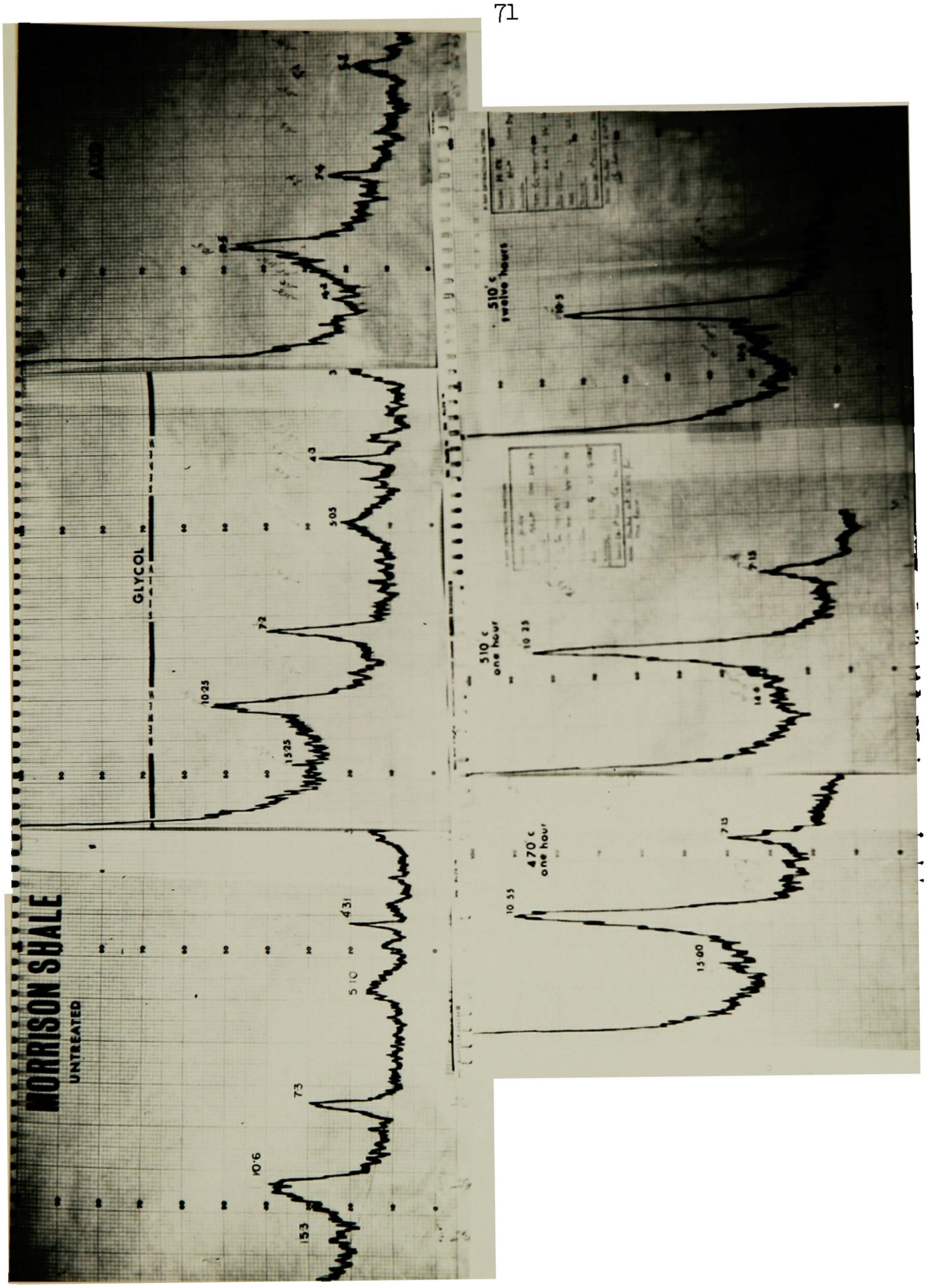


Figure 32. X-ray pattern of clay minerals of the gray Morrison shale. Sample from the west Rattler Gulch section at 270 feet from base.

up to about 18 inches in diameter, quartz and chert sand matrix, and siliceous cement. It reaches 35 ft. thick in southwest Rattler Gulch section and Van Curan Gulch section. The contact between this conglomerate and the uppermost bed of the Morrison appears to be concordant and probably disconformable. No channels were found cut into the top of Morrison, but the top appears undulatory across the area.

Sorting and Maturity of Morrison Sands

The Morrison sands have a graphic mean of 2.97 and inclusive graphic standard deviation of 0.707, moderately well sorted.

The upper part of Morrison contains mostly siltstone and shale. Clay matrix in the Morrison sandstones is less than 5%. Hence these sandstones are submature (Folk, 1965, p. 103). In spite of submature sorting, some of the sand grains are very well rounded having roundness values of about 3 or more according to Power's Visual scale of roundness.

COMPOSITION DIAGRAMS AND CLASSIFICATION

The triangular composition diagrams prepared for the Morrison sandstone from each of the sections bring out the following points (figs. 33,34,35).

(1) The percentage of the quartz grains varies from a maximum of 61.00% in Railroad section to a maximum of 81.00% in the southwest Rattler Gulch section. Thus the quartz percentage increases gradually northward.

(2) The percentage of rock fragments varies from a maximum of 62% in Railroad section to a maximum of 39% in William Gulch section. Thus the percentage of rock fragments decreases northward.

(3) Feldspar content is less than 1%.

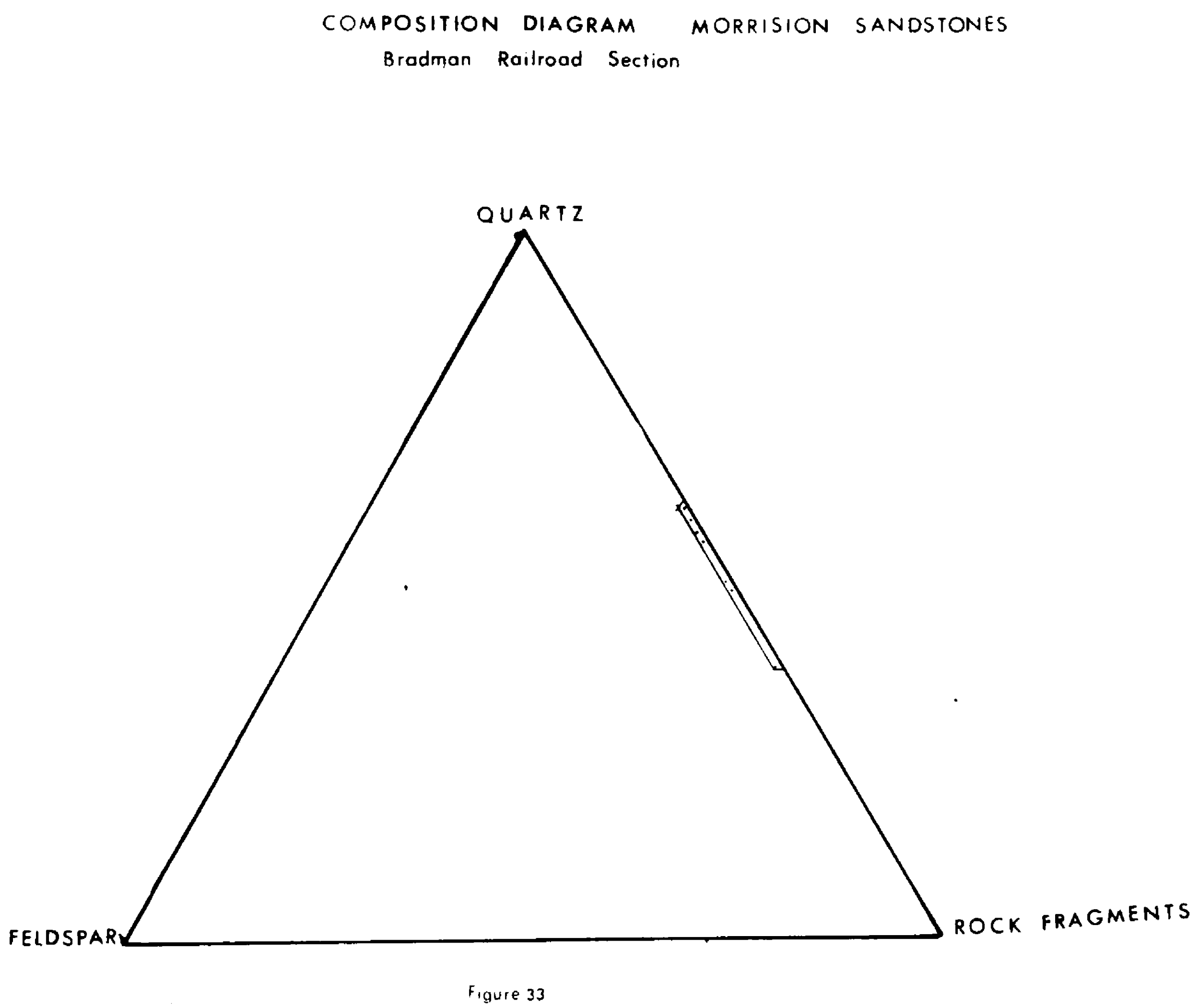


Figure 33. Composition diagram of Morrison Sandstone Bradman Railroad section.

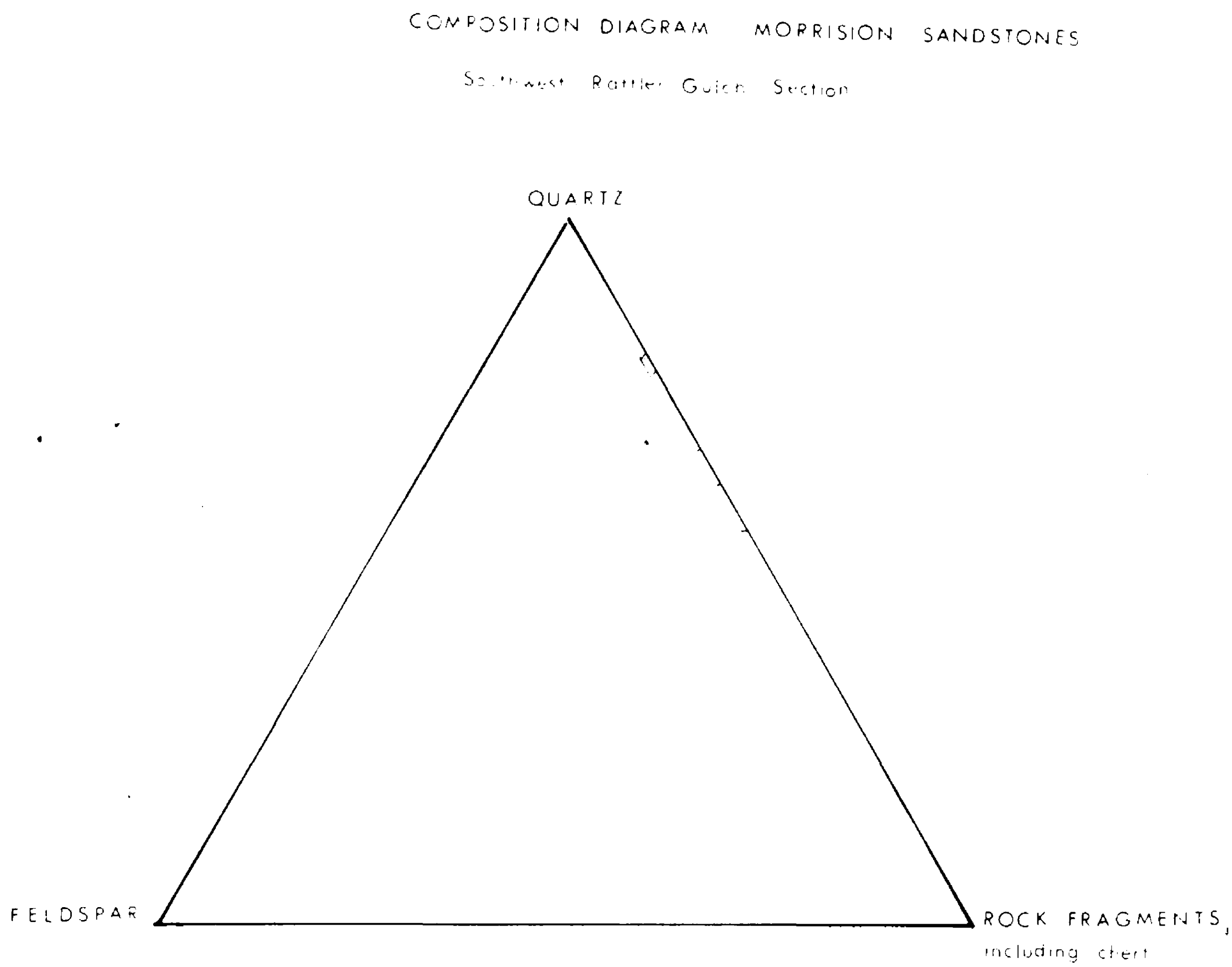


Figure 34. Composition diagram of Morrison sandstone. Southwest Rattler Gulch section.

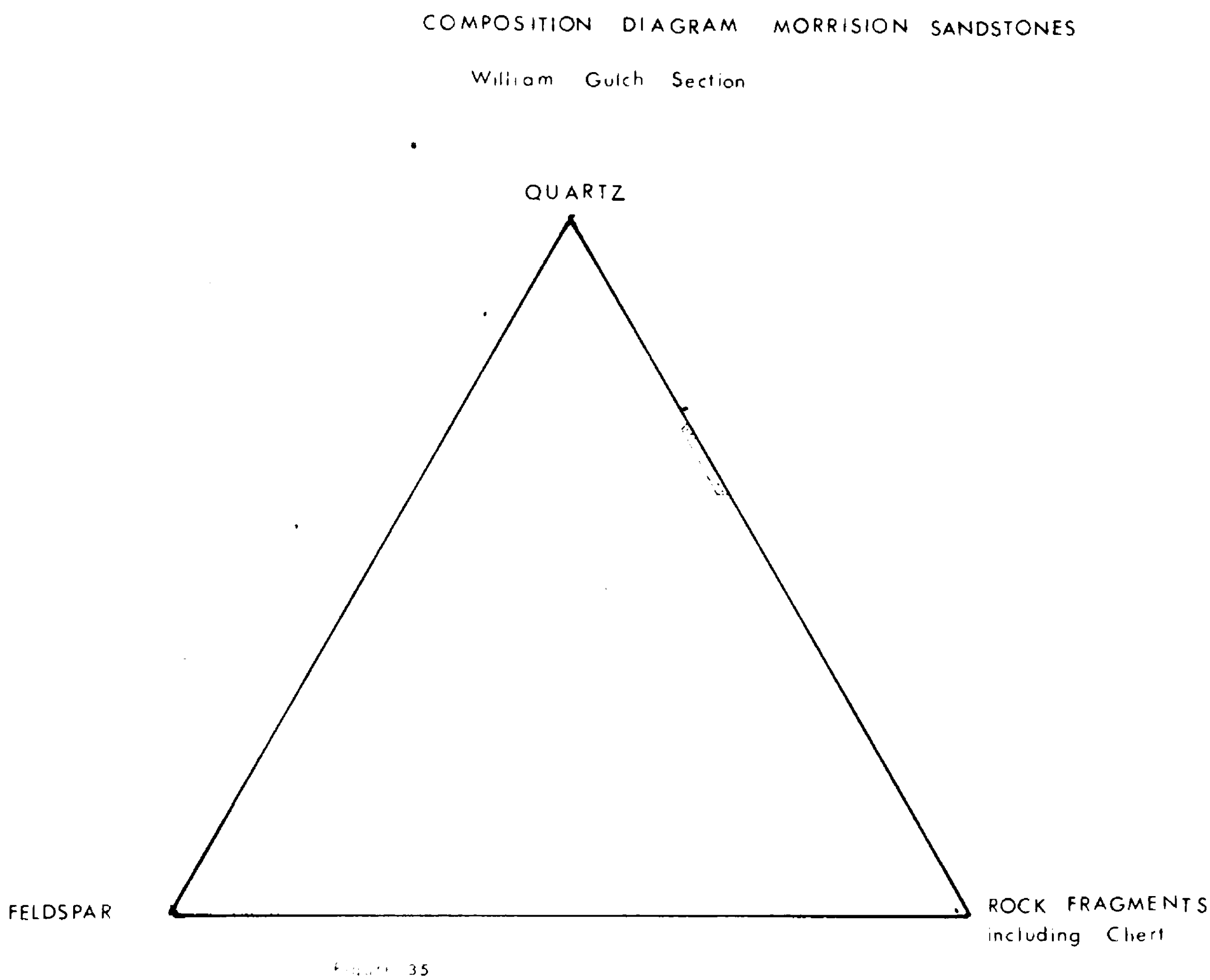


Figure 35. Composition diagram of Morrison sandstone. William Gulch Section.

The following table compares the variations in the maximum percentages of quartz, rock-fragments and feldspar of the Swift and the Morrison Formations:

Table No. 2

Name of Mineral, RF	Swift Formation		Morrison Formation	
	Maximum Percentages		Maximum Percentages	
	From	To	From	To
Quartz	85.5% in SW Rattler Gulch Section	49.00% in Railroad Section	81% in SW Rattler Gulch Section	61.00% in Rail-road Section
ROCK Fragments	80.00% in Railroad Section	54.00% in SW Rattler Gulch Section	62.00% in Railroad Section	39.00% in William Gulch Sec-tion.
Feldspar	2.00% in Railroad Section	1.00% in other sections	Less than 1.00% in all the sections	

NOMENCLATURE

It is very difficult to apply any of the established sandstone classifications to these rocks because of the difficulty of assigning the constituent minerals to any specific pole or group of minerals on the basis of which the sandstones are classified. These sandstones can best be described as follows:

Swift sandstones:

Moderate to well-sorted, fine-grained, subangular to subrounded, brown to yellowish brown, laminated and massive, quartz and calcite cemented, glauconitic, cherty, quartz sandstone deposited under shallow marine conditions.

Morrison sandstones:

Moderate to well-sorted, subrounded, gray, laminated, cross-bedded, and massive, quartz and calcite cemented, cherty, quartz, sandstone deposited in marginal low-level basin.

DIAGENESIS

Diagenetic changes which occurred in Morrison sediments can be interpreted by the study of the grain-contacts and types of cements.

DETRITAL GRAIN-CONTACTS

Common type of grain contact in the Morrison sandstones is straight-line contact. Other types of grain contacts are concavo-convex contacts among the quartz grains of the sandstones of the basal unit at Railroad and William Gulch sections, and 'massive sandstone' unit at southwest Rattler Gulch section; and interpenetrating grains in southwest Rattler Gulch section. (Figs. 36, 37).

TYPES OF CEMENT

There are two types of cement - quartz and calcite. Quartz cement which occurs as overgrowth on detrital quartz grains is relatively more abundant than that in the Swift sandstone and fills more than 10% of the pore-spaces. Original detrital grain-boundaries can be observed in some

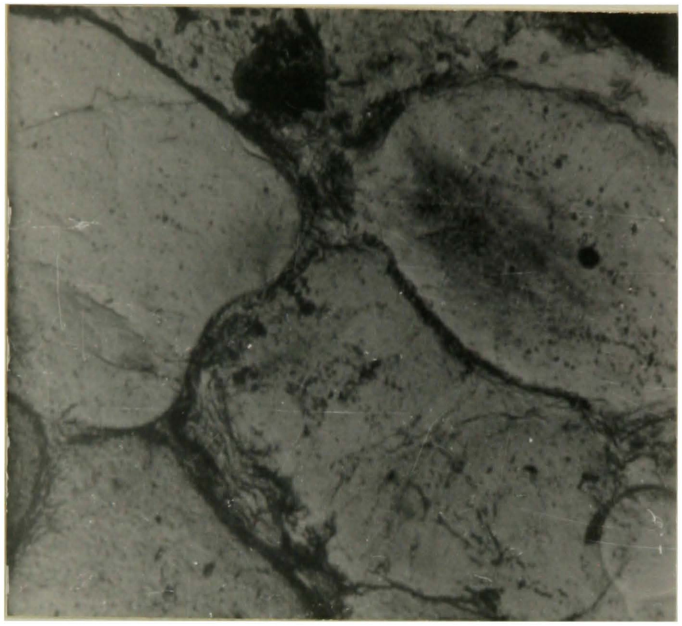


Figure 36. Concavo-convex contacts among the grains of the Morrison sandstone sample from Bradman Railroad section at 80 feet from base X 80.

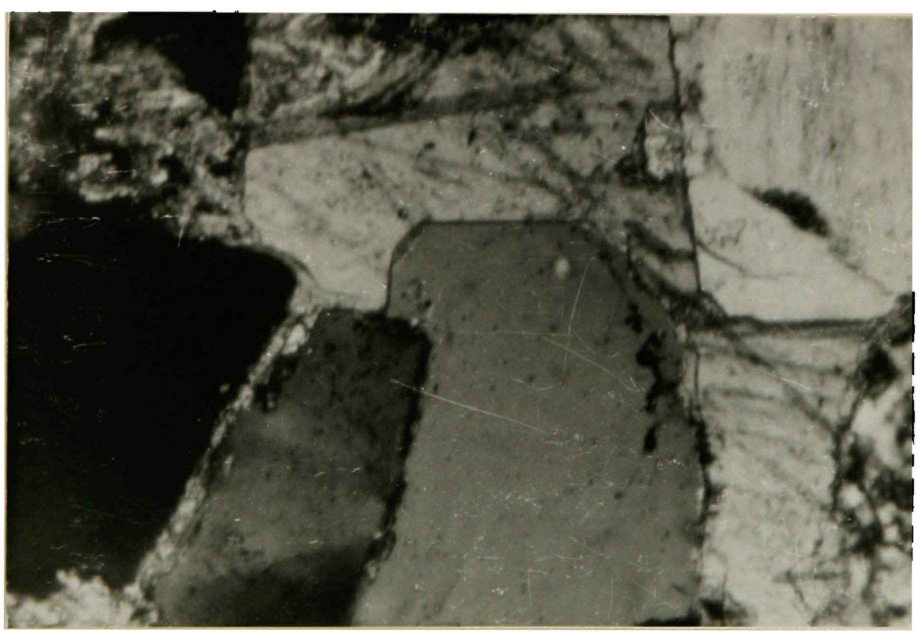


Figure 37. Interpenetrating grain contacts in the Morrison sandstone. Sample from southwest Rattler Gulch section at 120 feet from base X 100.

quartz-grains. There is no cement in basal unit of Railroad section, while the samples from William Gulch and southwest Rattler Gulch section contain relatively more cement. Calcite fills in the pore spaces among the quartz-grains and is relatively less than in the Swift sediments; averaging 19%. Calcite replaces quartz cement and parts of detrital quartz grains.

INTERPRETATION - MORRISON FORMATION

From the field-, slab- and thin-section studies the following genetic interpretations regarding source material, source area, transport medium and environments can be made. The boundary can also be interpreted from the combined study only.

Source Material

QUARTZ

Rounded quartz grains with reworked overgrowths indicate that the quartz grains are of second cycle and hence the source rocks are older sedimentary rocks. Some of the quartz grains are sharply broken in half, the sharp edges of which are not rounded off, which suggests that the quartz sand grains were slightly abraded during the last cycle.

CHERT

Similar to the Swift Sandstone, chert grains in the Morrison are of three types - 'clayey' chert, 'pure' chert and 'silt-bearing' chert. The same types of chert as in the Swift sandstone suggest that probably the source rocks for the Morrison sandstone were the same as those of the Swift. The chert might have been derived from the claystone-chert beds of the Phosphoria Formation of Permian age. Probably the rocks of the Phosphoria were still exposed and were eroded to form the Morrison sediments.

Again 'Pure' chert is more abundant in the Morrison Formation than in the Swift, which suggests that at least part of the chert might have been derived from bedded chert or chert nodules in limestone. The Rex chert of Permian age and Madison limestone of Mississippian age underlie the Jurassic rocks in this area and might have furnished the chert.

ROCK-FRAGMENTS

In addition to the chert, the rock-fragments in the Morrison sandstone beds include fine-grained sandstone, laminated claystone and limestone. The rock-fragments of fine-grained sandstone support the idea that older sandstone was one of the source-rocks. Laminated claystone grains were eroded from older claystone, probably the Sawtooth and Rierdon Formations of the Jurassic age or Phosphoria Formation of Permian age. Limestone grains indicate that limestone was one of the source rocks and probably limestone contained chert nodules which supplied some of the chert. The Madison limestone might have formed some of the source rocks.

HEAVY MINERALS

Heavy minerals are zircon, tourmaline and rutile which are the same as those in the Swift sandstone. Of these, tourmaline and rutile occur as inclusions in the quartz grains. Absence of less stable heavy minerals than these, suggest that probably older sedimentary rocks having this heavy mineral assemblage, formed the source rocks. Absence of characteristic metamorphic heavy minerals indicate absence of metamorphic source-rocks.

FELDSPAR

Though very minor in amount, the fresh plagioclase grains could possibly indicate that (1) the feldspar was rare in the source rocks, or (2) it was removed during extensive transport, or (3) it was decomposed and removed by weathering.

The sharp edges of the quartz grains indicate very little transport. Also the fresh feldspar grains suggest very little decomposition and weathering. Hence probably the feldspar was rare in the source-rocks.

CLAY-MINERALS

Among the clay minerals in the Morrison shales, mixed layered illite-montmorillanite is very prominent. In the mixed layered illite-montmorillonite phase, the percentage of illite is only 10%. Abundance of illite in the mixed layered illite-montmorillonite also suggests that, if detrital, the clay minerals might have been derived from older Paleozoic and pre-paleozoic rocks.

Thus the mineral composition of the Morrison rocks suggests that probably older sedimentary rocks served as sources and consisted of claystone, cherty mudstone, fine-grained sandstone, bedded chert and limestone. These are the rocks in the Tosi, Retort Members of the Phosphoria Formation and of upper Shedhorn member of Shedhorn Formation which directly underlie the Jurassic rocks in this area. 'Pure' chert might have been derived partly from the Madison limestone also. Some of the laminated claystone grains might have been derived from the Sawtooth and Rierdon Formations also.

Source Area

Intertonguing lenticular beds which are discontinuous and which cannot be traced from place to place suggest that the Morrison sediments are non-marine, probably channel deposits.

The cross-bedding is distinct in the cross-bedded sandstone of the basal unit at Railroad section and of the second unit in west Rattler Gulch section. Small scale straight cross-beds dipping to northeast at an angle of about 25° to 30° to the bedding planes suggest the current direction to be from southwest to northeast. Small scale, straight cross-beds, also, suggest weak currents capable to transport sand, silt and clay-size particles only.

Half-spherical sharp edged quartz grains suggest relatively small amount of transport. Thus probably the source area was not very far from the site of deposition. Possibly the slow flowing rivers transported and deposited the fine-sand, silt and clay in the flood plain region of the river-valley or 'valley-flat' region or marginal low level basin. The term 'valley-flat' includes both flood-plain and stream-channel portion of the lower part of a river valley (Twenhofel, 1950, p. 69). Small scale cross-beds indicate relatively weak currents which in turn suggest that the source area was not of very high relief.

Apparently the strand line separating Swift from Morrison sedimentation retreated and left behind a gently sloping region across which the rivers flowed and deposited the sediments in the deltaic regions of the river-valley. Peterson (1966, p. 126) suggests that at times a large lake developed in a low level region with internal drainage. The region west of this area was uplifted as a part of Laramide orogeny and an eastward flowing drainage system might have developed. In Drummond area a drainage system flowing to northeast is indicated by the cross-bedding directions.

Transport Medium

The lenticular discontinuous intertonguing nature of the Morrison rocks suggest non-marine deposits.

The grains of the Morrison sandstone are elongate to subelongate. This wide range of sphericity might have been inherited from the parent sedimentary rocks.

Sharply broken grains suggest relatively little transport or small input of mechanical energy. Though the clay matrix is minor, laminated claystone grains of sand size are present. These grains would have been disaggregated, had there been fast currents.

Small scale cross-beds which are straight and at an angle of 25° to 30° also suggest slow currents. Thus there were slow and weak currents in which sand-grains were transported small distances, probably by traction and which did not disaggregate claystone grains.

In that case the transport medium might have been slow river currents.

Environments

From the discussion of the source-material, - area and transport medium, the following points can be concluded:

(1) There was a gently sloping plain across which the rivers were interspersed with lakes.

(2) The currents were slow and of slightly changing carrying capacity which deposited the bed-load sediments of probably river-channel sands.

(3) In the west Rattler Gulch section, three lenses of concretionary argillaceous yellowish limestone were deposited in fresh water lakes containing dissolved calcareous material.

(4) There are relatively more shale beds than sand beds in the upper part of the Morrison in this area. The shales might have formed from deposition in the quiet waters. Perhaps a large lake formed on the coastal plain following the retreat of the Swift sea. The plant material depositing along with the settling clay and silt might have formed the carbonaceous shale which is found in the top portion of the Morrison at the Railroad and west Rattler Gulch sections.

There is a five foot thick yellowish-gray shale overlying the black carbonaceous shale in the west Rattler Gulch section which contains plate-like haematite-deposits. The haematite indicates oxidising conditions.

Very high percentage of illite ($\sim$90%) in mixed layered illite-montomorillonite of the Morrison shales might be due to warm and arid oxidising conditions during the later part of Morrison. Warm and arid climate is suitable for the development of alkaline soils in which illite is very stable. Thus, probably, warm and arid climate developed after the deposition of carbonaceous shale and probably prevailed during the deposition of the overlying basal Kootenai conglomerate. The gravels and pebbles of basal Kootenai conglomerate might have been transported by excessively strong currents caused by sudden rainstorms which occur occasionally in the desert climate (Peterson, 1966, pp. 128-129; Stokes, 1950, p. 97).

Thus the Morrison sediments probably were deposited in a gently sloping, slightly negative marginal basin traversed by slow rivers. At times the basin may have developed large lakes. The source rocks of the Morrison sediments were probably older sandstone, siltstone, claystone, claystone-chert, bedded chert and limestone. Quiet water lacustrine conditions existed in the later part of the Morrison during which the shale and fresh water limestone was deposited. Towards the end due to filling up of the basin, stagnant conditions developed in which the carbonaceous shale was deposited. After the deposition of the carbonaceous shale, probably warm and arid climate developed which might have existed throughout the deposition of basal Kootenai conglomerate.

Diagenesis

INITIAL DEPOSITIONAL STAGE

As stated earlier, the Morrison sediments were transported by traction and in suspension for a short distance by the slow currents. During the initial stage of deposition the interface between the sediments and the water might have been sharp. No distinct changes occurred except minor compaction of the sand grains and removal of excess water not filling the pore-spaces.

Interstitial water was still in contact of main water-body above the interface and there was not much difference in composition of interstitial water and of the water-body.

Early Burial Stage

With increase in depth of burial and compaction of the sediments, interstitial water was completely isolated from the surface waters and probably furnished some of the cementing minerals.

Quartz cement fills more than 10% of the porespaces in the Morrison sandstones whereas quartz cement fills less than 10% of the pore spaces in the Swift sandstones. Since river water contains more dissolved silica than sea water (Clark 1924), this difference in the degree of quartz cementation might result from the filling of the Morrison sand with the river water but the Swift sand with sea water. Some siliceous material might have been added also by the percolating waters moving through the pore spaces.

Quartz overgrowth suggests that pH conditions might have ranged up to maximum 8.3 to 8.5 pH because the solubility of silica increases significantly above 8.5 pH. Quartz overgrowth also suggests that temperature might not have been very high because solubility of silica increases significantly at high temperatures.

Thus due to (1) more dissolved silica in the river water within the Morrison than in the sea water within the Swift, (2) ranges in pH conditions below 8.5 pH and (3) moderate temperature, quartz cement was precipitated from the interstitial water during early burial stage of Morrison sediments.

Proportion of dissolved silica in interstitial waters was not uniform as indicated by varying overgrowths on quartz grains at different sections. Dissolved silica might have been very little at Railroad section and might be relatively more at William Gulch and southwest

Rattler Gulch sections. On the whole, there is more quartz cement in the Morrison rocks than in the Swift rocks which might be due to presence of more dissolved silica in interstitial water.

Concavo-convex and interpenetrating-contacts among the sand grains suggest dissolution of quartz at the points of contact due to compression. Redistribution of silica might have been more than in the Swift rocks.

LATE BURIAL STAGE

Proportion of calcite varies vertically and laterally which suggests varying amounts of dissolved calcareous material and locally varying conditions of crystallization.

As stated during the description of Swift Formation, probably pH conditions increased resulting into decrease of the solubility of calcite. Also with increased depth of burial of the sediments, the temperature also increased to some extent. If pressure of CO2 did not change much, solubility of calcite might have decreased with increase in temperature. Thus combined effect of increased pH and temperature, might have precipitated calcite cement during this stage.

Calcite cement is not as abundant as in the Swift rocks. Nevertheless, the quartz cement is replaced by calcite in some places. This might be due to simultaneous increase in solubility of quartz at high pH value and temperature conditions.

Siever (1959, pp. 76) and Degens, (1965, p. 75) do not agree with Krauskopf and state that pH conditions might not be important for replacement of quartz by calcite because according to them, solubility of silica is independent of pH conditions up to pH value 9.00, and not

8.3 to 8.5 pH as suggested by Krauskopf. The pH value of 9.00 is not common in natural environments. Instead of pH conditions, increase in temperature is very important to increase the solubility of quartz, according to both of them.

BOUNDARY BETWEEN THE SWIFT AND THE MORRISON FORMATIONS

At each of the five sections studied in detail a resistant well-exposed glauconitic fine-grained sandstone forms the top of the Swift. Glauconite in this sandstone is relatively more abundant than in lower parts of the Swift. Average grain-size of the glauconitic sandstone is 0.08 mm. It is overlain by shale which is well-exposed at Railroad section.

A medium grained yellowish brown sandstone overlies the shale and is well exposed at Railroad, William Gulch, and southwest Rattler Gulch sections. Glauconite is absent and average grain size is 0.20 mm. which is much larger than that of glauconitic sandstone. The cement in this sandstone at the Railroad section, is quartz with a little siderite.

Thus the medium grained non-glauconitic sandstone can be easily distinguished from the very fine-grained glauconitic sandstone of the Swift, in thin section. Distinct change in size and sudden disappearance of glauconite in the medium grained sandstone, and absence of calcite cement in the sample from Railroad section, suggest that the medium grained sandstone might have been formed in the conditions of deposition other than those for the lower glauconitic sandstone.

In addition to the thin-section study, lenticular discontinuous shape, colour of the shales and absence of marine fossils in the beds overlying glauconitic sandstone, suggest that they might have formed in non-marine conditions.

In that case the medium grained sandstone described above belongs to Morrison Formation. The probable boundary between the Morrison and the Swift might be between the glauconitic sandstone and the medium grained yellowish brown sandstone, and above or below the gray shale which is in between the two sandstones (Plate 1). Gray colour and thin parting planes of the shale are similar to those of the overlying shales of the Morrison. Again the clay minerals are mixed layered illite-montmorillonite, septachlorite, $14A^{o}$ chlorite and kaolinite (?). Percentage of montmorillonite in mixed layered illite-montmorillonite is the same as that in the Morrison shales, namely 10% (figs. 30 & 31). It is also a suitable marker for mapping in the field. Hence the boundary between Swift and Morrison is placed at the base of the gray shale overlying the glauconitic sandstone of the Swift (Plate 1).

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APPENDIX I

CLAY MINERALOGY

The study of the mineral composition of the Morrison rocks can be completed with the study of the clay minerals of the shales and mudstones which form a prominent part of the formation. The clay minerals of the shale specimens collected from (1) the Railroad section and (2) West Rattler Gulch section where the Morrison rocks are well-exposed, were studied by the standard x-ray diffraction method. The specimens from Railroad section include the shales of the Swift Formation also.

Purpose of study:

The clay minerals of the shales of Swift and Morrison were studied for the following purposes:

(1) To find the types of clay minerals present in these rocks,

(2) To determine the relative proportions of the clay minerals by semiquantitative method,

(3) To compare the types and relative proportions of the clay minerals of the shales of the Swift and the Morrison; and from this comparison to see whether the clay mineral data supports the placing of the shales overlying the glauconitic sandstone of the Swift Formation in the Morrison Formation,

(4) To find out to what extent the clay mineral data supports the source-rocks interpretation and environments of deposition suggested earlier in the description of stratigraphy and petrography.

Method of study of the clay minerals:

The standard x-ray diffractometer method was used to study the clay minerals. The field specimens were collected after removing the surface cover, so that there is minimum contamination of the clay minerals due to surface weathering.

The specimens were disaggregated in the laboratory by the sonic vibrator. The method suggested by Kinter and Diamond (1956), was used to prepare the oriented slides of the clay minerals. Clay specimens, oriented along the basal planes were prepared by allowing the clay minerals to settle from suspension on the ceramic plates.

Oriented clay-specimens are examined from 35° 2θ to 3° 2θ at the drive speed of $2\theta = 1^\circ$/min. by Cu k_α radiation, filtered through a Ni plate. The specimens were also given the following treatments and then re-examined by the same radiation.

(1) Glycol treatment,

(2) Heat treatment at (a) 470°c and (b) 510°c for one hour each and (c) 510°c for twelve hours,

(3) Acid treatment by gentle boiling for one hour in ~1N HCl.

Glycol treatment:

On treating the fresh oriented slides of the clay minerals with glycol, the mixed layered minerals like illite-montmorillonite, expand. The d-spacing of a large broad peak between 10A° and 14A° suggests the relative abundance of montmorillonite in the mixed layered illite-montmorillonite phase.

Heat-treatment:

The heat-treatment is given primarily to distinguish between the

7A° minerals, Kaolinite and Septa-chlorite. However this is not a very reliable test. It was believed that chlorite was stable even at temperatures as high as 400°c to 500°c, while Kaolinite was unstable beyond 400°c and the peak of Kaolinite disappeared on heating at high temperatures due to collapse of the structure. Recent study of the sediments containing 7A° chlorite and Kaolinite indicate that disappearance or decrease in the height of the peak at 7A° between 400°c and 500°c does not necessarily mean that chlorite is absent (Nelson, 1960, pp. 141; Warshaw, 1961, pp.1492). Both Nelson and Warshaw suggest that 7A° chlorite becomes unstable at high temperatures as well as on being treated with acid. Thus on heating at the temperature more than 400°c, the peak of 7A° either due to Kaolinite or due to chlorite disappears.

Acid treatment:

The acid treatment is given to eliminate the chlorite from the sample. The 7A° peak might be formed due to reflections from, (1) first order kaolinite, (2) first order septachlorite, or (3) second order 14A° chlorite. Second order 14A° chlorite can be distinguished by the presence of a peak at 14A°.

In order to distinguish between kaolinite and 7A° chlorite, the specimens treated with 1 N HCl and boiled for about one hour are examined. If the peak at 7A° is due to 7A° chlorite, it disappears, for the chlorite is dissolved in acid solution.

OBSERVATIONS

Sixteen specimens were examined by Cu K_α radiation filtered through a Ni plate. Each of the specimen was also examined after the application of different treatments mentioned in 'Method of Study of Clay Minerals.' Out of the sixteen shale specimens examined, eight are from the west Rattler Gulch section and eight from the Railroad section. The specimens from the railroad section include four shale specimens from the Swift Formation, while all the specimens from the west Rattler Gulch section are from the Morrison.

Results show that the major peaks are at 7A°, 10A° to 12A° and 14A° for all the specimens. (Figs. 18, 30, 31). The diffraction patterns suggest the following possible clay-minerals.

1. Mixed layered illite-montmorillonite - 10A° to 12A°.
2. 7A° chlorite or septachlorite - 7A°.
3. 14A° chlorite - 14A°.
4. Kaolinite (?) - 7A°.

The specimens were given different treatments in order to determine the following points:

(1) Whether the 7A° peak is due to kaolinite or chlorite,

(2) Whether the peak between 10A° and 12A° is from the mixed layered illite-montmorillonite phase and if so, to determine the proportion of illite and montmorillonite.

In order to determine the presence of kaolinite or chlorite or both, the specimens were given both the heat - and the acid-treatments.

On heating the specimens, and then re-examining the diffraction pattern, the peak at 7A° is observed to decrease and then to disappear at the temperature 510°c. This suggests the presence of kaolinite or 7A° chlorite or both. The peak between 10A° and 12A° expands by 0.10A° average, which indicates the presence of mixed layered illite-montmorillonite. However the heat-treatment does not indicate specifically the presence or absence of chlorite.

On treating with 1 N HCl, the peak at 7A° decreases or disappears in most of the specimens. This suggests that the specimens have probably both 7A° chlorite and a little kaolinite. The specimens from which 7A° peak disappears completely is probably due to presence of 7A° chlorite only.

On treating the specimens with glycol, the peaks between 10A° and 12A° expand by 0.10A° average, thereby confirming the presence of mixed layered illite-montmorillonite.

The probable clay minerals as shown by the above mentioned examination of the specimens in order of relative abundance are mixed layered illite-montmorillonite, 7A° chlorite, 14A° chlorite in shale specimens of the gray shale overlying glauconitic sandstone at railroad section and in the shale specimens of finer-grained unit of Morrison in west Rattler Gulch section, and kaolinite.

Proportion of Montmorillonite in mixed layered illite-montmorillonite:

The proportion of montmorillonite in the mixed layered illite-montmorillonite is determined by using the d-spacing of the peaks and Hower's tables (unpublished). The percentages of montmorillonite in the mixed layered illite-montmorillonite of all the specimens examined are given in Table No. 3.

The observations made by studying the diffraction patterns can be summarized as follows:

(1) the major clay minerals are the same in the shales of the Swift and Morrison Formations.

TABLE NO. 3

Proportion of montmorillonite in mixed-layered illite-montmorillonite:

Railroad Section Specimen No.	d 10/14A°	Proportion of montmorillonite
Rierdon shale	10.8 A°	20%
Swift shales:		
B6	11.00 A°	25%
B8	10.30 A°	10%
B10	11.00 A°	25%
B14	10.50 A°	20%
Morrison shales:		
B-17	10.30 A°	10%
B-18	10.30 A°	10%
B-kootenai	10.30 A°	10%
West Rattler Gulch section:		
H 15	10.30 A°	10%
H 16	10.50 A°	20%
H 20	10.20 A°	1% to 10%
H 23	10.30 A°	10%
H 25	10.30 A°	10%
H 28	10.30 A°	10%
H 31	10.30 A°	10%
H 34	10.30 A°	10%

(2) The clay minerals in these rocks are, in order of abundance, as follows:

(a) Mixed layered illite-montmorillonite,

(b) 7A° chlorite or septa chlorite,

(c) 14A° chlorite in some specimens and

(d) Kaolinite (?).

(3) Average proportion of montmorillonite of the mixed layered illite-montmorillonite of the shales of the Swift Formation varies from 10% to 25%, while that in the shales of the Morrison Formation is nearly 10%.

INTERPRETATION

Source of clay minerals

The clay minerals might be detrital and derived from older rocks, authigenic and formed later after deposition in suitable environments or might be diagenetic.

As suggested in the description of stratigraphy and petrography of the sandstones, the possible source rocks for the sand grains are the rocks of Phosphoria Formation of Permian. Also the clay minerals in the mudstone of the Phosphoria exposed in some parts of southwest Montana are found to be mixed layered illite-montmorillonite, illite and montmorillonite by Herr (1955) and Revney (1956, M.S. and Ph.D. theses respectively; unpublished). Thus the mudstones of Phosphoria might have been the source rocks of the detrital clay fraction. The Madison limestone of Mississippian and other paleozoic and pre-Cambrian Belt sediments also cannot be ruled out as possible source rocks.

Environments

Very high percentage of illite (~90%) in the mixed layered illite-montmorillonite of the Morrison shales support the warm and arid climate during the later part of the Morrison which is suitable for the development of alkaline soils in which the illite is very stable.

Boundary between the Swift and the Morrison Formations:

There is a 14 foot thick shale bed overlying the glauconitic sandstone of the Swift at the Railroad section. It forms the covered interval at other sections and the thickness changes laterally. The shale is overlain by the medium-grained sandstone at the Railroad section which is thought to be of the Morrison from the study of its petrography. The shale bed is included in the Morrison and the boundary between the Swift and the Morrison is placed at the base of this shale bed from (1) similarity of this shale to other shale beds of the Morrison overlying it, and (2) it being a convenient marker horizon for mapping in the area.

The proposition of montmorillonite in the mixed layered illite-montmorillonite phase of the Swift shales is more than that in the Morrison shales. The montmorillonite in the mixed layered phase of the Swift varies between 10% and 25% while that in the mixed layered phase of the Morrison, including the shale overlying the glauconitic sandstone of the Swift varies from 1% to 10%. Thus the proportion of montmorillonite, in the mixed layered illite-montmorillonite phase of the gray shale overlying the glauconitic Swift sandstone, which is the same as that in the overlying shales of Morrison, also supports the inclusion of the gray shale into the Morrison Formation.

APPENDIX II

The description of the measured sections and the petrographic description of the collected specimens:

BRADMAN Railroad Section: Section 1.

Location:

Railroad cut, south of the Rattler Gulch along the north side of the Clark Fork River; Section 21, T11N, R13W. This section can be approached by going along the trek-road on the south of the Highway nos. 10 and 93, about 3 miles in the west of Drummond, Montana. Here, the Ellis group is well exposed but the Morrison Formation is partly covered.

Number	Description	Thickness of the unit in feet	Feet Above Base
	Morrison Formation: 150 feet measured.		
29	Gray medium grained, hard, siliceous gravelly sandstone containing gravels of red jasper. Basal Kootenai.	-	210' above
28	Black, massive, poorly exposed, carbonaceous shale, the uppermost part of the Morrison Formation.	10'	200'-210'
27	Covered interval.	10'	190'-200'
26	Green, massive, poorly exposed bentonitic shale	10'	180'-190'
	covered interval	20'	160'-180'
	covered interval	12'	138'-150'
25	Poorly exposed, brown, calcareous siltstone.	8'	130'-138'

Number	Description	Thickness of the unit in feet	Feet Above Base
24	Gray, heterogeneous, massive, cross-bedded, fine-grained, compact, calcareous, cherty sandstone. Petrography: Interlocked, and penetrating grains; Median - 0.15 mm; upper size limit - 0.20 mm; Moderately sorted; Roundness - 2 to 2.5 cement - secondary quartz, calcite; fine-grained sandstone: common quartz - 58.9%, chert 31.45%, chalcedony - 0.67%, SRF - 8.34%	10'	120'-130'
23	Gray, hard, ridge-forming, fine-grained, calcareous, cherty sandstone; with two sets of joints perpendicular to each other. Petrography: Interlocked and cemented grains; Md - 0.20 mm, upper size limit - 0.25 mm; well sorted, R - 1 to 2, due to euhedral to subhedral overgrowth; Fine-grained sandstone; CQ - 61.83%, Ch - 20.41%, Chal - 0.98%, SRF - 12.95%, VRF - 0.14%.	10'	110'-120'
22	Purple to yellowish gray, massive, fine-grained, argillaceous, sandstone. Petrography: Interlocked and penetrated grains; Md - 0.2 mm, upper size limit - 0.3 mm, well sorted, R-2 to 3, Cm - secondary quartz. Fine-grained sandstone; CQ - 49.51%, Ch - 22.62%, Chal - 1.21% SRF - 9.23%, Mica - 0.24%.	10'	100'-110'
21	Gray, 'salt and pepper', massive, cross-bedded, siliceous, cherty sandstone. Petrography: Loose-grained, Md - 0.20 mm, USL - 0.47%, well sorted, R - 2 to 3, CM - small amount of secondary quartz; Fine-grained sandstone; CQ - 55.13%, Ch - 30.00%, Chal - 0.91%, SRF - 13.16%, Mica - 0.30%.	10'	90'-100'

Number	Description	Thickness of the unit in feet	Feet Above Base
20	Gray, slabby fine to medium grained, siliceous, cherty sandstone. Not distinctly visible cross-beds present. Petrography: Interlocked and welded; Md -0.15 to 0.20, USL - 0.45 mm, well sorted, R - 2 to 3, clay matrix present, CM - secondary quartz. Slightly muddy sandstone; CQ - 47 to 48.5%, CH - 38 to 40.7%, Chal - 0.79 to 1.12%, SRF - 9.40%, Feldspar - 0.07%, Mica - 0.26%.	10'	80'-90'
19	Gray, 'salt and papper,' massive, siliceous, cherty, fine-grained sandstone; Petrography: Interlocked and welded: MD - 0.26 mm, USL - 0.45 mm, moderately, sorted; R - 3 to 4, CM - secondary quartz little clay matrix present, siderite (?); Fine-grained sandstone. CQ - 37.37%, Ch - 58.20%, SRF - 12.81%, Chal - 1.26%, Feldspar - 0.50%.	6'	74'-80'
18	Gray, fissile, laminated, shale. Clay-minerals: Mixed layer illite-montmorillonite Montmorillonite - 10%; chlorite.	7'	67'-74'
17	Gray, fissile, laminated shale. Clay-minerals: Mixed layer Illite-montmorillonite. Mont. - 10%, chlorite.	7'	60'-67'
	SWIFT FORMATION - 60'		Measured
16	Yellowish, massive, compact, calcareous, glauconitic sandstone having calcite veins; Warm burrows and trails present. Petrography: Interlocked, little welded; Md - 0.5 mm.,	3'6"	56'-6"-60'

Number	Description	Thickness of the unit in feet	Feet Above Base
	USL - 0.47 mm., moderately sorted, R - 2 to 3, CM - calcite and quartz; Muddy sandstone. CQ - 42.69%, Ch - 39.93%, Chal - 0.68%, SRF - 14.3%, Feld. - 0.07%; Fossils - Pelecypods.		
15	Gray, weathered into yellowish, alternate coarse and fine-grained layered, calcareous, cherty, glauconitic sandstone; slightly disturbed due to folding; Ripple marked by one set of small scale ripples of wave length 3"; Inclusions of thin layers of shale and limy shale, present (6"). Burrows and trails present. Petrography: Cemented, little welded; Md - 9.1 mm, USL - 0.2 mm; moderately sorted; R-3; CM - calcite and secondary quartz; fine-grained sandstone; CQ - 45.30%, Ch - 34.00%, SRF - 14.69%, VRF - 0.66%, Feld. - 0.18%; Fossils - Crinoids, Pelecypods.	15'6"	41'-56'6"
14	Gray laminated, limy shale. Clays 1 Illite-Mont. mixed layered 2 Chlorite. Mont. - 15 to 20%.	1'	40'-41'
13	Light gray, layered, fine-grained, jointed, ripple-marked, less-compact, calcareous, cherty sandstone. Two sets of joints perpendicular to each other present; Petrography: Cemented, little welded, MD - 0.5 mm., USL - 0.20 mm, moderately sorted, R -3, CM - calcite and quartz, muddy sandstone. CQ - 41.80%, Ch - 39.84%, SRF - 17.58%, VRF - 0.45%, Feld. - 0.75% Fossils - Pelecypods.	4'7"	35'5"-40'
12	Dark gray, laminated shale.	0'5"	35'-35'5"

Number	Description	Thickness of the unit in feet	Feet Above Base
11	Gray, fine-grained, laminated, jointed by one set of joints, parallel to strike direction, ripple marked by one set of asymmetrical small scale ripples of wavelength 3". Petrography: Cemented, loosely packed; Md - 0.1 mm, USL - 0.2 mm; well sorted, R - 3, CM - Calcite and secondary quartz; fine-grained sandstone; CQ - 31.46%, Ch - 42.71%, SRF - 19.59%, Feld. - 1.73%, Mica - 0.19%, Fossils - Pelecypods, crinoids.	3'	32'-35'
10	Dark gray, laminated shale with few pebbles and pelecypods. Clay minerals: 1 Illite - Montmorillonite. 2 Chlorite. Mont. - 25%.	5'8"	26'4"-32'
9	Yellowish brown, fine grained, massive sandstone containing pebbles of chert and pelecypods; Calcite veins in lower part. Petrography: Cemented, little welded; Md - 0.2 mm, USL - 0.6 mm; moderately sorted; R-2, CM - Calcite, little secondary quartz; Muddy sandstone. CQ - 17.82%, Ch - 49.10%, SRF - 25.21%, VRF - 0.21%, Feld. - 0.86%, Hvs - tourmaline and zircon - 0.43%; Fossils - Pelecypods, crinoids.	7'	19'4"-26'4"
8	Dark gray, laminated, shale having the inclusions of the layers, 2" thick, of siltstone and very fine grained sandstone; disturbed due to local folding; Clay minerals. 1. Illite - Mont. (mixed layers) 2. Chlorite. Mont. 10 to 15%.	2'6"	16'10"-19'4"

Number	Description	Thickness of the unit in feet	Feet Above Base
7	Dark gray heterogenous, fine to very fine grained sandstone; small scale, not distinct, cross-beds present. Petrography: Mostly calcite grains. Very few rounded quartz grains.	2'4"	14'6"-16'10"
6	Dark gray, laminated, shale with the inclusions of 2" thick layers of siltstone and fine-grained sandstone; Clay minerals: 1. Illite-Montmorillonite 2. Chlorite Mont. - 25%	7'6"	7'-14'6"
5	Yellowish brown, massive, fine-grained distinctly observed ripple marked, sandstone. Small scale interference ripples; small veins of calcite in joints and fractures; Petrography: Little welded, cemented; Md - 0.20 mm, USL - 0.45 mm, well sorted, R - 2 to 3, CM - Calcite and little quartz; Fine-grained sandstone. CQ - 36.6%, Ch - 38.42%, SRF - 17.48%, VRF - 0.43%, Feld. - 0.21%; Fossils - Pelecypods, crinoids.	2'6"	4'6"-7'
4	Gray, fine-grained, soft, sandstone; Petrography: Cemented, little welded; Md - 0.20 mm, USL - 0.45 mm; well-sorted; R 2 to 3; CM - Calcite and quartz; fine-grained sandstone; CQ - 31.9%, Ch - 26.43%, SRF - 17.43%, Chal - 0.27%, Feld - 0.27%, Mica - 0.27%. Fossils - Pelecypods, Crinoids.	1'	3'6"-4'6"
3	Dark gray, fine-grained, massive, heterogenous, cherty sandstone;	1'	2'6"-3'6"

Number	Description	Thickness of the unit in feet	Feet Above Base
	Petrography Cemented, little welded; Md - 0.25 mm, USL - 0.6 mm, well-sorted, R-3 to 4, CM - Calcite and quartz, fine-grained sandstone; CQ - 16.12%, Ch - 54.96%, SRF - 8.41%, HVS - tourmaline, zircon, rutile-0.98%, Fossils - Pelecypods, crinoids.	1'	2'6"-3'6"
2	Gray, fine-grained, cherty, sandstone with plant impressions, wood fragments, and some chert pebbles.	1'6"	1'-2'6"
	Petrography Cemented, loosely packed, MD - 0.2 mm, USL - 0.47 mm, Moderately sorted, R - 3 to 4, CM - Calcite and quartz, fine-grained sandstone. CQ - 19.52%, Ch - 53.17%, SRF - 23.59%, VRF - 0.26%, Feld - 0.13%, Hvs - tourmaline, rutile - 0.66%, Fossils - Pelecypods.		
1	Dark gray, massive, coarse-grained, cherty conglomerate, overlying disconformably on the Rierdon limestone.	1'	0'-1'
	Petrography Cemented, MD - 0.25%, USL - 3.5 mm, (pebbles), poorly sorted, R - 3 to 4, CM - calcite and quartz, conglomerate Chert pebbles are fossiliferous Distinct impressions of Spicules, crinoids.		

Explanation:

MD - Median, USL - Upper size limit, R - Roundness, CM - Cement, CQ - Common quartz, Ch - Chert, Chal - Chalcedony, SRF - Sedimentary rock fragment, VRF - Volcanic rock fragment, Feld - Feldspar, Hvs - Heavy minerals.

Williams Gulch Section - Section 2

Location:

Near Williams Gulch, in the west of the Mulky Gulch; SE part of section 12, T11N, R14W. This section is on the northern side of the highway 10 and 93 and is behind a house. The well-exposed rocks of Rierdon Formation can be seen even from the highway. Another better exposed section is on the other side on the northern slope of the same hill in the valley of a streamlet. This section was first located and measured by Dr. Honkala.

Number	Description	Thickness of the unit in feet	Feet Above Base
	Morrison Formation: 285' measured.		
24	Coarse grained, heterogenous, ridge-forming, basal Kootenai Conglo. Large pebbles (18" diameter) of black chert present.	-	-
23	Brownish gray, massive, poorly exposed, cross-bedded, fine-grained cherty sandstone. Petrography: Interlocked and penetrating grains; Median - 0.1 mm, Upper size limit - 0.17 mm, Moderately sorted, roundness - 2 to 3; Cement - calcite and secondary quartz; Fine-grained sandstone. Common quartz - 56.50%, Chert - 19.65%, Chalcedony - 1.63%, SRF - 15.73%.	12'	285'-273'
22	Gray, massive, poorly exposed, fine-grained, cherty, sandstone. Petrography: Interlocked; median- 0.15 mm, upper size limit - 0.19 mm, well sorted, roundness - 2 to 3, cement-quartz and calcite: Fine-grained sandstone; Common quartz - 56.50%, chert - 19.65%, Chalcedony - 1.63%, SRF - 15.73%, Mica - 1.10%, Heavies - zircon - 0.1%, Dolomite crystals - 2.07%.	8'	265'-273'

Number	Description	Thickness of the unit in feet	Feet Above Base
21	Brownish gray, cross-bedded by small scale cross-beds, fine-grained cherty sandstone; Petrography Interlocked; median-0.12 mm, upper size limit - 0.22 mm, well sorted, roundness - 2 to 3, cement-quartz and calcite; Fine-grained sandstone. Common quartz - 60.18%, Chert - 27.20%, Chalcedony - 1.44%, SRF - 27.20%, Mica including sericite - 0.91%, Dolomite crystals - 2.10%.	10'	255'-265'
20	Covered interval.	48'	207'-255'
19	Brown, slabby, fine-grained, cherty, calcareous, sandstone; Petrography: Interlocked; cemented; median - 0.07 mm, upper size limit - 0.16 mm, moderately sorted, roundness - 2, cement - quartz and calcite, fine-grained sandstone. Common quartz - 66.16%, chert - 19.84%, chalcedony - 0.35%, SRF - 10.16%, mica - 0.62%, Dolomite crystals - 0.89%.	2'	205'-207'
18	Brown, slabby, fine-grained, cherty calcareous sandstone; Petrography: Interlocked; cemented; median - 0.08 mm, upper size limit - 0.21 mm, moderate to poorly sorted, roundness, 2 to 3, cement - quartz and calcite, fine-grained sandstone. Common quartz - 87.61%, chert - 20.34%, chalcedony - 0.22%, SRF - 17.25%, mica - 1.1%, Heavies - 0.11%.	10'	195'-205'
17	Light gray, slabby, fractured, fine-grained, cherty, calcareous sandstone;	10'	185'-195'

Number	Description	Thickness of the unit in feet	Feet Above Base
	Petrography: Interlocked; cemented; median - 0.15 mmupper size limit - 0.19 mm well-sorted, roundness - 2, cements - quartz and calcite, fine-grained sandstone; common quartz - 71.51%, chert - 19.38%, Chalcedony - 2.02%, SRF - 14.54%.	10'	185'-195'
16	Covered interval	30'	155'-185'
15	Yellowish gray, massive, fine-grained, cherty, calcareous sandstone; Petrography Interlocked and cemented, median - 0.15 mm, upper size limit - 0.20 mm, well sorted, roundness - 2. Cements - Quartz and calcite; Fine-grained sandstone. Common quartz - 57.37%, chert - 25.29%, chalcedony - 1.71%, SRF - 11.05%, mica - 3.06%.	10'	145'-155'
14	Yellowish gray, massive, ridge-forming, fine-grained, cherty, calcareous sandstone: Petrography Interlocked, penetrating grains; median - 0.17 mm, upper size limit - 0.20 mm, moderately sorted, roundness - 2, cement - quartz and calcite; common quartz - 59.48%, chert - 21.10%, chalcedony - 2.03%, SRF - 15.90%, mica - 0.11%.	10'	135'-145'
13	Grayish, laminated, poorly exposed, cherty, calcareous sandstone. Petrography Interlocked less; median - 0.15 mm, upper size limit - 0-2 mm; moderately sorted, roundness - 2 to 3, cement - quartz and little calcite:	10'	125'-135'

Number	Description	Thickness of the unit in feet	Feet Above Base
12	Covered interval	53'	72'-125'

Swift Formation: 72' measured

Number	Description	Thickness of the unit in feet	Feet Above Base
11	Gray, massive, ridge-forming,cherty, calcareous, glauconitic(?) Sandstone. Petrography: Interlocked, penetrating and cemented grains; median - 0.09 mm, upper size limit - 0.21 mm, well-sorted, roundness - 2 to 2.5, cement - calcite and quartz; Fine-grained sandstone. Common quartz - 65.57%, chert - 17.20%, chalcedony - 0.24%, SRF - 15.26%, Mica - 0.12%.	7'	65'-72'
10	Dark gray, massive, resistant, well-exposed, fine-grained, cherty, calcareous, sandstone. Petrography: Interlocked penetrating and cemented, median - 0.08 mm, upper size limit - 0.22 mm, well sorted, roundness - 2, cements - quartz, calcite, fine-grained sandstone. Common quartz - 67.69%, chert - 10.58%, SRF - 14.13%.	10'	55'-65'
9	Gray, laminated, fragile, poorly exposed, fine-grained, cherty, calcareous, sandstone; Petrography: Loose grained, cemented; median - 0.07 mm, upper size limit - 0.19 mm, moderately sorted, roundness - 2 to 1, cements - calcite and quartz, fine-grained sandstone. Common quartz - 61.75%, chert - 17.07%, chalcedony - 0.22%, SRF - 14.38%, VRF - 0.33%, mica - 0.22%.	8'	47'-55'
8	Yellowish gray, laminated, fragile, fine-grained, cross-bedded but not distinct, poorly-exposed, cherty, calcareous sandstone:	12'	35'-47'

Number	Description	Thickness of the unit in feet	Feet Above Base
	Petrography Cemented, median - 0.08 mm, upper size limit - 0.15 mm, moderately sorted, roundness 2 to 1, cements - calcite and quartz, very fine-grained sandstone; Common quartz - 65.12%, chert - 21.21%, SRF - 14.00%.		
7	Gray, massive, cross-bedded, but not distinct, cherty, calcareous sandstone; Petrography Interlocked and cemented; median - 0.09 mm, upper size limit - 0.19 mm, moderately sorted, roundness - 2 to 1, cements - calcite and quartz, fine-grained sandstone; common quartz - 77.88%, chert 10.91%, SRF - 6.62%. Fossils - pelecypods.	5'	30'-35'
6	Covered interval	5'	25'-30'
5	Gray, massive, fine-grained, poorly-exposed, calcareous, cherty sandstone. Petrography Loosely packed, cemented; median - 0.10 mm, upper size limit - 0.18 mm, moderately sorted, roundness - 2, cements - quartz and calcite, fine-grained sandstone. Common quartz - 37.69%, chert 34.14%, chalcedony - 0.66%, SRF - 18.84%, VRF - 0.22%, Feldspar - 0.22%, mica - 0.66%. Fossils - Pelecypods, Crinoids.	5'	20'-25'
4	Green, laminated, poorly exposed shale.	2'	18'-20'
3	Gray, poorly exposed, calcareous, cherty sandstone. Petrography: Loosely packed, cemented; median - 0.12 mm, upper size limit - 0.22 mm, moderately sorted, roundness - 2 to 2.5, cement - calcite and quartz; fine-grained sandstone. Common quartz - 38.03%, Chert - 41.11%, Chalcedony - 1.93%, SRF - 17.75%, Feldspar - 0.96%, Heavies - 0.19%. Fossils - Pelecypods, crinoids.	3'	15'-18'

Number	Description	Thickness of the unit in feet	Feet Above Base
2	Dark, gray, massive, heterogenous, calcareous, cherty, sandstone with abundant, pelecypods and oysters. Petrography: Interlocked and penetrating; median - 0.15 mm, upper size limit - 0.22 mm, moderately sorted, roundness - 2 to 1, cements - quartz and calcite; fine-grained sandstone. Common quartz - 22.11%, chert - 50.60%, chalcedony - 1.34%, SRF - 22.94%, VRF - 0.16%, Feldspar - 0.16%. Fossils - Crinoids, pelecypods.	10'	5'-15'
1	Grayish, massive, coarse-grained, ridge-forming, heterogenous, calcareous, cherty, conglomeratic sandstone. Gravels of chert present; Overlying disconformably on Rierdon limestone. Petrography: Loosely packed, cemented; median - 0.15 mm, upper size limit - 0.2 mm, moderately sorted, roundness - 2 to 3. Cement - calcite and quartz, conglomeratic sandstone. Common quartz - 50.90%, chert - 28.87%, chalcedony - 0.72%, SRF - 9.02%, VRF - 0.36%, Feldspar - 0.72%. Fossils - Crinoids, Pelecypods.	5'	0'-5'

Southwest Rattler Gulch Section - Section 3

Location:

About one and a quarter miles in the SW of the Rattler Gulch; northern part of section 16, T11N, R13W. This section is situated just below the border between sections 9 and 16 in the valley of a stream flowing in the south. It can be approached by climbing up the eastern slope from the place where ridge of the basal Kootenai conglomerate is exposed on the trek-road of Rattler Gulch, and then walking in the SW direction about one and a quarter miles. The rocks of the Swift as well as Morrison Formations are well-exposed. Dr. Winston first located this section.

Number	Description	Thickness of the unit in feet	Feet Above Base
34	Gray, coarse grained, heterogenous, conglomerate containing gravels of chert, and some of which are as big as 18" in diameter, of basal Kootenai.	-	-
33	Covered interval	23'	272'-295'
32	Yellowish brown, poorly exposed, gravelly sandstone. Petrography: Cemented, median - 0.08 mm, upper size limit - 2.5 mm (gravels), poorly sorted, roundness - 2 to 3, cements - quartz, fine grained sandstone. Common quartz - 72.00%, chert - 15.5%, chalcedony - 2.5%, SRF - 9.30%, mica - 0.60%, Heavies - tourmaline, rutile, zircon - 0.10%.	7'	265'-272'
31	Covered interval	15'	250'-265'
30	Reddish brown, massive, very fine-grained, cherty, calcareous sandstone;	10'	240'-250'

Number	Description	Thickness of the unit in feet	Feet Above Base
	Petrography: Loosely packed, cemented; median - 0.06 mm, upper size limit - 0.07 mm, well sorted, roundness - 2 to 3, cement - calcite and quartz, fine-grained sandstone; common quartz - 68.43%, chert - 10.96%, chalcedony - 0.09%, SRF - 13.66%, mica - 0.38%, Heavies - zircon - 0.38%, dolomite crystals - 0.57%.		
29	Covered interval	5'	235'-240'
28	Reddish brown, massive, fine-grained, poorly exposed, cherty calcareous sandstone; Petrography Loosely packed, cemented; median - 0.06 mm, upper size limit - 0.08 mm, moderately to well sorted, roundness - 2, cement - calcite, very fine grained sandstone. Common quartz - 74.75%, chert - 8.67%, chalcedony - 0.12%, SRF - 16.33%. mica - 0.24%, Heavies - tourmaline, zircon - 0.24%, Dolomite crystals - 0.12%.	5'	230'-235'
27	Covered interval	40'	190'-230'
26	Gray, chunky, shale, weathering into thin laminations which separate from each other easily.	10'	180'-190'
25	Dark gray, massive, poorly exposed, fine-grained sandstone; Petrography Penetrating, cemented; median - 0.12 mm, upper size limit - 0.20 mm, moderately sorted; roundness - 2, cements - calcite, quartz: Fine-grained sandstone. Common quartz - 52.15%, chert - 38.76%, chalcedony - 1.53%, SRF - 11.83%, Heavies - zircon, rutile - 0.15%, Dolomite crystals - 4.15%.	10'	170'-180'

Number	Description	Thickness of the unit in feet	Feet Above Base
24	Gray, slabby, fine-grained, cherty, calcareous sandstone., Petrography Interlocked, cemented; median - 0.12 mm, upper size limit - 0.20 mm, moderately sorted, roundness - 2, cement - quartz, calcite. Fine-grained sandstone; Common quartz - 70.22%, chert - 13.18%, SRF - 11.68%, mica - 0.37%, Dolomite crystals - 1.38%	11'-6"	158'5"-170'
23	Reddish gray, jointed, massive, poorly exposed, cherty, calcareous sandstone. Petrography: Loosely packed, cemented; median - 0.06 mm, upper size limit - 0.08 mm, moderately sorted, roundness - 2 to 3, cement - calcite, very fine-grained sandstone. Common quartz - 77.06%, chert - 10.13%, chalcedony - 0.31%, SRF - 11.06%, mica - 0.15%, Heavies - 0.15%, Dolomite - 0.15%.	8'6"	150'-158'6"
22	Covered interval	9'6"	140'6"-150'
21	Red, poorly exposed, soft siltstone. Petrography Loosely packed, median - 0.05 mm, upper size limit - 0.06 mm, poorly sorted, roundness - 2, cement - calcite, siltstone. Common quartz-chert, mica.	10'6"	130'-140'6"
20	Red, poorly exposed, soft siltstone. Petrography Loosely packed, cemented; median - 0.05 mm, upper size limit - 0.06 mm, poorly sorted; roundness - 2, cement - calcite, siltstone. Common quartz, chert, SRF, mica.	10'	120'-130'

Number	Description	Thickness of the unit in feet	Feet Above Base
19	Grayish brown, compact, lineated,cherty, calcareous sandstone, Petrography Interlocked, cemented, median - 0.18 mm, upper size limit - 0.2 mm, well sorted, roundness - 2 to 3, cement - quartz, calcite; Fine-grained sandstone; Common quartz - 58.46%, chert - 29.41%, chalcedony - 2.09%, SRF - 12.44%, mica - 0.27%, Dolomite - 3.6%.	10'	110'-120'
18	Gray, compact, lineated, cherty, calcareous, sandstone: Petrography Interlocked, penetrating, median - 0.20 mm, upper size limit - 0.22 mm, well-sorted, roundness - 2 to 3, cements - quartz, calcite, Fine-grained sandstone; Common quartz - 58.56%, chert - 20.18%, chalcedony - 0.73%, SRF - 14.93%, Dolomite crystals - 3.00%, mica - 0.27%.	10'	100'-110'
17	Gray, massive, fine-grained, cherty, calcareous sandstone; Petrography Interlocked, penetrating, median - 0.15 mm, upper size limit - 0.2 mm, well-sorted, roundness - 2 to 3, cement - quartz, calcite, Fine-grained sandstone. Common quartz - 74.37%, chert - 10%, chalcedony - 0.62%, SRF - 14.90%, mica - 0.24%, Heavies - zircon - 0.25%, Dolomite - 1.37%	1'	99'-100'
16	Gray, massive, cross-bedded, ridge forming, jointed, cherty, calcareous, sandstone. Petrography Interlocked, penetrating, grains; median - 0.2 mm, upper size limit - 0.23 mm, well-sorted, roundness - 2 to 2.5, cement - quartz, little calcite; fine-grained sandstone. Common quartz - 63.50%, chert - 18.81%, chalcedony - 0.43%, SRF - 14.93%, mica - 0.42%, Dolomite - 2.20%.	2'	97'-99'

Number	Description	Thickness of the unit in feet	Feet Above Base
15	Gray, massive, cross-bedded, distinctly at an angle of - 30° by straight small cross-beds, ridge-forming, jointed, cherty, calcareous, sandstone.	7'	90'-97'

Petrography

Interlocked, penetrating; median - 0.2 mm, upper size limit - 0.23 mm, well sorted, roundness - 2 to 3, cements - quartz, little calcite; Fine-grained sandstone. Common quartz - 72.44%, chert - 12.70%, chalcedony - 1.12%, SRF - 13.0%, mica - 0.24%, Dolomite - 2.11%

Swift Formation - 90' measured.

Number	Description	Thickness of the unit in feet	Feet Above Base
14	Faintly cross-bedded, massive, ridge-forming, fine-grained, cherty, calcareous, glauconitic (?) sandstone;	10'	80'-90'

Petrography

Closely interlocked, penetrating; median - 0.08 mm, upper size limit - 0.12 mm, moderately sorted, roundness - 2 to 3, cement - quartz and calcite; Fine-grained sandstone; common quartz - 76.11%, chert - 5.05%, chalcedony - .26%, SRF - 17.3%, mica - 0.43%, Heavies - zircon, tourmaline, rutile - 0.37%, Dolomite - 0.08%.

Number	Description	Thickness of the unit in feet	Feet Above Base
13	Gray, cross-bedded, massive, ridge-forming, fine-grained, cherty,calcareous, glauconitic sandstone.	5'	75'-80'

Petrography

Interlocked, cemented; median - 0.07 mm, upper size limit - 0.19 mm, moderately sorted, roundness - 2 to 3, cements - quartz, calcite; Fine-grained sandstone. Common quartz - 65.85%, chert - 11.62%, chalcedony - 0.65%, SRF - 17.25%, mica - 0.46%, Dolomite - 0.93%, Fossils - crinoid.

Number	Description	Thickness of the unit in feet	Feet Above Base
12	Gray, laminated, fine-grained, cherty, calcareous, sandstone. Petrography Interlocked closely; and penetrating, median - 0.08 mm, upper size limit - 0.15 mm, well-sorted, roundness - 2 to 3, cement - quartz, calcite. Fine-grained sandstone. Common quartz - 62.61%, chert - 11.25%, chalcedony - 0.80%, SRF - 13.36%, mica - 1.30%, Dolomite - 1.00%.	5'	70'-75'
11	Covered interval	20'	50'-70'
10	Gray, cross-bedded, fine-grained, cherty, calcareous sandstone. Petrography Interlocked and cemented; median - 0.08 mm, upper size limit - 0.10 mm, moderately sorted, roundness - 2, cement-calcite; Fine-grained sandstone, Common quartz - 80.58%, chert - 6.23%, chalcedony - 0.22%, SRF - 10.7%, mica - 0.22%.	10'	40'-50'
9	Gray with yellowish stain, laminated fine-grained, cherty, calcareous sandstone. Petrography Interlocked, cemented, median - 0.09 mm, upper size limit - 0.19 mm, moderately sorted, roundness - 2 to 3, cement - quartz, calcite; Fine-grained sandstone. Common quartz - 54.96%, chert - 23.77%, chalcedony - 1.25%, SRF - 16.36%, mica - 0.15%, Heavies - tourmaline, rutile - 0.15%, Dolomite - 1.10%.	10'	30'-40'
8	Gray, slabby and laminated, fine-grained, cherty, calcareous, sandstone. Petrography Loosely packed, median- 0.08 mm, upper size limit - 0.1 mm, moderately sorted, roundness - 2, cement - quartz, calcite;	5'	25'-30'

Number	Description	Thickness of the unit in feet	Feet Above Base
	Fine-grained sandstone. Common quartz -81.33%, chert - 5.49%, chalcedony - 0.58%, SRF - 8.29%, Heavies - 0.19%.		
7	Gray, cross-bedded,at an angle of 30°, by small, straight, cross-beds, massive, fine-grained, cherty, calcareous sandstone. Petrography: Interlocked, penetrating, median - 0.12 mm, upper size limit - 0.19 mm, moderately sorted, roundness - 2 to 3, cement - quartz, calcite, fine-grained, sandstone; common quartz - 75.25%, chert - 12.02%, chalcedony - 0.33%, SRF - 11.85%, mica - 0.50%, Dolomite - 1.18%.	5'	20'-25'
6	Gray, massive, fine-grained, cherty, calcareous, sandstone. Petrography Interlocked, cemented; median - 0.12 mm, upper size limit - 0.19 mm, moderately sorted, roundness - 2 to 3, cement - quartz, calcite; Fine-grained sandstone. Common quartz - 74.93%, chert - 10.77%, chalcedony - 0.45%, SRF - 11.90%, Feldspar - 0.09%, mica - 0.45%, Heavies - tourmaline, 0.27%.	10'	10'-20'
5	Gray, massive, cross-bedded by small scale, cross-beds. Fine-grained, cherty, calcareous sandstone. Petrography Interlocked, penetrating, median - 0.12 mm, upper size limit - 0.2 mm, moderately sorted, roundness - 2 to 2.5, cement - quartz and calcite; fine-grained sandstone. Common quartz, 70.09%, chert - 9.95%, chalcedony - 0.45% SRF - 18.88%, mica - 0.15%, Dolomite crystals - 0.30%.	4'	6'-10'

Number	Description	Thickness of the unit in feet	Feet Above Base
4	Gray, coarse-grained, heterogenous, massive, conglomerate containing chert gravels. <u>Petrography</u> Interlocked, cemented; median - 0.15 mm, upper size limit - 3.5 mm, poorly sorted, roundness - 2 to 3, cement - calcite, little quartz conglomerate. Common quartz, chert pebbles and sand grains, containing impressions of spicules,crinoids, SRF, chalcedony.	1'	5'-6'
3	Gray, fine-grained, massive, heterogenous, cherty, calcareous sandstone, with pelecypods. <u>Petrography</u> Loose grained, cemented, median - 0.06 mm, upper size limit - 0.08 mm, moderately sorted, roundness - 2 to 1, cement - quartz, calcite; Fine-grained sandstone. Common quartz - 62.45%, chert - 16.08%, chalcedony - 2.29%, SRF - 30.65%, mica - 0.38%, Fossils - Crinoids.	1'	4'-5'
2	Gray, fine-grained, massive, heterogenous, cherty, calcareous, sandstone. <u>Petrography</u> Interlocked, cemented; median - 0.16 mm, upper size limit - 0.20 mm, well-sorted, roundness - 2 to 3, cement - quartz, calcite, Fine-grained sandstone. Common quartz - 70.45%, chert - 12.48%, chalcedony - 0.71%, SRF - 13.20%, mica - 0.42%, Heavies - tourmaline, rutile - 0.28%.	3'	1'-4'
1	Gray, coarse-grained, heterogenous massive, conglomerate containing, chert-gravels, clams and wood-fragments. Overlies Rierdon limestone, disconformably.	1'	0'-1'

Number	Description	Thickness of the unit in feet	Feet Above Base
	Petrography: Interlocked, cemented, median, - 0.2 mm, upper size limit - 3.6 mm, poorly sorted, roundness - 2.5 to 3, cement - quartz, calcite; Conglomerate with chert pebbles. Common quartz - 34.48%, chert - 34.45%, chalcedony - 3.87%, SRF - 16.80%, Heavies - tourmaline, zircon, rutile - 0.21%. Fossils - Spicules, Crinoids in the chert pebbles.		

West Rattler Gulch Section - Section 4.

Location:

About one mile in the west of Rattler Gulch; southern part of section 9, T11N, R13W. This section is situated just above the border between sections 9 and 16, T11N, R13W; and is exposed in the upstream portion of the same stream in which the section 3 is exposed. It can be approached by climbing up the Western slope from the place where the ridge of the basal Kootenai conglomerate is exposed and then walking about one mile in the west of the Rattler Gulch. The rocks of the Morrison Formation are very well exposed, particularly the shales.

Number	Description	Thickness of the unit in feet	Feet Above Base
43	Coarse grained, heterogenous, massive, ridge-forming, conglomerate containing large chert-pebbles.	20'	356'-336'
42	Reddish black, iron-concretion bearing, poorly exposed, shale. Clay minerals: 1. Illite-Montmorillonite. 2. 14A$^{\circ}$ chlorite. 3. 7A$^{\circ}$ chlorite.	10'	326'-336'
41	Yellowish gray, fine grained, cross-bedded by small cross-beds, fine-grained, cherty sandstone. Petrography Interlocked, cemented; median-0.08 mm, upper size limit - 0.12 mm, moderately sorted, roundness - 2 to 2.5; Fine-grained sandstone, common quartz, chert, SRF, iron-concretions:	5'	321'-326'

Number	Description	Thickness of the unit in feet	Feet Above Base
40	Yellowish, brown, very fine-grained, poorly exposed siltstone.	5'	316'-321'
39	Black, carbonaceous, laminated, well-exposed shale containing thin strings of coal. Clay minerals 1. Illite-montmorillonite. 2. 7A° chlorite.	12'	304'-316'
38	Yellowish, massive, concretionary, argillaceous fresh water limestone; Petrography Interlocked euhedral grains of calcite, about 0.1 mm in size. Porosity about 20%. Clay minerals 1. Illite-montmorillonite. 2. 7A° chlorite. Montmorillonite - 10%.	2'	302'-304'
37	Gray, massive, well-exposed shale Clay minerals 1. Illite-montmorillonite. 2. 7A° chlorite.	5'	297'-302'
36	Gray, massive, well-exposed shale. Clay minerals: 1. Illite-montmorillonite. 2. 7A° Chlorite. Montmorillonite - 10%.	5'	292'-297'
35	Gray, massive, well-exposed, shale Clay minerals: 1. Illite-montmorillonite, 2. 7A° Chlorite. Montmorillonite - 10% Specimens - H_{35}, H_{36}, and H_{37} are from the same shale-bed.	8'	284'-292'
34	Yellowish, massive, concretionary argillaceous limestone.	2'	282'-284'

Number	Description	Thickness of the unit in feet	Feet Above Base
34	Petrography Interlocked, euhedral grains of calcite; median - 0.1 mm. Clay minerals: 1. Illite-montmorillonite. 2. Very little 7A° chlorite.		
33	Yellowish gray, bentonitic, shale; poorly exposed, covered on surface by grayish soil; specimen collected after digging 2'. Clay minerals: 1. Illite-Montmorillonite. 2. 7A° chlorite.	10'	272'-282'
32	Gray, massive, poorly exposed, shale. Clay minerals: 1. Illite-montmorillonite. 2. 7A° chlorite. 3. 14A° chlorite - small amount. Montmorillonite - 10%.	7'	265'-272'
31	Olive-gray, massive poorly exposed, shale, covered on surface by yellowish gray soil; Clay minerals: 1. Illite-montmorillonite. 2. 7A° chlorite.	5'	260'-265'
30	Olive-gray, massive, poorly exposed, shale, covered on surface by yellowish gray soil. Clay minerals: 1. Illite-montmorillonite. 2. 7A° chlorite.	5'	255'-260'
29	Olive-gray, massive, poorly exposed, shale covered on surface by yellowish gray soil. Clay minerals: 1. Illite-montmorillonite. 2. 7A° chlorite. Montmorillonite - 10%. Specimens H_{29}, H_{30}, H_{31} are from the same bed of shale.	3'	252'-255'

Number	Description	Thickness of the unit in feet	Feet Above Base
28	Grayish olive, massive, well exposed shale. Clay minerals: 1. Illite-montmorillonite. 2. 7A° chlorite. 3. 14A° chlorite	2'	250'-252'
27	Grayish olive, massive well-exposed, shale. Clay minerals: 1. Illite-montmorillonite. 2. 7A° chlorite 3. 14A° chlorite. Montmorillonite - 10%. Specimens H_{27} and H_{28} are from the same bed of shale.	4'	246'-250'
26	Grayish olive, massive, shale. clay minerals. 1. Illite-montmorillonite. 2. 7A° chlorite.	3'	243'-246'
25	Yellowish gray, massive, bentonitic, poorly exposed shale, Fresh specimen collected after digging 2'.	5'	238'-243'
24.	Grayish olive, laminated, poorly exposed, shale. Clay minerals 1. Illite-montmorillonite. 2. 7A° chlorite. Montmorillonite - less than 10%.	2'	236'-238'
23	Yellowish white, massive, concretionary, argillaceous limestone. Petrography Interlocked, euhedral to subhedral, grains of calcite about 0.1 mm, in size. Clayey material present.	2'	234'-236'
22	Green, poorly exposed, massive, shale. Clay minerals. 1. Illite-montmorillonite. 2. 7A° chlorite. 3. 14A° chlorite.	8'	226'-234'

Number	Description	Thickness of the unit in feet	Feet Above Base
21	Yellowish, fine-grained, siltstone poorly exposed. Petrography Interlocked, cemented; median - 0.05 mm, well sorted, siltstone. Common quartz, chert, calcite, cements.	10'	216'-226'
20	Green, laminated shale, poorly exposed. Clay minerals: 1. Illite-montmorillonite. 2. 14A° chlorite. 3. 7A° chlorite. Montmorillonite - 10%.	2'	214'-216'
19	Green laminated poorly exposed shale. Clay minerals: 1. 14A° chlorite. 2. Illite-montmorillonite. 3. 7A° chlorite. Montmorillonite - 10%. Specimens H_{19} and H_{20} are of the same shale-bed.	4'	210'-214'
18	Covered interval	50'	160'-210'
17	Red, fine-grained, lineated siltstone. Petrography Interlocked, cemented, median - 0.05 mm, very fine-grained, siltstone. Common quartz - chert, calcite cement.	3'	157'-160'
16	Red, fine-grained, lineated, siltstone. Petrography Interlocked, cemented; median - 0.05 mm, siltstone. Common quartz, chert, calcite, cement.	5'	152'-157'
15	Dark gray, massive, fine-grained, cherty, calcareous sandstone. Indistinct cross-beds at low angles.	5'	147'-152'

Number	Description	Thickness of the unit in feet	Feet Above Base
15	Petrography Interlocked, cemented; median - 0.07 mm, upper size limit - 0.1 mm, well sorted, roundness - 2 to 2.5, fine-grained sandstone. Common quartz - 68.2%, chert - 11.1%, SRF - 17.2%, mica 2.02%, Heavies - 0.48%.		
14	Covered interval	37'	110'-147'
13	Brownish gray, massive, cross-bedded, by small scale cross-beds, fine-grained, cherty, calcareous, sandstone. Petrography Interlocked, cemented; median - 0.07 mm, upper size limit - 0.1 mm, roundness - 2 to 2.5, Fine-grained sandstone. Common quartz, chert, chalcedony, SRF, mica.	10'	110'-100'
12	Gray, laminated, loose-grained poorly exposed, cherty, calcareous sandstone. Petrography Interlocked, cemented; median - 0.08 mm, upper size limit - 0.12 mm, well-sorted, roundness - 2 to 2.5, fine-grained sandstone. Common quartz, chert, chalcedony, SRF, mica.	10'	90'-100'
11	Brownish gray, massive, cross-bedded, by small cross-beds, fine-grained, cherty, calcareous, sandstone. Petrography Interlocked, cemented; median - 0.07 mm, upper size limit - 0.10 mm, roundness - 2 to 2.5, fine-grained sandstone. Common quartz, chert, SRF, Heavies - zircon.	10'	80'-90'
10	Covered interval probably of shale which overlies Swift sandstone.	10'	70'-80'
	Swift Formation - 70' measured		
9	Grayish, brown, massive, ridge-forming, fine-grained, glauconitic sandstone. It contains few pebbles of chert. Indistinct cross-beds are present between 65' and 70'.	20'	50'-70'

Number	Description	Thickness of the unit in feet	Feet Above Base
9	Petrography Interlocked, cemented; median - 0.08 mm, upper size limit - 0.1 mm, roundness - 2 to 3, moderately sorted, fine-grained sandstone.		
8	Grayish brown, massive, ridge-forming, fine-grained, glauconitic, sandstone.	7'	43'-50'
	Petrography Interlocked, cemented, median - 0.07 mm, upper size limit - 0.1 mm, well sorted, roundness - 2 to 2.5, fine-grained sandstone. Common quartz, chert, SRF, chalcedony, Heavies - tourmaline, rutile.		
7	Covered interval	13'	30'-43'
6	Gray, laminated, soft, poorly exposed, fine-grained, calcareous cherty sandstone.	10'	20'-30'
	Petrography Interlocked, cemented; median - 0.08 mm, upper size limit - .1 mm, well sorted, roundness - 2 to 3, fine-grained sandstone. Common quartz, chert, chalcedony, SRF, Heavies - tourmaline, rutile.		
5	Gray, fine-grained, massive, calcareous, cherty sandstone, containing clayballs.	9'	11'-20'
	Petrography Cemented, interlocked: median - 0.08 mm, upper size limit - 0.1 mm, well sorted, roundness - 2 to 3, fine-grained sandstone. Common quartz, chert, chalcedony, SRF, calcite cement, mica		
4	Yellowish gray, medium grained, calcareous cherty, conglomeratic sandstone.	1'	10'-11'
	Petrography Closely packed, cemented; median - 0.08 mm, upper size limit 2.5mm, poorly sorted, roundness - 2 to 2.5, conglomeratic sandstone.		

Number	Description	Thickness of the unit in feet	Feet Above Base
4	Common quartz, chert, chalcedony, SRF, mica traces. Fossils - spicules and crinoids in pebbles of chert.		
3	Yellowish gray, medium to fine-grained, calcareous, cherty sandstone. Petrography Interlocked, cemented; median - 0.15 mm, upper size limit - 0.25 mm, moderately sorted, roundness - 2 to 2.5, fine-grained sandstone. Common quartz, chert, chalcedony, SRF.	4'	6'-10'
2	Yellowish gray, medium to fine-grained, cross-bedded by small scale cross-beds, calcareous cherty sandstone; few pebbles of chert present. Petrography Cemented, loosely packed, median - 0.1 mm, upper size limit - 0.15 mm, moderately sorted, roundness - 2 to 3, cements - calcite, quartz, Fine grained sandstone, common quartz, chert, chalcedony, SRF. Fossils - Spicules in the pebbles of chert.	5'	1'-6'
1	Yellowish gray, coarse-grained, massive, heterogeneous, conglomerate, overlying Rierdon limestone, disconformably. Petrography Cemented; median- 0.12 mm, upper size limit - 2.5 mm, poorly sorted, roundness - 2 to 3, cement - calcite, conglomerate common quartz, chert, chalcedony, SRF. Fossils - Spicules, crinoids in the chert pebbles.	1'	0'-1'

Van Curan Gulch Section - Section 5

Location:

Van Curan Gulch, in the west of the Little Bear Creek; WSW part of section 18, T11N, R14W. This section can be approached by going along the trek road in Van Curan Gulch on the north side of the highway 10 and 93, about one half a mile and then following up-stream of a small stream. The section is exposed on the western slope of the valley of the stream. The rocks of the Ellis group are well-exposed, but a large part of the Morrison Formation is covered. This section was located and mapped by Mr. Rausmessen. It is also mapped by Dr. Kauffman (1963).

Number	Description	Thickness of the unit in feet	Feet Above Base
15	Gray, coarse grained, hetero-genous, ridge forming, siliceous conglomerate; chert pebbles of about 18" diameter present.	15'	
14	Reddish gray, massive, fine-grained, poorly exposed, cherty sandstone. Petrography Loose grained, cemented, median - 0.05 mm, upper size limit - 0.08 mm, moderately sorted, roundness - 2 to 2.5, siltstone. Common quartz, chert, calcite cement.	10'	235'-225'
13	Reddish gray, massive, fine-grained, poorly exposed, very fine grained sand-stone .	9'	225'-216'
12	Reddish brown, massive, fine grained clayey siltstone. Petrography Closely packed, little cemented: median - 0.04 mm. Cement - calcite, Common quartz, little chert, clay matrix, calcite.	11'	205'-216'

Number	Description	Thickness of the unit in feet	Feet Above Base
11	Covered interval	10'	195'-205'
10	Reddish brown, fine-grained clayey siltstone - poorly exposed. Petrography Little cemented, median - 0.04 mm, calcite-cement. Common quartz, little chert, clay matrix, calcite.	9'	186'-195'
9	Majore covered interval. Overlying the Swift sandstone.	111'	75'-186'
	Swift Formation: 75' measured		
8	Gray, faintly cross-bedded, fine-grained, not well exposed, cherty, calcareous sandstone. Petrography Interlocked, cemented, median - 0.15 mm, upper size limit - 0.20 mm, moderately sorted, roundness - 2, cements - calcite and quartz, fine-grained sandstone.	12'	63'-75'
7	Covered interval	18'	45'-63'
6	Yellowish gray, massive, jointed limonite stained, fine-grained, cherty, calcareous sandstone; Petrography: Interlocked, cemented; median - 0.15 mm, upper size limit - 0.20 mm, well sorted, roundness - 2 to 3, cements - calcite, quartz, fine grained sandstone. Common quartz - 55.00%, chert - 31.00%, SRF - 12.50%, chalcedony - 1.00%, Heavies - tourmaline, rutile - 0.05%. Note: Calcite in fillings in the joints. It forms resistant ridge.	10'	35'-45'

Number	Description	Thickness of the unit in feet	Feet Above Base
5	Yellowish gray, laminated, limonite stained, fine-grained, cherty, calcareous sandstone. It contains few pelecypods. <u>Petrography</u> Interlocked, cemented; median - 0.21 mm, upper size limit 0.45 mm, well sorted, roundness - 2, cements - Quartz, little calcite; Fine to medium grained sandstone. Much overgrowth due to quartz cement. Common quartz - 60.14%, chert - 25.85%, chalcedony - 0.88%, SRF - 12.33%. Fossils - Pelecypods,	10'	25'-35'
4	Gray, massive crossbedded, by small scale crossbeds, fine-grained cherty, calcareous sandstone. <u>Petrography</u> Interlocked, cemented, median - 0.15 mm, upper size limit - 0.23 mm, roundness - 2 to 3, well sorted; cements - quartz, calcite; Fine to medium grained sandstone, common quartz - 52.33%, chert - 28.61%, SRF - 13.99%, chalcedony - 0.63%.	5'	20'-25'
3	Gray, massive, crossbedded, fine-grained, cherty, calcareous sandstone. <u>Petrography</u> Interlocked, interpenetrated, grains; median - 0.20 mm, upper size limit - 0.22 mm, well sorted, roundness - 2, cements - quartz, little calcite; medium grained to fine-grained sandstone. Common quartz - 49.06%, chert - 32.07%, chalcedony - 1.97%, SRF - 12.90%, Mica - 0.23%, Dolomite crystals - 0.11%.	10'	10'-20'
2	Dark gray, massive, ridge forming, cherty, calcareous, sandstone; containing abundant Pelecypods.	5'	5'-10'

Number	Description	Thickness of the unit in feet	Feet Above Base
2	Petrography Interlocked, cemented; median - 0.22 mm, upper size limit - 0.83 mm, one grain of 1.8 mm size, moderately sorted, roundness - 3, cements - calcite and quartz, fine grained sandstone. Common quartz - 28.13%, chert - 51.28%, Chalcedony - 3.24%, SRF - 15.79%, Dolomite crystals - 0.43%, Fossils - Pelecypods, crinoids.		
1	Dark gray, massive, coarse grained, conglomeratic, calcareous sandstone with pebbles of chert. It forms base of Swift, is similar to basal conglomerate of Swift at 'B' section and overlies disconformably Rierdon limestone.	5'	0'-5'
,	Petrography Interlocked, cemented; median - 0.45 mm, upper size limit - 3.3 mm, poorly sorted, cements - calcite, quartz; conglomeratic sandstone. Common quartz - 31.05%, chert - 49.50%, chalcedony - 2.50%, SRF - 16.80%. Fossils - Pelecypods; spicules in chert pebbles.		