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# An evaluation of flysch provenance - example from the Gramscatho Group of southern Cornwall

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Recent work has suggested that plate tectonic environments can be reconstructed utilizing clast mode petrography and bulk geochemistry of flysch sandstones. An assessment of the relative effects of processes that may modify sedimentary composition is made by examining the clast modes, bulk geochemistry and general petrography within a graded turbidite unit of the Gramscatho Group. Within the medium-fine sand lower half of the turbidite unit, clast mode variation *is* limited. The geochemistry of the sample suite is dominated by the non-framework matrix mineralogy with progressive element enhancement in the more muddy fractions of the unit. Although variations in element absolute abundances occur as a function of grainsize-related matrix content, the ratios of many element pairs (e.g. Ti-K, Cr-Y) remain constant, implying no major change in matrix composition through the unit. Diagenetic, metamorphic and microstructural effects are the dominant controls on the modification of original sediment composition. These processes are qualitatively evaluated in terms of the relative effects they will have on the endmember compositions of the various provenance diagrams.

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## Introduction

The Gramscatho Group of southern Cornwall is divided into two main parts (Holder and Leveridge 1986) comprising a northern parautochthonous region separated from a series of allochthonous units to the south by the Carrick Thrust (Leveridge et al. 1984). Structural and sedimentological evidence exists within the Gramscatho Group for the inversion of a late Eifelian-Frasnian flysch basin during the Hercynian orogeny.

Distinction between the various plate tectonic models proposed for the evolution of the Rhenohercynian Zone (which invariably include the Gramscatho Group) is hampered by the lack of geological constraint. To this end Floyd and Leveridge (1987) utilized a new approach by combining analysis of both the petrography and geochemistry of Gramscatho flysch sandstones to determine their provenance and the possible tectonic setting of the Gramscatho basin.

## Provenance studies and objectives

Provenance is concerned with the determination of the nature, composition, identity and dimensions of the source rocks, relief and climate in the source area(s), and to some extent the effects of transportation. It is largely dependent upon petrographic analysis of the derived sediment and its ultimate goal is to establish a palaeogeography for the part of the crust in question.

The relationship between petrography and the correct evaluation of provenance as defined above is by no means straight forward. This paper attempts to assess (i) the major controls operating on the petrography of the derived Gramscatho sediments, and (ii) whether a petrographic and geochemical analysis of a single sample of a turbidite unit can be considered representative of the composition of the unit as a whole. The results are then considered in terms of the implications for plate tectonic determination via sediment provenance.

The data are derived from a detailed petrographic and geochemical study of a 1.7m thick turbidite unit from the Portscatho Formation at Pednvadan in Roseland (GR: SW 88253595).

## Petrographic methods

In order to quantify provenance, a system of petrographic variables is created which essentially describe the composition of a particular sandstone. The variables utilized in this study (Table 1) are similar to those reported by previous workers (e.g. Dickinson and Suczek 1979). Volcanic and metavolcanic lithics are reported together due to the inherent difficulties of separating the effects of intrabasinal and extrabasinal metamorphism in this category. The Qm(p) category is used to describe quartz grains > 0.0625mm present within other lithic grains (see below), and silt-sized material in the 0.03-0.0625mm range is recorded separately for completeness, but not included in the recalculated parameters.

The Gazzi-Dickinson method of point-counting is utilized (Ingersoll et al. 1984) which maximises information on source rock type. This tends to "filter out" transport-related modification of the provenance signature by minimizing the variation of modal composition with grainsize.

## Statistical considerations

Once the petrographic variables and counting technique have been established, a modal analysis of the sand-sized fraction (0.0625 - 2mm) is achieved by point-counting thin sections of the sample concerned. For acceptable reliability in the majority of the petrographic subclasses approximately 1000 points per sample have been counted for this study. The reliability of the reported result can be expressed in terms of ±2 standard

Table 1. Detrital modes used in present study.

Qm - Monocrystalline Quartz > 0.0625mm.

Qm(p) - Monocrystalline Quartz > 0.0625mm within a polycrystalline matrix.

Qp - Polycrystalline Quartz with average crystal size < 0.0625mm.

P - Plagioclase Feldspar > 0.0625mm. K - Potassium Feldspar > 0.0625mm.

Q+F- Quartz and Feldspar grains > 0.03mm but < 0.0625mm - (c. silt).

Lv/Lvm - Volcanic and metamorphosed volcanic rock fragments.

Lsm - Metasedimentary rock fragments.

Ls - Sedimentary rock fragments.

Phyllosilicates - Mainly Chlorite and Mica.

D - Opaques and heavy minerals.

Matrix - Material < 0.03mm (as long as not contained in a clast).

deviations (Van der Plas and Tobi 1965) which account for 95% of the expected error distribution about the recorded point. These statistical variations in sample populations are not the only source of error, as some Gramscatho sandstone grains are highly altered, or their nature obscure, such that misclassification is inevitable. Hence, the reported values of 2 standard deviations must be considered minimum values for the total counting errors.

## Controls on provenance

The operational limitations in terms of point-counting methods and the associated statistical considerations described above constrain our interpretation of the derived sediment composition. We now assess the relationship between the latter and the original source area composition(s) in terms of the individual processes that may cause a divergence of the two. These processes can be classified as either extrabasinal or intrabasinal.

## Extrabasinal processes

Very little direct evidence exists on which to base even a qualitative assessment of processes occurring within the extrabasinal area. However, consideration should still be given to the effects of climate, relief and transport processes within this domain and their control on the severity of weathering (see discussions in Suttner et al. 1981; Basu 1985; Ricci-Lucchi 1985).

## Intrabasinal processes

### *Final depositional mechanism at emplacement*

This represents the final stage of sediment transport and will generally transfer material to the deeper levels of the basin. Fluid dynamic processes operating during the deposition of deep-water sandstone-mudstone facies associations can be categorized as either selective or massive (Ricci-Lucchi 1985). Selective processes allow the sediment particles some degree of freedom and thus sorting can occur on the basis of size, shape and density. Massive processes tend to inhibit such behaviour and lead to very poorly sorted deposits in which compositional fractionation is unlikely. Most of the deposits within the Portscatho Formation of the Gramscatho Group have been deposited out of turbidity currents of varying densities and as such, turbulence will act as a supporting force that permits individual behaviour of grains to produce the characteristic vertical grading observed in the resulting bed. Hence compositional fractionation of the preremobilized shelf-edge sediment is a distinct possibility. In this context we need to know how representative a single sample collected from a turbidite unit is of the bulk composition of that unit.

### *Diagenesis, metamorphism and microstructural development*

In terms of the Gramscatho Group, sediment deposition was followed by deep burial and diagenesis, and subsequent deformation and metamorphism during the Hercynian orogeny (Holder and Leveridge 1986). These processes could obviously play a very important role in modifying sediment composition.

## Results

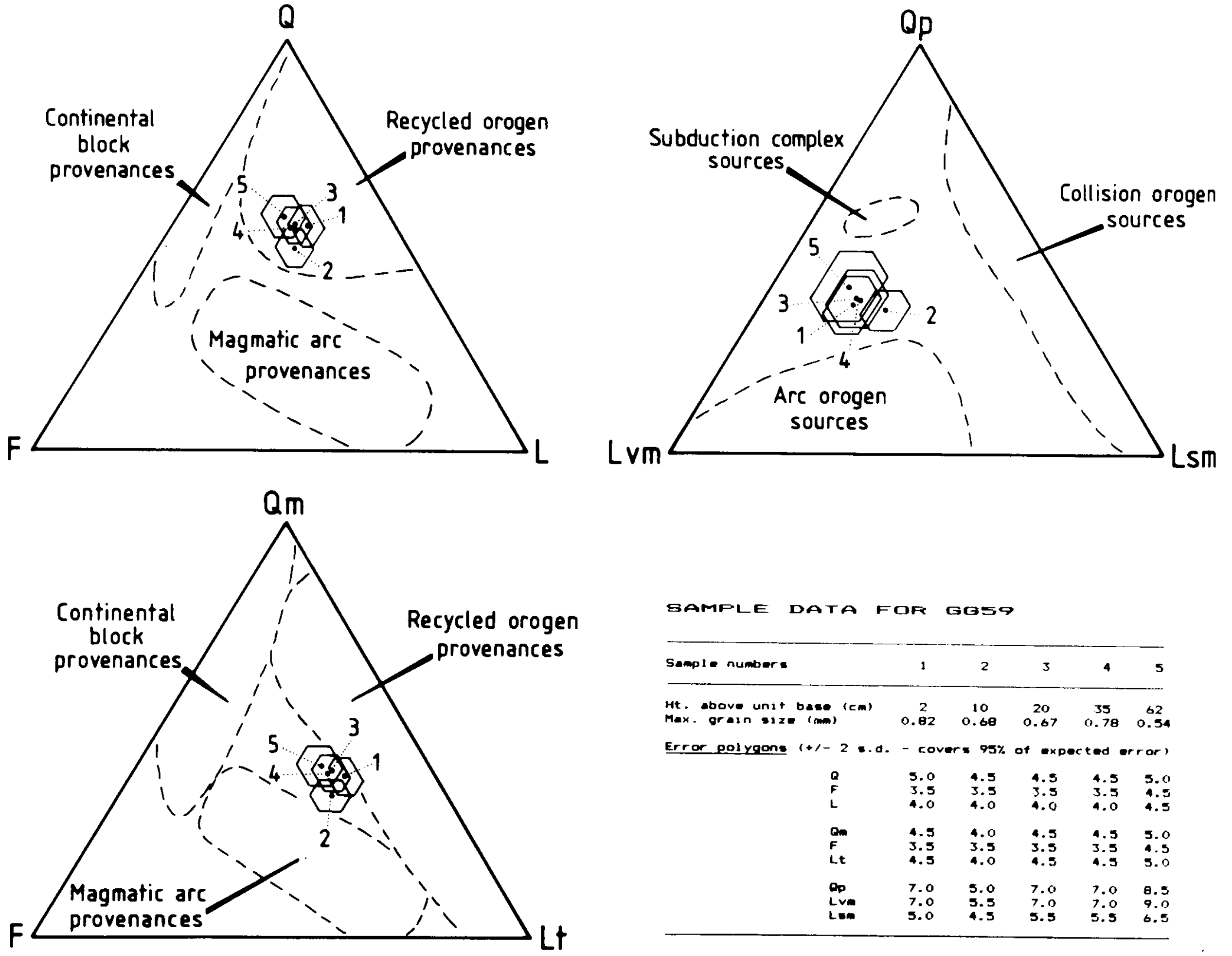
### *Data presentation and technique*

Nine samples (1-9) were taken at various heights from within the graded unit (field number GG59), so as to be representative of the various textural and possible compositional variations present. Five of these samples (1-5) were analysed petrographically by the methods previously described, whereas all samples were geochemically analysed for major and trace elements by XRF Spectrometry. Petrographic and geochemical data are presented in Table 2. An indication of grainsize was obtained by measuring the longest quartz grain axis present within each thin section, though grains showing truncation by cleavage seams or extremely large aspect ratios were not included. Such a measurement might be a more relevant indicator than modal grainsize of variation in flow competence as the turbidite was deposited (Sadler 1982). The modal grainsize values are considerably lower: samples 1-4 fall within the finer part of the medium sand category, samples 5-7 within the coarse to medium part of the fine sand category, whereas samples 8 and 9 represent silty muds.

Table 2. Framework modes and geochemical data for different sections of a Gramscatho turbidite unit (sample GG59).

| Smpl no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Ht above unit base(cm) | 2 | 10 | 20 | 35 | 62 | 80 | 115 | 140 | 170 |
| Framework modes (%) | | | | | | | | | |
| Q | 55 | 49 | 55 | 54 | 57 | | no | data | |
| F | 18 | 23 | 21 | 21 | 22 | | | | |
| L | 27 | 27 | 25 | 24 | 22 | | | | |
| Qm | 39 | 34 | 40 | 40 | 42 | | | | |
| F | 18 | 23 | 21 | 21 | 22 | | no | data | |
| Lt | 43 | 42 | 40 | 39 | 37 | | | | |
| Qp | 37 | 35 | 38 | 38 | 41 | | | | |
| Lvm | 45 | 39 | 43 | 43 | 43 | | no | data | |
| Lsm | 19 | 26 | 19 | 20 | 16 | | | | |
| Major oxides (wt.%) | | | | | | | | | |
| $SiO_2$ | 71 | 71 | 71 | 72 | 70 | 70 | 69 | 66 | 57 |
| $TiO_2$ | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.7 | 0.9 | 1.1 |
| $A1_2O_3$ | 13 | 13 | 13 | 13 | 14 | 14 | 14 | 16 | 20 |
| $Fe_2O_3$* | 5.1 | 4.6 | 4.6 | 4.6 | 4.9 | 4.6 | 5.1 | 5.8 | 8.1 |
| MnO | 0.1 | 0.1 | 0.1 | 0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| MgO | 1.8 | 1.6 | 1.6 | 1.6 | 1.7 | 1.6 | 1.7 | 2.1 | 2.7 |
| CaO | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 |
| $Na_2O$ | 2.8 | 3.9 | 3.1 | 3.2 | 3.1 | 3.5 | 2.8 | 2.1 | 1.5 |
| $K_2O$ | 1.7 | 1.7 | 1.6 | 1.6 | 1.8 | 1.7 | 2 | 2.8 | 4.1 |
| $P_2O_5$ | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| LOI | 2.1 | 2 | 2 | 2 | 2.2 | 2.3 | 2.6 | 2.9 | 4.4 |
| Total | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 100 |
| Trace elements (ppm) | | | | | | | | | |
| Ba | 420 | 417 | 414 | 402 | 457 | 463 | 485 | 624 | 888 |
| Ce | 43 | 41 | 50 | 60 | 51 | 55 | 47 | 61 | 76 |
| Cr | 95 | 90 | 91 | 94 | 96 | 96 | 92 | 108 | 129 |
| Cu | 13 | 8 | 12 | 10 | 10 | 14 | 16 | 21 | 30 |
| Ga | 15 | 15 | 16 | 13 | 16 | 16 | 13 | 18 | 27 |
| La | 35 | 35 | 39 | 39 | 34 | 39 | 39 | 43 | 55 |
| Nb | 7 | 6 | 5 | 6 | 7 | 7 | 8 | 10 | 14 |
| Nd | 18 | 23 | 45 | 26 | 58 | 45 | 52 | 65 | 56 |
| Ni | 43 | 41 | 44 | 40 | 48 | 48 | 46 | 53 | 60 |
| Pb | 12 | 12 | 15 | 14 | 17 | 19 | 19 | 20 | 37 |
| Rb | 70 | 71 | 69 | 66 | 74 | 72 | 82 | 110 | 165 |
| Sr | 150 | 160 | 163 | 160 | 145 | 148 | 126 | 103 | 79 |
| V | 122 | 120 | 113 | 119 | 125 | 123 | 129 | 152 | 185 |
| Y | 15 | 15 | 15 | 17 | 19 | 23 | 20 | 25 | 32 |
| Zn | 62 | 55 | 58 | 56 | 63 | 67 | 69 | 76 | 99 |
| Zr | 195 | 197 | 192 | 204 | 216 | 224 | 236 | 242 | 193 |
| $K_2O$/ $TiO_2$ | 10 | 11 | 11 | 9.4 | 7.6 | 6.4 | 6.3 | 4.1 | 2.5 |
| Sr/Y | 2.7 | 2.7 | 2.6 | 2.6 | 2.5 | 2.4 | 2.7 | 3.2 | 3.9 |
| CIA | 67 | 61 | 65 | 64 | 65 | 64 | 66 | 70 | 74 |

Results for the five petrographically analysed samples are displayed in Fig. 1 using recalculated primary parameters. The statistical data accompanying these samples have been plotted as error polygons around the relevant points. As samples 3 and 4 "share" an error polygon of similar dimension only one has been plotted on the diagram as the points are closely adjacent. Selected geochemical data are exhibited in Fig. 2.



SAMPLE DATA FOR GG59

| Sample numbers | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Ht. above unit base (cm) | | 2 | 10 | 20 | 35 | 62 |
| Max. grain size (mm) | | 0.82 | 0.68 | 0.67 | 0.78 | 0.54 |
| Error polygons (+/- 2 s.d. - covers 95% of expected error) | | | | | | |
| | Q | 5.0 | 4.5 | 4.5 | 4.5 | 5.0 |
| | F | 3.5 | 3.5 | 3.5 | 3.5 | 4.5 |
| | L | 4.0 | 4.0 | 4.0 | 4.0 | 4.5 |
| | Qm | 4.5 | 4.0 | 4.5 | 4.5 | 5.0 |
| | F | 3.5 | 3.5 | 3.5 | 3.5 | 4.5 |
| | Lt | 4.5 | 4.0 | 4.5 | 4.5 | 5.0 |
| | Qp | 7.0 | 5.0 | 7.0 | 7.0 | 8.5 |
| | Lvm | 7.0 | 5.5 | 7.0 | 7.0 | 9.0 |
| | Lsm | 5.0 | 4.5 | 5.5 | 5.5 | 6.5 |

Figure I. Greywacke samples ( 1-5) collected from a single Gramscatho turbidite unit (GG59) plotted on various framework mode diagrams (Dickinson and Suczek 1979) that discriminate between different sandstone provenances. The data used for plotting the error polygons are listed in the table.

## *Modal data (Fig. 1)*

All 5 samples analysed form a reasonably coherent group irrespective of which classification diagram is used. The error polygons usually show considerable overlap, except in the case of sample 2 in the Qp-Lvm-Lsm plot (Fig. 1). No definite trends exist within the statistical limits, except sample 2 seems to constantly represent a slightly more primitive composition (being relatively rich in lithics and feldspar), whereas sample 5 seems to represent a slightly more evolved composition (being relatively rich in quartzose material). At best a very crude translation of the modal composition towards the Q-pole with deceasing grainsize may occur.

On any one diagram sample 5 (finest grain size) shows the largest error polygon, whereas all sample error polygons are much larger on the Qp-Lvn-Lsm plot (Fig. 1). The former effect is brought about by the increase of matrix content to 30-40% in the finest sample, thus causing a concomittant reduction in the number of framework grains counted. In the latter case, the use of a subpopulation diagram automatically reduces the total number of points included in the count. Both effects result in a marked deterioration of the sample statistics and may mitigate against the use of certain samples of sub-population diagrams in a diagnostic role.

## *Geochemical data (Fig. 2)*

Samples with a sand grade grainsize (1-7) have relatively uniform SiO2 (~71%), low total Fe2O3+MgO, very low CaO, and K2O/Na2O values (0.5-0.7) typical of quartz-intermediate sandstones (Crook 1974). In trace element terms they are characterized by moderate to high levels of Ba, Rb, Sr and the light REE, together with low abundances of Cr, Ni and V, typical of greywackes derived from dominantly acidic precursors (cf. Floyd and Leveridge 1987). In common with more argillaceous rocks, the silty mudstones of the turbidite unit (samples 8 and 9) have higher absolute abundances of most elements relative to the sandy samples, although both Na2O and Sr are lower, whereas Zr is variable.

Fig. 2 illustrates the strong covariance between pairs of elements - (i) the relatively constant inter-element ratio for TiO2-K2O and Cr-Y regardless of absolute abundance, and (ii) the negative correlation of Sr-Y with variation in the ratio from 10.9 - 2.5. All the diagrams (Fig. 2) show a crude systematic variation in absolute abundance relative to the approximate modal grainsize of the sample (that roughly decreases from sample I to 9). Samples 8 and 9 (the silty mudstones) and sometimes sample 7 can be considered distinct from the rest of the unit on this basis, although the characteristic inter-element ratios are still maintained.

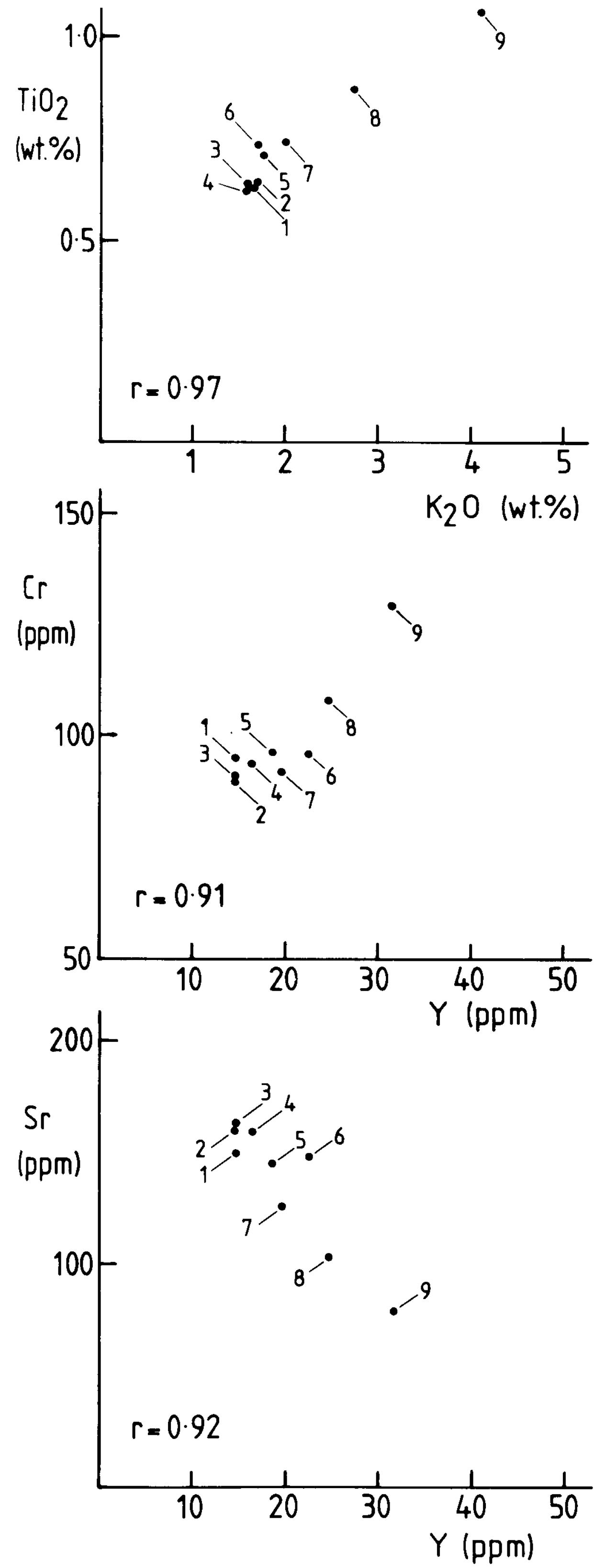


Figure 2. Linear covariance between pairs of elements (r = correlation coefficient) for greywacke samples (1-9) collected from a single Gramscatho turbidite unit (GG59). In general terms the proportion of matrix increases and the grainsize decreases from samples 1-4 (medium sand) through to 9 (silty mud).

## Discussion

We shall now assess the possible controls on sediment composition, as described previously, in the light of the petrographic and geochemical data presented above.

### *Extrabasinal controls*

As mentioned previously, little direct evidence exists for even qualitative determination of extrabasinal controls. However, two lines of indirect evidence exist: (i) the feldspar and unstable lithic content is relatively high; the sediments are therefore relatively immature and substantial modification is unlikely to have occurred, though particularly labile components may have been totally eradicated, and (ii) the syn-orogenic nature of the basin is likely to be inconsistent with wide shelf areas at the basin margin, and hence sediment would probably be able to bypass any littoral environment relatively easily, again avoiding compositional modification.

### *Intrabasinal controls*

Fractionation processes operating during final deposition of the derived sediment can be expected to cause sorting on the basis of size, shape and density. This sorting would modify composition by acting on (i) the fundamental grainsize-related compositional variation present in the intermediate sediment "storage" area prior to remobilization, and (ii) the slightly different hydrodynamic properties of the various framework grains. The net result would be a grainsize-related divergence of sample on the petrographic variation diagrams.

Such effects were quantitatively assessed in terms of the framework mode compositions for samples 1-5 (representing the sand-dominated part of the unit), and found to be minimal within the error limits. It should be noted, however, that samples 1-5 do not show an extreme variation in modal grainsize.

Due to their fine grainsize, samples 8 and 9 could not be meaningfully analysed by such petrographic methods, although the bulk geochemistry suggests they are still related to the rest of the unit. The geochemical variation exhibited by the sample spectrum is related to their grainsize and as such represents the progressive "dilution" of fine-grained matrix by framework clasts. Thus, fine-grained samples contain more matrix than coarse-grained ones and a higher absolute abundance of elements which reside within the clay minerals of unmetamorphosed greywackes (Spears and Amin 1981). However, the opposite relationship shown by Na and Sr, both of which are concentrated in the coarser grained fractions, suggest they are related to the presence of modal plagioclase that may have undergone more complete degradation in the finer fractions.

The implication of the above results is that the matrix composition is consistent throughout the unit, and as such samples 8 and 9 also represent deposition from the turbidity current rather than later hemi-pelagic sedimentation. The matrix composition, however, is unlikely to be totally independent of framework mode composition, because of the possible effects of diagenesis and metamorphism on matrix generation (see below).

### *Diagenesis, metamorphism and microstructural development*

The overprint of diagenesis by pumpellyite-actinolite facies metamorphism (Barnes and Andrews 1981) necessitates the study of the two together as the effects are rather similar. Burial and tectonic-related compaction/flattening resulted in the conversion of some lithic fragments to "pseudomatrix" (Dickinson 1970). Although this does not alter the actual composition of the sediment, some operator error is inevitable and so the apparent (analysed) composition is distorted. Oxidation of ferromagnesian minerals within volcanic rock fragments may produce similar errors by obscuring the true parentage of the grain. Albitization and sericitization of feldspar and widespread chlorite development probably occurred during both diagenesis and metamorphism and was accompanied by recrystallization of fine-grained matrix material. In view of the relatively high content of unstable lithics and feldspar still preserved within the rock, it seems highly likely that this finegrained matrix material was largely derived from their diagenetic degradation in a manner similar to that proposed by Whetten and Hawkins (1970). Metamorphism would accentuate these replacement processes. No evidence exists for a carbonate cement phase or carbonate in association with epidote or sphene as the products of albitization of calcic plagioclase. Neither do we have evidence for complete dissolution of primary phases as the resultant secondary porosity (Hayes 1979) would be totally eliminated by compaction.

The regional metamorphism was synchronous with D, (Barnes and Andrews 1981) and a rough (S,) cleavage (Gray 1978) penetrates the sandy portion of the unit. Pressure solution and reaction-related dissolution processes (Beach 1979) resulted in the removal of some quartz from the system and truncated grains can be seen adjacent to micaceous seams. In addition, many detrital quartz grains show marginal areas of recrystallized quartz intergrown with S,-parallel growth of small chlorites. This can be interpreted either as a corrosion front (Shannon 1978) or an overgrowth feature (Gray 1978). The latter is preferred in this study and such material is classified as matrix rather than part of a clastic grain.

Compositional modification of clast mode parameters due to these processes is very difficult to assess quantitatively. Such processes as described are not as selective as fluid dynamic sorting and so they are expected to result in the coherent movement of the entire sample population within framework mode diagrams. The resultant direction of movement relative to the original sediment composition, depends on the dominant process operating with respect to the three endmember compositions of triangular diagrams. This obviously has fundamental implications for the interpretation of plate tectonic environments from framework mode parameters (see fields in Fig. 1). Although the data presented here is limited to a single unit from the Portscatho Formation there is a discrepancy in its clast mode distribution relative to that of Floyd and Leveridge (1987) from the same formation.

Factors that are considered important in assessing the movement of clast populations in framework mode diagrams are as follows:
*Q-F-L diagram*. With increasing severity of intrabasinal processes, the diagenetic replacement of feldspar and rock fragments, together with some misidentification of lithics as pseudomatrix, is thought to be dominant over removal of quartz by pressure solution. The resultant movement of original sediment composition would be towards the Q-pole.
*Qm-F-Lt diagram*. Diagenetic removal of feldspar and lithics may be subordinate in this case to modification of Qm to Qp by crystal plastic processes, or all three may cancel each other out. The net result would be either no change to the original sediment composition, or a tracking towards the Lt-pole.
*Qp-Lvm-Lsm diagram*. The combination of diagenetic removal of Lvm and Lsm, and the increase of Qp by crystal plastic processes could lead to the original composition tracking towards the Qppole.

All of these changes are on the basis of recalculated primary parameters, hence the absolute values are not important, but relationships between relative proportions of individual endmembers are.

## Conclusions

1. Framework mode petrography over the lower 0.62m of a 1.70m-thick graded turbidite unit (samples within the medium sand - fine sand category) does not change significantly as a result of selective processes operating during final deposition.
2. The bulk geochemistry of the same unit suggests that although variations in absolute abundances of elements may occur as a function of grainsize-matrix content relationship, the ratios of many element pairs remain constant, implying matrix composition remains constant throughout the unit.
3. The most significant processes in the modification of original detrital Gramscatho Group sediment compositions are diagenesis, metamorphism and microstructural development and may result in erroneous assessments of provenance. Hence, if provenance is to be used as a basis for plate tectonic interpretations, all processes that modify the original detrital mineralogy should be taken into account.

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