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# SOME OBSERVED TEXTURAL AND PETROGRAPHIC VARIATIONS OF THE BASAL KNOX SANDSTONE IN EAST TENNESSEE

Stephen E. Collins
*Tyler, Texas*

## Introduction

This paper was prepared with the aid of the facilities offered by the University of Tennessee. The writer wishes to express his appreciation to the Department of Geology and Geography of the University of Tennessee and especially to Dr. F. Donald Bloss who offered invaluable guidance and criticism.

Stratigraphic studies (Rodgers, 1953) indicate that the source direction of sediments composing the Cambro-Ordovician formations within the Valley and Ridge province of East Tennessee has not always been constant. During all of Rome and most of Conasauga deposition, clastic debris was predominant to the northwest whereas non-clastic material was more abundant to the southeast. During the subsequent Knox deposition, except for a few relatively thin sandstone beds, only carbonate material was deposited. On the basis of a regular chert increase in a northwesterly direction, Rodgers (1953, p. 60) believes the source area during the deposition of the Knox was still located to the northwest. At the end of Early Ordovician time, following the deposition of the Knox formation, there was a period of sub-aerial erosion following which the seas re-advanced and this time deposited a higher proportion of clastic sediments to the southeast rather than to the northwest. This reversal of clastics from the northwest to the southeast probably indicates that a major change in the direction of the source area occurred between Middle Cambrian and Middle Ordovician time.

Rodgers (1953, p. 60) suggests:

> The same area to the northwest that furnished sand to the Rome sea, and mud to the Conasauga sea, presumably the Canadian shield and its southward extensions, was virtually a peneplain during the deposition of the Knox, undergoing deep chemical weathering and furnishing chiefly the products of chemical decay: silica and carbonates. Only in Middle Ordovician time did significant amounts of detrital sediment, and then from a "normal" southeastern source, reappear in what is now East Tennessee.

Within the Valley and Ridge province of East Tennessee layers of dolomitic sandstone occur at the base of the Late Cambrian Copper Ridge formation (basal Knox). This lowermost sandstone underlies about 3000 feet of Upper Cambrian to Middle Ordovician carbonates and overlies 350 to 2000 feet of

Upper and Middle Cambrian carbonates, and thus is important for mapping purposes as well as sedimentological research.

A study of some of the textural and petrographic variations of this Late Cambrian sandstone was made in an attempt to discover its source direction and perhaps to determine the nature of its origin. In order to evaluate regional trends, samples were collected from nearly all of the strike belts along which the sand is exposed in East Tennessee (See Plate II). From the samples collected, the median diameter, phi quartile deviation (sorting), roundness, and per cent feldspar were determined and plotted geographically so that regional trends could be more easily observed.

## Stratigraphy

The basal Knox sandstone studied crops out along many belts in East Tennessee (Plate II). Bridge and Oder (Bridge, 1956, p. 16) describe it from a measured section in the New Market, Tennessee, quadrangle as a thin, one to two inches thick, platy, sugary, brown sandstone and consider it to be the base of the Copper Ridge. The writer observed the sand to range from one-half to eighty inches in thickness with a general thinning to the south and southwest (Plate I); as a consequence of the thinning, the sand may be easily overlooked in these areas. In the westermost strike belts the sandstone was not observed by the writer.

The sandstone on fresh exposure is a white-to-buff colored, moderately to highly indurated dolomitic quartz sandstone with some silica and local limonite cement. Upon weathering the sandstone is leached and becomes extremely friable, altering to a more reddish or reddish brown color. Some of the beds appear massive when fresh, but weathering reveals thin lenses of clay along dolomitic partings. The weathered outcrop thus appears as a more thinly bedded sand zone with layers ranging from one-half to twelve inches in thickness. The sandstone-dolomite contacts are sharp in some places and gradational in others; no evidence of an unconformity was seen.

## Physiographic Setting

Outcrops of this sandstone are confined to the Valley and Ridge province, known locally as the Great Valley of East Tennessee; here the valley attains a maximum width of forty miles. To the west the sandstone, if it exists, is buried under the more recent sediments of the adjacent Appalachian Plateaus province or Cumberland Plateau section. To the east lies the Blue Ridge province, which consists mostly of metamorphosed sedimentary rocks and some igneous rocks.

## Structural Setting

The strata within the Valley and Ridge province have been intensely folded and faulted by compression forces from the southeast. Subsequent erosion has removed the upper part of the folded and faulted strata and exposed the sandstone in a series of sub-parallel strike belts throughout the eastern half of the valley floor. The resulting frequency of exposures has unfortunately been accompanied by a telescoping of the strata which reduced the width of the geosyncline many miles. For this reason direct distance relationships can be made only along the same strike belt.

## Previous Work

To the writer's knowledge, no study has been made of this basal Knox sandstone over the general area described in this

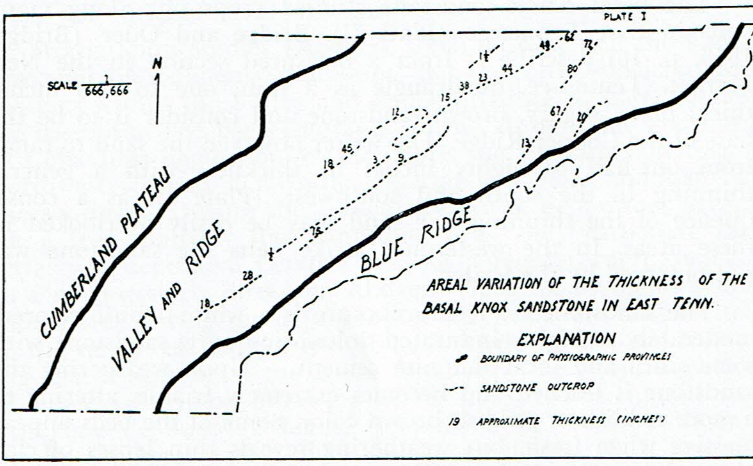


Plate I

paper. Robert L. Wilson (personal communication) used this sandstone to map the contact between the Maynardville formation and the Copper Ridge formation in the Maryville area south of Knoxville. C. E. Prouty (1936) made a similar study of the basal Chepultepec sandstone around the Norris Reservoir region. R. L. Nicholas (1956) made a study of the arenaceous beds of the Conococheague (Copper Ridge equivalent) limestone in Virginia.

## Sampling Procedure

Samples were generally collected at roadcuts along the nonfaulted contacts between the Maynardville and Copper Ridge as determined from Rodgers' (1953) Geologic Map of East Tennessee. Since the Copper Ridge with its cherty residual soil is easily distinguished from the underlying Maynardville, the

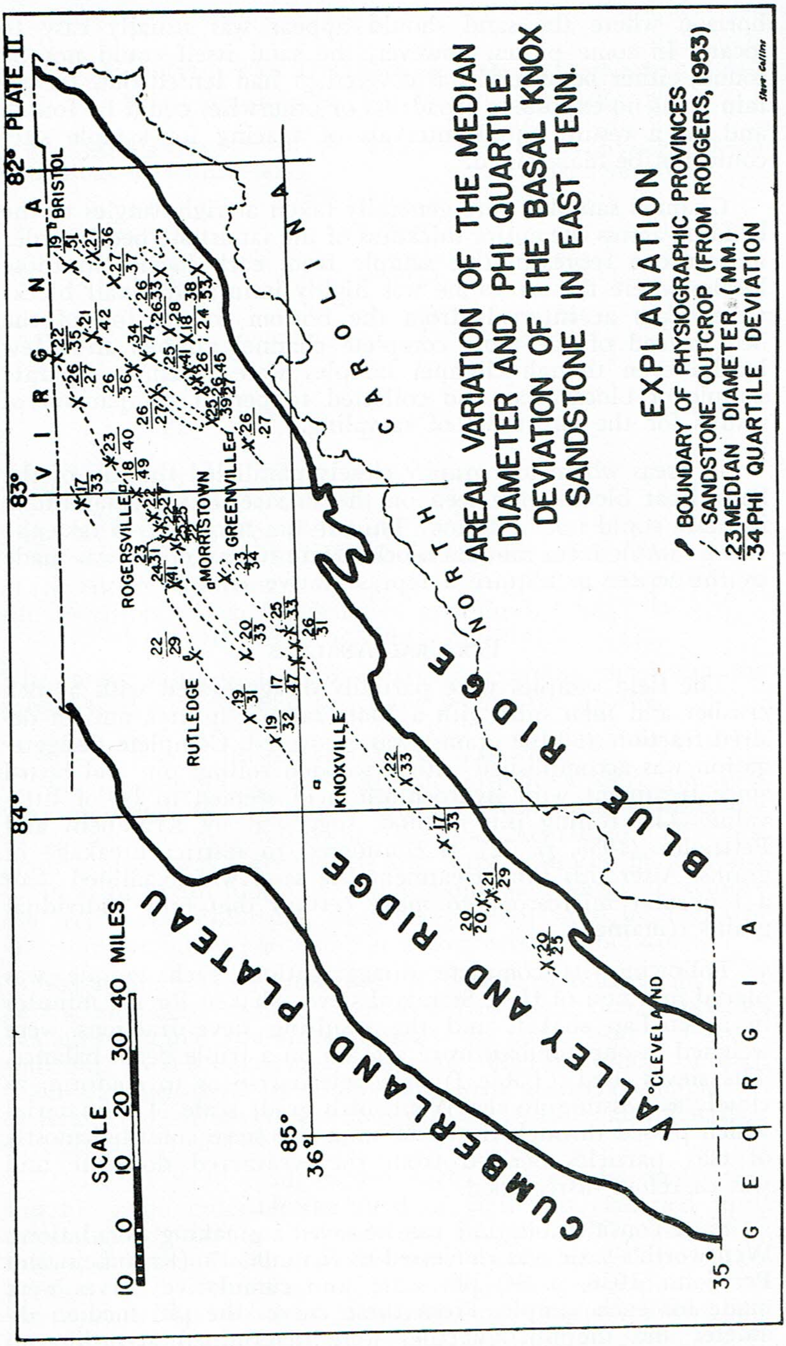
PLATE II
AREAL VARIATION OF THE MEDIAN DIAMETER AND PHI QUARTILE DEVIATION OF THE BASAL KNOX SANDSTONE IN EAST TENN.
EXPLANATION
BOUNDARY OF PHYSIOGRAPHIC PROVINCES
SANDSTONE OUTCROP (FROM RODGERS, 1953)
.23 MEDIAN DIAMETER (MM.)
.34 PHI QUARTILE DEVIATION
SCALE
10 0 10 20 30 40 MILES
VIRGINIA
NORTH CAROLINA
GEORGIA
CUMBERLAND PLATEAU
VALLEY AND RIDGE
BLUE RIDGE
BRISTOL
ROGERSVILLE
MORRISTOWN
GREENVILLE
RUTLEDGE
KNOXVILLE
CLEVELAND
82°
83°
84°
85°
36°
35°

PLATE II

horizon where the sand should appear was usually easy to locate. In some places, however, the sand itself could not be found, either because it was covered or had lensed out. In certain areas no exposures (roadcuts or otherwise) could be found, and, as a result, equal intervals of spacing for sample sites could not be maintained.

Channel samples were generally taken at right angles to the bedding across the entire thickness of the sandstone bed in order to secure a representative sample from each locale. In those locales where the sandstone was highly indurated, small blocks were taken at intervals from the bottom to the top of the bed instead of the more complete channel sample. In a few locales even though channel samples were taken, a separate sample of blocks was also collected to permit comparison of results for the two types of sampling.

In areas where topography closely paralleled the dip of the beds, float blocks were seen on the surface, but the sandstone in place could not be found. Thus it was necessary to take the entire sample from random blocks. Here too an effort was made by the writer to acquire a representative sample.

## Textural Analysis

The field samples were partially disaggregated with a rock crusher and then split with a Jones sample splitter until a desired fraction (50-100 grams) was recovered. Complete disaggregation was accomplished with a wooden rolling pin and board since treatment with hydrochloric acid seemed to be of little value. The rolling pin method, suggested by Krumbein and Pettijohn (1938, p. 72), is considered to restrict breakage of grains. After this final treatment the sand was examined with a binocular microscope to make certain that only individual grains remained.

Following its complete disaggregation, each sample was placed in a nest of U. S. Standard sieves, shaken for ten minutes in a Ro-Tap shaker, and the resulting sieve fractions were weighed to one-hundredths of a gram on a triple beam balance. The sieves used (Table I) were selected so as to conform, as closely as possible, to the Wentworth grade scale. The material which passed through the 0.062 mm. size sieve consisted mostly of clay particles derived from the weathered dolomite and was therefore disregarded.

Since considerable time can be saved in making calculations, Wentworth's scale was converted to Krumbein's (Krumbein and Pettijohn, 1938, p. 84) phi scale and cumulative curves were made for each sample. From these curves the phi median diameter and the phi quartiles were determined according to

TABLE I

COMPARISON OF OPENINGS OF THE SIEVES USED WITH DIVISIONS OF THE WENTWORTH SCALE

| Sieves Used (Openings in Millimeters) | Divisions of the Wentworth Scale (in Millimeters) |
|---|---|
| 1.000 | 1.000 |
| .710 | .707 |
| .500 | .500 |
| .350 | .354 |
| .250 | .250 |
| .177 | .177 |
| .125 | .125 |
| .088 | .088 |
| .062 | .062 |

the accepted methods of sedimentology (Krumbein and Pettijohn, 1938, p. 234). For the reader's convenience the phi median diameter was reconverted to the millimeter value. The spread of the curves or sorting was expressed as QD Phi, the phi quartile deviation, which is calculated as follows:

$$\text{QD Phi} = (Q_3\text{Phi} - Q_1\text{Phi})/2.$$

The larger value of the phi quartile deviation, the wider the spread of the curves, and hence the poorer the sorting.

## ROUNDNESS MEASUREMENT

The one-eighth to one-sixteenth millimeter sieve fractions were quartered for two single and seven composite samples until an amount approximating one gram remained. This one gram sample was next boiled for three minutes in a dilute solution of hydrochloric acid and stannous chloride to remove the iron stain. Following this, the samples were impregnated and thin sections were made in a commercial laboratory.

Krumbein (1941) published a visual roundness chart of pebble silhouettes whose roundness had been determined by Wadell's original roundness formula to range from 0.9 (well rounded) to 0.1 (extremely angular). The roundness of each grain was estimated by comparison with a special adaptation of Krumbein's silhouettes proposed by F. D. Bloss and described by Stickney (1955).

Traverses were made across each thin section and every suitable grain entering the field of view was classified until approximately fifty grains had been examined. The roundness values of the individual grains were then averaged to obtain a value for the whole sample. To eliminate personal bias, the writer made the roundness measurements without knowing the location of the sample. Occasional grains exhibited secondary enlargement and in many cases the edges of the quartz grains appeared to have been corroded markedly by the carbonate cement. Grains showing these features were excluded from the roundness determinations. The results of the roundness study are illustrated in Plate III.

## Petrography

The sandstone consists dominantly of quartz with minor amounts of feldspar, chert, and occasional heavy mineral accessories such as zircon, tourmaline, and opaque minerals. Although no formal heavy mineral analysis was made, tourmaline, zircon, and opaque minerals seemed to become more abundant toward the northeast. The dominant cement is dolomite, though a few samples were cemented by silica and more rarely by limonite. According to Grout's terminology the sandstone could generally be classified as a calcareous quartz sandstone (Grout, 1932, p. 275). However, those samples where the feldspar content is greater than ten percent may be better classified as feldspathic sandstones (Pettijohn, 1949, p. 227).

The majority of the quartz grains appeared to be normal, clear, igneous quartz (Krynine, 1940, p. 15). They contained no strain shadows and few inclusions. Another variety which characteristically contained many inclusions and exhibited undulatory extinction was considerably less abundant. Some of the grains of this type possessed an extinction resembling microcline twinning and could easily be mistaken for microcline, Under Krynine's classification (1940, p. 17), these grains could be called modified igneous quartz or possibly a metamorphic variety.

Chert particles, usually well rounded, were noted quite frequently in the southern and southwest samples.

Since feldspar seemed to be the most abundant, relatively unstable mineral, the per cent frequency of feldspar grains in each (unsieved) sample was determined by counting. As was done for the roundness studies, each sample was quartered and freed of iron stains; it was then mounted and studied in an oil of index 1.538. Since the common potash and soda rich feldspars have an index of less than 1.538 whereas the quartz has a greater index, the Becke line method was usable to distinguish these feldspars from quartz. The calcium-rich feldspars are subject to quick destruction so that the systematic error introduced by using this method is probably slight. In general, the feldspars were also recognized by their cleavage traces, altered appearance, twinning, and the higher degree of roundness. Interference figures were used to determine the identity of grains which looked anomalous.

Random traverses were made across the scattered grains until a minimum of three hundred grains had been counted. The

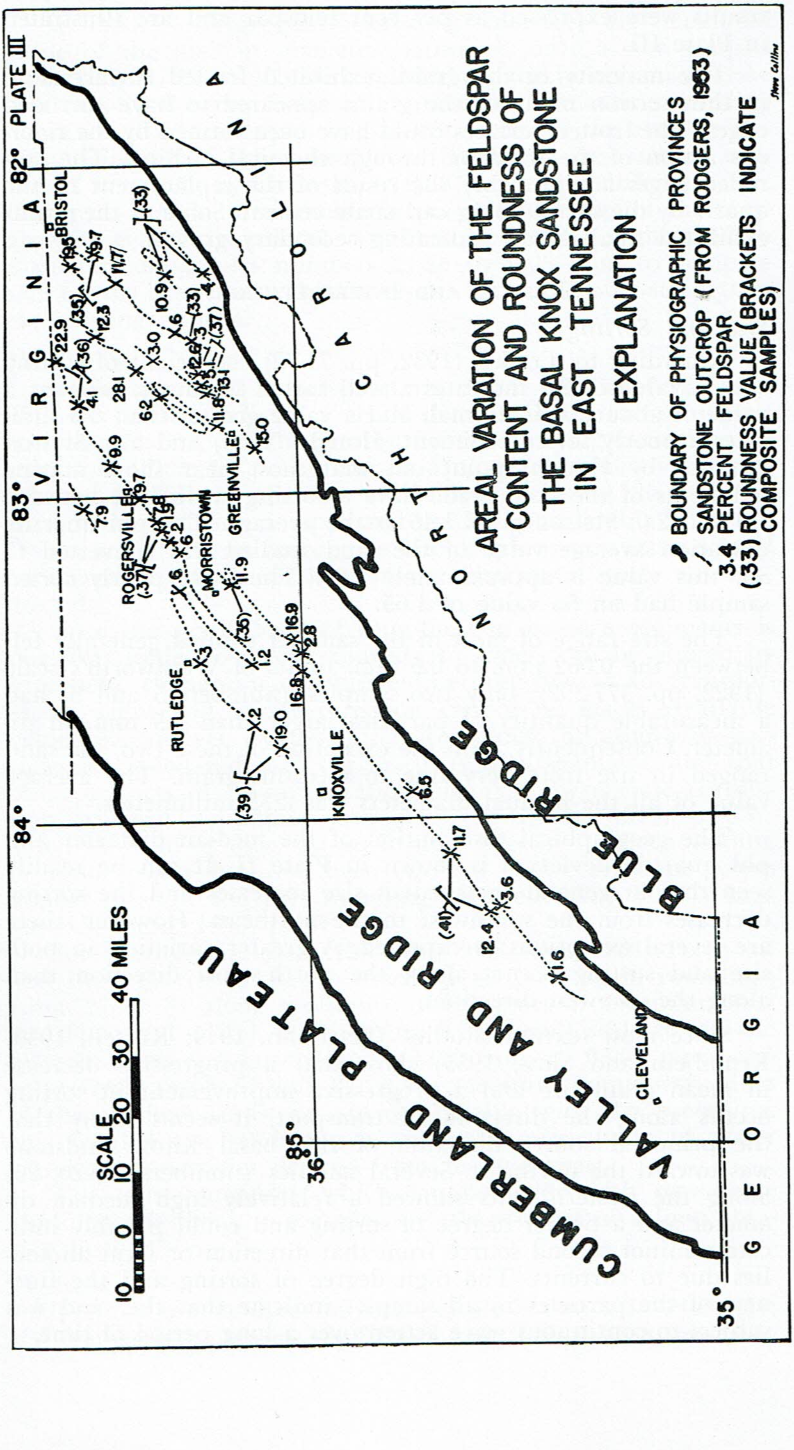
PLATE III
AREAL VARIATION OF THE FELDSPAR CONTENT AND ROUNDNESS OF THE BASAL KNOX SANDSTONE IN EAST TENNESSEE
EXPLANATION
BOUNDARY OF PHYSIOGRAPHIC PROVINCES
SANDSTONE OUTCROP (FROM RODGERS, 1953)
3.4 PERCENT FELDSPAR
(.33) ROUNDNESS VALUE (BRACKETS INDICATE COMPOSITE SAMPLES)
SCALE
0 10 20 30 40 MILES
VIRGINIA
NORTH CAROLINA
GEORGIA
BLUE RIDGE
VALLEY AND RIDGE
CUMBERLAND PLATEAU
BRISTOL
GREENVILLE
ROGERSVILLE
MORRISTOWN
RUTLEDGE
KNOXVILLE
CLEVELAND
82°
83°
84°
85°
36°
35°

PLATE III

results were expressed as per cent feldspar and are illustrated in Plate III.

The majority of the grains exhibited frosted surfaces and in thin section many of the grains appeared to have corroded edges. The frosted surfaces could have been formed by the rigorous action of the wind or through chemical etching. The corroded edges are probably the result of the replacement of the quartz by the surrounding carbonate cement. Some of the grains exhibited small facets indicating secondary growth.

## Results and Interpretations

### *Size and Sorting*

According to Trask's (1932, pp. 71-72) coefficient of sorting (So) a value of 2.5 indicates a well sorted sediment, whereas a value of about 3.0 is normal, and a value greater than 4.5 indicates a poorly sorted sediment. Hough (1940) and also Stetson (quoted by Hough) point out that most near shore marine sediments of the sand grade have a sorting coefficient between 1.0 and 2.0; Stetson gives 1.45 as the average. The phi quartile deviation average value of the sand studied was converted to So; this value is approximately 1.25. The most poorly sorted sample had an So value of 1.65.

The size range of most of the samples studied generally fell between the 0.062 mm. to 0.5 mm. limits of Wentworth's scale (1922, pp. 377-392); only two samples (numbers 5 and 9) had a measurable quantity of particles larger than 0.5 mm. in diameter. Consequently, with the exception of these two, the sand ranged in size from very fine to medium grain. The average value of all the median diameters was .233 millimeters.

The geographical distribution of the median diameter and phi quartile deviation is shown in Plate II. It can be readily seen that in general the median size increases and the sorting decreases from the southwest to the northeast. However there are several exceptions as expected. A greater variation in both size and sorting occurs along the north-south direction than along the east-west direction.

Since most textural studies (Pettijohn, 1949; Russell, 1939; Krumbein and Sloss, 1955) show that a progressive decrease in mean grain size and a progressive improvement in sorting occurs along the direction of transport, it seems likely that the principal source direction of this basal Knox sandstone was toward the northeast. Several samples (numbers 18, 20, 26) along the western belts showed a relatively high median diameter and a poorer degree of sorting and could possibly indicate a minor second source from that direction or local anomalies due to currents. The high degree of sorting and the fineness of the particles in all samples indicate that the sand was subject to continuous wave action over a long period of time.

Secondary overgrowths obviously increase the measured value of the median diameter. However, only a few samples (numbers 24, 25, 26, 27, 28) located along the westernmost strike belt contained overgrowths in abundance. The average median diameter of these samples is 0.23 mm. whereas the average median diameter of those samples adjacent to these which contained very few overgrowths is 0.20 mm. The difference, i.e. 0.03 mm., may be attributable in part to the effect of the overgrowths as well as to local variation. Reduction of the median diameters of samples numbers 24-28 by 0.03 mm. to compensate for the presence of these overgrowths would only strengthen the existing pattern.

*Roundness*

Roundness measurements on the 0.062 mm. to 0.125 mm. diameter grains indicate a small decrease from the southwest to the northeast with the greatest difference along a north-south direction (Plate III). The highest average roundness value was .41 and the lowest .33. The grains larger than 0.125 mm., although not measured, appeared to be considerably rounder. It was noted that an increase in size of grains was accompanied by increased roundness; however, no systematic study was conducted.

Since the significance of roundness in modern sediments is not fully understood and, indeed, roundness can be altered by diagenetic changes, a conclusive interpretation as to transportating agent and source direction cannot be made. Available evidence, however, suggests that roundness of sand size particles is a good index to the maturity of a sediment, and that only products of a long abrasion history show a close correlation between roundness and size (Pettijohn, 1949, p. 53). Whether wind or wave action is most effective in the rounding of sand grains has not been proven. However, dune sands appear to show the best rounding (Russell, 1939, p. 37; Beal and Shepherd, 1956, p. 51).

For particles in the 0.125 mm.-0.088 mm. class, Pettijohn and Lundahl (1943, p. 74) observed an increase in roundness from .27 to .31 along a distance of transport of six miles. Beal and Shepherd (1956, p. 51) using Krumbein's scale found the average dune and beach sand (0.125 mm. to 0.062 mm. size) respectively to be .51 and .37. If the measured roundness values of this ancient sandstone are comparable with the preceding, this basal Knox sandstone is composed principally of water transported particles derived from the northeast.

The only conclusion which can be made with reasonable confidence is that the particles are the product of a long abrasion history.

*Feldspar*

The per cent feldspar of each sample is shown in Plate III; the average is approximately 8.3 per cent. This value is probably high because the per cent was calculated by the counting method whereby (1) the small grains were given a weight equal to the large grains and (2) the feldspar tended to be more abundant in the smaller grain sizes. The areal variation of the feldspar content exhibits no constant trend although, with a few exceptions, the highest values occur to the north and northeast.

Since the ratio of an unstable mineral to a stable mineral commonly decreases away from the source area, in the absence from tributary sources (Pettijohn, 1931), the feldspar content further indicates the likelihood that the principal source was to the north and northeast. The few relatively high values to the southwest can be attributed either to concentration of the feldspar in the finer grain sizes (to the southwest the sand was finer grained) or to a second minor source in that direction.

## Summary and Conclusions

Krumbein and Sloss (1955, p. 368) consider the Knox dolomite to be an example of miogeosynclinal sedimentation. However, they also believe that the sandstones associated with miogeosynclinal deposits are usually (1) graywackes to sub-graywackes, (2) "salt and pepper" sandstones, or (3) abnormally thickened shelf sandstones.

On the other hand, the sandstone at the base of the Knox appears to be an example of stable shelf deposition. The occurrence of the beds as thin, widespread deposits, the high quartz content, the small grain size, and the high degree of sorting and rounding appear indicative of extensive, stable conditions of sedimentation with considerable transportation and winnowing of the particles before final deposition. It is therefore suggested by the writer that during the deposition of this sandstone the conditions within the miogeosyncline approximated those of a stable shelf environment.

According to Pettijohn (1949, p. 242) secondary overgrowths (if formed penecontemporaneously with deposition) indicate chemical attack on the rocks that have been exposed over a peneplained land area. Rodgers' (1953, p. 60) suggestion that the source to the northwest was under strong chemical attack is strengthened by the presence of relatively abundant quartz overgrowths in that direction.

The sand studied generally becomes progressively thicker, coarser, and more poorly sorted to the north and northeast. Increasing percentages both of feldspar and of modified igneous or metamorphic quartz plus a decrease in roundness toward these directions also indicate that the principal source of the sediments probably lay to the north and northeast. The local anomalies in grain size, per cent feldspar, and sorting exhibited by a few samples from the westernmost belts could possibly indicate either a minor second source or possibly a minor variation in current directions and competency.

The relative abundance of chert and abraded overgrowths in some samples and their absence or relative scarcity in other samples indicate a mixture of first and second cycle sediments.

Krynine (1940, p. 84) suggests that the peneplained area which existed in Late Cambrian time was broken by a few granitic monadnocks which furnished some of the feldspathic sandstones of the Upper Cambrian.

The writer suggests that a terrane of highly feldspathic rocks, possibly granitic and metamorphic, lay to the north and northeast which furnished the bulk of the sediments, whereas a minor source may have lain some distance to the west. It must be emphasized, however, that present evidence is not conclusive.

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