PETROGRAPHY OF MIDDLE TRIASSIC CROSS-BEDDED SANDSTONES IN NORTHEASTERN BRITISH COLUMBIA

PETROGRAPHY OF MIDDLE TRIASSIC CROSS-BEDDED SANDSTONES IN NORTHEASTERN BRITISH COLUMBIA

By

Gerald L. Goruk

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TITLE: Petrography of middle Triassic cross-bedded sandstones in northeastern British Columbia

AUTHOR: Gerald Lloyd Goruk, B.Sc. (McMaster University)

SUPERVISOR: Dr. G.V. Middleton

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SCOPE AND CONTENTS: An attempt is made to determine compositional and textural trends in the direction of sediment transport in middle Triassic cross-bedded sandstone samples collected from northeastern British Columbia. Petrographic measurements of textural and compositional properties were made and a multiple regression analysis was performed on 27 samples collected from a particular lithological unit. The general petrographic aspects of middle Triassic sandstones were investigated and are discussed.

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Abstract

54 cross-bed samples were selected for petrographic study from middle Triassic exposures in the Halfway-Sikanni Chief-Prophet River region of northeastern British Columbia.

Progressive changes in the characteristics of sediments can be detected by the analysis of a series of samples taken in the direction of transport. Textural and compositional measurements were made on 27 samples collected from the lower part of the Grey beds. Ten of the most promising variables were selected for trend study. Correlation coefficients between pairs of variables were computed to investigate inter-relationships, then a multiple regression procedure was applied to detect a trend in the direction of transport deduced by Pelletier (1960, 1961, 1962) from vector structure information.

An overall trend significant at the 1% level of probability was detected in the southwesterly direction using the most important compositional and textural variables. Quartz size and abundance and carbonate cement content were found to be significant in the regression thus demonstrating a trend in each of these variables in the downcurrent direction. The results of the multivariate analysis support Pelletier's paleocurrent study.

Cementing material was investigated; the most important volumetrically is calcite. Detrital carbonate was deposited at the same time as the sand and uniformly distributed by mechanical mixing. On lithifi-

cation, the carbonate was taken into solution and reprecipitated *in situ* as cement.

Organic detritus progressively replaced terrigenous material in the direction of transport so that rock-type is gradational between calcareous orthoquartzite and quartzose calcarenite but the calcarenitic texture has been obscured by re-crystallization.

Phosphate in the form of apatite internal fossil casts and shell material was precipitated in the basin of deposition, transported, abraded and the fine material carried downcurrent by the sorting process.

Terrigenous detritus composed of stable minerals was derived from an older sedimentary source (probably Permian, Pennsylvanian and Mississippian in age), and transported southwesterly over a low stable land surface in a turbulent shallow water environment.

Chapter I

INTRODUCTION

1. General

This study is concerned with middle Triassic cross-laminated rock that crops out within the Rocky Mountain foothills in the Halfway-Sikanni Chief-Prophet River region of northeastern British Columbia. This area (shown in Figure 1) bounded by 56°30' and 57°45' north latitude and 122°45' and 123°45' west longitude is approximately 80 miles long by 25 miles wide and is situated about 100 miles south of the Liard River and 50 miles north of the Peace River.

The purpose is three-fold: to show the stratigraphic and aerial distribution of cross-laminated rock in the Triassic of this area; to determine and relate textural and compositional changes to the direction of sediment transport; and to present conclusions based on petrography about source area, transportation and deposition of the sediment.

Study of primary current structures by Pelletier (1960, 1961, 1962) suggest an eastern and northeastern source area for Triassic sands which were transported southwesterly and laid down in shallow water on the eastern margin of the Western Triassic sea. According to Pelletier (1962, p. 24) the sands: "were transported in a generally southwesterly direction across a shallow-water platform into a deeper marine basin," and "were derived from a source northeast of the present study area.". In Pelletier (1960, Figure 1), directions of cross-bed means compared with those of ancient

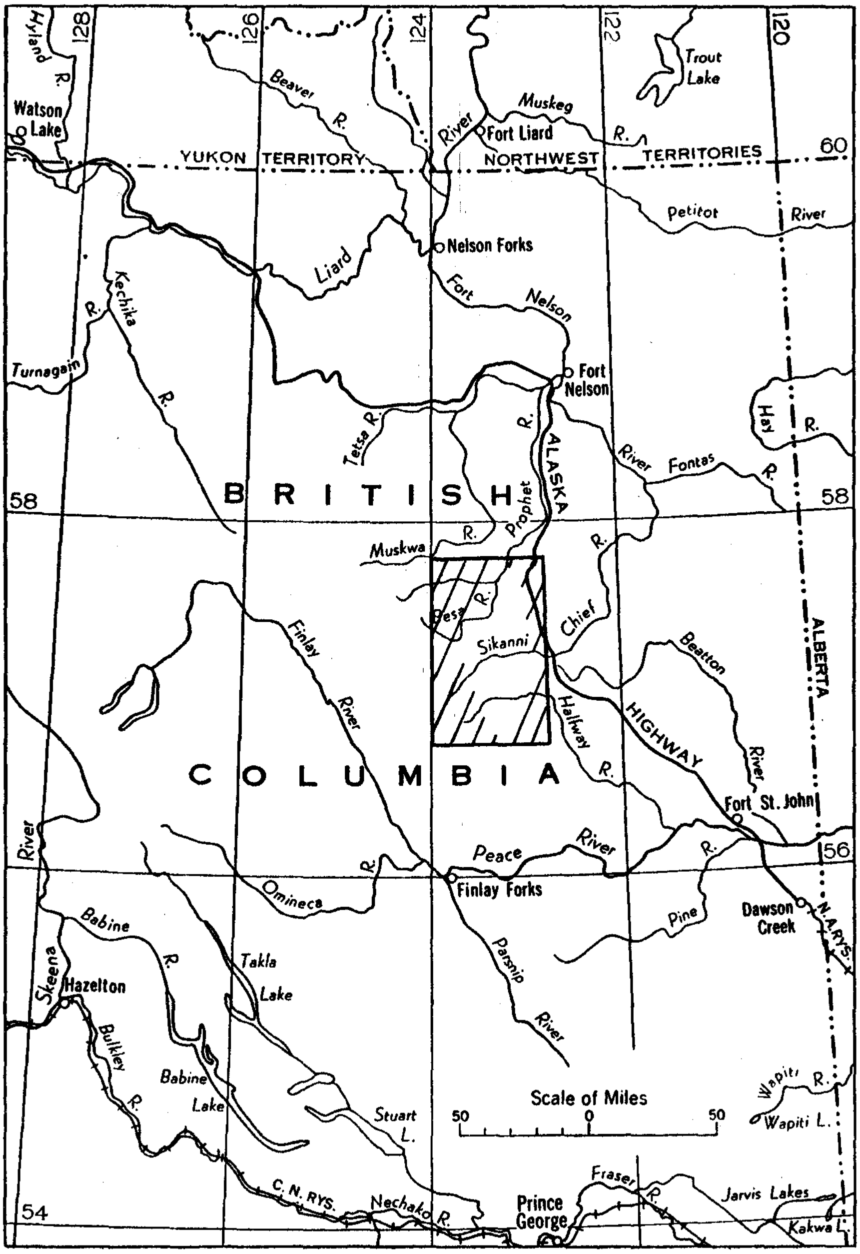


FIGURE 1 - Map of Northeastern British Columbia with outline of Thesis Area.

Triassic shore-lines (represented by mean ripple-mark trends), indicate that Triassic sediments were probably transported by wave-induced long-shore currents.

Subsurface study in the Peace River area by Hunt and Ratcliffe (1959) and surface study in the foothills by Colquhoun (1960) show that clastic ratios in the middle Triassic increase westerly. Colquhoun suggested that the sands were derived from a westerly source connected with an orogeny in the eu- or mio-geosyncline. Armitage (1962) in discussing Halfway sedimentation postulated a northwesterly source for the sand.

These conclusions as to direction of source area obviously differ from those of Pelletier.

2. Justification for Petrographic Study

Knowledge of the direction of sediment transport is important in understanding the sedimentation model in a particular basin, in correlating areally within the sedimentary sequence and ultimately in reconstructing the tectonic history.

Regional cross-bedding studies are a practical means in determining this direction but it is important that the vector structure information be confirmed by other information such as quantitative studies of texture and mineralogy.

Progressive changes in the characteristics of sediments can be detected by the analysis of a series of samples taken in the direction of transportation. These progressive changes might be in the mean grain size, mean shape or in the mineral composition of the sediment.

The writer participated during the final season of Dr. Pelletier's Triassic stratigraphy and sedimentation program. Besides collecting paleocurrent data the writer sampled cross-laminated rock for this petrographic study in order to detect and relate textural and compositional changes to the presumed southwesterly direction of sediment transport. It is found that the writer's results supplement and support Pelletier's paleocurrent study.

3. Method of Study

A clastic rock can be defined in terms of its petrographic properties such as mineralogy, grain size, shape, orientation and packing (Griffiths, 1958). Changes in some of these petrographic properties in a rock unit are a function of magnitude of transport energy and supply which in turn is a function of distance from the source. This statement can be represented by the equation $Y = f(X_1, X_2, X_3 \ldots X_n)$ where Y is the distance from the "source" and $X_1, X_2, X_3 \ldots X_n$ are appropriate petrographic properties.

Meaningful quantitative values for petrographic properties can be determined and the relative distance of each sample from the "source" can be calculated on the hypothesis that the direction of sediment transport is known from vector structure information. By substituting these values into the equation for each sample collected and employing the multiple regression procedure, trends in petrographic variables can be detected provided that such trends exist and that the statistical assumptions are correct.

4. Measurement of Petrographic Properties

Mineral composition was evaluated by identification of the constituents and estimation of their relative proportion by the point-count technique.

Grain size was measured by the maximum intercept diameter designated the a diameter.

Shape was expressed by the ratio b/a where b is the minimum intercept diameter.

Roundness was estimated visually by the comparison chart prepared by Powers (1953).

Grain packing was measured utilizing the packing density technique described by Kahn (1956).

One chemical property, phosphate content was determined by the Rapid Silicate Method developed by Shapiro and Brannock (1956).

Chapter II

STRATIGRAPHY

1. Brief Historical Summary

The Triassic was first recognized in the Peace River area by Dawson (1879) and in the Liard River area by McConnell (1891).

McLearn began his study in 1917 and published the first of his many papers about the Triassic in 1921. He assigned the Triassic beds of the Peace River foothills to the Schooler Creek Formation and in 1930 divided it into two lithological units.

In 1937 McLearn resumed field work in the Peace River area and described new species of ammonoids and pelecypods (McLearn, 1937a, b, 1939a, b, c, 1940a, b and 1941a). The higher beds of the Schooler Creek Formation which McLearn designated as the upper lithological unit of his 1930 paper he named the Pardonet member in 1940c and the lower beds, the lower or grey member.

In 1943 Hage made a geological reconnaissance along the newly built Alaska Highway between Fort St. John and Fort Nelson and collected Triassic fossils in the foothills on the Halfway and Sikanni Chief rivers. Kindle (1944) in the same year studied the beds in the Liard River area and assigned the names Grayling and Toad to the lower Triassic.

In 1944 McLearn investigated the Triassic north of the Peace River and in 1946a, b outlined the stratigraphy and occurrence of the fauna in the Halfway, Sikanni Chief, Prophet and Tetsa River valleys. In summarizing the formational classification, he noted that faunal evidence indicated that the nomenclature adopted for the Peace River foothills could be applied to exposures farther north. McLearn (1947a) presented a general survey of the Triassic stratigraphy between the Peace and the Tetsa rivers and subdivided the lower Grey beds of the Schooler Creek Formation in the south into two lithological units, the lower termed the Flagstones and the upper the Dark siltstones. In 1946 the upper beds in the Liard River valley were assigned the name Liard Formation by Kindle (published in an appendix to McLearn, 1947a).

In 1950 McLearn and Kindle summarized their major conclusions about the Triassic of northeastern British Columbia. They suggested that the Schooler Creek Formation be discarded as a stratigraphic term but the names Flagstones, Dark siltstones, Grey beds and Pardonet beds be retained temporarily until the lithological units are established as good mapping units. Subsequent work by McLearn (1960) dealt with more refined and extensive descriptions of the faunas.

Colquhoun (unpublished Ph.D. thesis, 1960) correlated Triassic rocks from the Liard River to the Athabaska River in Alberta. He studied subsurface and surface sections and used a formational terminology in the Peace River foothills that had been defined for the subsurface by Hunt and Ratcliffe (1959).

Pelletier in 1959 began a stratigraphy and sedimentation study of the surface Triassic in northeastern British Columbia and in 1960, 1961 and 1962 he published stratigraphic sections measured along the foothills belt between the Liard and Peace rivers. From observations of primary current structures he presented conclusions about direction of sediment transport and source area.

Tozer (1961) after extensive field work described the composition, distribution and correlation of the successive faunas contained in Triassic rocks of Western Canada and in 1962 published illustrations of leading index fossils.

Armitage (1962) proposed a new terminology for the lower Triassic in the subsurface east of the Peace River foothills and reviewed oil and gas occurrences in the Triassic.

The account of the stratigraphy that follows is based in part on the work which is reviewed above.

2. General Statement

The Triassic of northeastern British Columbia is characterized by two lithologies: dark calcareous siltstone and shale and massive beds of grey, calcareous quartzose sandstone and some limestone. The former lithology is well-developed in the Toad, Dark siltstones and Pardonet; the latter in the Liard and Grey beds.

The Triassic in the Liard River area has been subdivided into three lithological units: the Grayling, Toad and Liard formations; the Triassic sequence in the Peace River region: into the Grayling Formation, Toad Formation, Flagstones, Dark siltstones, Grey beds and Pardonet beds.

The Liard Formation in the north is correlative with the Flagstones and Dark siltstones farther south (McLearn and Kindle, 1950). Post-Liard beds in the north are absent due to the pre-Cretaceous unconformity except in the western foothills area where they have been recognized by Pelletier (1961, 1962).

Some of these lithological units have been given temporary lithological but not permanent geographic names. The table of Triassic formations appears in Figure 2.

3. Liard River Region

Kindle (1944) named the 1200-1500 foot sequence of platy, dark grey, calcareous siltstone and shale at the base of the Triassic in the Liard River area, the Grayling Formation. The Grayling has been observed as far south as the Peace River; it lies disconformably above the Permian and is conformable with the overlying Toad Formation.

The rocks of the Toad Formation were also described and named by Kindle (1944). This sequence consists of 600-1600 feet of dark grey, calcareous, massive and platy siltstone and shale with minor sandstone and limestone. It extends from the Liard River area south to the Peace River valley and is conformable with the overlying Liard Formation or with the Flagstones farther south.

Kindle first included Liard rocks in with the Toad sequence. Later in 1946 he separated the higher more massive and coarser-grained strata from the lower finer-grained beds and gave the name Liard Formation to the former. This unit is composed of grey, massive, calcareous sandstone with minor grey limestone and dark grey siltstone. Due to the pre-Cretaceous unconformity the thickness varies from 0 to 600 feet; the thickness of the Toad Formation is variable for the same reason. The Liard has been recognized in the Tetsa River valley and as far south as Gatho Creek which is just north of the thesis area.

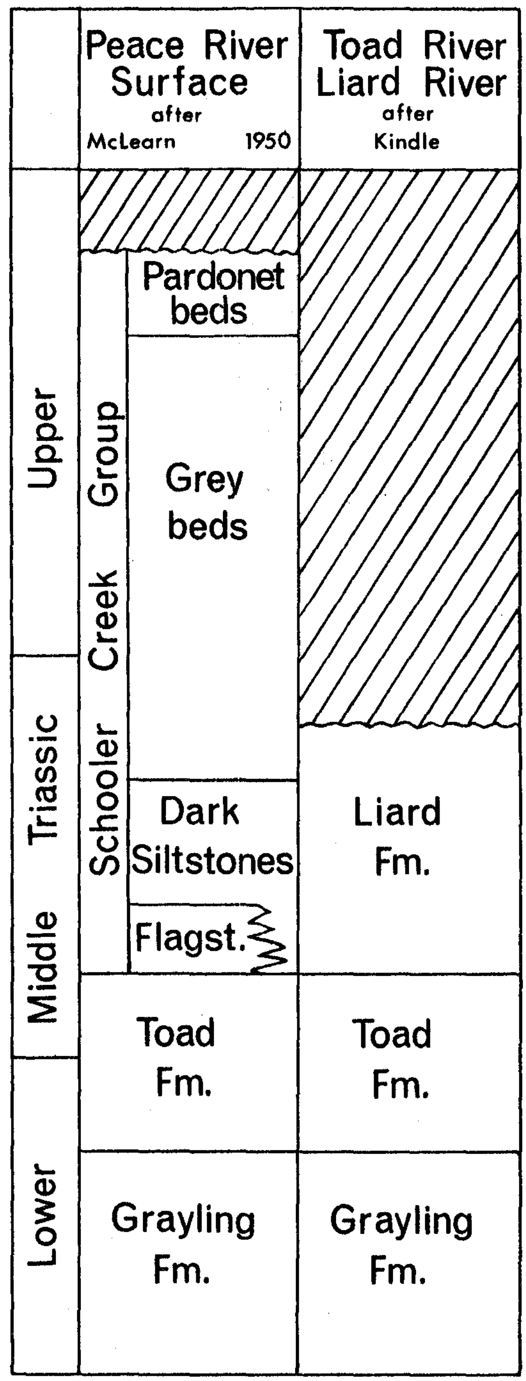


FIGURE 2 — TABLE of TRIASSIC FORMATIONS

4. Peace-Halfway-Sikanni Chief River Region

The Flagstones and Dark siltstones are provisional names assigned by McLearn (1947a) to two well-defined lithological units lying between the Toad Formation and the Grey beds in the Halfway and Sikanni Chief River valleys.

The Flagstones consist of 400 feet of grey, flaggy, thin-bedded calcareous siltstone and fine, massive, calcareous sandstone and limestone. This unit lies conformably between Toad rocks and the overlying Dark siltstones, a 100 to 450-foot sequence of dark calcareous shale, siltstone and limestone.

The Grey beds is another provisional name assigned by McLearn (1940) to the thick rock unit lying conformably between the Dark siltstones and the Pardonet beds. It consists of up to 2500 feet of massive, grey, calcareous, fine sandstone and grey limestone with minor calcareous siltstone and shale.

McLearn (1940) proposed the name Pardonet beds for the upper, finer and darker beds of the earlier Schooler Creek Formation. It is about 250 to 2000 feet thick and consists of a sequence of dark calcareous siltstone and limestone with minor calcareous shale and rare fine, calcareous sandstone. The upper contact with the overlying Jurassic is disconformable.

5. Important Lithological Units in this study

The Liard formation at Gatho Creek is composed of massive dark grey calcareous sandstone with softer sands forming recessive intervals between the massive ledges. It is 300 feet thick but is disconformably overlain by the Cretaceous.

In the Halfway River valley the Flagstones consist of 200 feet of dark, flaggy, calcareous siltstone with minor fine sandstone overlain by 200 feet of massive fine calcareous sandstone and minor limestone. The Dark siltstones above are represented by a 300 foot unit of dark shaly siltstone, limestone and shale with rare fine sandstone at the top. This unit thins northwards to the Sikanni Chief valley where it is approximately 100 feet thick and grades into Liard-type rock within the limits of the thesis area.

McLearn (1946a) described the Grey beds on the Sikanni Chief River valley as:

"comprising of 50 feet of hard massive thick-bedded calcareous fine sandstone which is overlain by massive calcareous fine sandstone with a 10 foot bed of limestone at the top. Above this, a concealed interval extends to where ledges of massive fine sandstone occur. From these ledges beds amounting to hundreds of feet are concealed. Above are ledges of massive grey fine sandstone and fine-grained limestone. These beds are overlain by the Pardonet beds.".

6. Definition of Terms

For reference purposes in this study the writer subdivides the Grey beds into three units: the lower, middle and upper Grey beds. The lower unit refers to McLearn's hard massive fine sandstones; the middle unit to the concealed interval above (including the few ledges of massive fine sandstone); and the upper unit to the top ledges of massive fine sandstone and limestone.

The lower Grey beds are less than 100 feet thick at the northeastern edge of the thesis area and thicken to approximately 400 feet at the southwestern edge (Pelletier, personal communication).

Chapter III

FIELD WORK

1. Distribution of Cross-beds

Cross-beds are common in the sand facies in the Triassic and were observed almost wherever sandstone crops out at the surface. Sands are rare in the Toad Formation and the Pardonet beds in the thesis area and so this study is confined stratigraphically to the middle Triassic.

For several reasons about one-half the samples collected were obtained from the lower Grey beds: it is an easily traceable unit throughout the area and therefore a promising one to study; it tends to crop out on ridge-tops and is generally quite accessible by helicopter; and the well-defined large cross-laminations within it are easy to locate at most exposures. Cross-beds were not so readily found in the recessive middle Grey beds and in the few sand horizons in the upper Grey beds and therefore sampling has been sparse in these units.

Liard cross-beds have been sampled at one northern locality in the thesis area; the time-equivalent Flagstones and Dark siltstones to the south have been only occasionally sampled because sand development is weaker in the Flagstones and sands are quite rare in the Dark siltstones.

2. Sampling Procedure

Samples were not randomly chosen. This would have involved taking localities at grid intersections, examining each section and selecting exposures from it at random by means of a table of random numbers and then selecting beds at random, etc. Such a procedure was impracticable from an operational view-point in this study; instead, representative samples were taken.

The total area was subdivided into large divisions and each of these treated in the same way: the aerial distribution of Triassic exposure in a division was mapped and then convenient suitably-spaced localities were selected and collections of cross-bed samples subsequently made.

Adequate coverage of the unit at a locality was obtained by choosing a sample from an exposure in say the lower, middle and upper part. Time did not permit measuring-in the sample position stratigraphically and it was often inconvenient to examine the complete section at a locality, so that in some areas several localities have to be grouped together to get complete coverage of a particular stratigraphic unit (such as the lower Grey beds).

Usually the first exposure encountered was the one selected for sampling and the largest cross-bed in the best-defined horizon at the exposure was sampled because the writer tended to be attracted to the larger cross-beds and decided to be systematic in sampling them.

Bias will not be introduced in the cross-bedding study, provided that there is no general tendency for the direction of large cross-beds to differ significantly from the direction of smaller cross-beds.

Some bias may be introduced in the petrographic study because of the tendency to sample only the more indurated, massive exposures. Since grain size tends to be correlated with bed thickness (cf. Pettijohn, 1957, p. 161), there is probably a tendency for over-representation in the sample of the coarser, more strongly cemented sandstones. The sampling

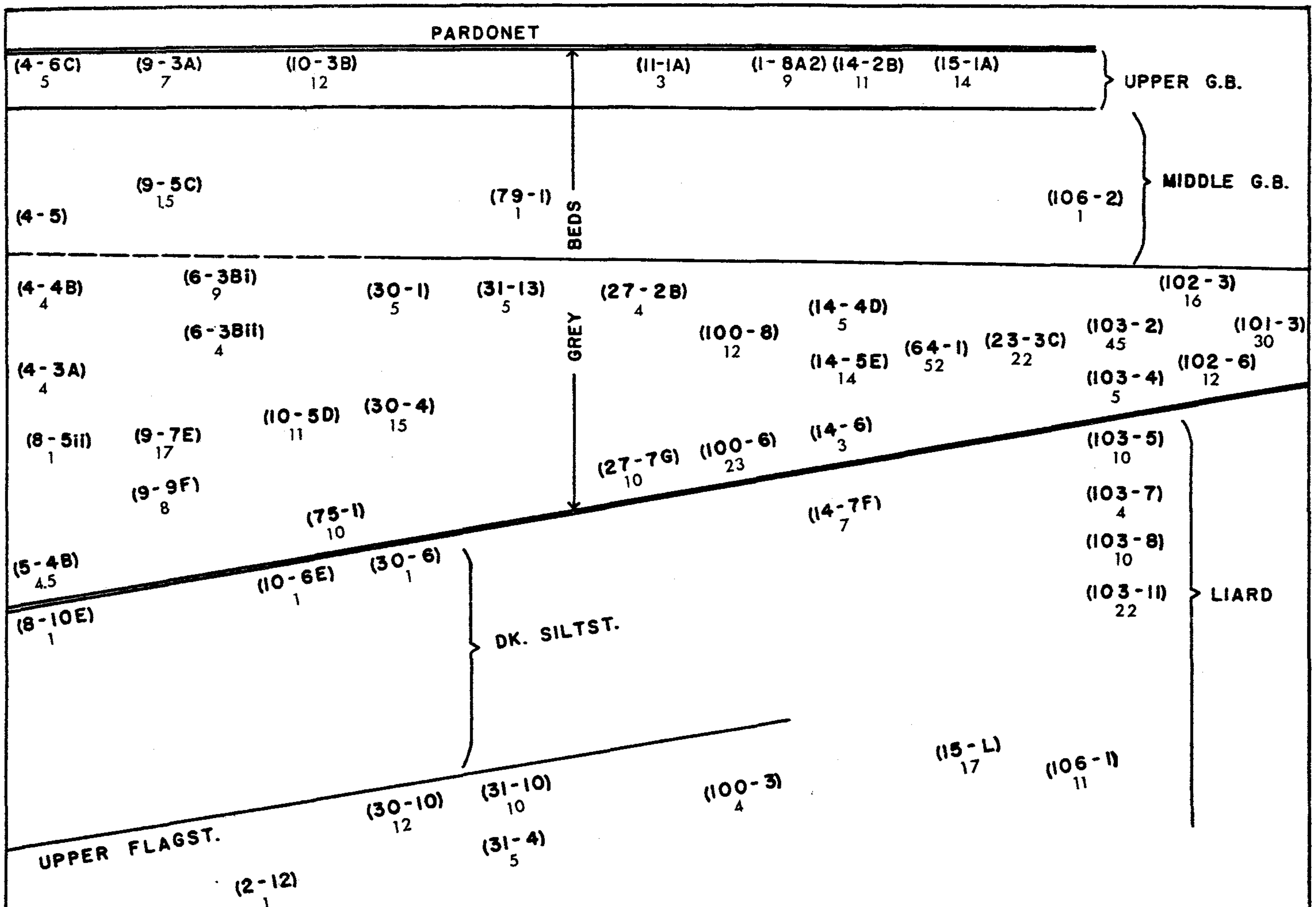


FIGURE 3 - Thickness of Cross-beds (in.)

procedure was, however , consistent over the area studied, so that regional trends, if any, cannot result simply from sampling bias.

3. Description of Summary Diagram (Figure 3)

This diagram (not drawn to scale) shows the relative vertical and lateral distribution in the southwesterly direction of cross-bed samples collected in the thesis area.

The source area lies to the northeast, represented by the right edge, and transport direction is toward the southwest, the left edge of the sheet. The Liard formation in the bottom half of the diagram grades into the Flagstones and Dark siltstones to the southwest. The Grey beds overlie the Liard formation and Dark siltstone, and are divided into lower, middle and upper units. The lower unit thickness in the southwesterly direction varies from less than 100 to approximately 400 feet.

Samples numbers have been located on the diagram according to their relative distance from the "source" and their relative stratigraphic position. The first part of each sample number (e.g. 100 to 100-8) refers to the section location shown in Figure 4 which illustrates the aerial distribution of cross-bed sample localities in the thesis area.

Below each sample number in Figure 3 is the thickness of the cross-bed from which the sample was taken. The vertical and lateral distribution of data collected from the various petrographic studies will subsequently be illustrated by means of such summary diagrams.

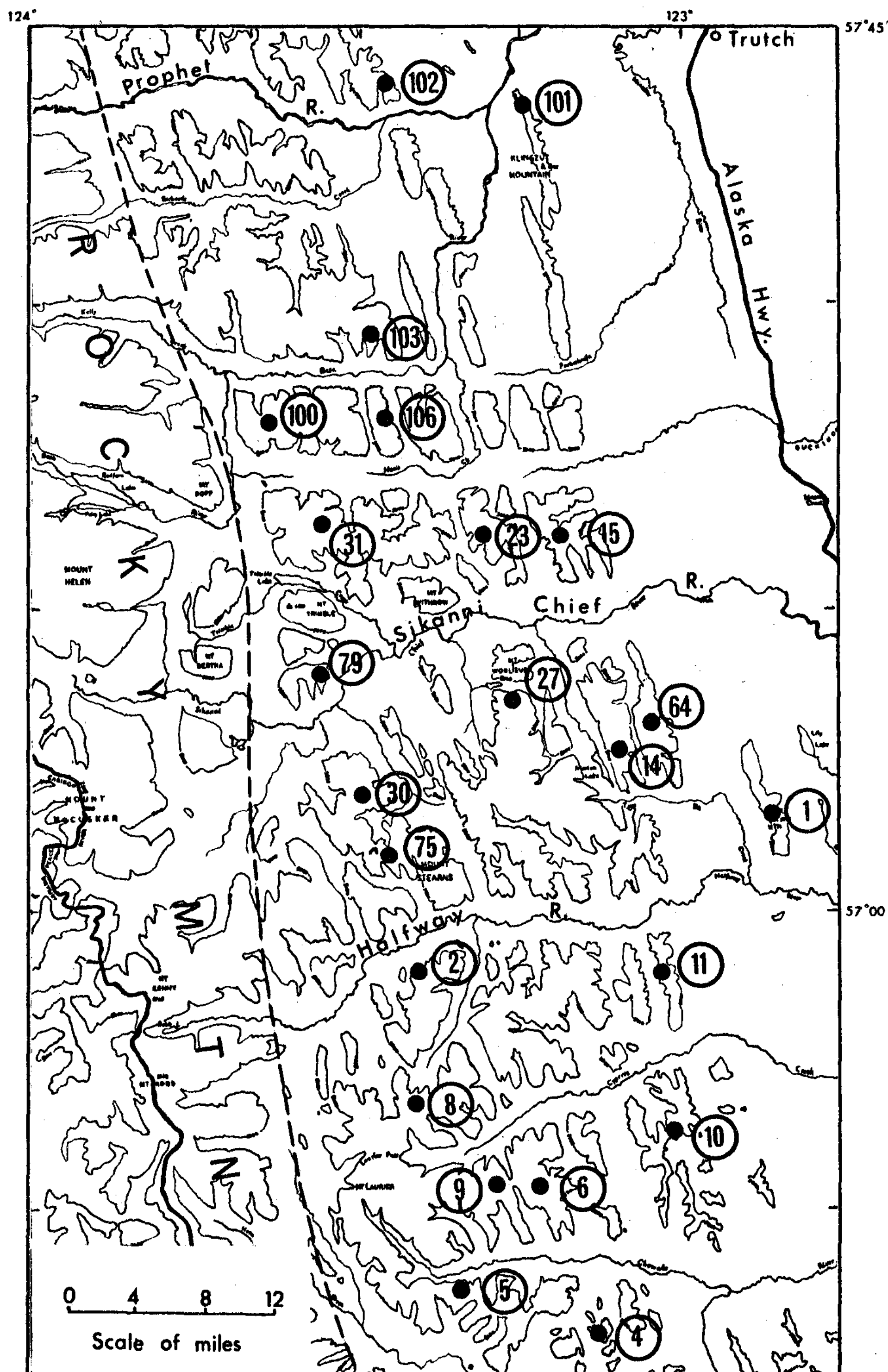


FIGURE 4 – CROSS-BED SAMPLE LOCALITIES

Chapter IV

PETROGRAPHY

1. Mineral Composition

Thin-sections were cut from each sample in a random direction normal to the plane of bedding. The following minerals were identified:

Quartz - Predominantly clear inclusion-free, but some inclusions of mica, dust bands and vacuoles. Extinction is slightly undulose to moderately strained. Several grains with abraded overgrowths and some corrosion by carbonate were observed. Several samples appear to have a biomodal grain size distribution.

Calcite - Most calcite occurs as a clear variable-sized crystal mosaic cement, often well-cleaved and twinned, with occasional outlines of former shell material. Detrital material, where distinguishable, is predominantly in the form of fossil fragments and shell fragments; some is in the form of crushed crypto-crystalline grains. The smallest detrital carbonate occurs as tiny 0.1 mm ovoid pellets, rarely with black carbonaceous spots.

Chert - Chert is generally micro-crystalline but often crypto-crystalline, sometimes with thin chalcedony veins. Rarely, tiny chalcedony spherulites may be incorporated within a larger chert mass or a large chalcedony spherulite may comprise a single grain. The colour ranges from very pale to dark brown. Grains sometimes appear to be interpenetrated by quartz and may be corroded by carbonate in the form of a thin rim of fibrous calcite with the long axis of the individual crystals perpendicular to the grain boundary.

<u>Silica cement</u> - The cement occurs as overgrowths on quartz grains in optical continuity; usually anhedral, filling in the pore space but rarely euhedral; it may be corroded by carbonate.

<u>Bitumin</u> - The bitumin is a pore filling, black to reddish brown in colour, and may stain tiny carbonate pellets.

<u>Silicate rock fragments</u> - These are predominantly fine-grained orthoquartzite with individual more or less equidimensional quartz grains displaying straight extinction. A few fragments consist of fine quartz, feldspar and mica grains cemented by silica.

<u>Collophane</u> - This is mainly in the form of prismatic shards or flakes and pellets. The shards, 0.1 - 0.2 mm and larger, are generally yellow to light brown in colour (but may be darker). Most are isotropic but a few are anisotropic with a wavy-type of extinction; the larger pieces sometimes show fractures. The pellets generally are dark brown, ovoid and quite small (0.1 mm), sometimes with a quartz or carbonate silt core, but may be larger, not so regular in outline and have included quartz silt. Rarely, collophane with included quartz silt has the shape of an internal cast of a small fossil and rarely collophane has the texture and shape of an organic fragment.

<u>Feldspar</u> - Approximately half the feldspar fraction consists of clear microcline grains; the remainder consists of twinned plagioclase (half albite and half sodic oligoclase); only the occasional grain shows slight weathering.

<u>Tourmaline</u> - There are three colour varieties, the first two most abundant: golden brown, yellowish green and bluish green.

<u>Dolomite</u> - Sucrose; micro-crystalline rhomb replacement of calcite.

<u>Mica</u> - Very rare; microscopic, clear acicular laths; probably sericite.

<u>Pyrite</u> - Trace; tiny granules.

2. Modal Analysis

The minerals identified and described above were grouped into 9 classes for modal analysis using the point-count technique developed by Chayes (1956). The classes were: quartz, carbonate cement, detrital carbonate, collophane, chert, silicate rock fragments, feldspar, silica cement and others. The total amount of quartz, carbonate and chert compose almost the entire volume of the rock in the samples collected; the first two classes are the most important.

Several thin-sections were preliminarily point-counted using 60 point traverses. The percentage of each of the mineral classes in the sample was determined at the completion of each traverse cumulatively. The variation in percent quartz was high between the first two traverses in each case but then leveled out to within 2% between traverses 3, 4 and 5.

A sampling plan of 300 points per thin section in five 60 point traverses was adopted for the following reasons: 300 points will probably give a satisfactory estimate of the proportions of the major constituents which are expected to have a wide range in variation; the remaining constituents are relatively rare and would require a large number of points for an accurate estimate of their amount. It is dubious whether the expenditure of time and effort in obtaining a precise estimate of the rare classes is worthwhile in this study and so precision was sacrificed by following a sampling plan of only 300 points.

Consistency in assigning grains to the various classes was ensured by devising operator definitions covering ambiguous situations where it is difficult to decide which mineral the point has fallen on and by using the same microscope magnification throughout the modal analysis. Thin sections (as in all the ensuing studies) were selected in a random order.

Precision of the method was determined by point-counting five thin-sections then duplicating them two weeks later trying to traverse as closely as possible to the original points. Another five thin-sections that had been analyzed at the same time as the first group were duplicated in the same way about one month later. The coefficient of variation for quartz was 3.6% (Appendix II, S-1) for chert whose arithmetic mean is 3.7% (S-2), it was much higher: 17.8%. Thus with the method of analysis used, the precision of estimates of the proportions of the major constituents should be reasonably high but the precision is relatively low for the minor classes.

Other possible sources of error lie in mistaken assignment of grains: counting untwinned feldspar as quartz or detrital carbonate as cement or collophane as bitumin in some instances.

An estimate of the first possible source was obtained by staining six thin-sections for potash feldspar. The results indicate that this source is probably negligible. Distinguishing between detrital carbonate and cement is highly subjective in many cases but the total carbonate content can readily be determined and this information may be just as valuable as individual estimates of the amounts of detrital material and cement. Difficulty in measuring collophane content which is of special interest was overcome by analyzing the samples chemically for phosphate. Percentage collophane is $\frac{100}{41.5} \times P_2O_5\%$.

3. Phosphate Analysis

Phosphate content in 44 samples was determined by the Rapid Silicate Method outlined in Shapiro and Brannock (1956). The method involves using a spectrophotometer to measure light of wave length 430 mu which is transmitted by a solution containing the molybdivanophosphoric acid complex. The value obtained for an unknown solution is compared with that of a known standard phosphate solution; thus percentage phosphate in the unknown can be calculated.

In the preliminary preparation of the sample a portion of the handspecimen was broken down to sand size with a mortar and pestle. It was split down to about a 1½ gram portion, ground to 150 mesh size in a grinding mill and then mixed for ½ hour.

0.25 gm of sample were weighed out and placed in a 150 ml beaker and 25 ml of 1-1 HNO_3 added by pipette. The beaker was placed on a steam bath for 2 hours to digest after which the solution was filtered into a 200 ml volumetric flask and made up to 200 mls.

Final treatment involved taking a 15 ml aliquot and following the procedure described in Shapiro and Brannock, p. 38.

In following this procedure the standard method was modified in not decomposing the sample with hydrofluoric acid before treatment with HNO_3. This method seemed to be justified because most if not all the phosphate appeared to be mineral P_2O_5 which should be decomposed by a strong acid such as HNO_3 alone. This fact was verified by the chemical analyst in the Geology Department at McMaster, who analyzed two of the samples by the standard method using HF and by the "HNO_3 extraction" method.

Results of Muysson's Analysis

Sample	Standard Method with HF	HNO_3 Extraction
9-3A	1.17%	1.15%
103-4	.045%	.04%

The HNO_3 extract yields slightly lower values but not enough to be concerned about. At least one investigator in the literature has used a similar technique. Fesenkova (1955) determined mineral P_2O_5 content in sandstones using an HCl extract without preliminary decomposition by HF.

Samples were treated in batches of eight, the seventh sample in each batch was replicated. The coefficient of variation determined for 6 replications was 0.93% (Appendix II, S-3) indicating high precision.

A possible criticism of the writer's method might be that the 1½ gm portion that was ground down to 150 mesh size in the preliminary preparation is too small to be a good sample of the handspecimen. Admittedly greater homogeneity would have been ensured by grinding down a larger portion. However, the writer offers the following evidence in support of his work:

1. The writer's values compare favourably with the values obtained by Muysson for the two samples previously mentioned. Muysson used about 25 gm samples for his determinations.

Sample	Muysson's values	The writer's values
9-3A	1.15%	1.12%, 1.14%
103-4	.04%	.05%, .05%

2. The results of the phosphate analysis in general agree with the results of petrographic study.

4. Relative Order of Abundance of the Mineral Constituents

Table 1 is a summary of the relative abundance of the mineral classes in samples collected from the lower Grey beds. The statistics used are arithmetic mean and range of variation based on 27 samples.

Table 1

Relative Order of abundance of the Mineral Constituents

Mineral Class		$\bar{X}$%	Range (%)
Quartz		51.1	19.5-80.0
Carbonate		42.4	6.3-83.6
Chert		3.2	0 -18.5
Silica cement		1.1	0 -11.7
Others*		1.1	0 -10.3
Quartzite		0.4	0 - 1.0
Phosphate+		0.14	0 - 0.92
Feldspar		0.06	0 - 0.3
Carbonate:	cement	37.7	6.5-81.5
	detrital	4.7	0 -49.0

* Predominantly bitumin but includes tourmaline and mica

+ Analytical determination

Figures 1-9 (Appendix I) display the values obtained for each of these mineral classes for all samples analyzed in the middle Triassic. Figures 10 and 11 show the results for samples in which dolomite and mica have been observed.

5. Grain Size

Maximum apparent grain diameter in thin-section was used as the measure of size in this study. It is designated the a diameter and is defined as the largest intercept across the grain or the longest symmetrical diameter in cases of ambiguity.

The most abundant and so most important mineral studied was quartz. Size of each quartz grain was calculated from the formula $\phi = -\log_2 ka$ where a is the maximum grain diameter in thin-section, a is measured in eye-piece micrometer units and k is a factor to reduce these units to millimeters. The phi scale is arithmetic and tends to normalize the log normal size distribution so that grain size in a sample can conveniently be represented by the arithmetic mean and sorting of the grains by the standard deviation.

A volumetric estimate of grain size in each sample was obtained by selecting grains for measurement by point-count. The number of grains to be measured per sample was suggested by the following experiment:

A small area was blocked out in one of the thin-sections (slide No. 102-6) and the a diameter of every grain measured. Four suitably-spaced traverses were then made of the area and every grain on each traverse was measured. Finally 10 grains on each of 4 traverses were chosen by point-count.

The number of grains measured by each of the three methods was 862, 157 and 40 with arithmetic mean phi of 2.51, 2.28 and 2.36 respectively. An estimate of mean phi using 20 grains (every second measurement of the 40 point run) gave a value of 2.45. Only the point-count method gives a volume frequency but the experiment demonstrates that estimates of mean size using just a few grains are comparable with those based on many grains. Of course a large number of measurements are needed if small differences between sample means are to be detected. In this study 40 grains were used to estimate quartz size, 10 grains from each of 4 traverses.

Possible sources of error in the size analysis lie in choice and measurement of the a diameter and modification of the grain by overgrowth and corrosion. No attempt was made to correct thin-section size data for comparison with sieve analysis data because this study is primarily concerned with comparison within the population.

The writer believes that operator error in the size analysis is slight; whenever attempted, measurements could easily be reproduced. Error due to grain modification by silica overgrowth is also believed to be unimportant because the detrital core in most cases is recognizable owing to the presence of a very thin carbonate rim around it. Modification due to carbonate corrosion, on the other hand, may be serious unless the amount of corrosion is relatively constant from sample to sample. If so, the range of variation of grain size within the population will not be affected, but the apparent diameter would be lessened. From the point of view of this study the effect is probably unimportant.

A similar size study was performed for the remaining less abundant detrital minerals. Mean size was based on 20 grains or a lesser number if 20 grains could not be readily found in a thin section. Instead of converting each grain measurement into phi units using the method outlined above, a scale was devised so that grain size in eye piece micrometer units could be assigned directly into ½ phi class intervals and mean phi calculated by the formula: $\bar{\phi} = \frac{\Sigma f_i m_i}{F}$ where f_i is the frequency of measurements in the i^{th} class, m_i is the mid-point of the i^{th} class interval in the phi scale and F is the total number of grains measured. This procedure was found to be more convenient where few measurements were involved and the highest possible accuracy not required.

Mean size for quartz and the other detrital minerals cannot strictly be compared because quartz grains were selected by point-count and grains of the minor minerals were selected wherever present in the thin-section; the former method gives a volume frequency but the latter, a diameter frequency sample. Nevertheless the results of the analyses should demonstrate the relative differences in size between the minerals studied.

6. Relative Order of Size of the Detrital Minerals

Table 2 is a summary of the mean size of detrital minerals in samples collected from the lower Grey beds. The arithmetic mean of mean quartz size is based on 27 samples; the mean of the other minerals is based on a variable number because each of these minerals does not occur in every sample.

Table 2

Relative order of size of the detrital minerals

Mineral	$\bar{X}_{\emptyset}$	Range ($\bar{\emptyset}$)	Number of samples
Quartzite	1.7	1.5 - 3.3	13
Chert	1.8	1.6 - 2.8	21
Quartz	2.4	1.7 - 3.0	27
Carbonate*	2.4	1.9 - 2.9	10
Collophane	2.7	2.2 - 3.3	8
Feldspar	2.8	2.3 - 3.5	8
Tourmaline	3.2	2.5 - 3.8	5
Carbonate (pellet)	3.7		1

* Crypto-crystalline carbonate and organic fragments. Shell material where recognizable is the largest clastic material in the rock. This is shown in Figure 19 (Appendix I) in which maximum diameter for shell material in the sample is compared with that of chert.

Figures 12-18 (Appendix I) show individual sample values for each separate mineral.

Testing most quartz phi distributions on probability paper showed that phi is approximately normally distributed in each case. Values of quartz size standard deviation (representative of sorting) are shown in Figure 14A (Appendix I) and indicate that sorting is generally good in samples collected from the lower Grey beds.

7. Shape

The measure of grain shape adopted was the ratio of the minimum to the maximum apparent diameter in thin-section. Minimum apparent diameter designated b is defined as the largest intercept at right angles to the a diameter. The ratio b/a (Ψ) is a measure of circularity and is an approximate measure of sphericity.

Thirteen thin-sections from the lower Grey beds were selected for quartz and chert shape measurement. Mean sphericity for both minerals was based on 20 grains. In the case of quartz the grains were chosen by point-count in order to give a volume frequency sample. The less abundant chert grains were selected for measurement from positions covering the entire slide.

Table 3 shows the arithmetic mean and the range of variation of mean quartz and chert sphericity in 13 samples studied.

Table 3

Sphericity of quartz and chert

Mineral	$\bar{X}_{\bar{\Psi}}$	Range ($\bar{\Psi}$)
Quartz	.73	.69-.76
Chert	.67	.61-.73

Figures 20, 21 (Appendix I) show individual sample values.

The reciprocal of b/a is Bakman's elongation quotient (1952). Forty quartz grain a/b values were plotted as histograms for each of several lower Grey beds samples. Comparison with Bakman's quartz histograms p. 23, show that they resemble his granite-source figure.

8. Roundness

Roundness of each grain was estimated visually by comparison with the roundness chart prepared by Powers (1953). Grain roundness frequency distributions for samples using Powers' scale tend to be skewed. To correct for deviations from normality in sample distributions, the six classes were converted to the Rho Scale, Folk (1955).

Mean roundness was calculated by the formula:

$\bar{p} = \frac{f_1(0.5) + f_2(1.5) + \dots + f_6(5.5)}{F}$ where $f_1, f_2 \dots f_6$ are the frequency of grains in each class, 0.5, 1.5 ... 5.5 are the mid-points of the Rho Scale class intervals and F is the total number of grains measured. Twenty grains selected by point-count were considered sufficient in estimating mean roundness.

Because the method is subjective to a large extent, variations in estimates by the same operator can be large. This fact has been verified by studies, such as that of Rosenfeld and Griffiths (1953), designed to evaluate the magnitude of operator error in measuring roundness.

Precision in measuring roundness in this study was determined by duplicating 7 thin-sections several weeks later. The coefficient of variation calculated was 6.7% (Appendix II, S-4).

Modification of grain roundness due to carbonate corrosion is another possible source of error. This could lead to serious error unless the amount of corrosion is relatively constant from sample to sample.

Roundness of quartz was measured in each sample and roundness of chert in 8 samples in the lower Grey beds. Qualitative estimates were made of the less abundant grains of quartzite, feldspar and tourmaline.

Table 4 summarizes the results obtained for roundness studies in the lower Grey beds.

Table 4

Roundness of the detrital minerals

Mineral	$\bar{X}_{\bar{p}}$	Range ($\bar{p}$)	Number of Samples
Chert	3.5	2.7 - 4.0	8
Quartz	3.2	2.1 - 3.7	27
Quartzite		2 - 4*	
Feldspar		2 - 4*	
Tourmaline		3 - 5*	

* Qualitative estimate

Plotting many of the quartz rho distributions on probability paper showed that rho is approximately normally distributed.

9. Grain Packing

The aggregate property of packing was measured in a few samples by packing density, P_D, defined by Kahn (1956) as $\frac{m \sum_{i=1}^{n} gi}{t} \times 100$ where n is the total number of grains in a given traverse, gi is the grain intercept of the i^{th} grain in the traverse, m is a magnification constant, and t is the length of the traverse. Only one traverse in a line parallel to the plane of the bedding was made in each of the thin-sections analyzed.

Six samples with low carbonate cement content in the lower Grey beds were measured. Summary results appear in Table 5 and individual sample values in Figure 24 (Appendix I).

Table 5

Grain packing values for some samples

$\bar{X}_{P_D}$ %	Range %	$\bar{X}$% Carbonate
74.1	70.3-76.2	23.8

One orthoquartzite was measured:

Sample	P_D%	% Carbonate
10-3B	76.8	0

Two samples with high carbonate cement:

Sample	P_D%	% Carbonate
100-8	61.5	52.0
14-4D	60.1	67.0

One quartzose calcarenite:

6-3Bi	72.8	70.3

10. Inter-Relationships among some of these Properties

Three of the properties investigated in the lower Grey beds: mineral composition, grain size and grain roundness appear to be promising for trend analysis using the multiple regression procedure. Of these, ten variables were selected: quartz %, carbonate cement %, detrital carbonate %, phosphate %, chert %, silica cement %, others %, quartz size, quartz standard deviation, quartz roundness; and the relationships between pairs of these variables were measured by the correlation coefficient r as a preliminary step in the trend study.

A perfect linear relationship between a pair of variables is expressed by a correlation coefficient of 1.00. The further the departure from linearity, the smaller the value of the coefficient. The coefficient accurately expresses the degree of association between pairs of variables only if the relationship is linear. In this study, visual inspection of scatter diagrams for the more important pairs confirms that the relationships are approximately linear.

Paired correlation coefficients for these 10 variables are presented in Table 6. Important relationships are marked by an asterisk which indicates significance at the 1% level of probability. The correlation matrix shows a number of significant positive and negative correlations which suggest the following relationships:

Table 6

Paired Correlation Coefficients for 10 Petrographic Variables

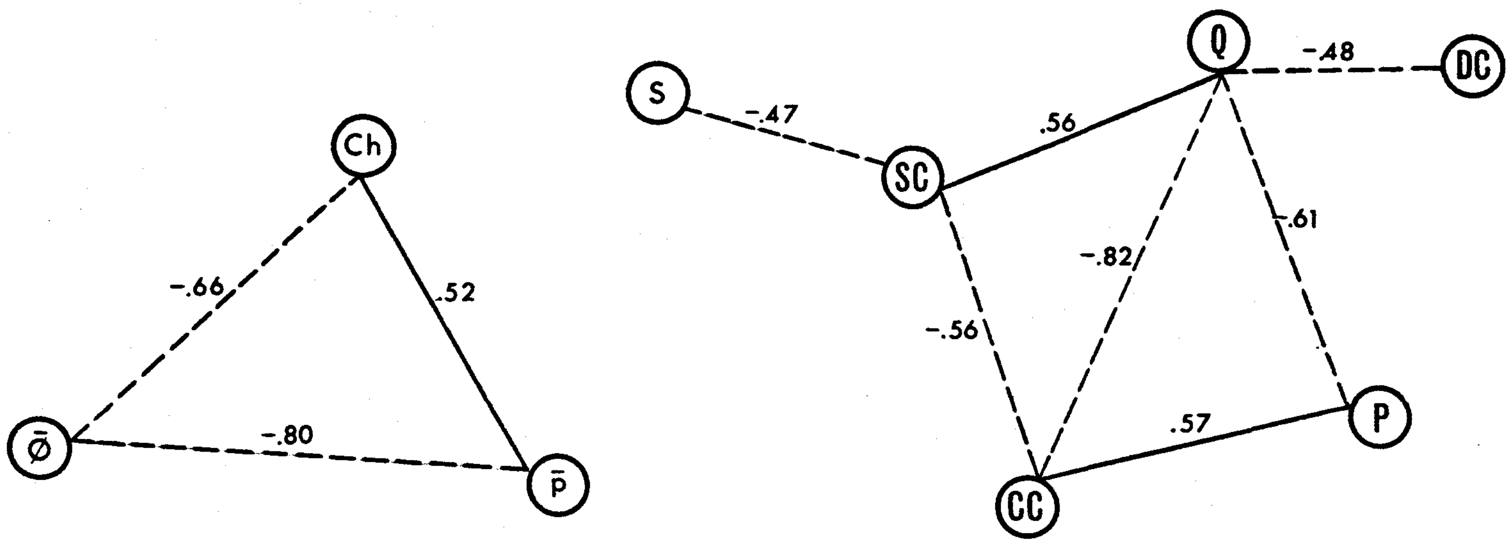
Qtz %	Carb Cem %	Detr Carb %	Phosph %	Chert %	Silica Cem %	Others %	$\bar{p}$	$\bar{\phi}$	S	
1.00	-.82**	-.48**	-.61**	-.14	.56**	.23	.12	-.04	-.28	Qtz %
	1.00	-.04	.57**	-.13	-.56**	-.37	-.14	.25	.25	Carb Cem %
		1.00	.20	.12	-.20	.09	-.11	-.15	.03	Detr Carb %
			1.00	.01	-.30	-.24	-.19	-.19	.17	Phosph %
				1.00	-.17	-.15	.52**	-.66**	.44	Chert %
					1.00	.07	-.01	.04	-.47**	Silica Cem %
						1.00	-.27	.25	-.23	Others %
							1.00	-.80**	.43	$\bar{p}$
								1.00	-.29	$\bar{\phi}$
									1.00	S

** $r \geq 0.45$, P .01 (Correlation coefficients ≥ 0.45 are significantly different from 0 at the 1% level of probability.)

1. Quartz and carbonate cement content vary antipathetically.
2. Quartz size and roundness vary antipathetically.
3. Phosphate and carbonate cement content vary sympathetically.
4. Chert content and quartz size vary sympathetically.
5. Quartz-rich samples tend to be better sorted and silica cemented.

These relationships are illustrated in Figure 5.

Cluster Diagram for Paired Correlation Coefficients



$r > 0.45, \quad P_{.01}$

FIGURE 5

Q QUARTZ
CC CARB. CEM.
DC DETR. CARB.
Ch CHERT
SC SILICA CEM.
P PHOSPH.
s STAND. DEV.

Chapter V

LATERAL AND VERTICAL VARIATION IN THE MIDDLE TRIASSIC

1. Lateral Variation in the lower Grey beds

Progressive changes in the characteristics of sediments can be detected by the analysis of a series of samples taken in the direction of transportation. A lateral trend in a lithological unit can be detected by setting up an equation relating distance from the "source" to each of the measured petrographic properties and testing the statistical significance of the results. Twenty-seven samples from the lower Grey beds were used in this statistical study.

In measuring distance from the "source", a northwesterly trending base-line was drawn on the aerial map through sample locality 101 which was taken as the origin, and distance of the other sample localities from the "source" were measured from this base-line in the southwesterly direction.

The sums of squares for each of the 10 variables and distance from the "source" was calculated, expressed in matrix form, this matrix was inverted and the regression coefficients and an analysis of variance computed showing the contribution of each of the variables to the sums of squares and the significance of the regression.

In performing a multiple regression it is necessary to run a number of trials in order to obtain the best possible regression because some of the variables contribute little to the sums of squares and should be removed in order to improve the regression.

In several preliminary trials it was found that some of the variables contributed little to the regression. These variables were removed until the regression became significant (with five variables). The regression was improved by removing one more variable (Chert %). Further removal of variables resulted in non-significance (at the 1% level).

Analyses of variance for separate regressions on quartz size and quartz abundance appear in table 7 and 8. Both regressions are significant at the 5% level of probability.

Table 7

Analysis of Variance for the Regression on Quartz Mean Size

	df	SS	MS	F
Due to regression:				
$X_1 - \bar{\phi}$	1	17.151	17.151	6.04*
About regression	25	70.960	2.838	
Total	26	88.111		

* Significant at the 5% level of probability

$F_{.95}(1, 25) = 4.24$

Table 8

Analysis of Variance for the Regression on Quartz Content

	df	SS	MS	F
Due to regression:				
X_1 - Quartz %	1	13.977	13.977	4.71*
About regression	25	73.985	2.959	
Total	26	87.962		

* Significant at the 5% level of probability

$F_{.95}(1, 25) = 4.24$

A regression was performed on the combination of variables: quartz size, roundness and quartz abundance and it was found to be significant at the 5% level. The analysis of variance appears in Table 9.

Table 9

Analysis of variance for the multiple regression on 3 variables

	df	SS	MS	F
Due to regression:				
$X_1 - \bar{\phi}$	1	17.151	17.151	7.10*
$X_2 - \bar{p}$	1	4.540	4.540	1.88
X_3 - Quartz %	1	10.888	10.888	4.51*
Total due to regression	3	32.579	10.860	4.50*
About regression	23	55.532	2.414	
Total	26	88.111		

* Significant at the 5% level of probability

$F_{.95}(3, 23) = 3.03$

The analysis of variance for the final regression selected which is significant at the 1% level and shows the contribution of each variable, is given in Table 10.

Table 10

Analysis of variance for the multiple regression on 4 variables

	df	SS	MS	F
Due to regression:				
$X_1 - \bar{\phi}$	1	17.151	17.151	8.72**
$X_2 - \bar{p}$	1	4.540	4.540	2.31
X_3 - Quartz %	1	10.888	10.888	5.54*
X_4 - Carb. cem. %	1	12.264	12.264	6.23*
Total due to regression	4	44.843	11.211	5.70**
About regression	22	43.267	1.967	
Total	26	88.110		

** Significant at the 1% level of probability

* Significant at the 5% level of probability

$F_{.99}(4, 22) = 4.31$

The equation for the regression is:

$$Y = 4.96 + 2.93(\bar{\phi}) - 0.08(\bar{p}) - 0.10(\text{Quartz }\%) - 0.08\ (\text{Carb. cem. }\%)$$

Each pair of compositional and textural variables is negatively correlated and so composition and texture produce one effect each. This is the reason why roundness shows a low contribution to the sums of squares. Reversing the position of the variables that compose each pair does not alter the regression coefficients or the total sums of squares contributed by each pair but only the individual contribution. The first textural variable used in the regression is significant at the 1% level in each case but the other textural variable is not significant at the 5% level. With carbonate cement % before quartz % in the regression, quartz is highly significant but carbonate cement is not significant.

The result of the multivariate analysis implies a decrease in quartz size downcurrent as would be expected with decrease in turbulence in this direction. The quartz is fine sand in size and the finer grains tend to be more angular than the larger grains, so that roundness decreases downcurrent and texture produces a single effect in the regression. The effect of roundness on the regression is not significant once grain size has been taken into account. This may be interpreted as showing that, for grains of equal size, there is no detectable change in roundness in the downcurrent direction.

Quartz abundance decreases downcurrent as it was expected to since terrigenous supply diminishes with distance from the source; the remainder of the sediment is essentially composed of carbonate so that composition also displays a single effect in the regression. Furthermore, texture and composition are correlated, because over a given distance where textural changes will be detectable, compositional changes will be apparent too.

Nevertheless, it may be inferred from the multiple regression that even for rocks of equal grain size, the percentage of quartz decreases in the downcurrent direction. If both quartz content and grain size are held constant, the amount of carbonate cement (as opposed to clastic carbonate) also decreases downcurrent. The change in carbonate cement however, is not detectable unless the effect of variation in quartz content is first removed.

If the petrographic variables in the samples in the thesis area are statistically analyzed separately, the variability of the values for the variables with distance from the "source" is sufficient that a downcurrent trend cannot be conclusively demonstrated. Even for the two most important variables, mean quartz size and quartz content, the correlation with distance is only 0.44 and 0.40, respectively. But when the four important petrographic variables are analyzed collectively, the multiple correlation increases to 0.71, a downcurrent trend can be demonstrated at the 1% level of probability and a trend can be inferred for each of the inter-correlated variables used (except quartz roundness). These results justify the application of multivariate statistics in this study.

The important assumptions made in using the statistical model are:

1. the error is normally distributed;
2. the error variance is homogeneous throughout the area;
3. the measurements were made without error.

The first assumption is probably valid. Even substantial deviations from normality could, however, probably not completely invalidate the results. The second assumption appears to be valid from inspection of the graphs (Appendix II, G-1-4) which show the important variables plotted against distance from the "source". The third assumption of measurements made without error is invalid as has been pointed out previously in discussing the methods of measurement of the petrographic properties. It is possible to make some other assumption about the error in the variables, and to determine a somewhat different regression on this basis.

The multiple correlation coefficient, R, is equal to 0.71, which is a fairly high value. This suggests that the difference between the simple least squares method and that obtained from some other technique would not be very great. To apply any other technique it would be necessary to make further assumptions, and the computation would be more complex. The usual justification for using only the simple least squares technique is that it is conventional to do so and that there is no guarantee that a more complex technique would give better results.

Table 11 illustrates the approximate lateral variation between upcurrent and downcurrent locations for variables in which trends have been inferred from the multiple regression. Values for six samples collected from the farthest upcurrent locations (two from each level) were grouped together and averaged, and eight samples from the farthest downcurrent locations were treated in the same way.

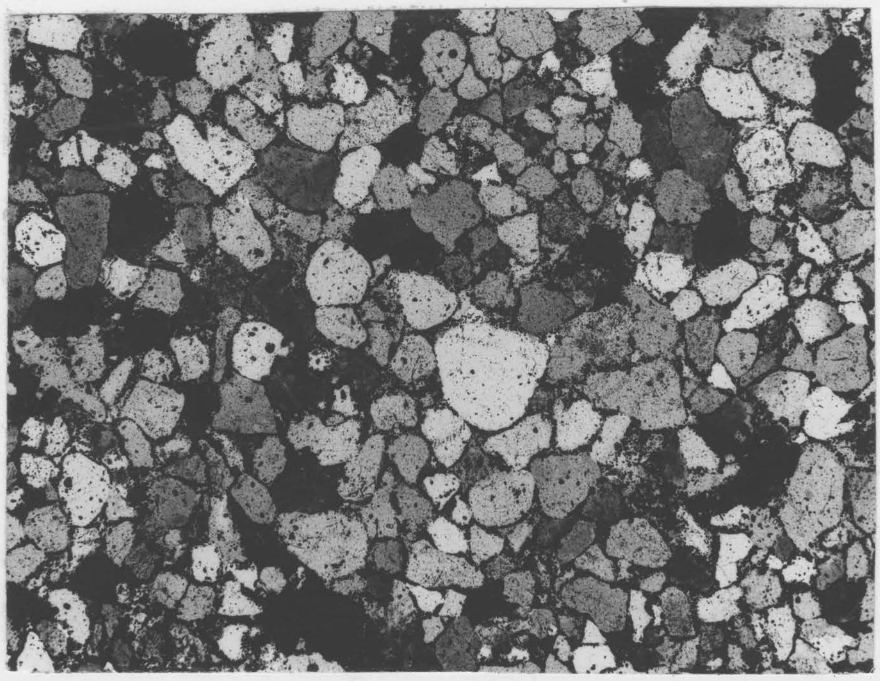
Table 11

Lateral variation in the lower Grey beds

Variable	Downcurrent Locations $\bar{X}$ N = 8	Upcurrent Locations $\bar{X}$ N = 6	Approximate Lateral Variation
Quartz	41%	57%	16%
Carbonate	52%	36%	16%
Chert*	2%	5%	3%
Phosphate*	0.2%	0	0.2%
Quartz size	2.6ϕ	2.1ϕ	0.5ϕ

* Weak trend suggested by the correlation coefficients.

Plate I (1, 2) - Lateral Variation in Size and Roundness



1. Typical upcurrent sample (T.S. No: 23-3C). Polarized light. X42.

2. Typical downcurrent sample (T.S. No: 9-7E). Polarized light. X42.

No trend can be demonstrated for sphericity in the samples investigated from the lower Grey beds. Extreme values of mean sphericity for samples of both quartz and chert were tested by means of a t-test (Appendix II, S-5, 6) but no significant difference between them could be detected. If a trend does exist, a larger number of grains would have to be measured in order to detect such small differences.

2. Vertical Variation in the lower Grey beds

Stratigraphic variation of appropriate petrographic variables was tested by means of an analysis of variance using a two-way crossed design with replication. The samples were grouped into 4 columns and 3 rows: columns represent lateral location and rows represent upper, middle and lower vertical position. Two samples were used per cell so that all but three of the samples collected from the lower Grey beds were utilized.

There is some overlap in grouping the samples with respect to lateral position but this was unavoidable due to the limited number of samples collected; otherwise it would have been necessary to use an analysis of variance model with single observation. The method adopted was considered best because almost all the samples were used. Analyses of variance for several petrographic variables investigated are tabulated in Appendix II, S-8-10.

There is a significant difference in quartz (and carbonate) content at the 5% level of probability between vertical position in samples from the lower Grey beds; but no significant variation could be demonstrated for quartz size or quartz roundness.

Table 12 shows arithmetic mean values for quartz % and carbonate % at each of the three vertical positions. Quartz appears to be more abundant in the middle level; carbonate in the upper level. Means for collophane and silica cement are included in the table.

Table 12

Vertical variation in the lower Grey beds

Level	Number of Samples	Quartz $\bar{X}$%	Carbonate $\bar{X}$%	Phosphate $\bar{X}$%	Silica Cement $\bar{X}$%
Upper	N = 10	40	55	0.26	1.2
Middle	N = 9	69	25	0	2.1
Lower	N = 8	46	47	0.16	0

3. Lateral and Vertical Variation in other parts of the Middle Triassic

Little can be said about the middle and upper Grey beds because sampling has been sparse and values obtained are quite variable. There appears to be a decrease in grain size downcurrent but no trends can be statistically demonstrated.

Again, sampling has been sparse in the Liard and equivalent rocks and so statistical study is not warranted, but clearly there is a difference between Liard and Dark siltstones and Flagstones-type cross-laminated rock.

Arithmetic means of the various petrographic properties have been calculated for the seven Liard samples and for the three most downcurrent samples collected from the Dark siltstones and Upper Flagstones. The results appear in Table 13.

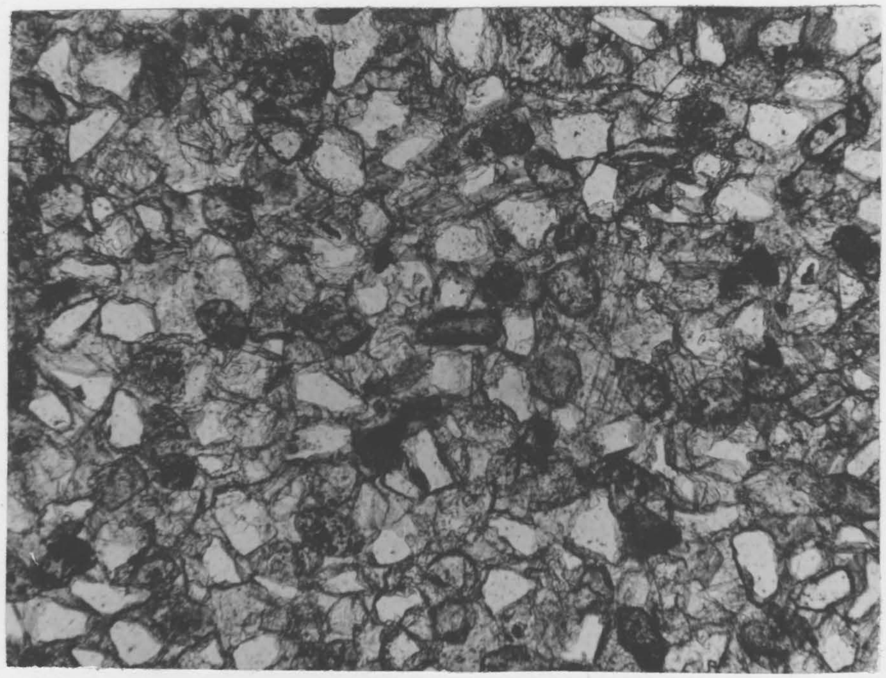
Table 13

Lateral variation in the Liard Formation and equivalent rocks

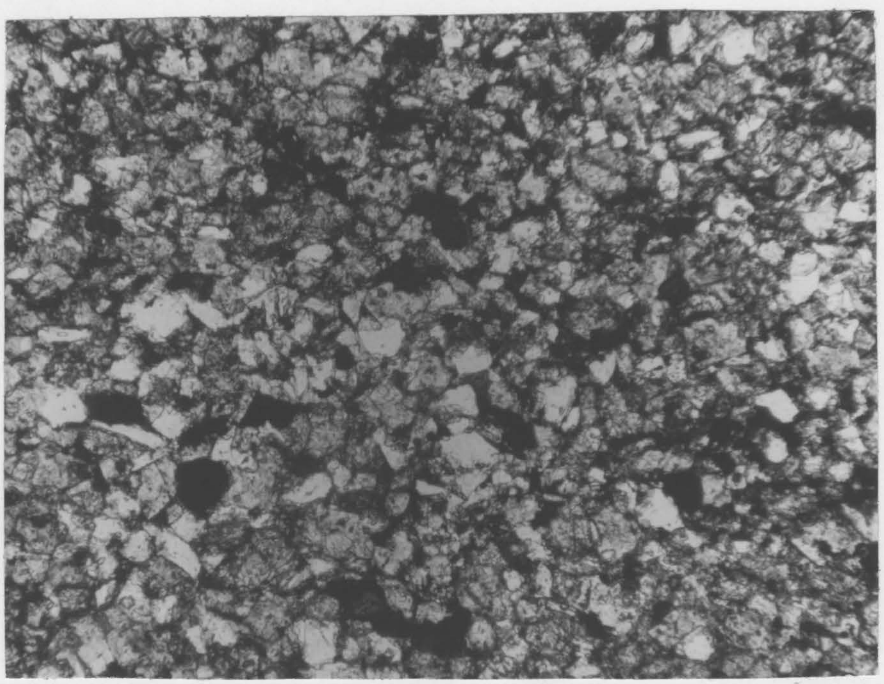
Variable	Dark siltstones and Flagstones $\bar{X}$ N = 6	Liard $\bar{X}$ N = 7
Quartz	18%	45%
Carbonate	74%	50%
Detrital carbonate	47%	4%
Chert	0.5%	2%
Bitumin	3%	1%
Phosphate	1%	0.2%
Quartz size	3.9Ø	2.7Ø

The only notable vertical variation in the variables is in amount of phosphate. The average value based on 5 samples in the Upper Flagstones is 0.4%; in the Dark siltstones, 1%.

Plate II (1, 2) - Examples of Flagstones-type Lithology



1. (T.S. No: 100-3). Note high carbonate pellet content. Plain light. X116.



2. (T.S. No: 5-Iii). Very fine-grained. Opaque material is mainly bitumin. Plain light. X113.

Chapter VI

OTHER ASPECTS OF THE PETROGRAPHY

1. Silica cement

Silica cement is distributed through the quartz-rich middle level in the lower Grey beds and occurs in several samples collected from the upper Grey beds and the Liard formation. It is not important volumetrically, composing only a few percent of the samples except in two instances where it reaches 12-13%.

It appears to have an erratic stratigraphic distribution in the middle Triassic and often an erratic distribution within the sample itself. In most of the samples, even in those with high carbonate content, patches can be found where quartz grains are cemented by silica.

Silica cement is present as secondary enlargements on quartz grains, deposited in optical continuity with the original grain. It usually fills the pore space between the detrital grains but rarely it does not and a euhedral crystal form is developed. Commonly a thin rim of micro-crystalline carbonate is trapped between the detrital core and the authigenic overgrowth, but in rocks with high secondary silica content these rims are not observed.

2. Carbonate cement

Calcite cement is distributed in cross-laminated rock throughout the middle Triassic and tends to become the major constituent of the sample at downcurrent localities in the thesis area.

At upcurrent locations where calcite cement is not so important volumetrically, calcite cement occurs as large crystals enclosing a few quartz grains. Commonly euhedral calcite overgrowths extend out from carbonate grains which usually are fragments of organic material. Large crystals which enclose several quartz grains have formed where several grains occur close together and the overgrowths have joined to form a single crystal.

Calcite cement at downcurrent locations may occur as an extensive intergranular system with floating quartz grains evenly distributed throughout the thin-section. Packing density which measures the aggregate property of the rock is lower for these samples than those in which calcite cement is a less important constituent.

Cementing calcite which includes floating quartz grains ranges from finely granular or micro-crystalline to a mosaic of subhedral grains with well-developed rhombohedral cleavage and fair twinning. Subhedral calcite is generally found in larger intergranular pores where it has developed without interfering with adjacent quartz grains. Occasionally major fossil features are outlined by impurities within the cement.

The formation of this second type of calcite cement with floating quartz grains is believed to be an extension of the first process described for large calcite crystals which enclose several quartz grains, only in the latter case, more carbonate grains were originally present in the sediment. Calcite overgrowths extended out from the carbonate detritus, joined with other calcite enlargements and formed an extensive intergranular network which volumetrically may compose the main part of the rock.

Occasionally, calcite cement is partly or entirely replaced by micro-crystalline dolomite rhombs but not to an important extent: only nine of the samples collected are dolomitized.

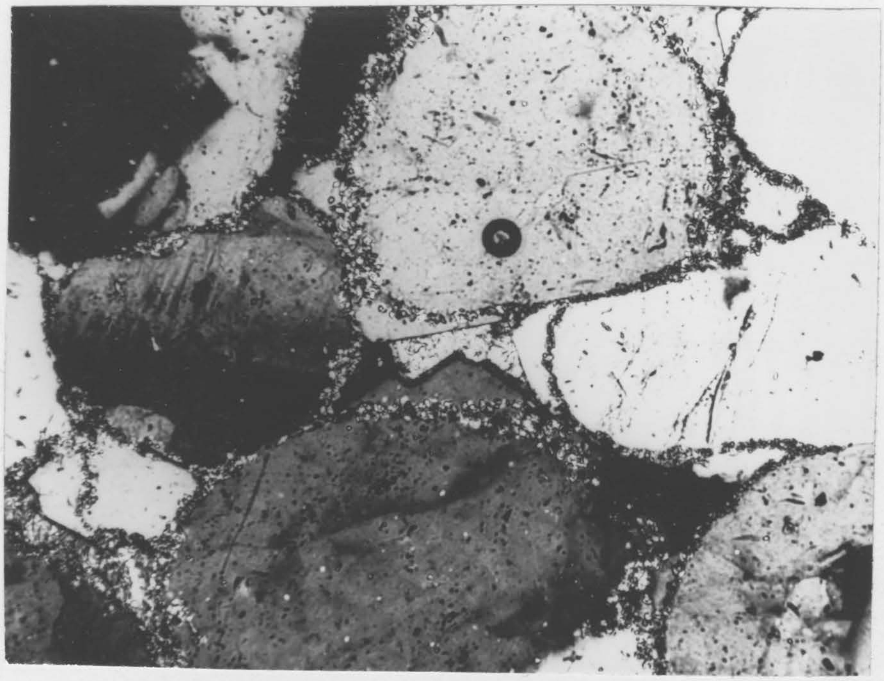
3. Age Relationships between the cements

There is conflicting evidence as to the age relationships between the cements. Some evidence suggests that calcite cement is pre-secondary silica and other evidence suggests that calcite cement is post secondary silica.

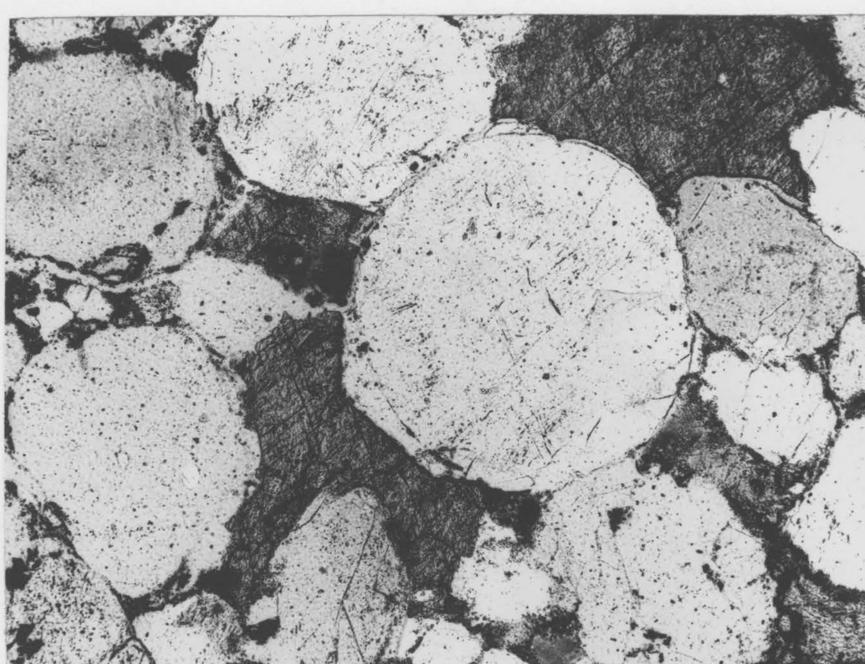
Early calcite cementation is indicated by the occurrence of a thin rim of micro-crystalline carbonate between the secondary silica enlargement and the detrital quartz core in silica cemented rocks but carbonate rims are not always present, notably in samples with high silica content. In some rocks, calcite may surround the quartz grains while in the same sample other grains may show silica overgrowths with included micro-crystalline rims, again suggesting early calcite cementation. It is possible that some calcite may be post secondary silica if carbonate ions in the interstitial solution in small areas near carbonate grains prevented the silica from depositing on the quartz grains and calcite was later precipitated in its place.

Occasionally, euhedral quartz enlargements may be observed against calcite (and may be partly replaced by calcite) and rarely, calcite cement may be found as a pore-filling against euhedral quartz enlargements, thus suggesting post secondary silica cement. Where calcite surrounds quartz grains with no silica overgrowths, it is possible that calcite has entirely replaced secondary silica.

Plate III (1, 2) - Age Relationships between Cementing Material



1. Calcite pore-filling (centre of photograph) against euhedral secondary silica. Micro-crystalline carbonate between overgrowths and detrital quartz cores. (T.S. No: 30-4). Plain light. X134.



2. Euhedral quartz overgrowth (partly replaced) against calcite. There is no carbonate between the overgrowth and the detrital quartz core. (T.S. No: 30-4). Plain light. X87.

Such conflicting evidence in the Triassic samples can be interpreted in terms of the following cycle:- (1) early calcite cementation, (2) deposition of secondary silica, (3) deposition of calcite, (4) dolomitization. The first three are dependent on the physical conditions at the time of cementation and may be interchanged from place to place in the middle Triassic sand facies.

4. Phosphate

Apatite is the mineral incorporating phosphate in the samples collected. The vertical and lateral distribution of phosphate in the thesis area is shown in Figure 8 (Appendix I).

A small amount of apatite is in the form of recognizable internal casts of small pelecypods and brachiopods in which apatite has cemented the internal quartz or carbonate silt to form a cast of the interior of the fossil. The carbonate shell casing may or may not surround the internal phosphatic material; in one example the shell has also been replaced by apatite.

Some of the apatite is in the form of tiny ovoid 0.1 mm long pellets, many of which show a quartz or carbonate silt core; these are believed to be the end-product of abrasion of internal casts. Intermediate between these two end-members are variable-sized but usually quite small well-rounded apatite grains with included quartz silt. It is possible that some of the 0.1 mm apatite pellets without quartz cores may have a faecal origin because of the general correspondence in shape and size to carbonate pellets, which may be faecal.

The remainder of the apatite is in the form of pieces of thin delicate fossil shell. The largest piece observed was about ½mm in length; the smaller fragments are believed to be the product of abrasion and are small flakes or prismatic shards of variable size. As indicated by their peculiar texture, rare shards may be bone splinters, but by far the majority of shards appear to have been derived from phosphatic shell.

Thus there are two important types of phosphorite in the middle Triassic cross-bed samples: (1) pelleted phosphorite derived from internal casts of small fossils; and (2) bioclastic phosphorite.

Shards of the second type occur throughout the middle Triassic. They are the most common phosphatic constituent of the lower Grey beds; and some of the finer flakes intermixed with bitumin occur in the Dark siltstones and Flagstones.

Clearly-distinguishable apatite casts are limited to samples with high recognizable bioclastic content in the middle Triassic; variable-sized apatite grains are sparse in the Grey beds and not observed in the very fine sediment. Tiny pellets intermixed with carbonate pellets occur in the Dark siltstones and Flagstones; they are quite abundant in two middle Triassic samples (one in the Dark siltstones and the other in the middle Grey beds; both at downcurrent locations).

There are two possible origins for the apatite in these rocks: (1) the material is terrigenous having been derived from a northeasterly source; and (2) it is allochemical, formed somewhere in the basin of deposition.

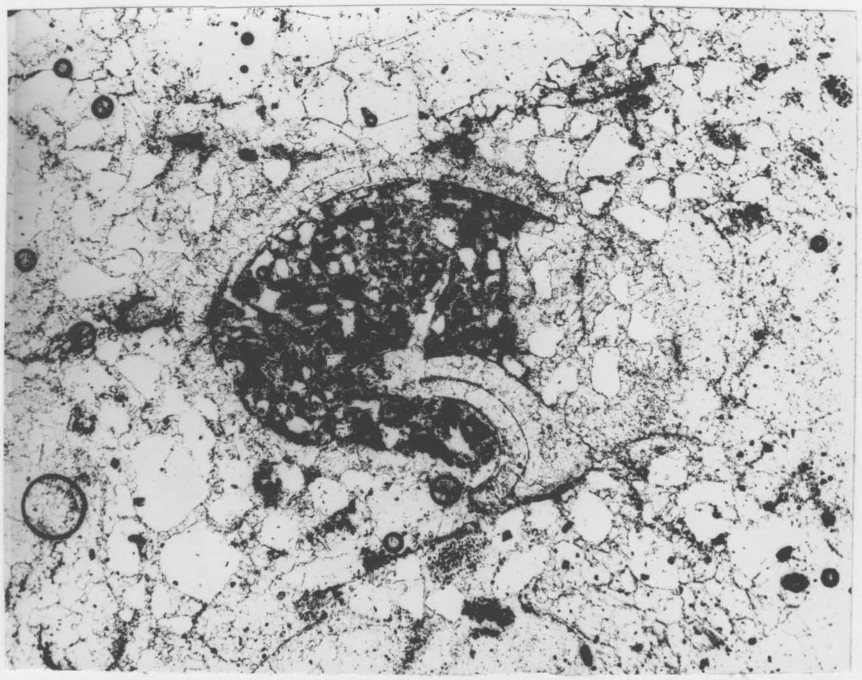
A close relationship between phosphate and carbonate content in the samples is evident from the nature of the phosphatic material itself and from the correlation between carbonate and phosphate content, so that it is improbable that the material was derived from a terrigenous source. If the material were terrigenous, there is no reason why phosphate should not occur in the high-quartz middle level of the lower Grey beds (which probably is a near-shore zone).

The apatite must therefore have precipitated in the basin of deposition. Some of the phosphatic material has not moved very far from the place of precipitation because occasional clearly-recognizable casts have been found. Most of the apatite, however, was transported and abraded to smaller size. Perhaps the lack of apatite grains in the size range between recognizable fossil casts and small pellets is due to the unstable nature of the larger grains, which on transportation tend to be easily abraded to smaller size. Resultant fine material has been carried into deeper water and deposited with fine sediment so that samples collected from, say, the Dark siltstones tend to show higher phosphate content than samples collected from the lower Grey beds.

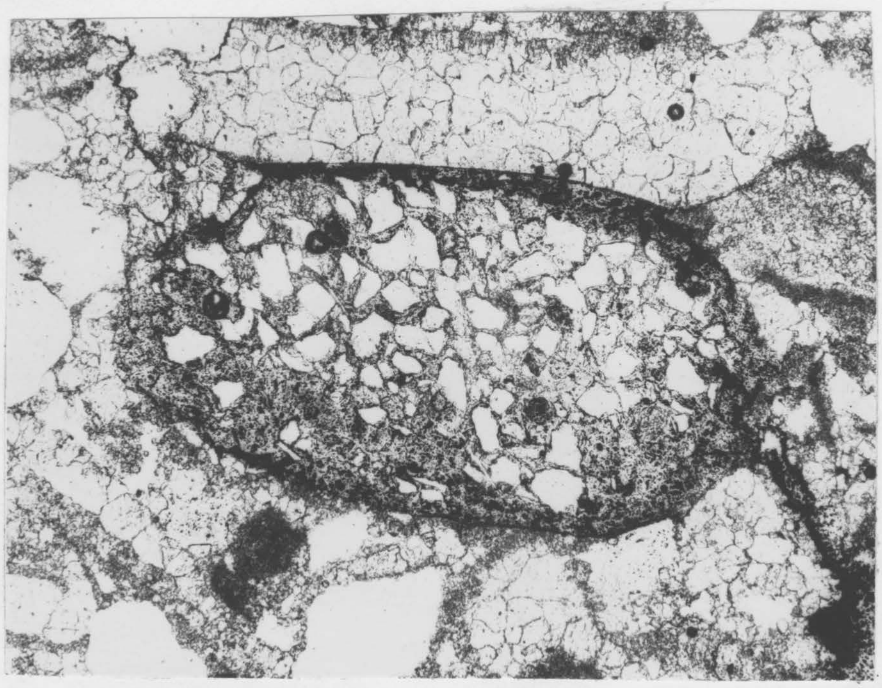
It appears from the preceding discussion that phosphate has been precipitated organically in banks composed predominantly of shells of organisms that prefer a firm substratum. This bioclastic material together with internal apatite casts, shell and perhaps some bone material were broken up by the currents and scavengers, sorted, transported seaward and distributed throughout the sand.

Triassic phosphorites were formed in shallow water similar to the Meade Peak (Honkala, 1953 and McKelvey and others, 1959) and the Mexican phosphorites (Rogers and others, 1956). Probably, as McKelvey postulated for the Meade Peak, Triassic sediments were deposited on a gently shoaling bottom that received cold phosphate-rich waters from the open sea.

Plate IV (1-5) <u>Sequence in the derivation of some of the Pelletal Phosphorite</u>

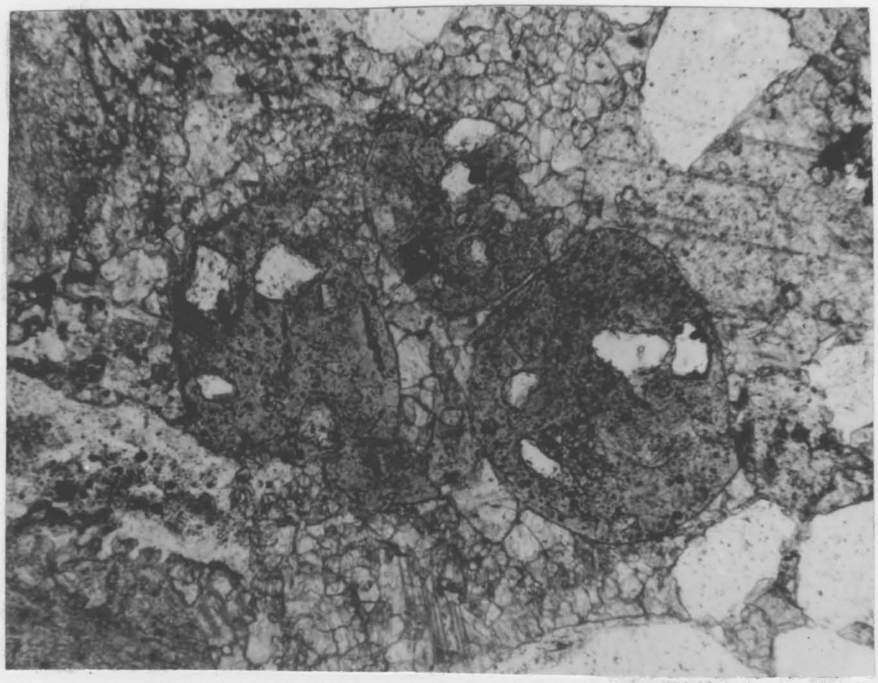


1. Internal apatite fossil cast with external carbonate shell.
(T.S. No: 103-8). Plain light. X44.

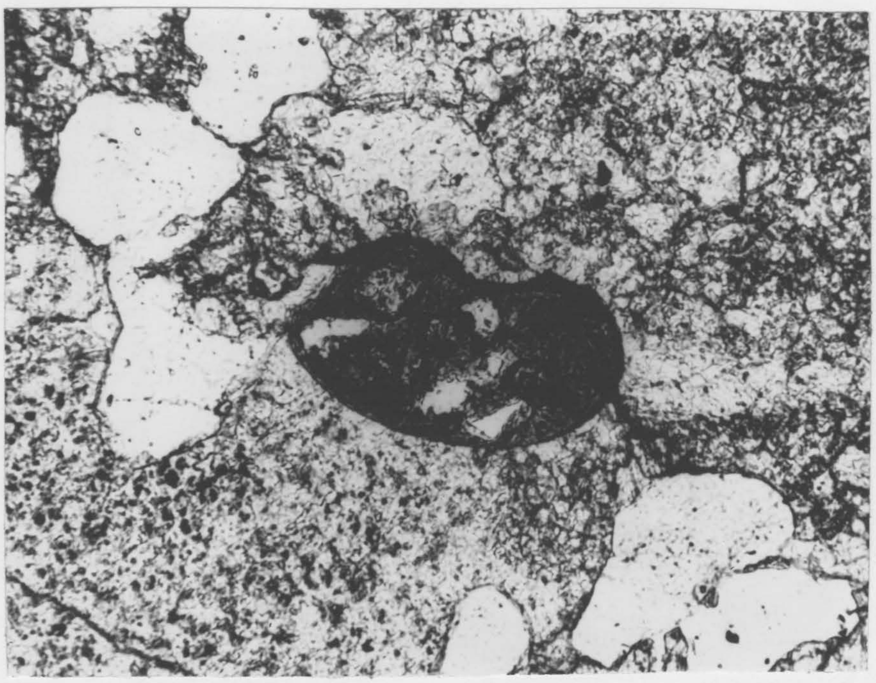


2. Internal apatite cast without carbonate shell. (T.S. No: 6-3Bi).
Plain light. X68.

Plate IV (cont'd)

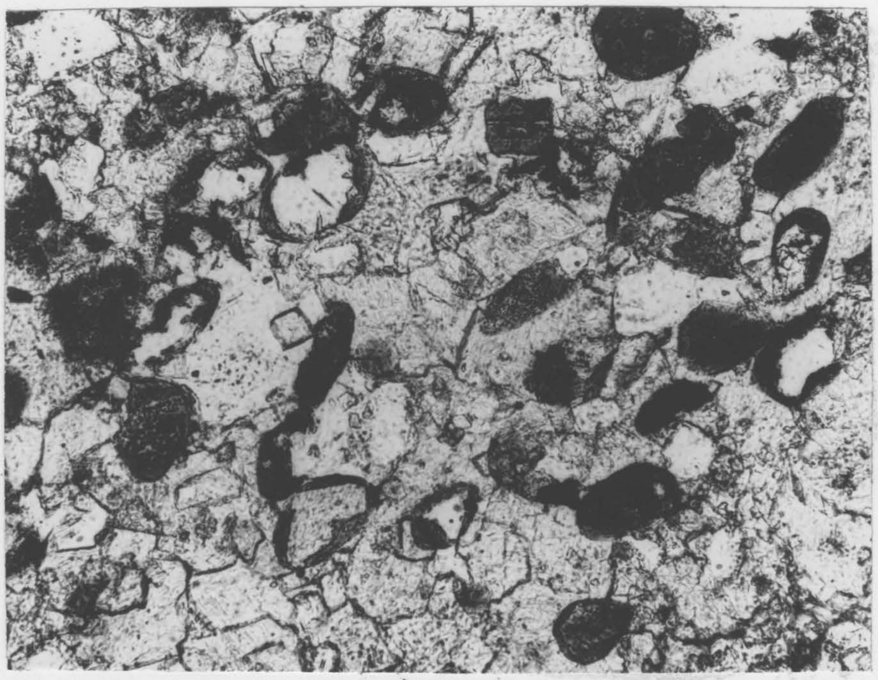


3. Pellets with included quartz silt. (T.S. No: 11-1A). Plain light. X137.



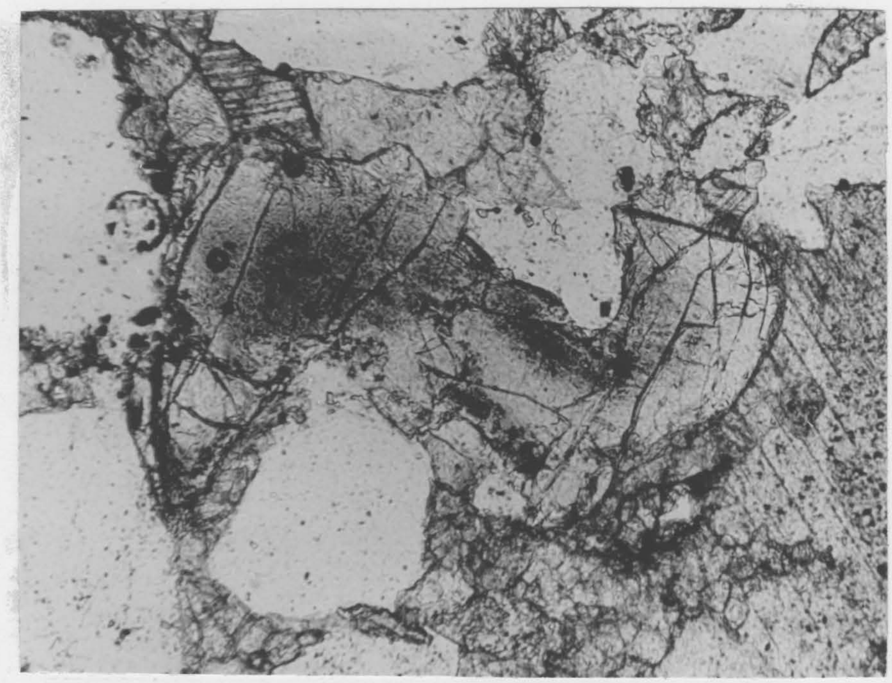
4. Pellet with included quartz silt. (T.S. No: 11-1A). Plain light. X160.

Plate IV (cont'd)

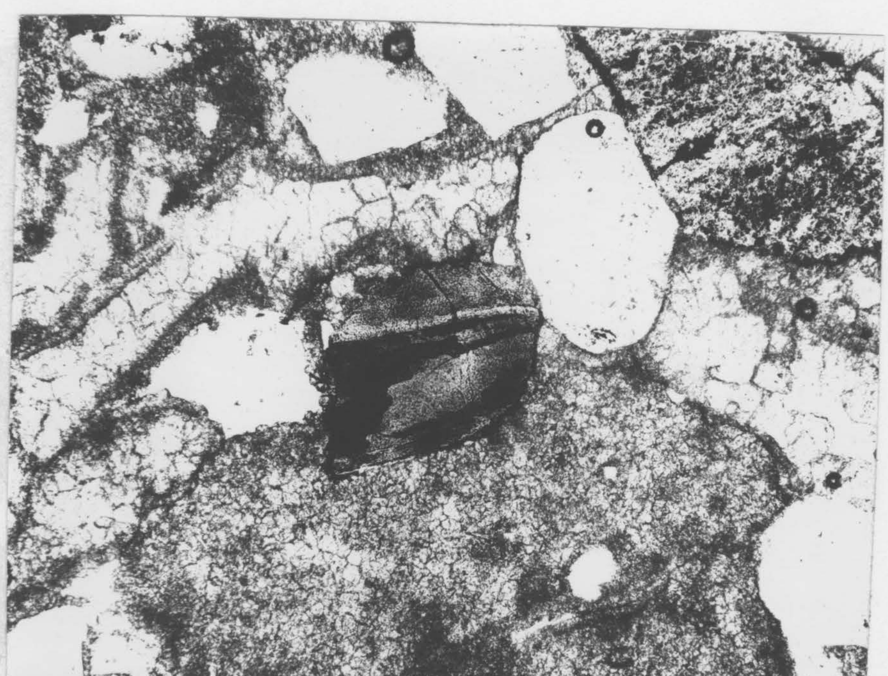


5. Pellets with detrital quartz cores. (T.S. No: 9-5C). Plain light. X220.

Plate V (1-5) - Examples of Bioclastic Phosphorite

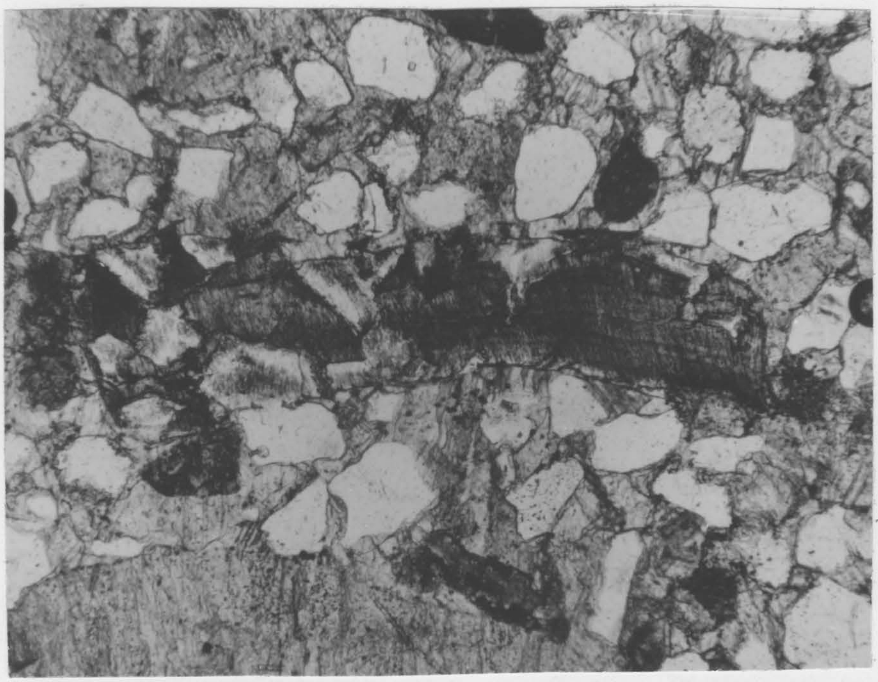


1. Phosphatic shell fragment. (T.S. No: 4-4B). Plain light. X130.

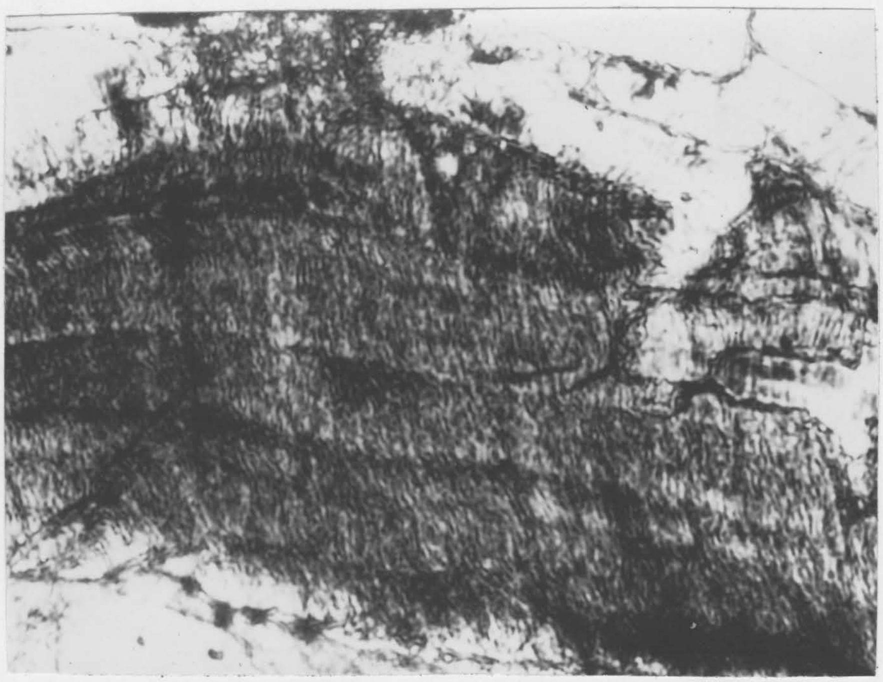


2. Collophane shard. (T.S. No: 6-3Bi). Plain light. X90.

Plate V (cont'd)

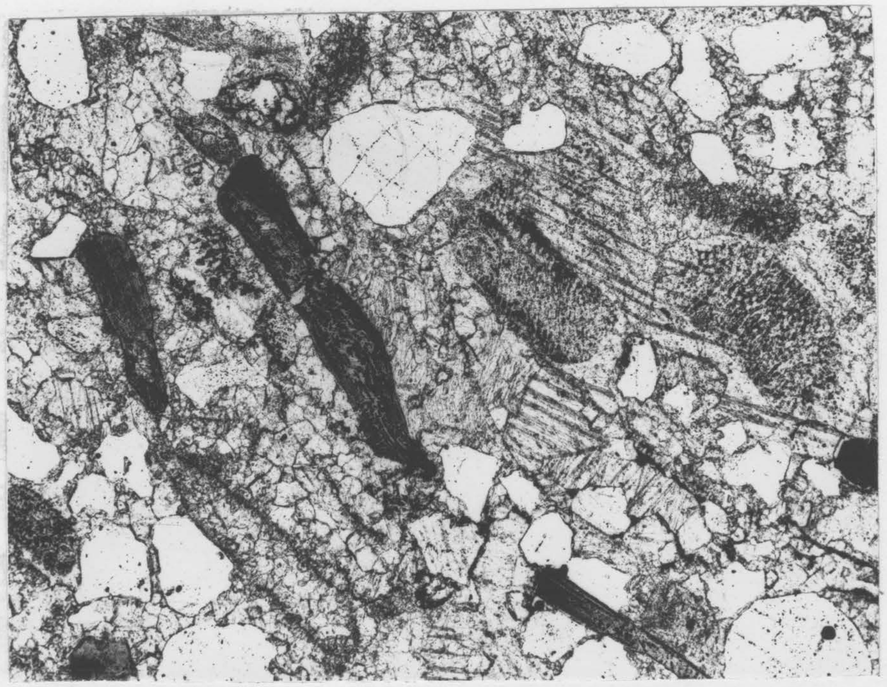


3. Phosphatic shell fragment. (T.S. No: 30-10). Plain light. X110.



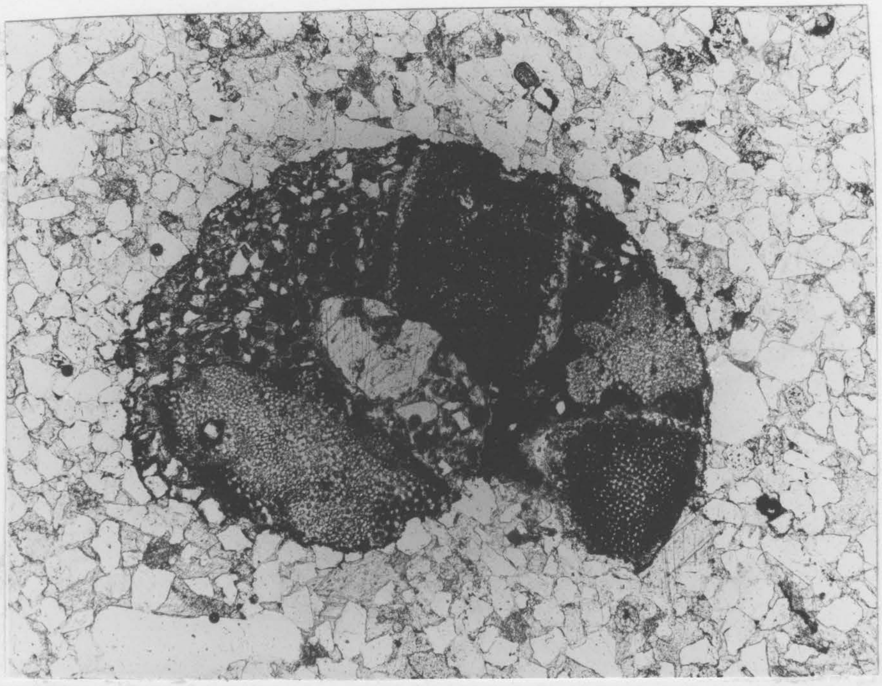
4. Close-up of shell fragment in T.S. No: 30-10. Plain light. X440.

Plate V (cont'd)

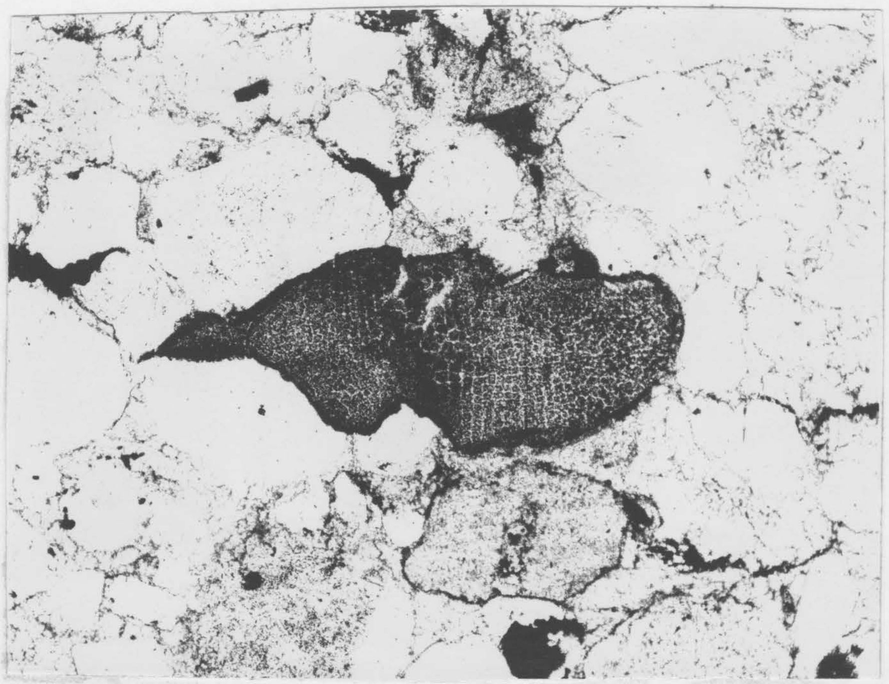


5. Prismatic collophane shard (possibly a bone splinter). (T.S. No: 11-1A). Plain light. X50.

Plate VI (1, 2) - Origin of Phosphatic organic fragments



1. Apatite replaced fossil. (T.S. No: 30-10). Plain light. X50.



2. Phosphatic organic fragment. (T.S. No: 9-3A). Plain light. X80.

5. Classification of Cross-laminated Rock-types

Cross-laminated rocks in the sand facies which is typically developed in the Grey beds and Liard formation are classified texturally as fine sandstone with rare medium sand development; those in the Flagstones and Dark siltstones where the sand development is weaker are classified as very fine sandstone or possibly coarse siltstone in some cases.

The mineralogy of the samples collected from the middle Triassic is quite simple. The modal analyses are separated into terrigenous, allochemical and orthochemical end-members: quartz and chert, carbonate, silica cement respectively, recalculated to 100% and plotted on the ternary diagram.

Representative samples were treated in this manner, Figure 6. The scatter of sample points show that the composition of cross-laminated rocks in the middle Triassic is gradational between two end-members, orthoquartzite and quartzose limestone.

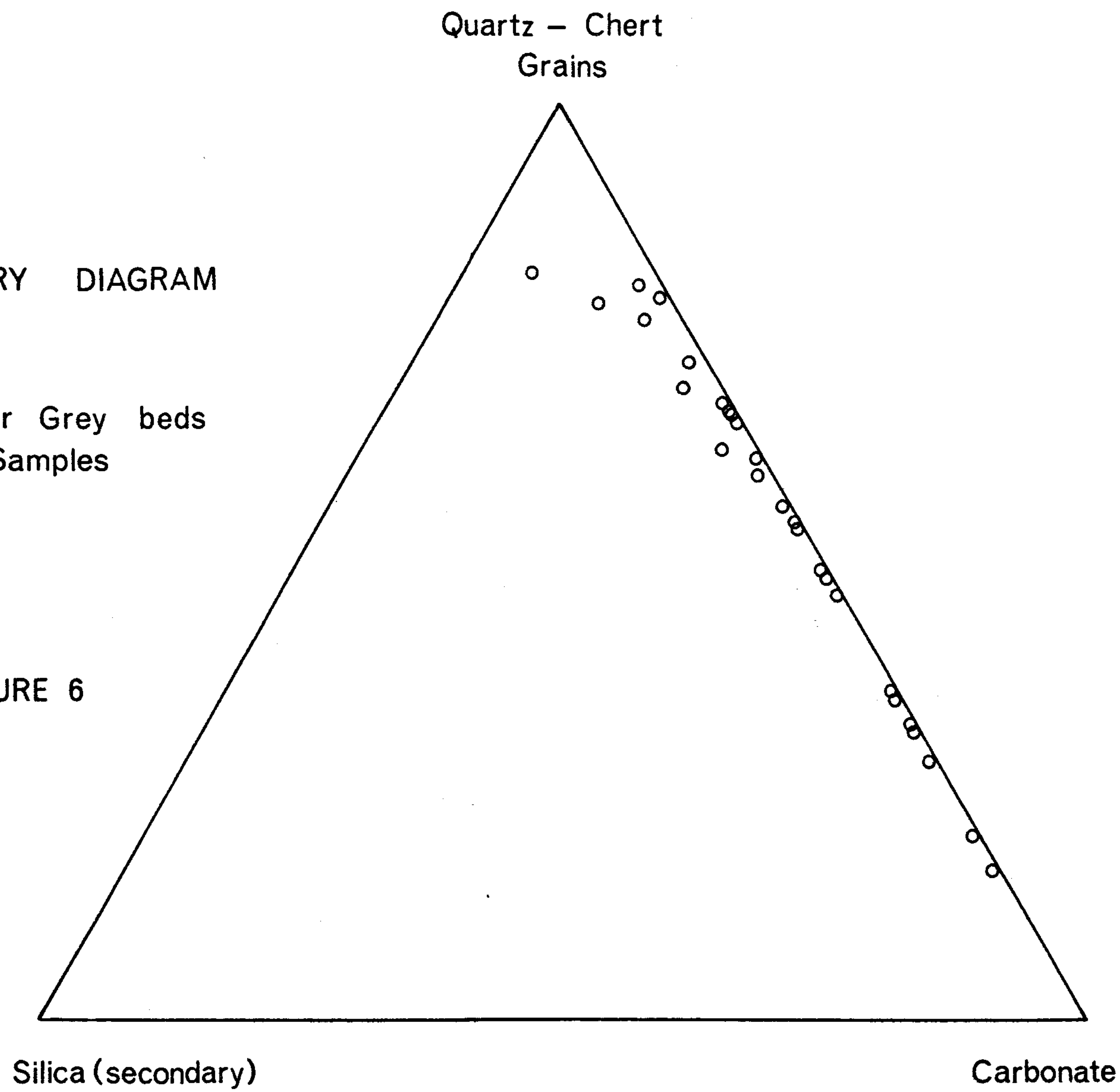
Samples from the lower Grey beds show this gradation well and are here classified on the basis of mineralogy and texture as fine calcareous orthoquartzite, predominant in upcurrent locations and fine quartzose limestone (recrystallized) or quartzose calcarenite, predominant at downcurrent locations.

Samples of cross-laminated rock in the Flagstones and Dark siltstones are classified as very fine quartzose calcarenite or coarse quartzose calcsiltite.

TERNARY DIAGRAM

o Lower Grey beds Samples

FIGURE 6



6. Source Area

The immediate source area is an area of older sediments as shown by:

1. A stable mineral assemblage.
2. Abraded secondary enlargement on the rare quartz grain.
3. Fair rounding of the larger quartz grains.
4. Presence of chert and quartzite.
5. The high roundness of the tourmaline grains.

Originally the material may have been derived from a granitic terrain as is indicated by the clear, relatively inclusion-free spherical quartz and the sphericity studies, but feldspar content is too low for a direct derivation from igneous rocks. There are no minerals present which suggest a basic igneous or metamorphic source.

The fact that quartz grains do not show abraded secondary enlargement does not preclude the possibility of an earlier sedimentary cycle. Cementation in the earlier cycle may have been by carbonate, or the last cycle of transportation may have abraded away all traces of earlier silica cement.

The mineral suite is entirely composed of stable minerals. The unstable varieties have been lost during the earlier cycles of erosion or by earlier periods of intrastratal solution.

Except for the larger grains, rounding is not particularly high. This is due to the fine size of most of the grains. The finer sizes tend to be more angular than the larger sizes (with equal distance of transport) because the finer grains are more difficult to round. More than one cycle of erosion would probably be required to obtain the degree of rounding exhibited by the larger grains.

Quartzite is strictly a minor constituent but chert locally becomes important with values greater than the typical 1-4% expected from reworking an older chert-bearing sandstone. This is suggestive of a nearby source with perhaps limited supplies of chert (e.g. a thin chert-bearing limestone formation).

Calcareous sandstones, quartzites, cherty sandstones, chert beds and cherty limestones have been reported in the Permian, Pennsylvanian and Mississippian system, and probably rocks from these systems to the northeast and east furnished middle Triassic terrigenous detritus.

SUMMARY AND CONCLUSIONS

Cross-beds are common in middle Triassic sandstones that crop out in the thesis area. The best development observed was in the lower part of the Grey beds and in the Liard Formation.

A trend significant at the 1% level of probability can be demonstrated in the southwesterly direction by means of a multiple regression using quartz and carbonate abundance, quartz grain size and roundness values obtained from 27 samples collected in the direction of transport from the lower part of the Grey beds. The first three were found to be significant in the regression thus demonstrating a trend in each of these three variables in the downcurrent direction. The results of the multivariate analysis support Pelletier's paleocurrent study.

Quartz abundance decreases downcurrent and carbonate cement content varies antipathetically. Investigation of the cementing material showed that most of the carbonate originally was allochemical detritus as is evident from the evenly distributed floating quartz grains in thin-section, and relict organic outlines in the cement. Apatite was also found to be allochemical from its association with fossil material and so phosphate content varies sympathetically with carbonate cement. No downcurrent trend can be demonstrated for phosphate by the multiple regression but phosphate and carbonate cement content are correlated and so a weak trend is inferred in phosphate content.

The less carbonate cement present in the rock the more quartz grains there are and the grains tend to be better sorted and silica cemented. Thisis suggestive of a nearshore more turbulent zone in which the sediment had been better worked and less organic detritus was present.

Quartz grain size decreases downcurrent and roundness varies antipathetically because smaller grains are more difficult to round. Chert abundance is positively correlated with quartz grain size and so a weak trend in chert abundance downcurrent has been inferred.

No lateral trend could be demonstrated (or inferred) for: silica cement %, others %, quartz standard deviation or sphericity in the lower Grey beds.

Table 14 shows approximate values of the variables in which trends have been inferred in the lower Grey beds at upcurrent and downcurrent locations in the thesis area. Corresponding values for these variables in the Liard and equivalent rocks are also shown but no lateral trends can be statistically demonstrated.

Compositional and textural features indicate that the source area for cross-bedded sediments in the middle Triassic was an area of older sedimentary rock located to the northeast of the thesis area. Sediment composed of stable minerals was transported over a low broad stable shelf and deposited in shallow water on a well-aerated bottom with active currents.

As the current was strong, the fines were washed away and the remaining fairly-well sorted sediment was deposited down the front of an advancing series of cross-beds. Currents probably were not steady but fluctuated considerably as is evident from the lateral variation in scale of cross-bedding at a sample locality. A general decrease in quartz size and thickness of cross-beds (Appendix II, G-5) indicates a decrease in current strength in the direction of transport.

Pelecypods and brachiopods grew on a well-aerated bottom in quieter water offshore. Moderate wave and current action and scavengers of various types broke most of the shells and associated phosphatic material and the debris was spread evenly over the bottom and intermixed with the sand. Progressing seaward, shell detritus gradually replaced the inorganic material.

In deeper water the sediment is largely composed of tiny ovoid pellets which may have a faecal origin. More probably, the pellets are composed of highly abraded organic material which has been sorted out by the current and carried seaward until current strength diminished. Fine bitumin and apatite were carried along and deposited with this material.

Table 14

Summary of Lateral Variation in the Middle Triassic

	Dark Siltstones Flagstones $\bar{X}$ N = 6	Liard $\bar{X}$ N = 7	Lower Grey beds Downcurrent* $\bar{X}$ N = 8	Lower Grey beds Upcurrent $\bar{X}$ N = 6
Quartz	18%	45%	41%	57%
Carbonate	74%	50%	52%	36%
Detrital Carb.	47%	4%		
Chert	0.5%	2%	2%	4%
Phosphate	1%	0.2%	0.2%	0
Bitumin	3%	1%		
Quartz size	3.9Ø	2.7Ø	2.6Ø	2.1Ø

* About 40-50 miles separate upcurrent and downcurrent locations.

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Appendix I

Summary Diagrams

1. Quartz %
2. Carbonate cement %
3. Detrital carbonate %
4. Chert %
5. Silica cement %
6. Others %
7. Quartzite %
8. Phosphate %
9. Feldspar %
10. Dolomite
11. Mica
12. Quartzite - Mean size
13. Chert - Mean size
14. Quartz - Mean size

14A. Quartz - Standard deviation

15. Bioclastic carbonate - Mean size
16. Collophane - Mean size
17. Feldspar - Mean size
18. Tourmaline - Mean size
19. Bioclastic carbonate and chert - Maximum size
20. Quartz - Mean sphericity
21. Chert - Mean sphericity

Appendix I (cont'd)

22. Chert - Mean roundness

23. Quartz - Mean roundness

24. Packing density

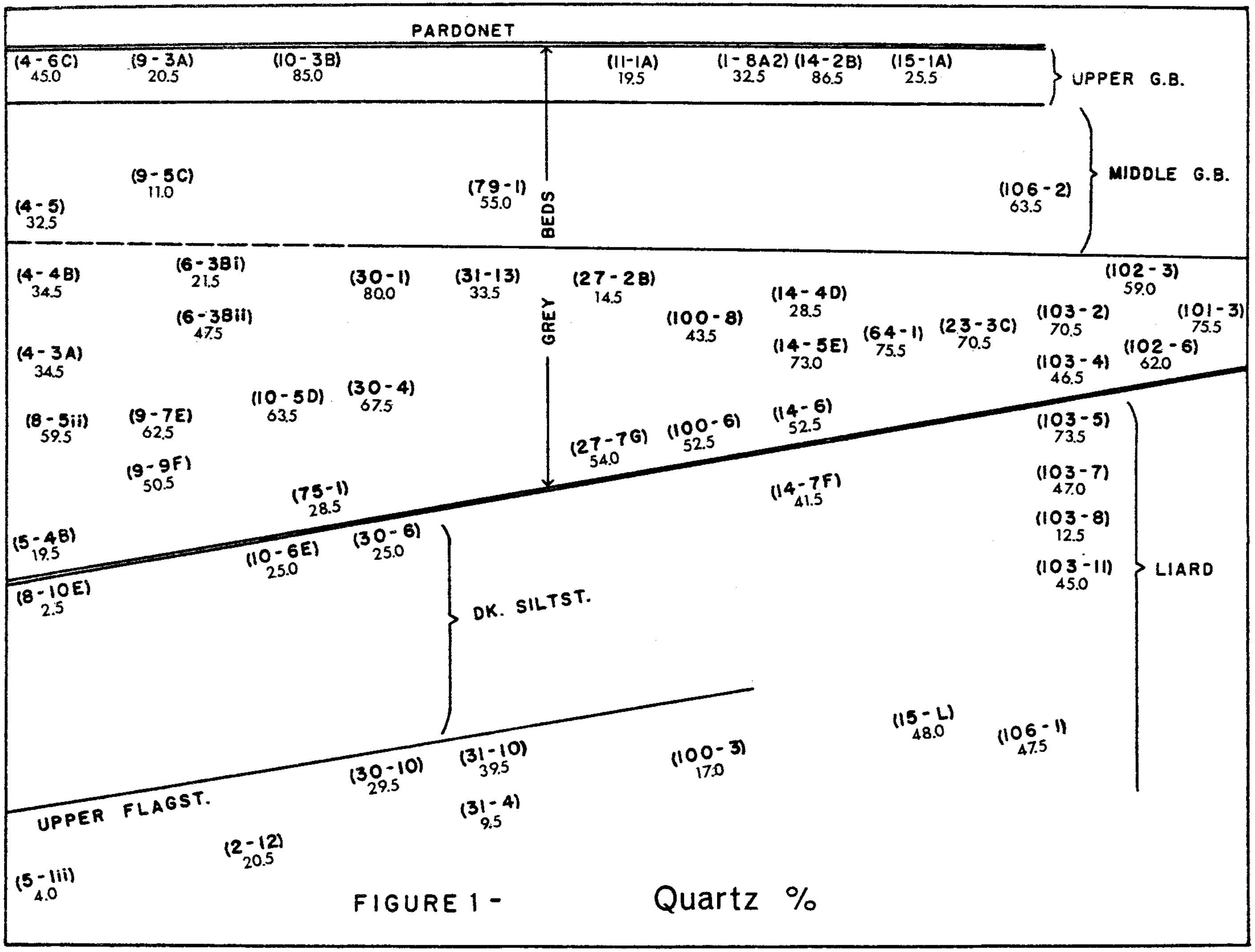


FIGURE 1 - Quartz %

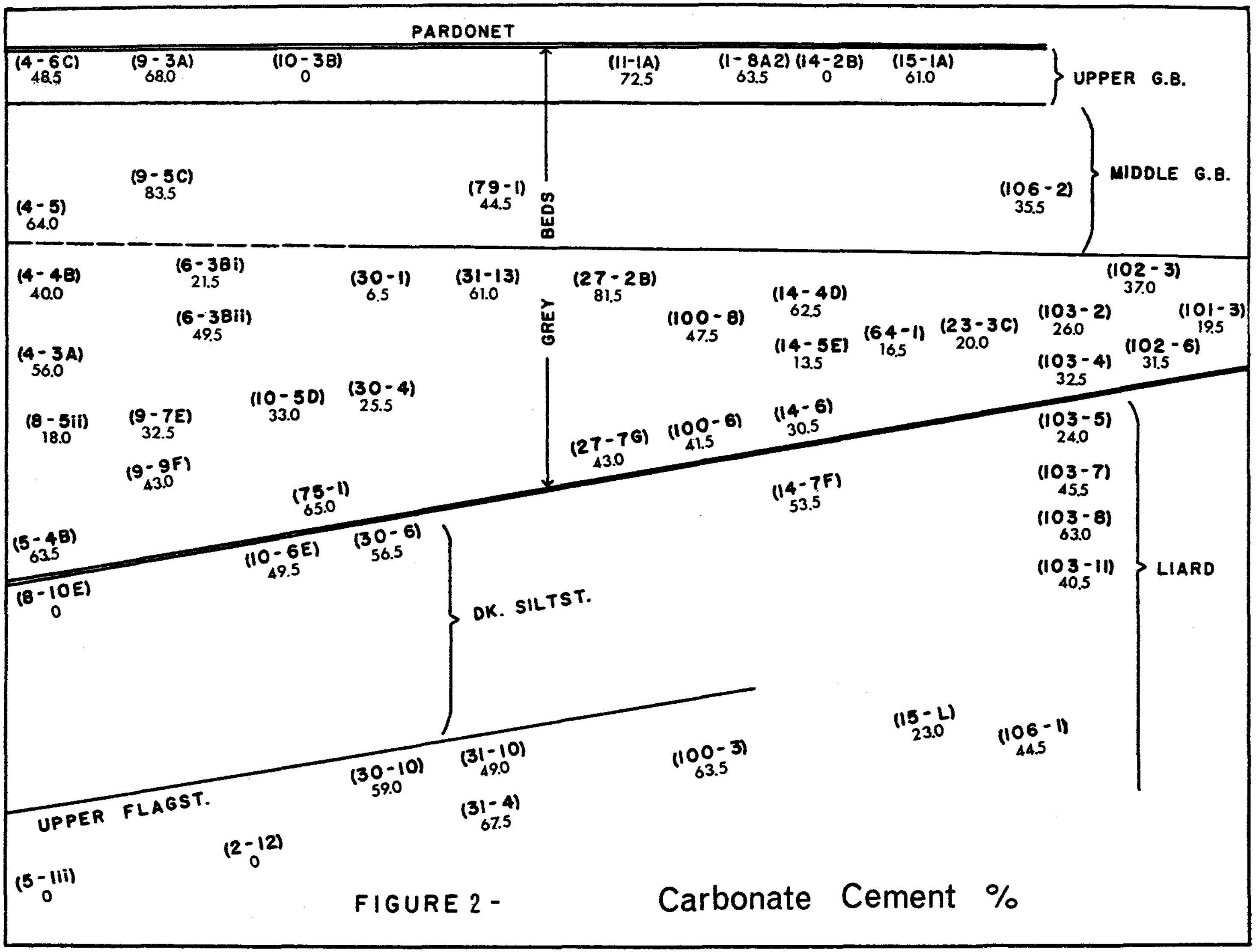


FIGURE 2 - Carbonate Cement %

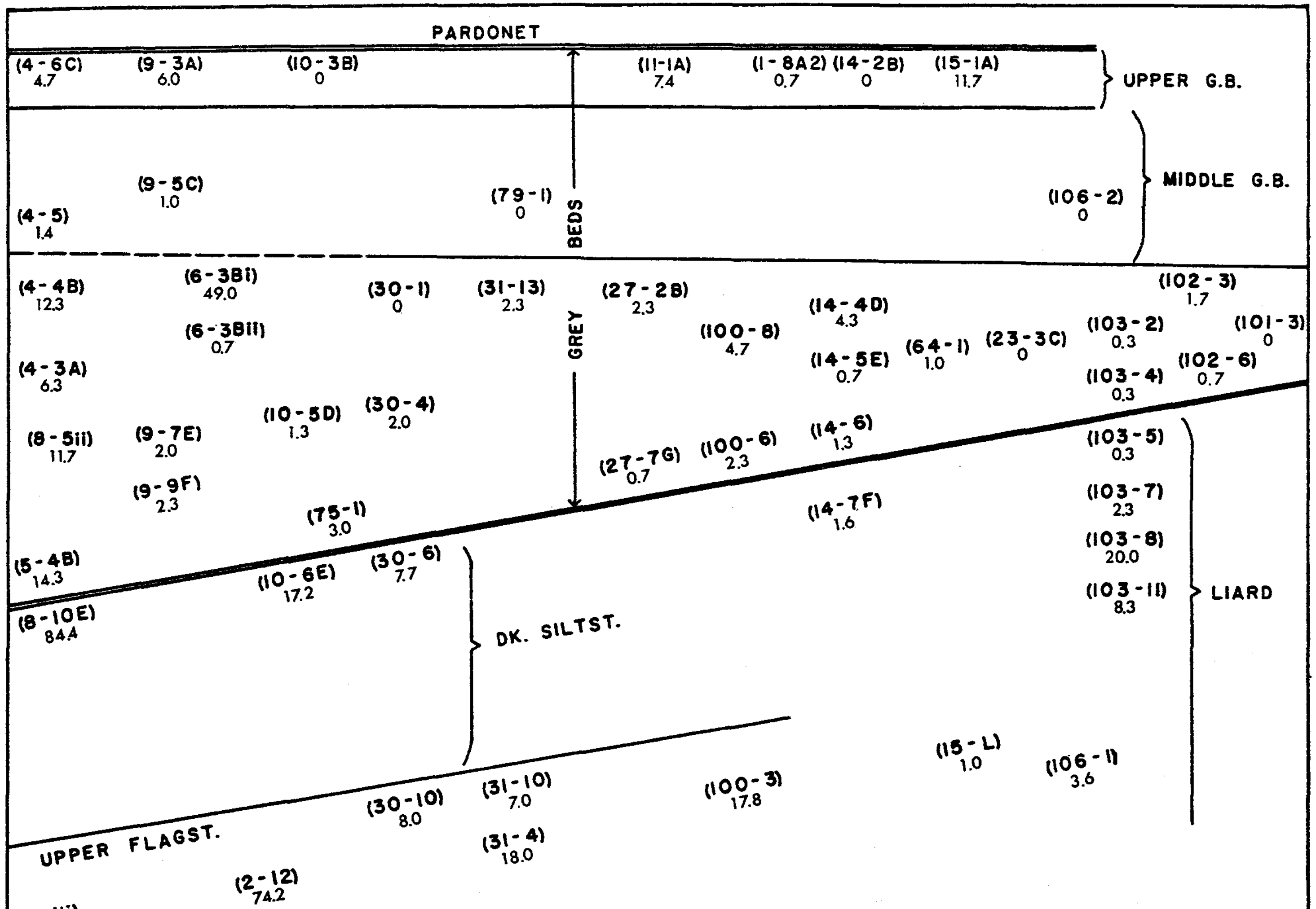


FIGURE 3 - Detrital Carbonate %

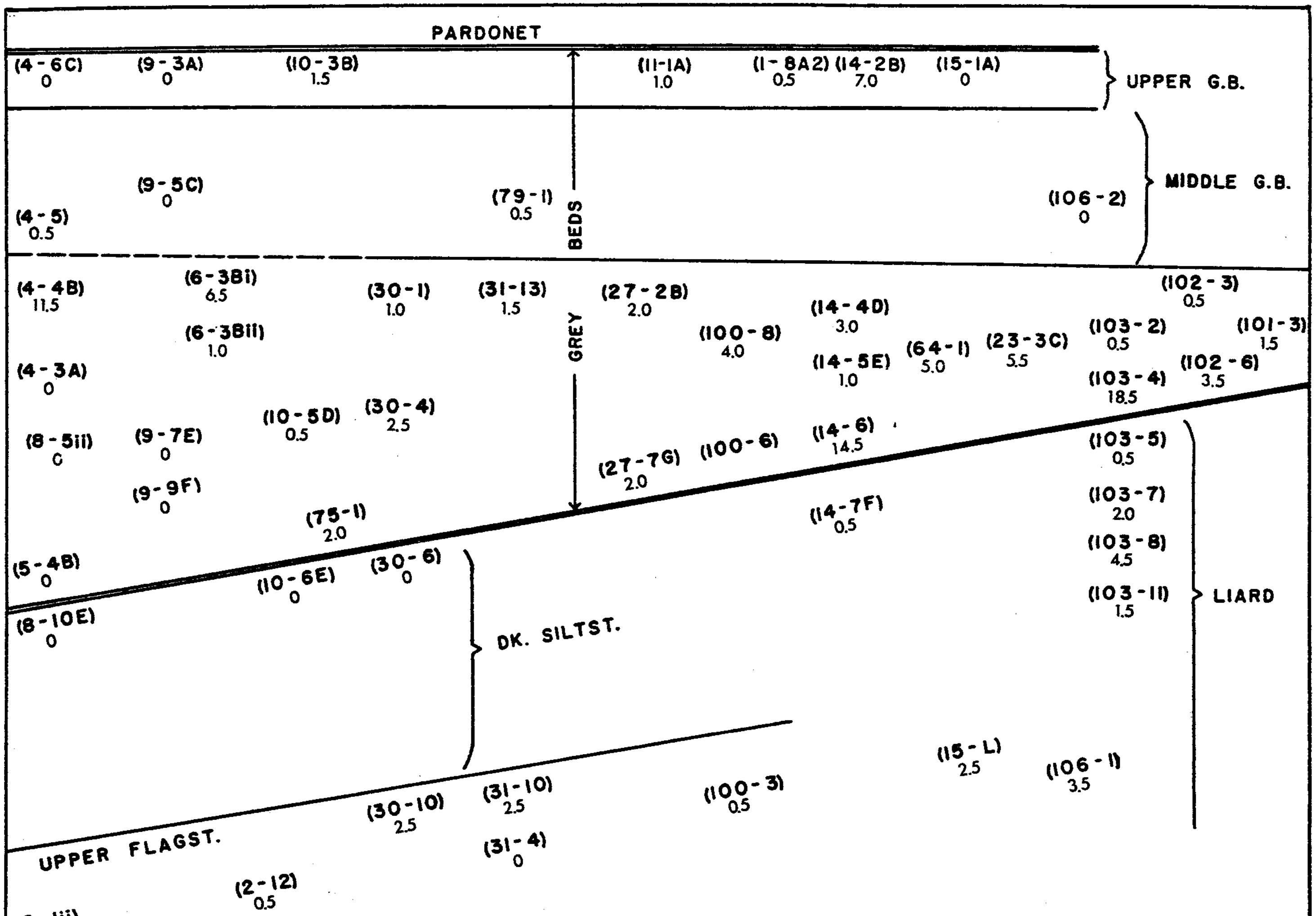


FIGURE 4- Chert %

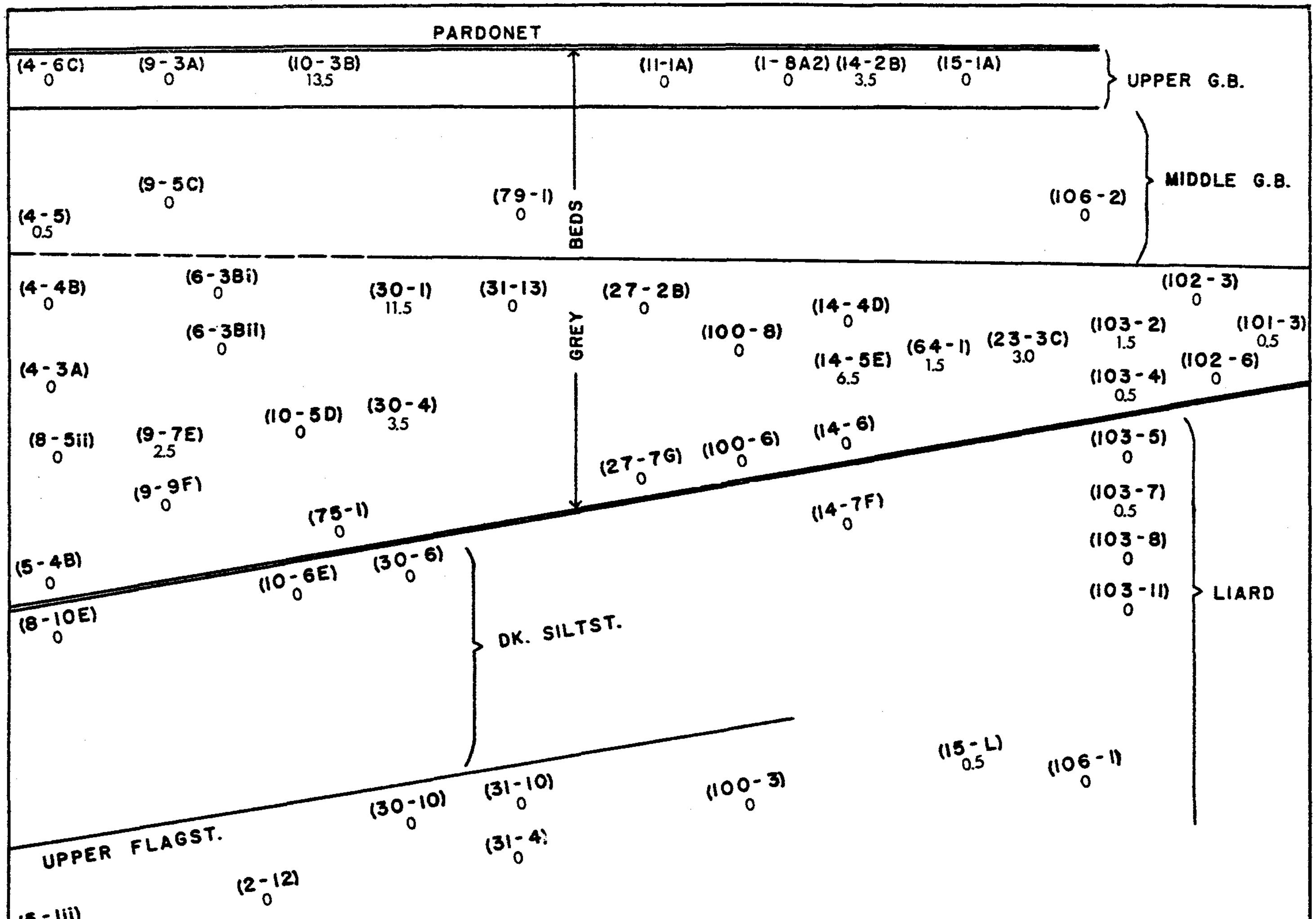


FIGURE 5 - Silica Cement %

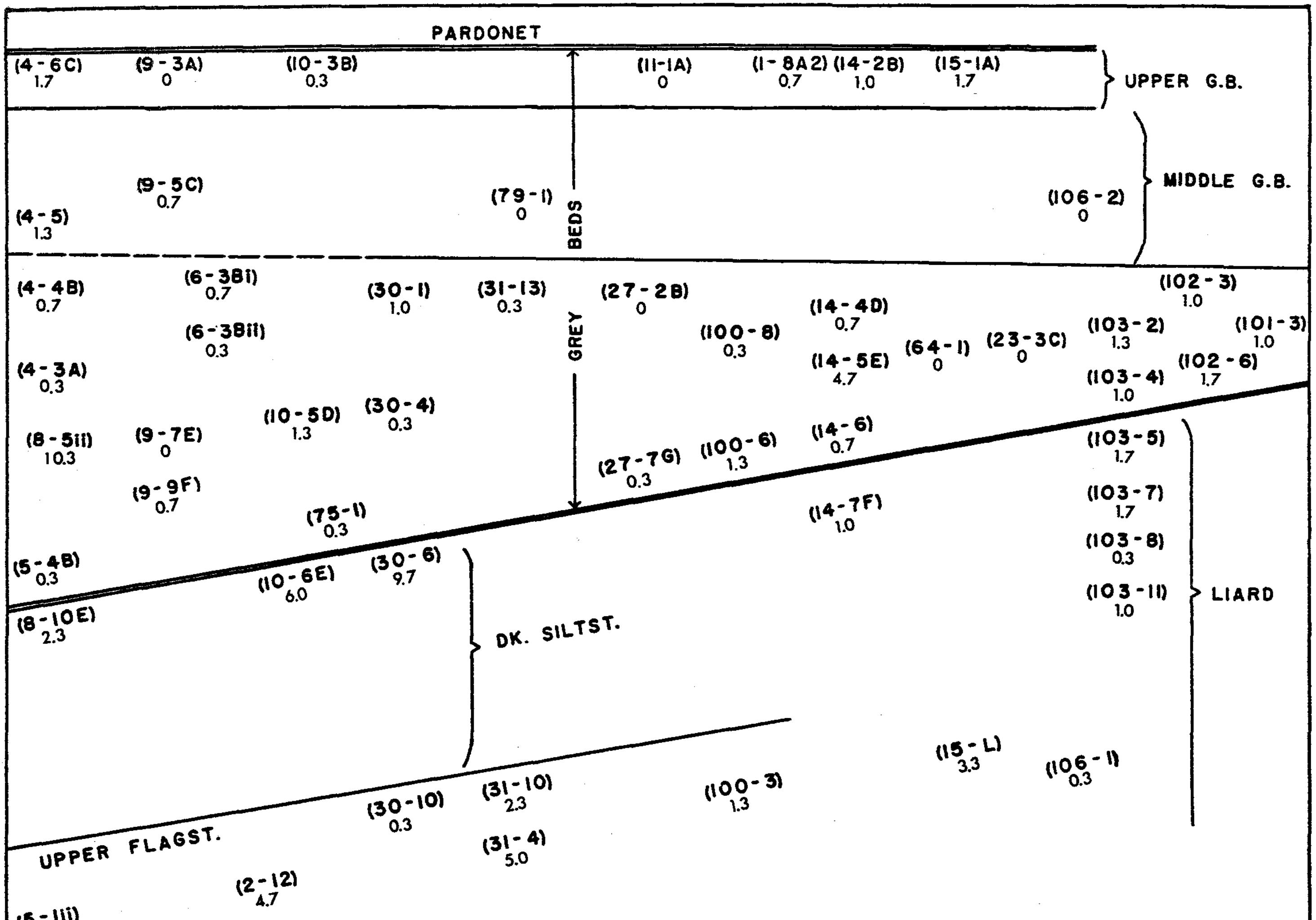


FIGURE 6 - Others %

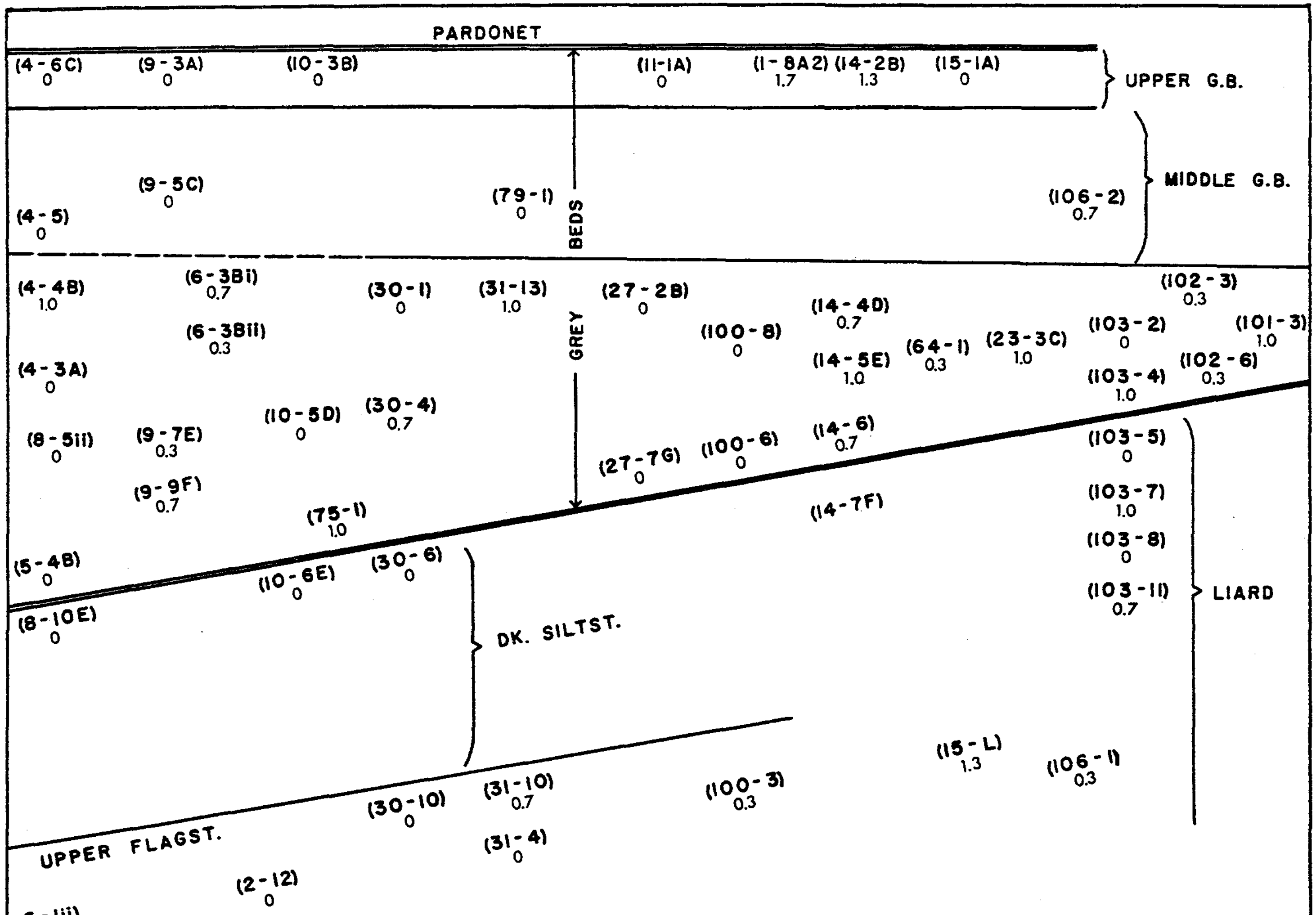


FIGURE 7 - Quartzite %

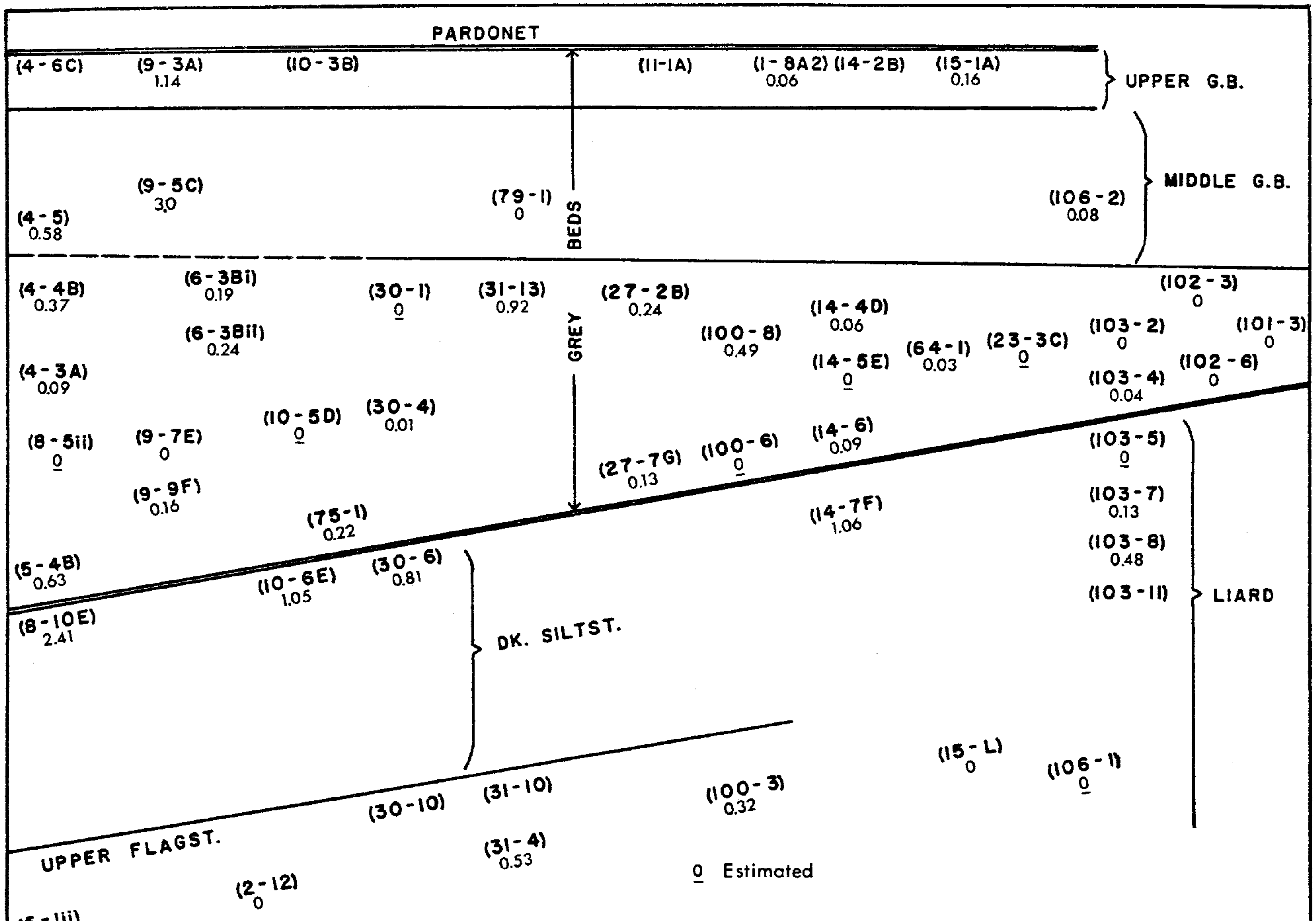


FIGURE 8 - Phospate %

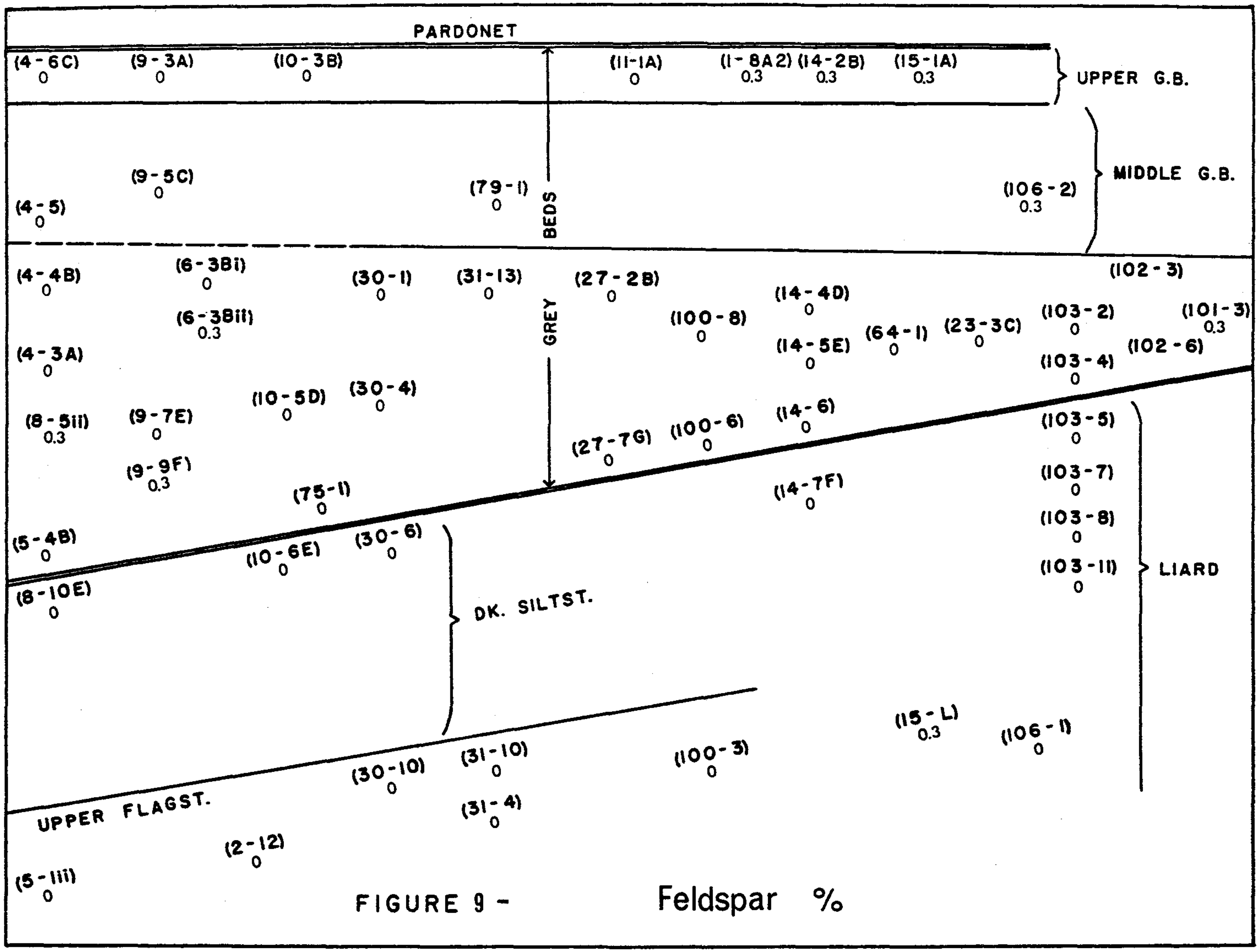


FIGURE 9 - Feldspar %

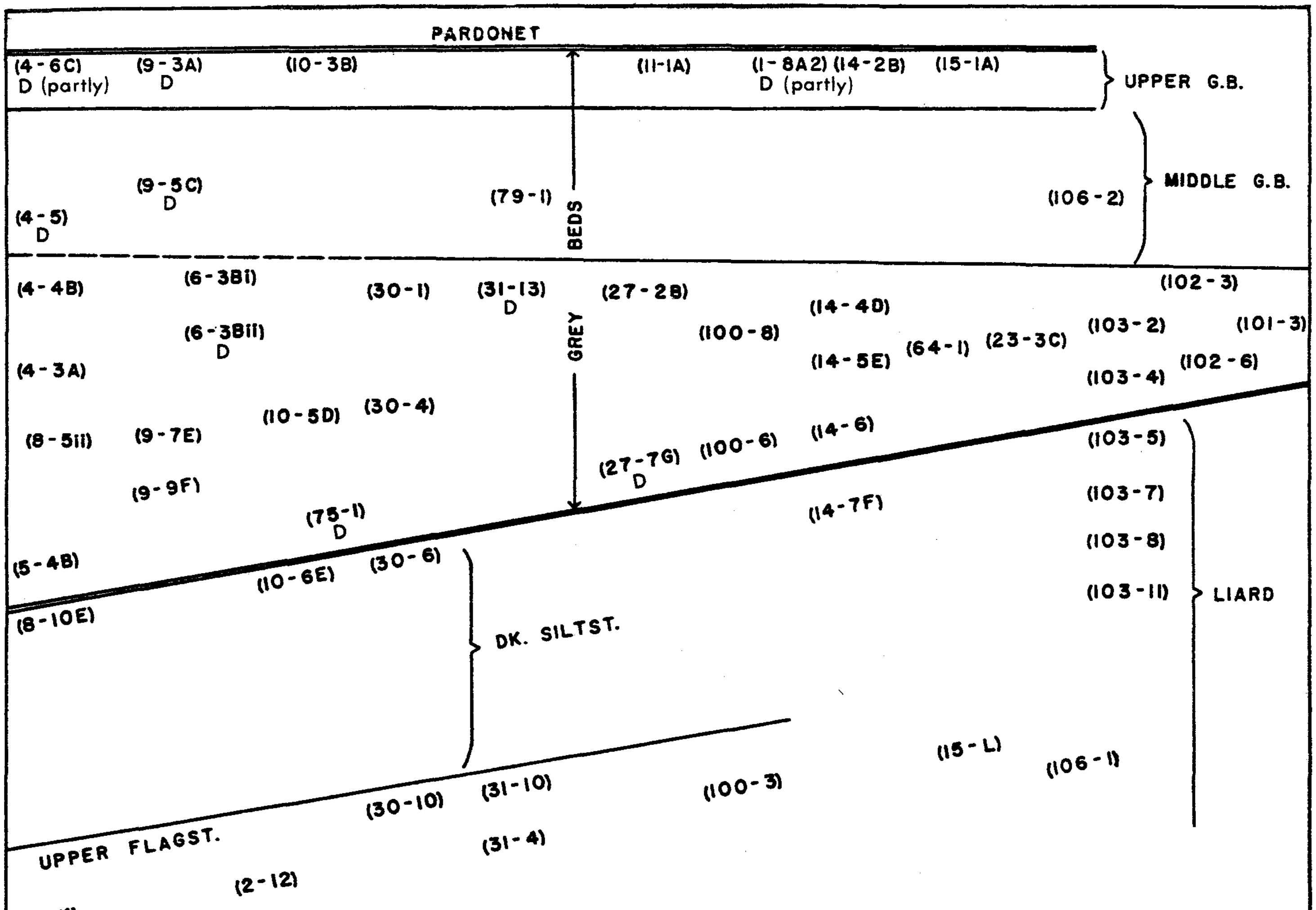


FIGURE 10 - Dolomite

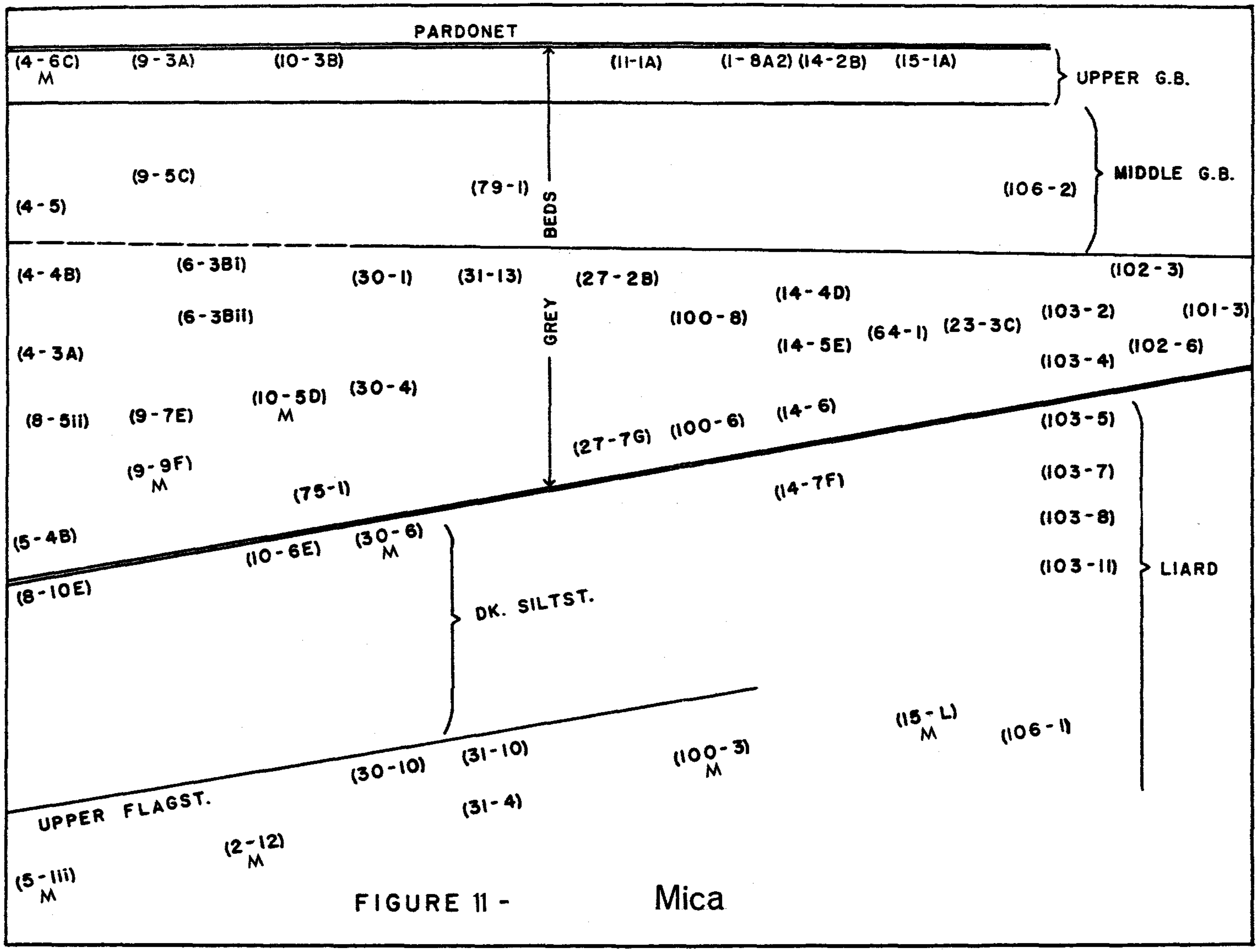


FIGURE 11 - Mica

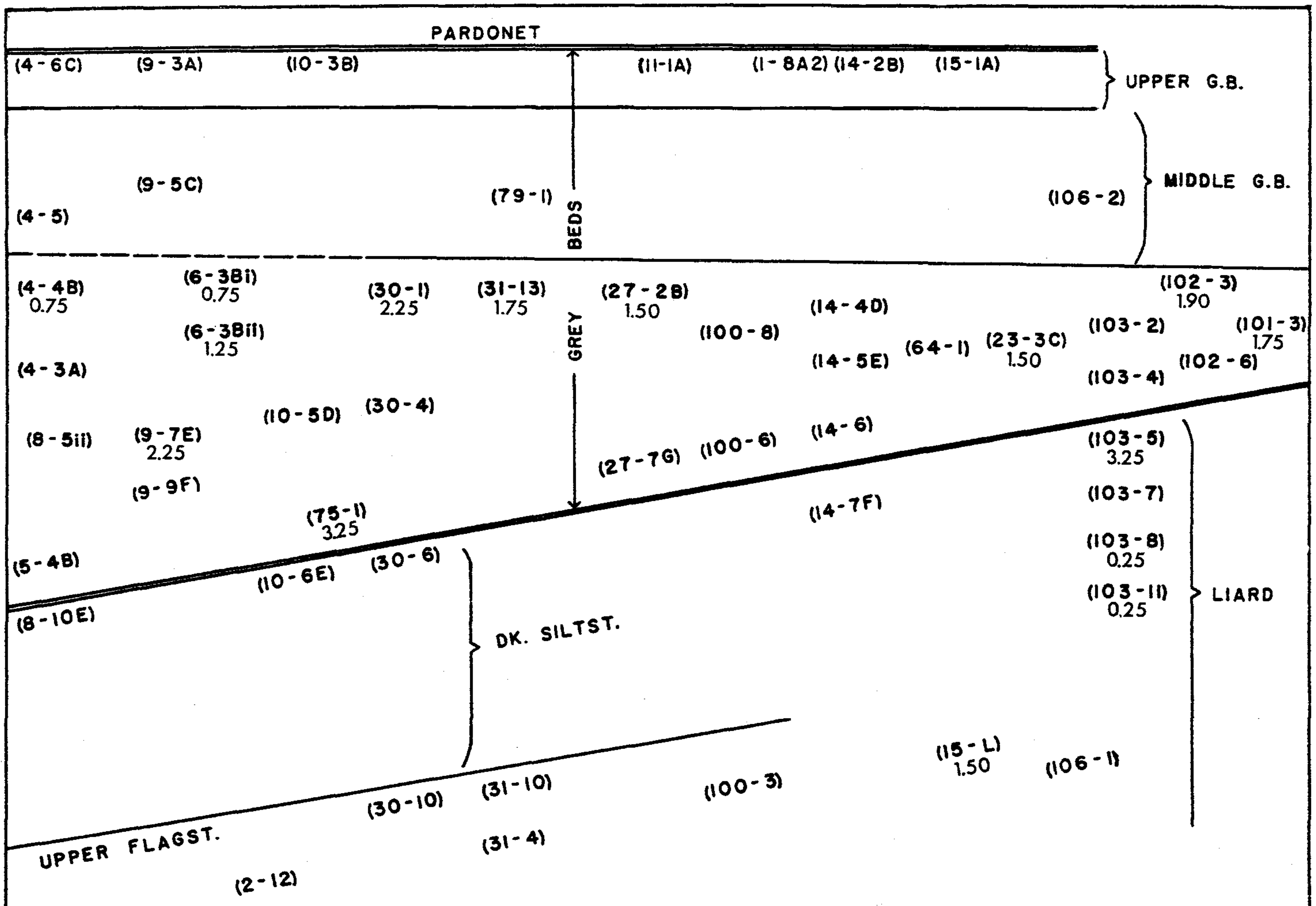


FIGURE 12 - Quartzite · Mean Size

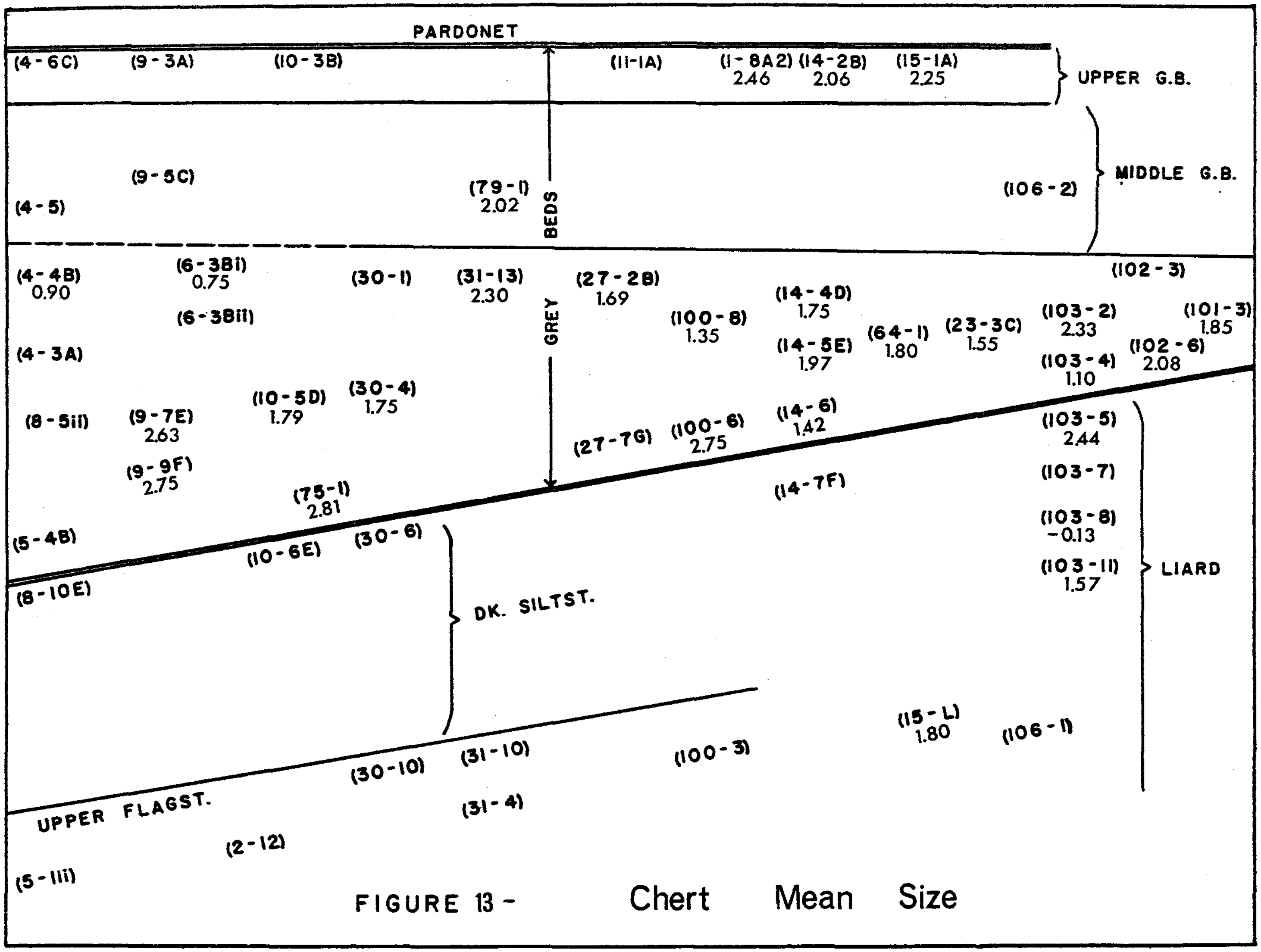


FIGURE 13 - Chert Mean Size

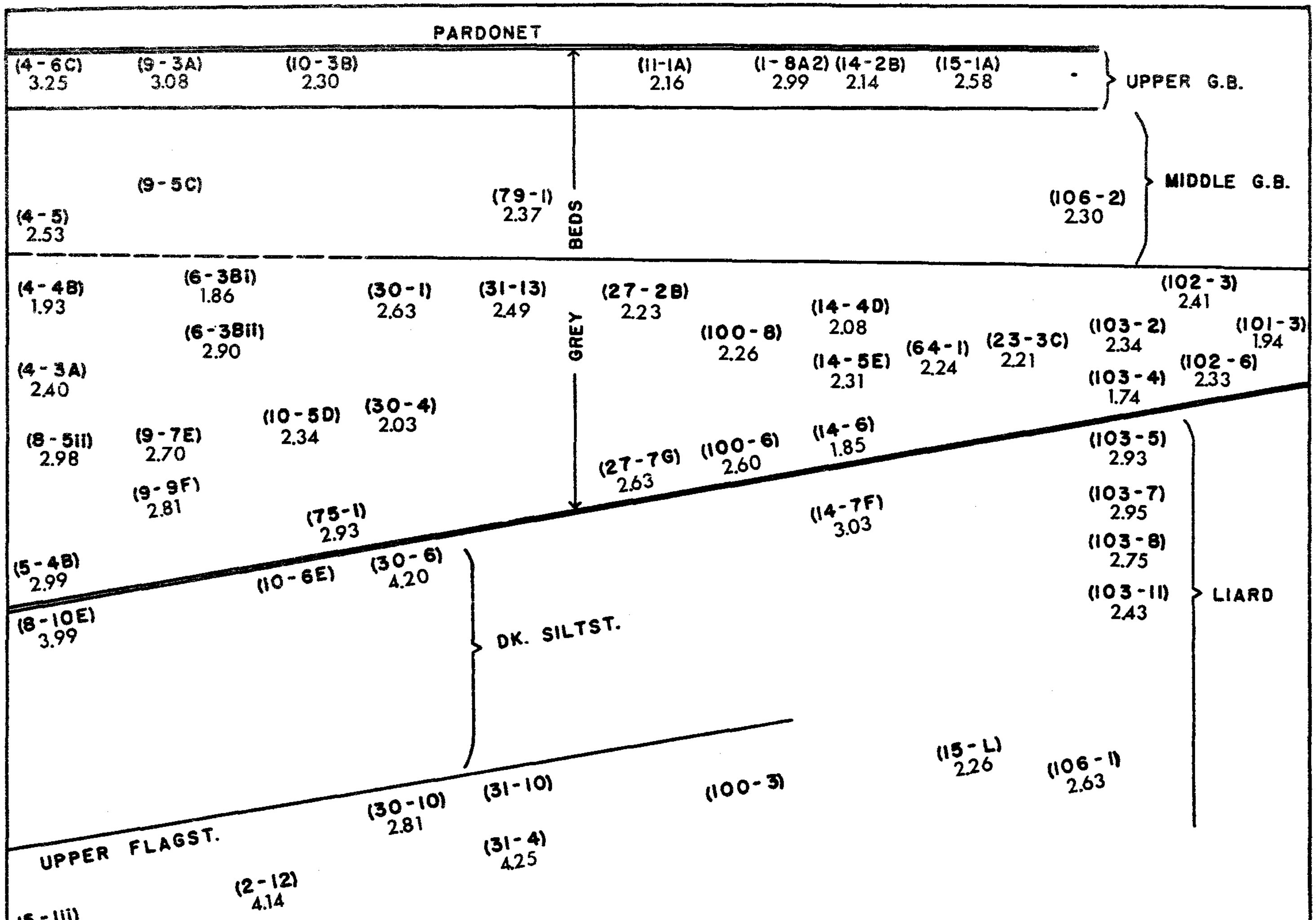


FIGURE 14 - Quartz· Mean Size

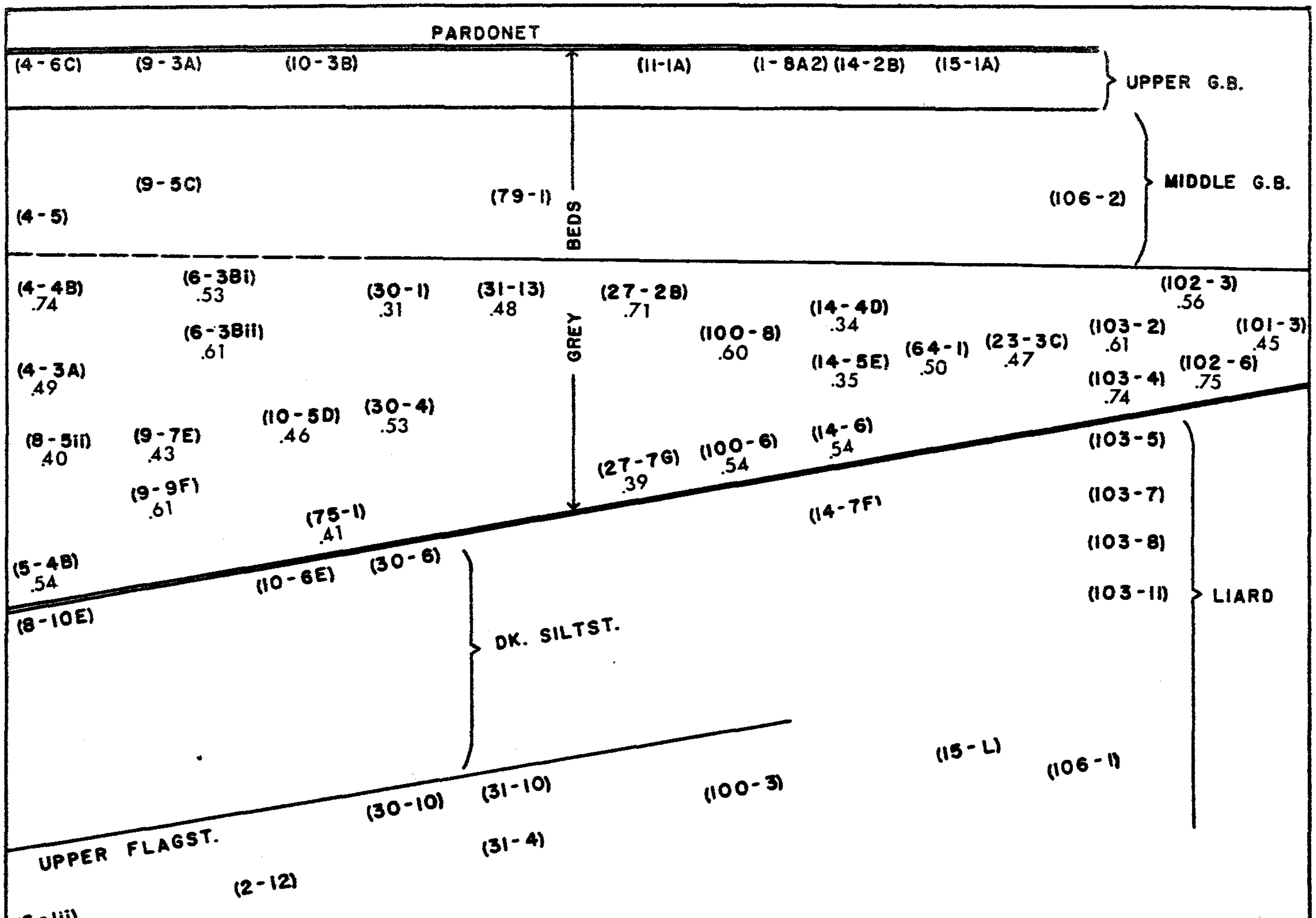


FIGURE 14A - Quartz · Standard Deviation

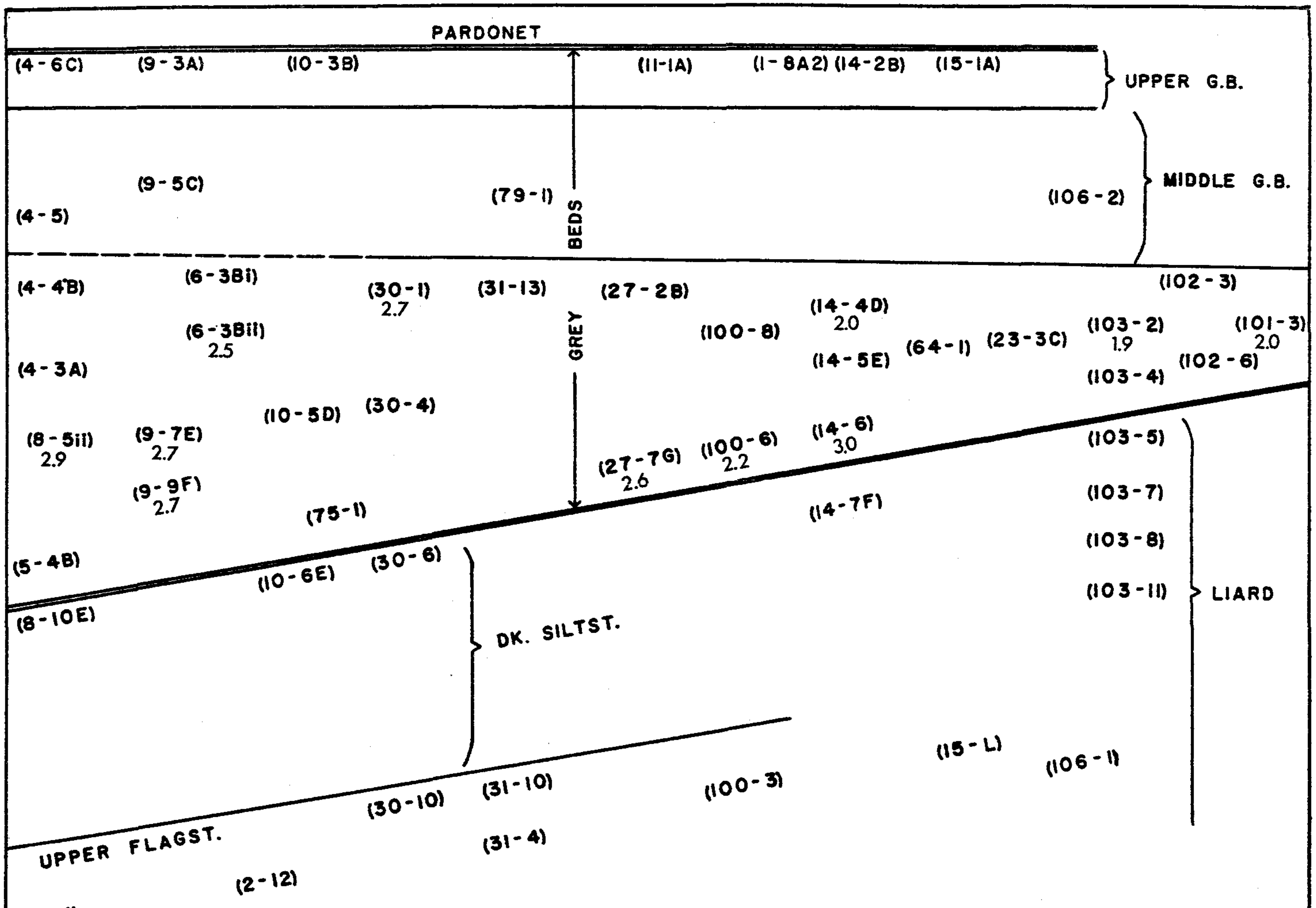


FIGURE 15 - Detrital Carbonate Mean Size

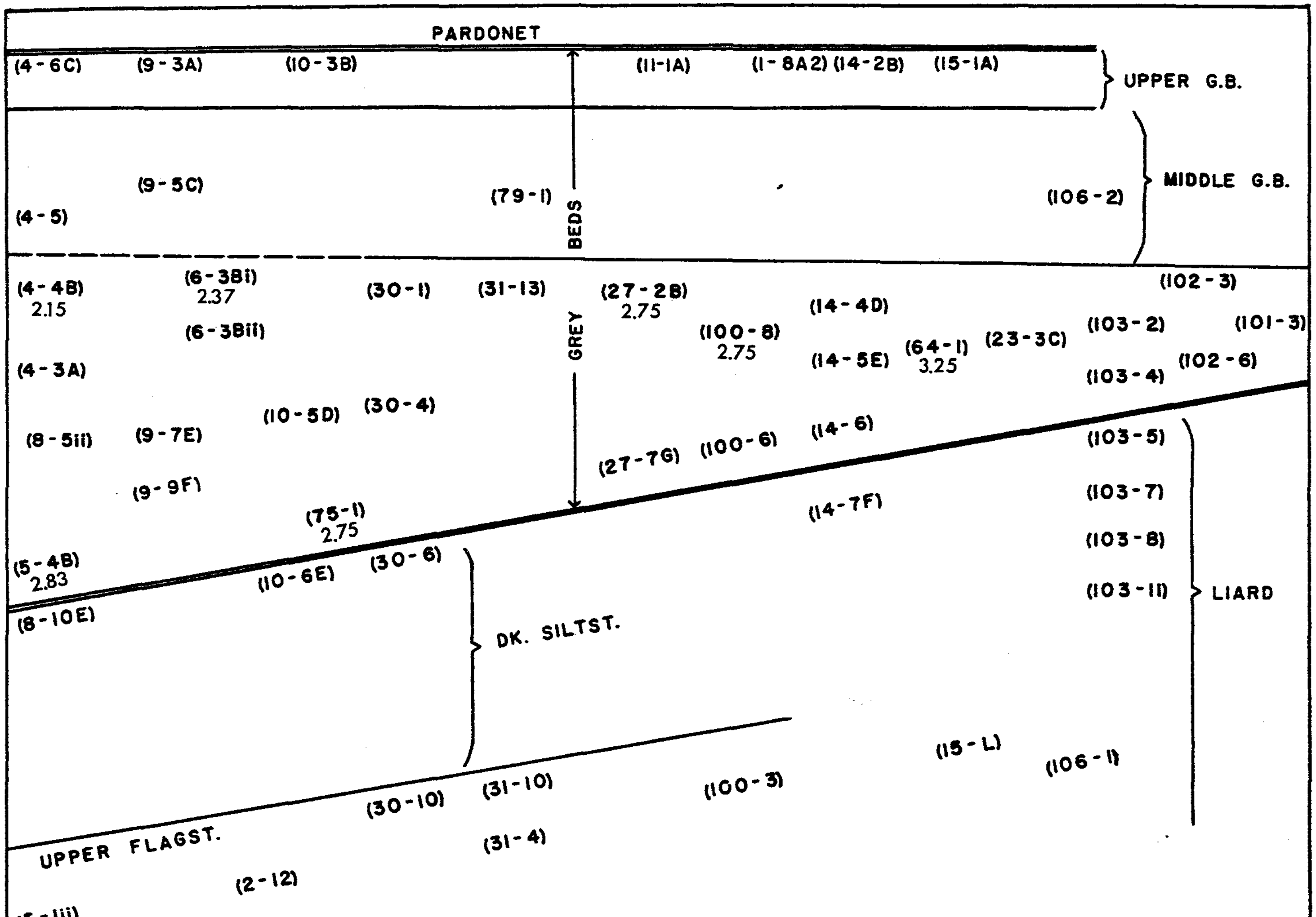


FIGURE 16 - Collophane · Mean Size

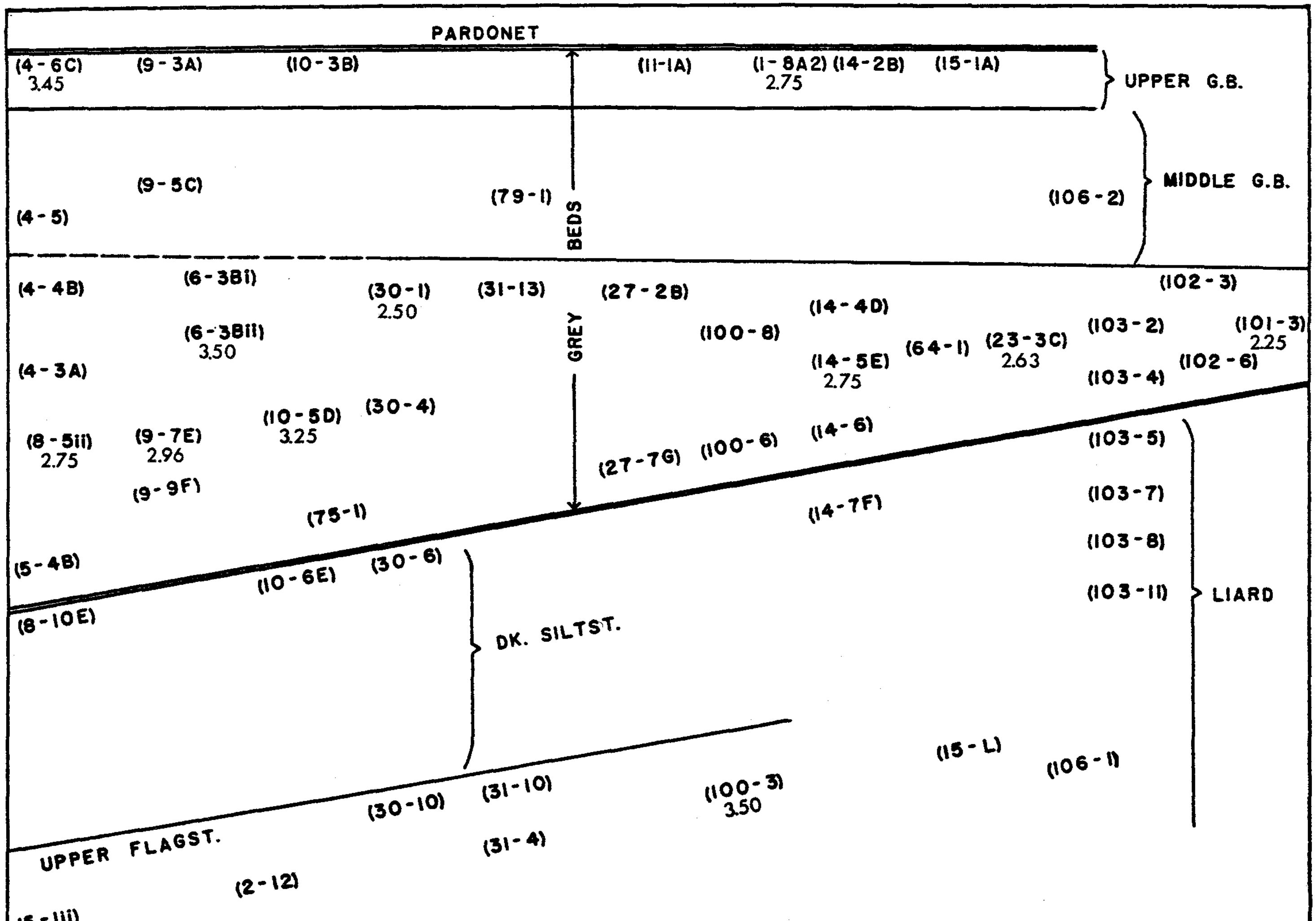


FIGURE 17 - Feldspar · Mean Size

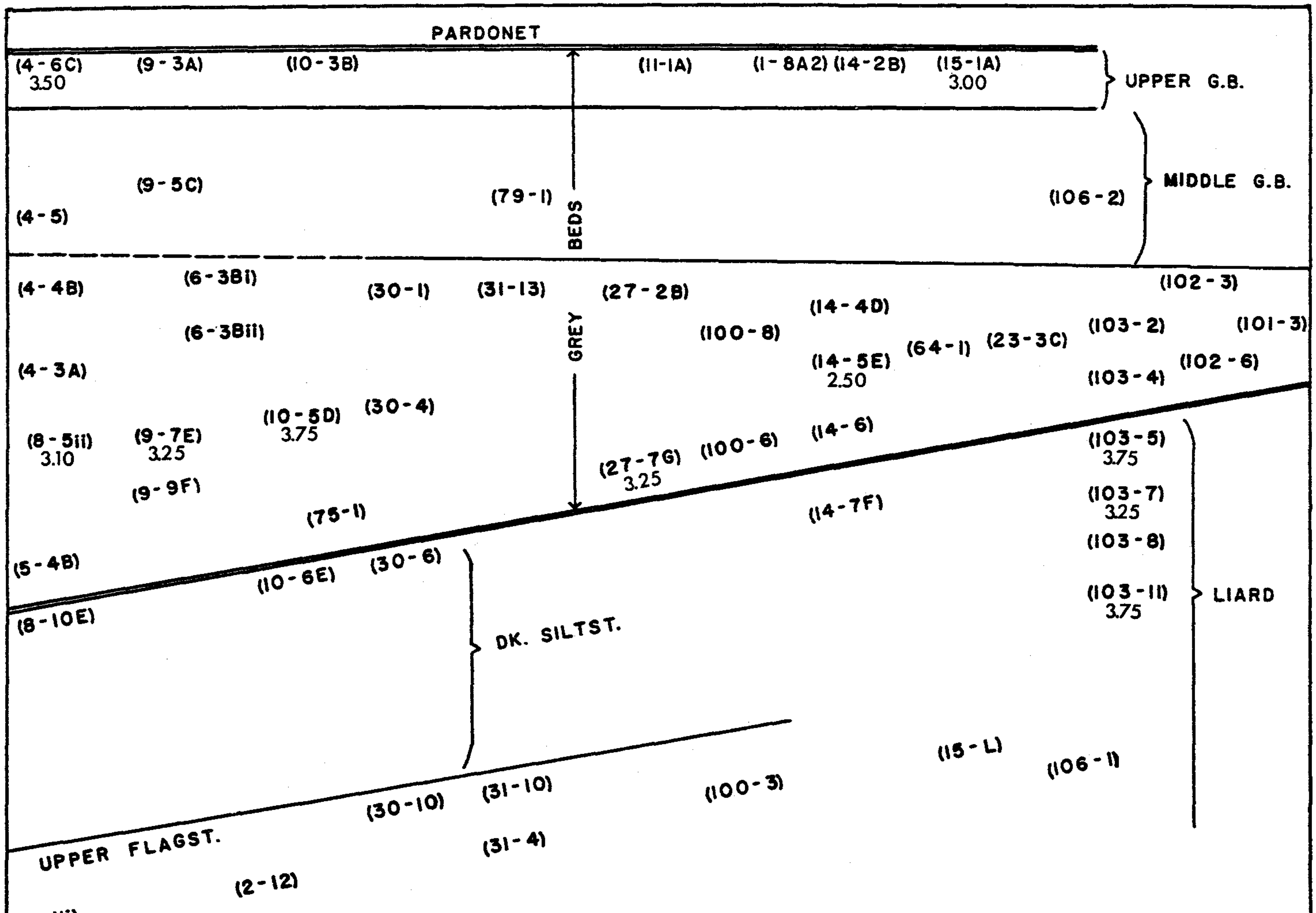


FIGURE 18 - Tourmaline · Mean Size

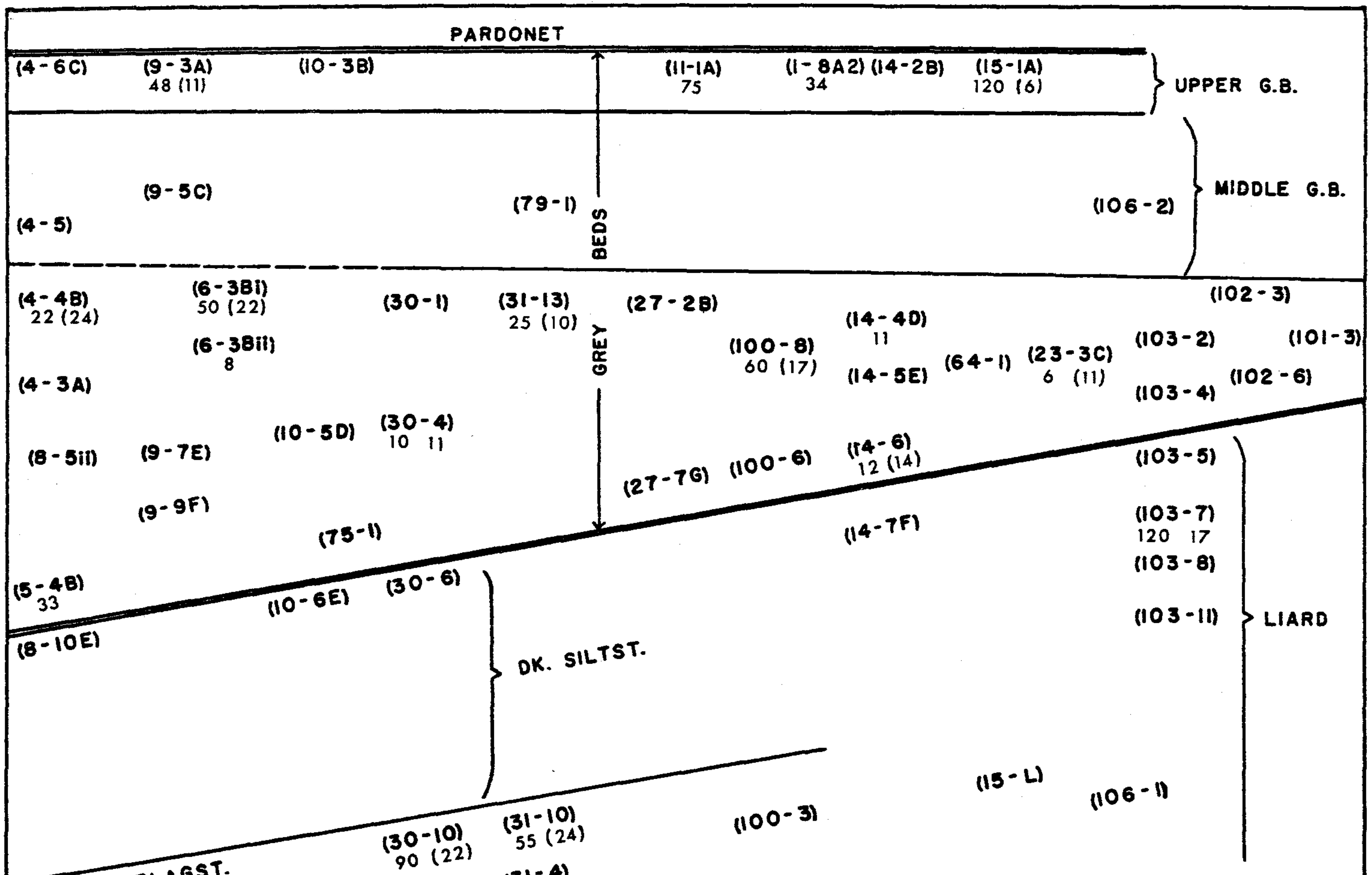


FIGURE 19 - Bioclastic Carbonate & Chert ( ). Max. Size (ocular scale units)

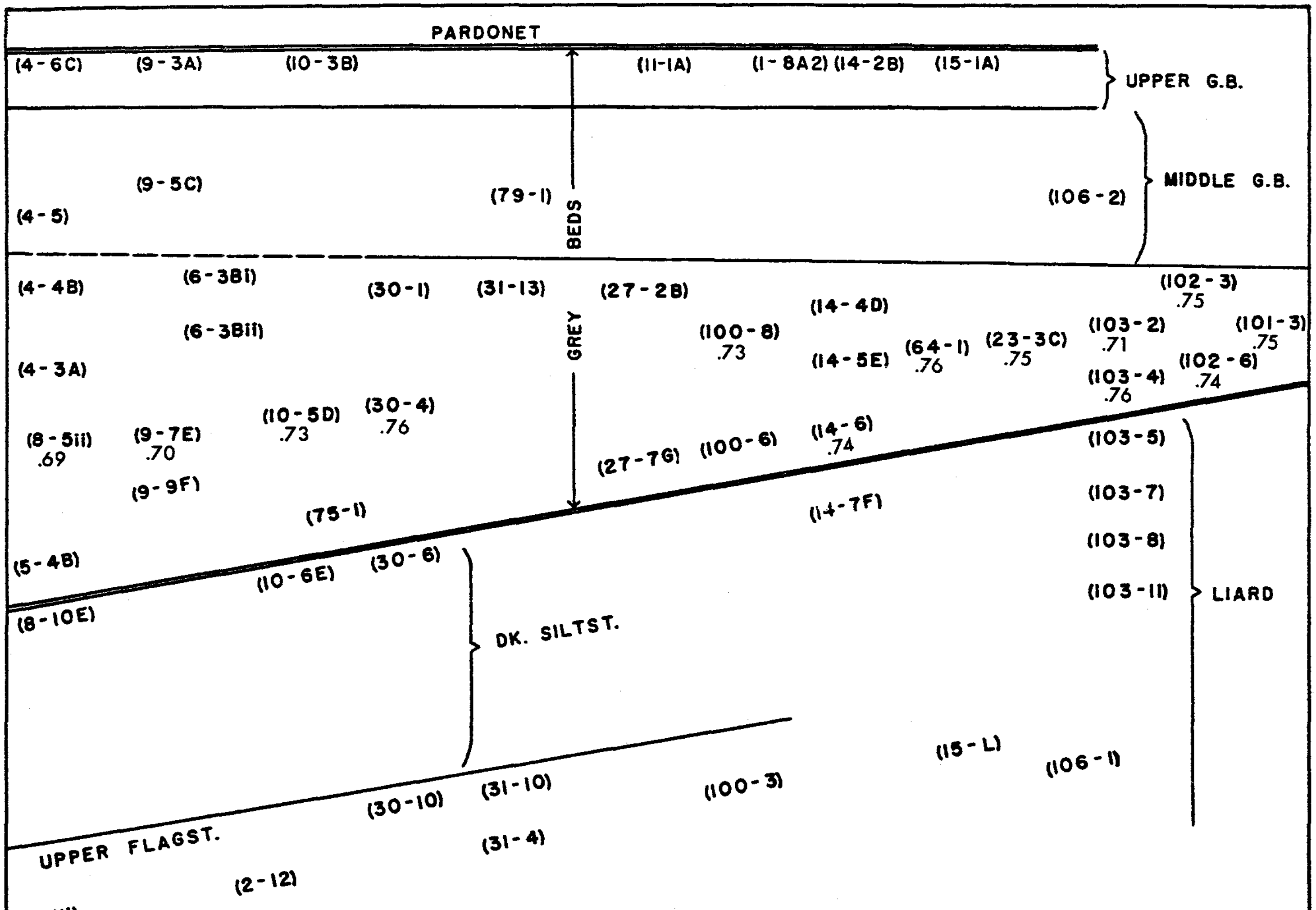


FIGURE 20 - Quartz · Mean Sphericity

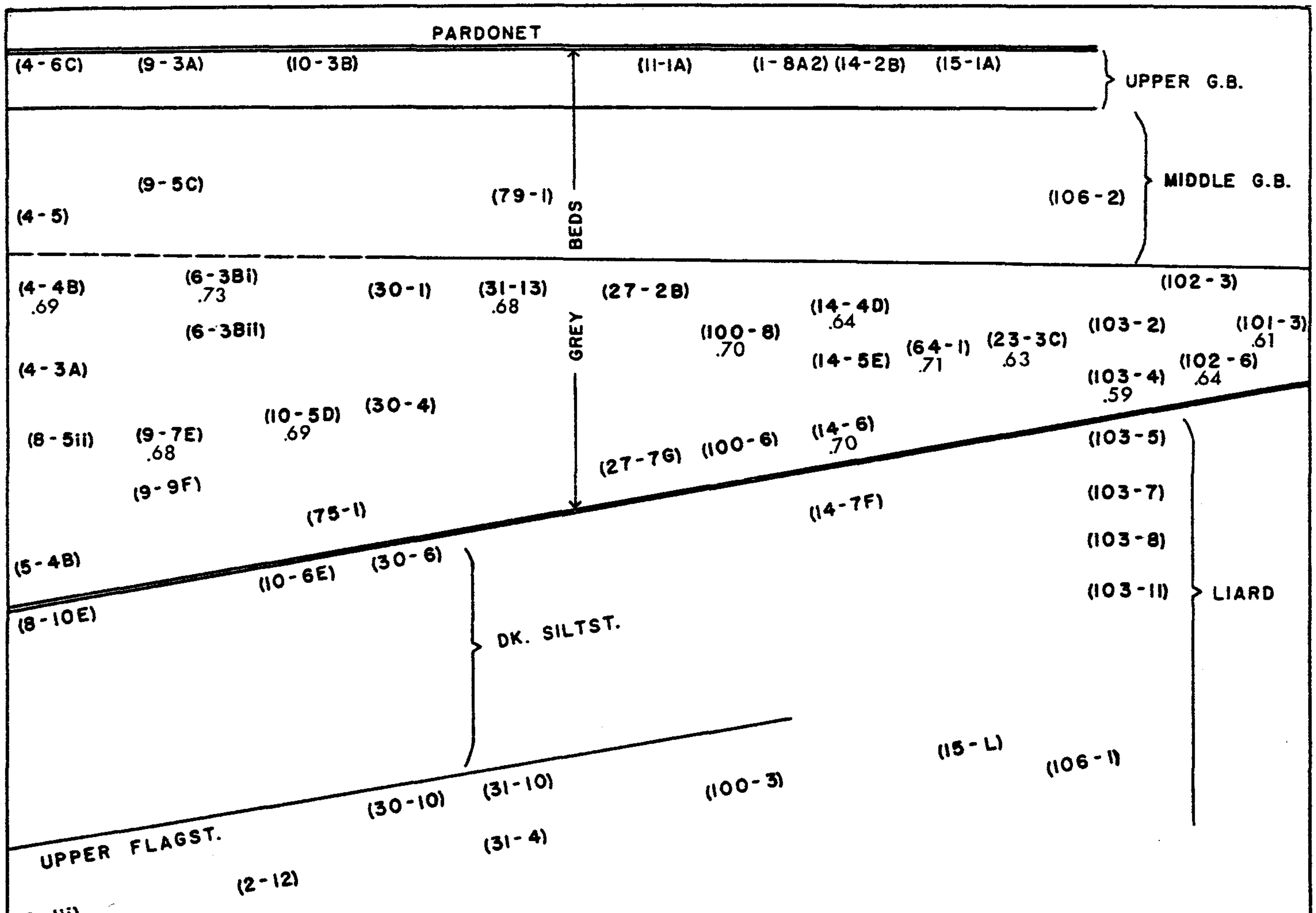


FIGURE 21 - Chert · Mean Sphericity

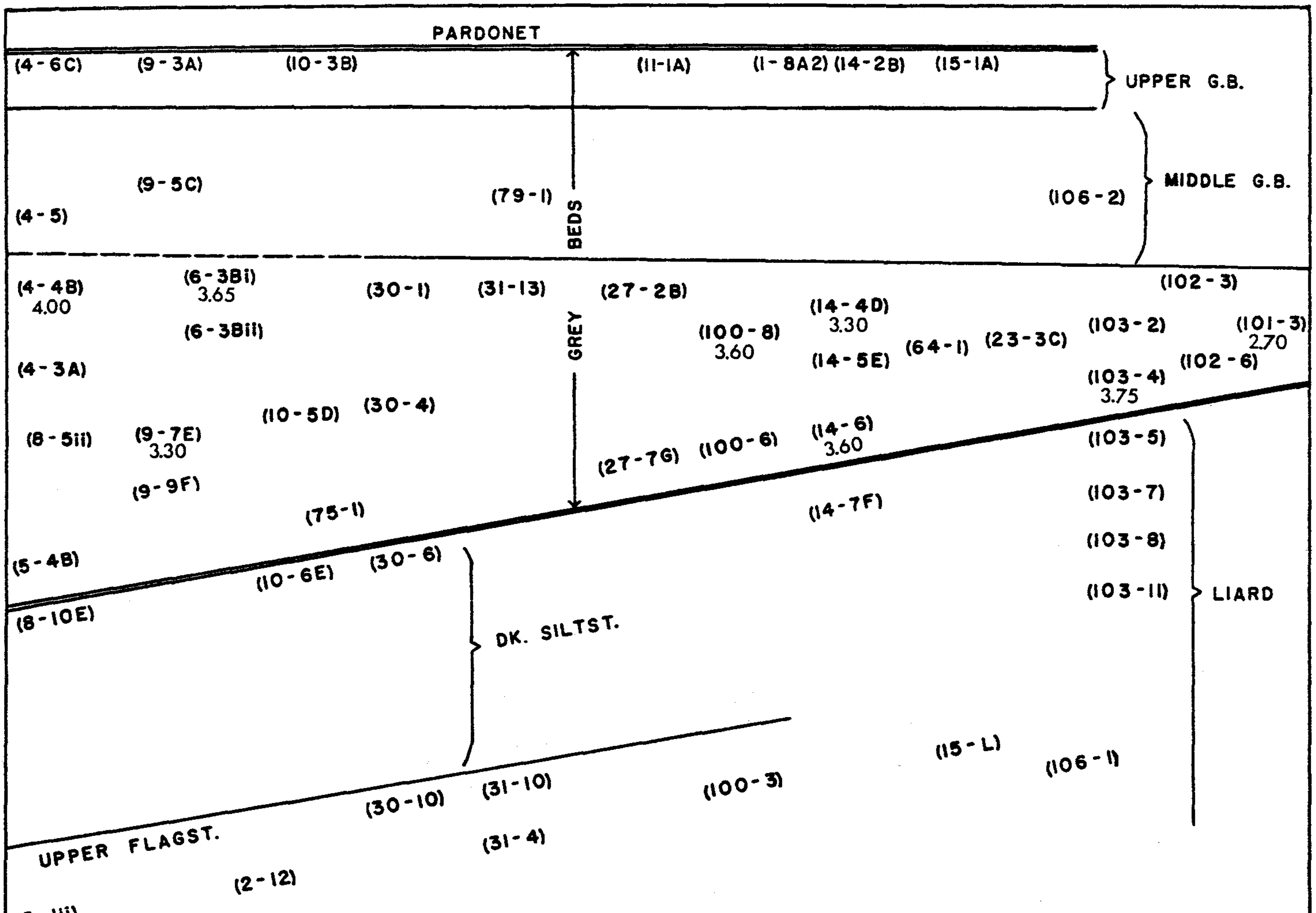


FIGURE 22 - Chert · Mean Roundness

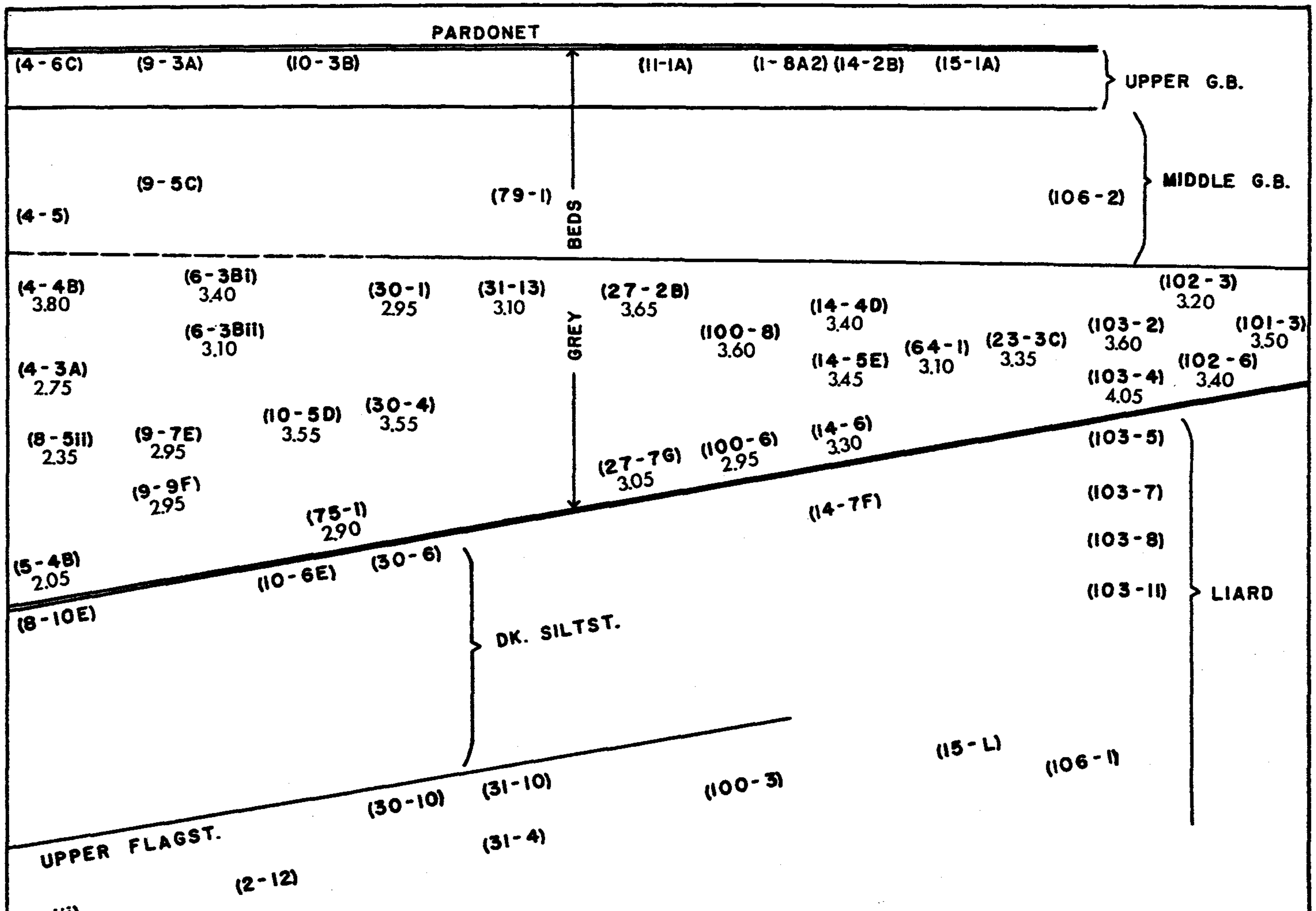


FIGURE 23 - Quartz Mean Roundness

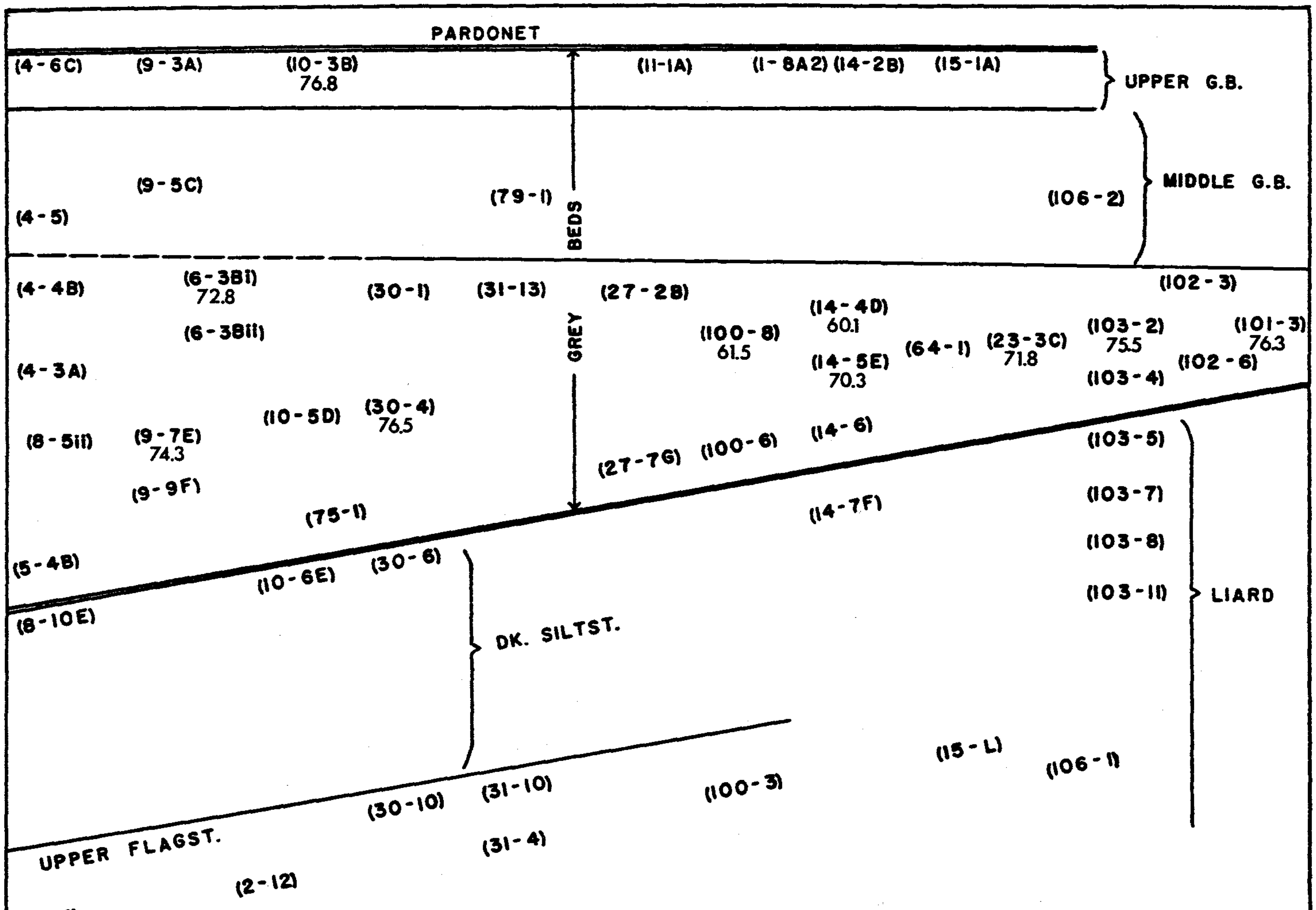


FIGURE 24 - Packing Density

Appendix II

Statistics and Graphs

Statistics

1. Quartz precision
2. Chert precision
3. Phosphate precision
4. Roundness precision
5. t-test - Quartz sphericity
6. t-test - Chert sphericity
7. Sampling model used to determine vertical variations in the lower Grey beds
8. Analysis of Variance - Quartz %
9. Analysis of Variance - Quartz size
10. Analysis of Variance - Quartz roundness

Graphs

1. Quartz size - Distance
2. Quartz roundness - Distance
3. Quartz % - Distance
4. Carbonate cement % - Distance
5. Thickness of sample cross-beds - Quartz size

Quartz Precision

S-1

Thin-section no.		1st run (%)	2nd run (%)	Difference (%)	$(\text{Difference})^2$
1	30-5	68.7	67.3	1.4	1.96
2	103-4	49.3	46.7	2.6	6.76
3	6-3Bii	48.3	47.7	0.6	0.36
4	14-7F	41.7	41.6	0.1	0.01
5	106-1	51.0	47.7	3.3	10.89
6	14-5E	73.7	73.0	0.7	0.49
7	27-7G	51.7	54.0	2.3	5.29
8	100-8	41.3	43.7	2.4	5.76
9	103-11	40.7	45.0	4.3	18.49
10	101-3	75.3	75.7	0.4	0.16
					50.17

$$SD = \sqrt{\frac{\sum(\text{Difference})^2}{N}} \qquad \bar{X} = 42.05\%$$

$$= \sqrt{\frac{50.17}{20}} \qquad = 1.584$$

Coefficient of variation = $\frac{SD(100)}{\bar{X}}$ where $\bar{X}$ is the arithmetic mean

$$= 3.6\%$$

Chert Precision

S-2

Thin-section no.		1st run (%)	2nd run (%)	Difference (%)	$(Difference)^2$
1	30-5	2.7	2.3	0.4	0.16
2	103-4	16.3	18.3	2.0	4.00
3	6-3Bii	1.3	1.0	0.3	0.09
4	14-7F	1.3	0.3	1.0	1.00
5	106-1	3.6	3.6	-	-
6	14-5E	0.7	1.0	0.3	0.09
7	27-76	1.3	2.0	0.7	0.49
8	100-8	4.3	4.0	0.3	0.09
9	103-11	3.0	4.3	1.3	1.69
10	101-3	0.7	1.7	1.0	1.00
					8.61

$$SD = \sqrt{\frac{8.61}{20}} = 0.656 \qquad \bar{X} = 3.685$$

$$\text{Coefficient of Variation} = \frac{0.656(100)}{3.685}$$

$$= 17.8\%$$

Phosphate Precision

S-3

	Sample no.	1st run (%)	2nd run (%)	Difference (%)	$(\text{Difference})^2$
1	9-3A	1.12	1.14	0.02	.0004
2	100-3	0.32	0.32	-	-
3	103-4	0.05	0.05	-	-
4	4-3A	0.09	0.10	0.01	.0001
5	9-8I	0.22	0.20	0.02	.0004
6	103-7	0.13	0.14	0.01	.0001
					.001

$$SD = \sqrt{\frac{.001}{12}} = .003 \qquad \bar{X} = 0.323$$

$$\text{Coefficient of Variation} = \frac{.003(100)}{0.323} = 0.93\%$$

Roundness Precision

S-4

Thin-section no.		1st run $\bar{p}$	2nd run $\bar{p}$	Difference	$(\text{Difference})^2$
1	103-4	4.05	3.95	0.10	0.01
2	30-4	3.55	3.70	0.15	0.0225
3	4-3A	2.75	3.05	0.30	0.09
4	31-13	3.10	3.00	0.10	0.01
5	6-3Bii	3.10	3.40	0.30	0.09
6	14-5E	3.45	3.40	0.05	0.0025
7	4-4B	3.80	3.10	0.70	0.49
					0.7150

$$SD = \sqrt{\frac{0.715}{14}} = 0.226 \qquad \bar{X} = 3.385$$

$$\text{Coefficient of Variation} = \frac{0.226(100)}{3.385} = 6.7\%$$

t-test - Quartz sphericity

$\bar{X}_1 = .76 \qquad N_1 = 20 \qquad s_1^2 = .0256$

$\bar{X}_2 = .69 \qquad N_2 = 20 \qquad s_2^2 = .0250$

Test H: $u_1 = u_2 \qquad \sigma_1 = \sigma_2 = \sigma$ which is unknown

$$Sp^2 = \frac{(N_1 - 1)s_1^2 + (N_2 - 1)s_2^2}{N_1 + N_2 - 2} = \frac{.4863 + .4758}{38} = .0253184$$

$$Sp = .159117$$

$$t = \frac{u_1 - u_2}{Sp\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} = \frac{.76 - .69}{.159117\sqrt{\frac{1}{20} + \frac{1}{20}}} = 1.391$$

$= .05 \qquad t_{.025,38} < t < t_{.975,38}$

$t_{.975,38} = 2.02$

$\therefore$ Accept H: $u_1 = u_2$

t-test - Chert sphericity

$\bar{X}_1 = .71 \qquad N_1 = 20 \qquad S_1^2 = .0302$

$\bar{X}_2 = .61 \qquad N_2 = 20 \qquad S_2^2 = .0292$

Test H: $u_1 = u_2 \qquad \sigma_1 = \sigma_2 = \sigma$ which is unknown

$$Sp^2 = \frac{(N_1 - 1)S_1^2 + (N_2 - 1)S_2^2}{N_1 + N_2 - 2} = \frac{.5548 + .5747}{38} = .0297237$$

$Sp = 0.172405$

$$t = \frac{u_1 - u_2}{Sp\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}} = \frac{.71 - .61}{.172405\sqrt{\frac{1}{20} + \frac{1}{20}}} = 1.834$$

$= .05 \qquad t_{.025,38} \leqslant t \leqslant t_{.975,38}$

$t_{.975,38} = 2.02$

$\therefore$ Accept H: $u_1 = u_2$ at the 95% level of significance

Sampling Model used to determine vertical variations in the lower Grey beds S-7

(2 way - crossed model with replication)

	A	B	C	D (Lateral Location)
a	X_{111}	X_{211}	X_{311}	X_{411}
	X_{112}	X_{212}	X_{312}	X_{412}
b	X_{121}	X_{221}	X_{321}	X_{421}
	X_{122}	X_{222}	X_{322}	X_{422}
c	X_{131}	X_{231}	X_{321}	X_{421}
	X_{132}	X_{232}	X_{322}	X_{422}
(Vertical Position)				

4-3A	30-1	27-2B	14-4D
6-3Bii	31-13	100-8	102-3
8-5ii	10-5D	14-5E	103-2
9-7E	30-4	64-1	101-3
5-4B	75-1	100-6	103-4
9-9F	27-76	14-6	102-6

Analysis of Variance - Vertical Variation in the lower Grey beds S-8

- Quartz %

Source of Variation	df	Sums of Squares	Mean Squares	F
Between Vertical Position	2	3179.236	1589.619	3.60*
Between Lateral Location	3	430.405	143.468	<1 NS
Interaction	6	1084.434	180.739	<1 NS
Error	12	3015.565	251.297	
Total	23	7709.640		

* Significant at the 5% level of probability

NS - non significant

Analysis of Variance - Vertical Variation in the lower Grey beds S-9

- Quartz size

Source of Variation	df	Sums of Squares	Mean Squares	F
Between Vertical Position	2	0.068	0.033	<1 NS
Between Lateral Location	3	1.526	0.508	3.5*
Interaction	6	0.409	0.068	<1 NS
Error	12	0.897	0.074	
Total	23	2.900		

* Significant at the 5% level of probability

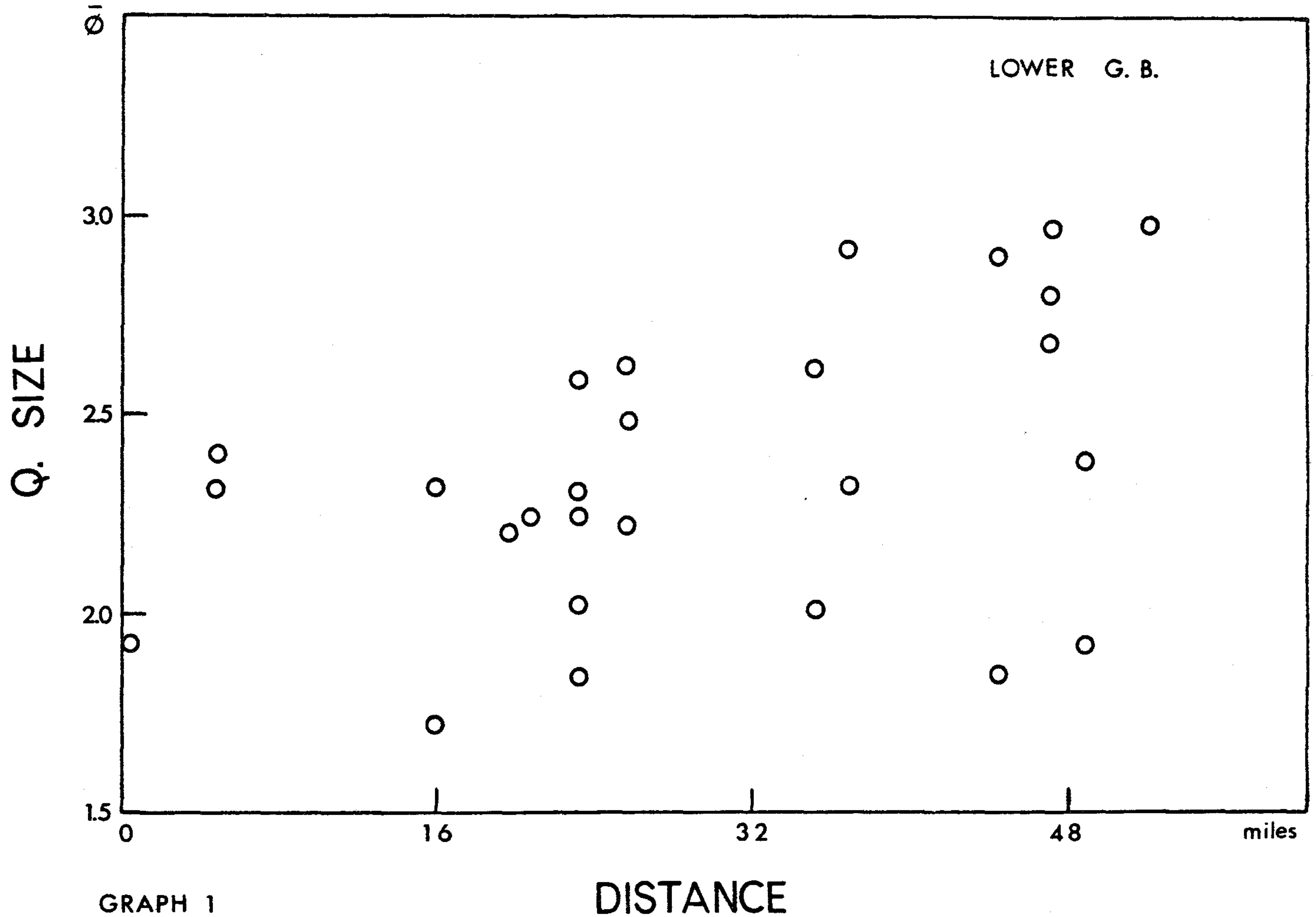
NS - non significant

Analysis of Variance - Vertical Variation in the lower Grey beds S-10

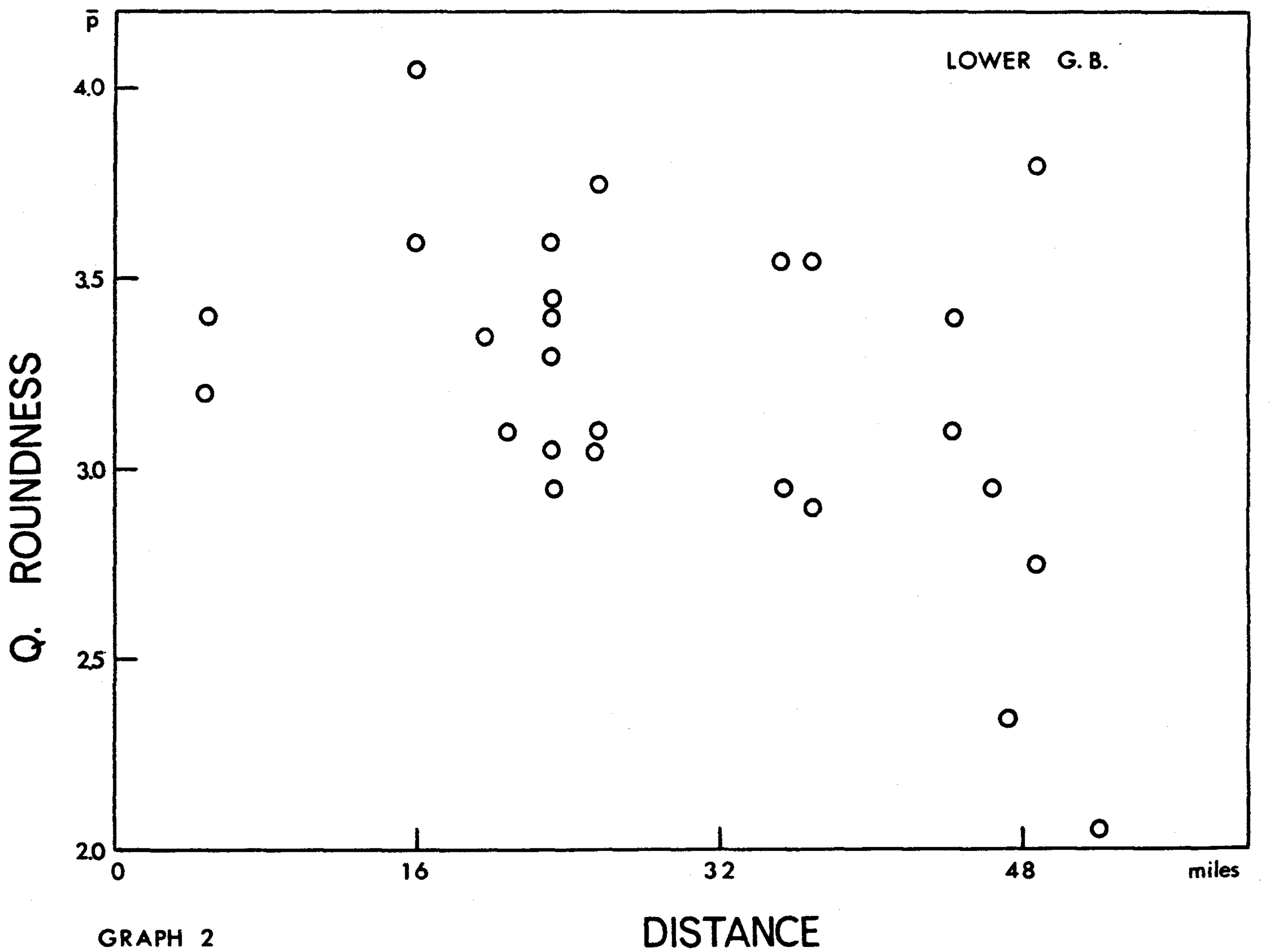
- Quartz Roundness

Source of Variation	df	Sums of Squares	Mean Squares	F
Between Vertical Position	2	0.664	0.332	<1 NS
Between Lateral Location	3	3.401	1.133	<1 NS
Interaction	6	4.208	0.701	1.4NS
Error	12	5.823	0.485	
Total	23	14.096		

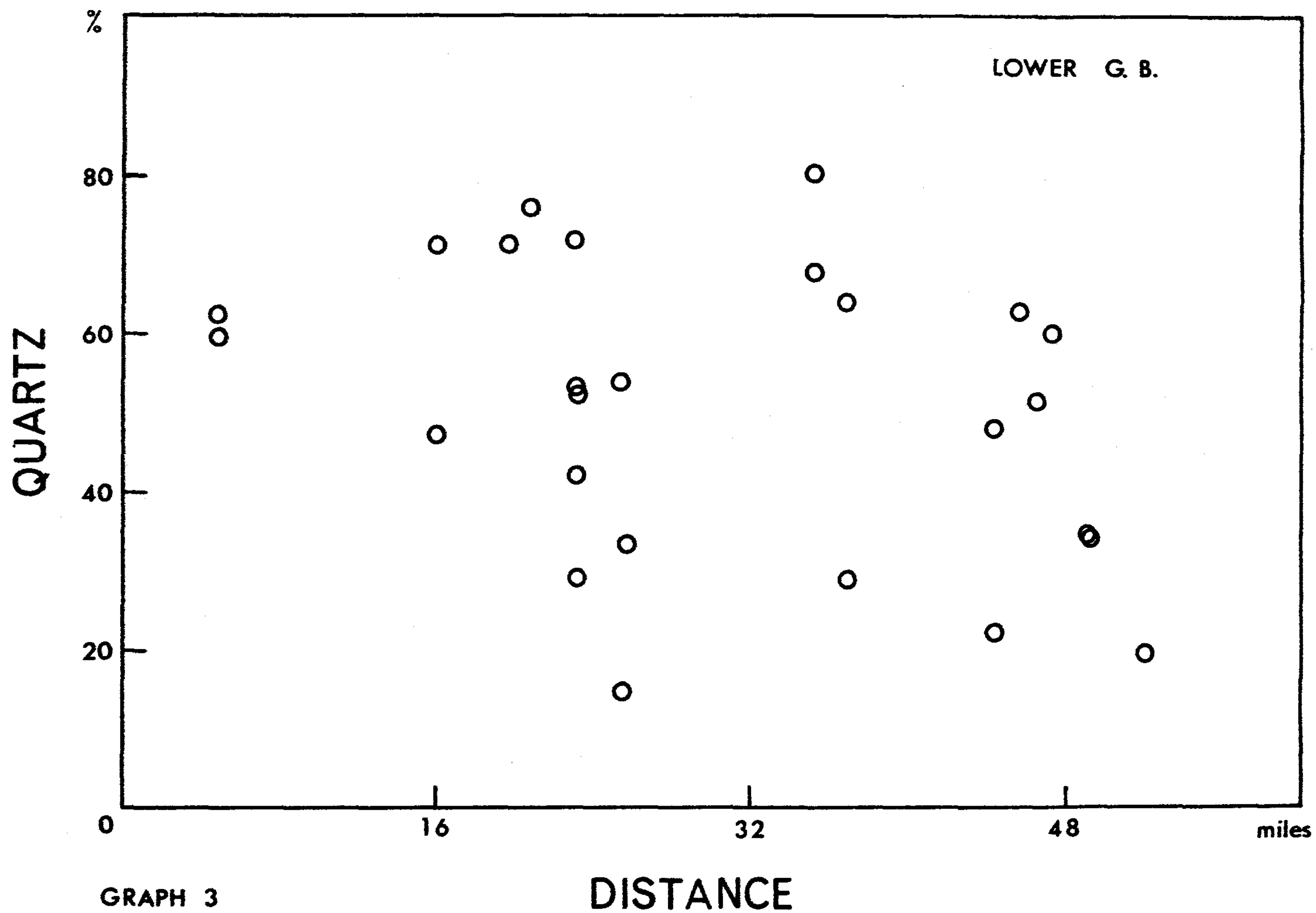
NS - non significant



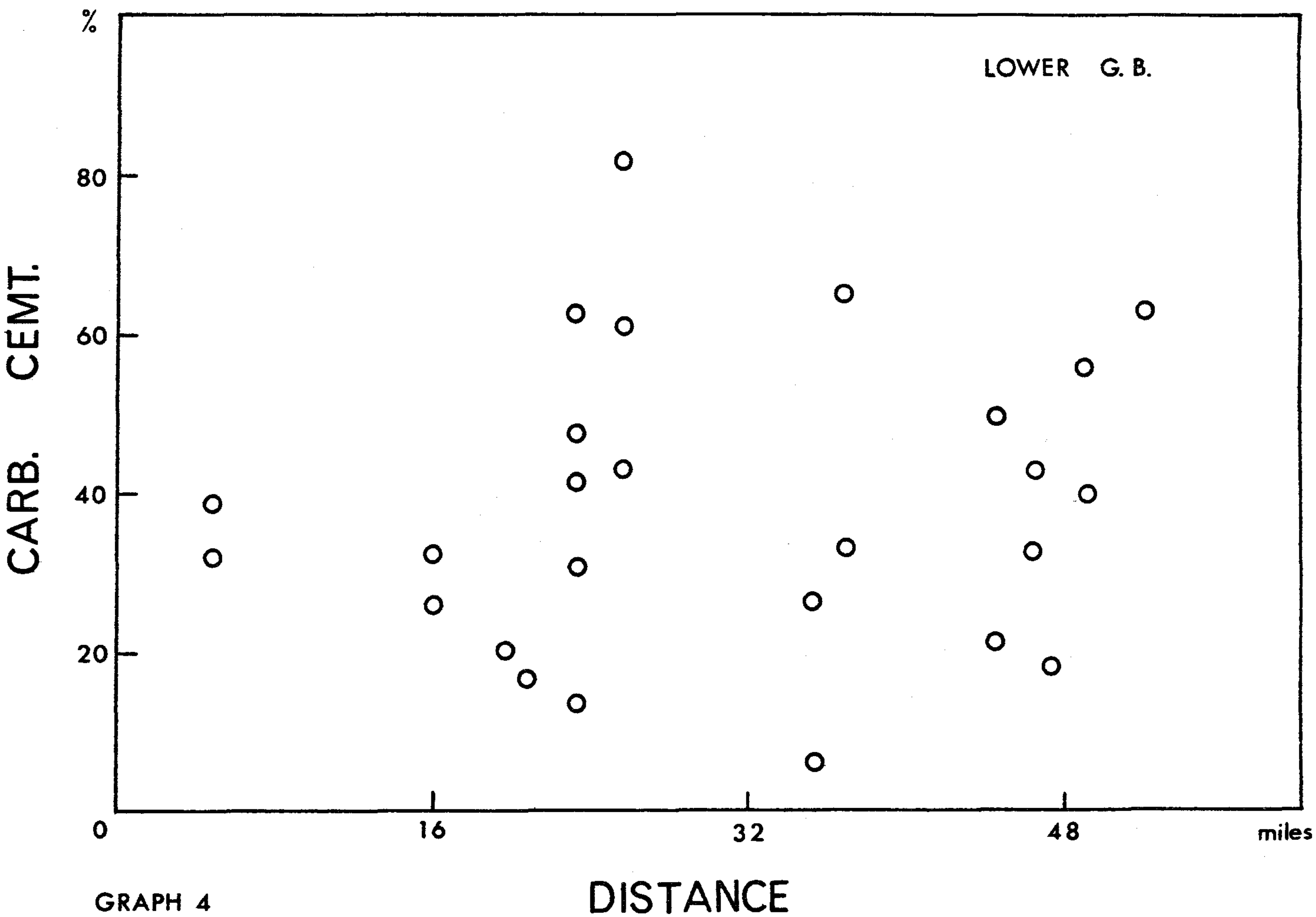
GRAPH 1



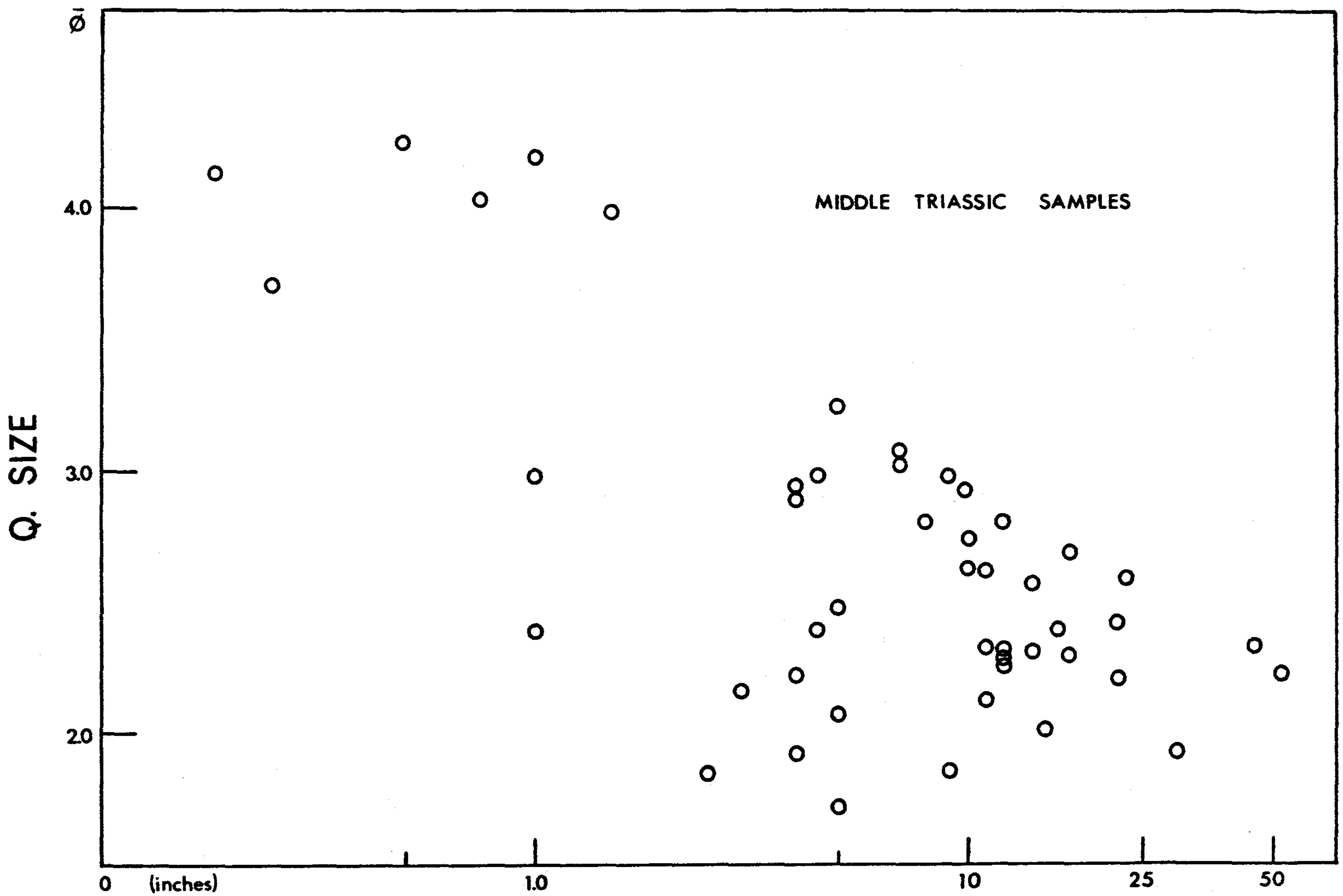
GRAPH 2



GRAPH 3



GRAPH 4



GRAPH 5

THICKNESS of CROSS BEDS