QUANTITATIVE EXAMINATION OF IMMATURE SANDSTONES BY POINT-COUNT AND X-RAY MODAL ANALYSIS

By T. Finlow-Bates*

ABSTRACT

A region of hitherto undifferentiated Jurassic immature sandstones from the western side of the North Island of New Zealand was separated into two lithofacies (I and II) by visual examination and the separation confirmed by point-count analysis. Comparison of the modal compositions obtained by X-ray and point-count methods suggest that the volcanic material of lithofacies II is more acid than lithofacies I and that lithofacies II has been subject to greater diagenetic alteration.

SUMMARY

Quantitative results obtained by point-counting immature sandstones are susceptible to very large errors. Failure both to appreciate the magnitude of counting and sampling errors and to standardise or at least state the basis for operator decisions, make comparisons between the results of different workers of doubtful reliability. A discussion of counting, sampling and operator errors are included to acquaint the reader with the basis of the author's conclusions.

A region of hitherto undifferentiated Jurassic immature sandstones from the western side of the North Island of New Zealand was separated into two lithofacies (I and II) by visual examination and the separation confirmed by point-count analysis. Lithofacies II contained a higher percentage of rock fragment material and a greater proportion of volcanic rock fragments compared to lithofacies I. X-ray diffraction modal analysis, when carefully interpreted, provided useful additional information. Comparison of the modal compositions obtained by X-ray and point-count methods suggested that the volcanic material of lithofacies II is more acid than lithofacies I and that lithofacies II has been subjected to greater diagenetic alteration.

INTRODUCTION

Welsh (1967), working on immature sandstones in Scotland, claimed it was difficult to compare reliably his quantitative mineralogical results with those of other authors working on similar rocks in neighbouring areas. This situation also appears to have arisen amongst New Zealand workers on immature sandstones (e.g. Elliot, 1967; Mayer, 1969). The use of point-counting as the only method to obtain modal data, and a lack of recognition of the errors associated with the method, are thought to have contributed greatly to this problem. Petrographic examination of immature sandstones of probable Jurassic age from an area east of Otorohanga suggested that they could be separated into two distinct lithofacies. Modal analysis by point-counting and X-ray diffraction (Nelson and Cochrane, this issue) was carried out in an attempt to confirm this suggestion.

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FIG. 1. Locality map showing boundary between lithofacies I and II.
METHODS AND THEIR ASSOCIATED ERRORS

Point-counting

Fourteen thin sections, seven from each suspected lithofacies, were chosen as representing the compositional limits of each facies, and point-counted using a Swift point-counter and stage. In order to obtain maximum reliability of results for the time spent point-counting, considerable importance is attached to the choice of point-count area, the distance between the points, and the number of points to be counted. By isolating and defining two types of error, expressed here as counting and sampling errors, one can find the ideal arrangement of these variables.

Counting Error

Van der Plas and Tobi (1965) state that "when a modal analysis of a thin section is made, there is obviously a relationship between the number of points counted and the accuracy of the result". The area of a thin-section that is point-counted will possess a certain composition. The statistically small fraction of this area that influences the point-count (i.e. the number of points) will indicate a composition that deviates from the true composition. The difference between these two values is the counting error. Since the true composition is not known one can only express the counting error statistically as a probable error that can be assessed by considering the standard deviation as follows:

If \( p \) is the true volume percentage of material within a point-count class and \( n \) is the total number of counts made then \( \sigma \), the standard deviation, is defined as \( \sqrt{\frac{p(100-p)}{n}} \) and our point-count value has a 68% chance of falling within \( p \pm \sigma \). Because this gives such a wide margin of error it is preferable to regard the probable error as \( p \pm 2\sigma \). This factor is called the counting variance (Vc) and there is then a 95% chance that the point-count value will fall in this range. Since \( p \) is the value we are trying to find it is a reasonable approximation to use the estimated value (\( p' \)) to find Vc. The graph constructed by Van der Plas and Tobi (1965) has been used to calculate Vc.

Sampling Error

The preceding section discussed how closely the point-count results approximate the true composition of the area of the thin section analysed. It is now necessary to consider how closely the composition of the area of thin section studied relates to the composition of the whole rock. Obviously 10 square centimetres of a conglomerate are not as representative of the total rock as 10 square centimetres of a fine sandstone. Although such sampling problems cannot as yet be considered theoretically, an empirical method has been developed by Bayly (1960).
Bayly defines sampling variance (Vs) as a function of the area of the thin section analysed and the coarseness of the rock, such that

\[ Vs = \frac{2200 \, p' \, (100 - p')}{A \, (IC)^2} \]

where

- \( p' \) = estimated percentage of material within a point-count class
- \( A \) = the area of the thin section analysed
- \( IC = \frac{1250}{\text{length of a line crossing 50 grains}} \)

Bayly provides tables to facilitate rapid assessment of this error.

**Expected Standard Error**

To get a relation between Vs and Vc Bayly defines the expected standard error \( Ep \), as \( \sqrt{Vs + Vc} \). This function allows assessment of the optimum values for Vs and Vc and hence for point-count distance and area. It is of little value to increase the total number of points counted if the sample error is already larger than the counting error.

For example, suppose:

\[ p' = 10\% \text{ and } Vc = \pm 3\% \text{ (for 400 counts)} \]

and \( Vs = \pm 5\% \)

then \( Ep = \sqrt{8} = 2.828 \)

By doubling the count, if \( p' = 10\% \) then \( Vc = \pm 2.2\% \) and \( Ep = \sqrt{7.2} = 2.683 \). Hence twice the effort has only decreased the expected standard error by an insignificant amount. However, Bayly's claim that the ideal situation is when Vs = Vc is difficult to justify. Since Vs is the easiest error to alter it seems sensible to reduce it as far as possible. For this reason in this study the maximum area possible (limited by the maximum point-count distance on the Swift point counter) was analysed. For studies where an absolute magnitude for sampling error is not desired the error can be considered insignificant when the point-count distance is larger than the largest grain. The 0.3 mm maximum distance of the Swift stage is therefore a serious handicap for studies on coarse grained rocks.

In view of the magnitude of operator errors (see below) a long count was not justified in the present study. Typical values for Vc read from the graph of Van der Plas and Tobi (1965) for the 400 points counted are:
Typical values for Vs are

\[
\begin{align*}
p' &= 80\% & V_c &= \pm 4\% \\
p' &= 50\% & V_c &= \pm 5\% \\
p' &= 20\% & V_c &= \pm 4\% \\
p' &= 10\% & V_c &= \pm 3\% \\
p' &= 5\% & V_c &= \pm 2\% \\
\end{align*}
\]

A count of 800 points would have reduced \( V_c \) by only one or two percent.

**Operator Errors**

Despite the magnitude of counting and sampling errors in point-counting it is probably operator error that has caused the greatest discrepancy between the results of different workers on immature sandstones. In these rocks one of the most important operator decisions is the distinction between altered rock fragment material and matrix.

Most authors have defined matrix as material with a grain size less than 0.02 mm. The writer believes it is this totally inadequate definition that has led to much of the so-called greywacke matrix controversy. Different workers have undoubtedly made quite different decisions as to what is and what is not matrix. For example, chloritised and sericitised rock fragments, sericitised feldspars, soft mudstone fragments squashed between grains, and the chlorite commonly found between sutured grain contacts, have variously been regarded as matrix by certain authors and not by others. Patches of secondary minerals are commonly regarded as matrix if less than 0.02 mm but are arbitrarily discarded if they become larger.

An example of varying interpretation based on varying definition is provided by studies on immature sandstones of the Permian-Jurassic Waipapa Group in Northland. Elliot (1967) disagreed with the argument of Mayer (1965) concerning the origin of matrix in these rocks. Mayer claimed that if the theory of a secondary origin for matrix (Cummins, 1962) is correct then all similar rocks of the same age should have the same matrix content. This writer agrees with Elliot's argument that secondary matrix formation is probably dependent on the availability of water (a highly variable component) and hence similar rocks could have very different matrix contents. Elliot then suggested that secondary matrix formation is a function of time and claimed, directly from the
point-count data, that since the older Permian rocks of his study contained a higher content of matrix (28.4% to 72.2%) than did Mayer's Jurassic rocks (3.8% to 50.4%), then the matrix of the Waipapa Group is most likely secondary. However, an investigation of Elliot's thin sections shows they contain a very large quantity of highly altered discrete volcanic rock fragments that were assigned to matrix by Elliot. Study of Mayer's work indicates that he placed only very highly altered fragments in the matrix class. This means that both writers in their discussions on the origin of matrix are attempting to explain the formation of two different, though related, phenomena and hence would be unlikely to come to the same conclusion. It should be obvious that if highly altered material is counted as matrix (which may be achieved by point-counting with the nicols crossed) then a secondary matrix will be favoured. It is procedures and decisions such as these that led Welsh (1967) to conclude that it is difficult to compare reliably the modal analyses of different workers on immature sandstones. Such a comparison would be possible if authors would define, and perhaps standardize, their terms.

In this study point-count modal analysis was carried out to provide information on provenance and hence any material that fell beneath the cross hairs was judged initially as a mineral or rock fragment. If it was at all possible to assess the original nature of a component before alteration it was assigned to that class. Discrete sedimentary material that had been squeezed between the harder fragments were counted as non-indurated sedimentary rock fragments. Zones of crushing and patches and veins of secondary minerals were omitted entirely as they give no evidence on provenance. Because the feldspar was often untwinned in composite quartz-feldspar rock fragments it was difficult to separate them from composite quartz fragments and as a result both were placed in the same point count class.

X-RAY MODAL ANALYSIS

X-ray modal analysis was undertaken to give information on the total mineral composition of the rock. By comparison with the point-count totals of the mineral species present some idea is gained of the gross mineralogical composition of the rock fragments. Nelson and Cochrane (this issue) discuss two problems of the X-ray method that became critical in the rocks studied; namely the problems of accurately determining:

1) the clay percentage when it is high
and
2) the total feldspar percentage when a number of different feldspar compositions are present in the same sample.

The clay percentage is uncertain because it is gauged from a non-basal peak whose height is greatly affected by the ordering of the
TABLE I: Point-count modal analyses of the sandstones

<table>
<thead>
<tr>
<th>Specimen</th>
<th>LITHOFACIES I</th>
<th>LITHOFACIES II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17283 17282 17285 17290 17289 17260 17262</td>
<td>17276 17272 17291 17281 17268 17279 17294</td>
</tr>
<tr>
<td>Fresh Quartz</td>
<td>3 4 2 3 4 3 3</td>
<td>4 0.5 3 1 1 4 5</td>
</tr>
<tr>
<td>Strained Quartz</td>
<td>13 9 13 8 13 7 12</td>
<td>6 2 8 1 tr 8 3</td>
</tr>
<tr>
<td>2nd Cycle Quartz</td>
<td>2 0.5 7 4 1.5 8 1</td>
<td>3 3 3 - tr - 2</td>
</tr>
<tr>
<td>Comp. Q and Q-F</td>
<td>13 5 20 10 5 7 4</td>
<td>7 1 5 tr 2 2 6</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>13 7 25 8 12 6 9</td>
<td>4 3 4 8 5 6 8</td>
</tr>
<tr>
<td>Potassium Feldspar</td>
<td>tr tr tr tr 0.5 1</td>
<td>tr 0.5 - tr - tr tr</td>
</tr>
<tr>
<td>V.R.F.</td>
<td>28 40 10 40 35 41 39</td>
<td>51 62 55 71 72 57 54</td>
</tr>
<tr>
<td>I.S.R.F.</td>
<td>1 3 1 4 6 6 8</td>
<td>6 1 5 6 6 7 5</td>
</tr>
<tr>
<td>N.I.S.R.F.</td>
<td>4 6 4 3 2 7 5</td>
<td>2.5 6 tr 3 4 4 3</td>
</tr>
<tr>
<td>M.R.F.</td>
<td>17 15 12 8 10 8 7</td>
<td>6 4 8 1 2 2 8</td>
</tr>
<tr>
<td>Accessories</td>
<td>4 6.5 4 6 6.5 1.5 3</td>
<td>1.5 4 3 3 2 4 2</td>
</tr>
<tr>
<td>Matrix</td>
<td>2 4 2 6 5 5 8</td>
<td>9 13 6 6 6 6 4</td>
</tr>
</tbody>
</table>

Comp. Q and Q-F = composite quartz and quartz-feldspar grains; V.R.F. = volcanic rock fragments; I.S.R.F. = indurated sedimentary rock fragments; N.I.S.R.F. = non-indurated sedimentary rock fragments; M.R.F. = metamorphic rock fragments.

Specimen numbers refer to thin sections in the Geology Department collection, University of Auckland.
clay lattice. Also, because a small increase in peak height represents a large increase in clay content, the positioning of the base line can affect the clay total quite considerably.

Thin section study indicated that at least two plagioclase compositions were present in all the rocks. In many cases it was difficult to decide which of the minor X-ray peaks represented these discrete compositions. Accordingly, the samples were re-run at a slower speed across the major feldspar peaks and the likely positions of the important feldspars transferred to the quantitative scan. Because of the varying degrees of reliability the overall totals were not recalculated to 100%.
RESULTS AND DISCUSSION

When plotted on triangular diagrams (Figs. 2a and 2b) the point-count results (Table 1) give quite satisfactory differentiation of lithofacies I and II. For the triangular diagrams the composite quartz and quartz-feldspar fragments have been placed in the metamorphic rock fragment grouping since by observation this is thought to be their source. Although the boundaries of the two lithofacies are not separated by more than the expected errors of point-counting, the average points for both facies are well separated. Also, the points near the lithofacies boundary in the triangular plots are well separated geographically. Modal distinction between the lithofacies can be summarised as follows:

Lithofacies I — Well indurated grey-blue medium sandstones made up of less than 75% rock fragments of which less than 65% are of volcanic origin.

Lithofacies II — well indurated grey-blue medium sandstones made up of more than 75% rock fragments of which more than 70% are of volcanic origin.

The rocks of lithofacies I also contain appreciable quantities of quartz, feldspar and metamorphic rock fragments.

X-ray modal analysis indicates that lithofacies I has a greater percentage of feldspar than lithofacies II and slow scanning through 27° – 29° 2θ indicates that lithofacies I has the greater variation in feldspar composition (see Table 2). Lithofacies II contains more clay than lithofacies I. Petrographic examination suggests the high clay content of lithofacies II is more a function of diagenetic alteration of an initially high feldspar content rather than of depositional origin.

The point-count quartz totals for lithofacies I are substantially higher than for lithofacies II although the X-ray totals are only slightly greater. Therefore it seems likely that the source for lithofacies II provided a greater amount of acid volcanic material than that for lithofacies I. This relation is substantiated by visual examination of the thin sections but would not have been suspected without quantitative data.

When the sandstones were point-counted, a class of fine-grained material remained that did not fit into the mineral or rock fragment categories. This material was placed in the matrix class and existed
<table>
<thead>
<tr>
<th></th>
<th>LITHOFACIES I</th>
<th></th>
<th>LITHOFACIES II</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17283</td>
<td>17282</td>
<td>17285</td>
<td>17290</td>
</tr>
<tr>
<td>Quartz</td>
<td>19</td>
<td>21</td>
<td>32</td>
<td>20</td>
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<tr>
<td>Plagioclase (An$_{20-40}$)</td>
<td>28</td>
<td>25</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>Plagioclase (Albite?)</td>
<td>21</td>
<td>17</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Plagioclase (?)</td>
<td>6</td>
<td>8</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Potassium Feldspar</td>
<td>5</td>
<td>4</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Clay</td>
<td>18</td>
<td>21</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Calcite</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>97</td>
<td>97</td>
<td>96</td>
<td>82</td>
</tr>
</tbody>
</table>

Specimen numbers refer to thin sections in the Geology Department collection, University of Auckland.
mainly as thin bands of clay separating and apparently coating certain grains. It is uncertain whether this material was:

1) deposited as a coating on the grains during transport and deposition, as suggested by the presence of such coatings around quartz grains;

2) deposited as a free fine grained primary matrix, as suggested by its presence in small pools;

or

3) a later alteration product of the grain boundaries, as suggested by its most common occurrence around volcanic rock fragments.

The volume of this material is small (2 to 13%) and is directly, but weakly, proportional to the volume of volcanic and sedimentary rock fragments. From this relationship, and by observation, it is suggested that much of the matrix is of secondary origin. However the coatings around certain non-mafic mineral grains suggest that a little of this material was primary. Optical and X-ray study suggests a chloritic composition for this matrix.

ACKNOWLEDGEMENTS

The author wishes to record his thanks to Dr. P. F. Ballance for discussion and reading of the section of an M.Sc. thesis that this paper covers and to Mr. C. S. Nelson for help with the X-ray study and for critically reading the manuscript.

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