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A geochemical study of turbidites in the Bude and Crackington formations north of Exeter

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Geological mapping at 1:10 000 scale of the Exeter district (1:50 000 Geological Survey Sheet 325) as part of the Lyme Bay to Bristrol Channel project has assigned outcrops of Culm Measures strata lying to the north and south of the Crediton Trough to the Bude and Crackington formations, respectively. This stratigraphy is based on comparison with the adjacent Okehampton district (Edmonds *et al.* 1968) to the west. The succession comprises varying proportions of turbiditic sandstones interbedded with shales and siltstone. In general, the Crackington Formation turbidites are thin (<500mm) and are volumetrically subordinate to shale and siltstone; they are considered to be distal with respect to the sediment sources. The Bude Formation turbidites are interbedded with siltstone and some thin dark-coloured shales; they are commonly rather thicker than the Crackington Formation sandstones, but most show distal characteristics. In places, much thicker sandstones occur, which are interpreted as proximal or amalgamated (i.e. compound-bedded) turbidites. In both formations are scattered thinly bedded micaceous sandstones, which are not obviously of turbiditic origin.

Chemical data for samples from these formations (Table 1) are presented in Fig. 1 in the form of normalised multi-element diagrams (cf. Haslam 1990). The normalising values used are those for average upper continental crust (Taylor and McLennan 1985, p46; except P_2O_5 from Weaver and Tarney 1984). The extent to which the diagram for a detrital sediment differs from a horizontal line is determined by (1) how the source rocks differ from average upper continental crust and (2) the chemical and physical processes involved in weathering, transport, deposition and diagenesis.

Four distal turbidite samples from the Bude Formation are plotted in Fig. la. When compared with typical greywackes from different tectonic settings (Bhatia and Crook 1986), these analyses show a strong resemblance to those from passive margins, derived from earlier sedimentary and metasedimentary rocks (plotted, for comparison in Fig. la).

The jagged patterns are characteristic of mature detrital sediments, depleted in mobile elements relative to the crustal average and correspondingly enriched in the elements that are hosted by minerals resistant to weathering (quartz, tourmaline, iron-titanium oxides, chromite, zircon and rare-earth-bearing heavy minerals). Thus, Si is above the crustal average, representing an abundance of quartz. Ti, Cr, Y and Zr are also above the average, indicating concentrations of iron-titanium oxides, chromite and zircon. The high values of Li and B probably reflect the presence of tourmaline in the detritus (see below). In contrast, the rocks are depleted in Ca (strongly), Na, Mg (variably), Mn (variably), Cu (variably), Sr and Ba - all elements which are readily leached during weathering, water-borne transport and diagenesis and therefore tend to be depleted in detrital sediments. The samples are also depleted, through less strongly, in Be, Al, P, Rb, Nb, Pb and U. The low Ca and Na, and the relatively low K/Al ratios, suggest that there is little feldspar present. In addition to quartz and resistate heavy minerals, the rocks are probably made up of micas and clays, including illite and chlorite.

This depletion in elements that are susceptible to chemical weathering and enrichment in elements that occur in chemically resistant minerals are characteristic features of mature sediments. The geochemistry is therefore consistent with the known derivation of the sediments, from Lower Palaeozoic sedimentary rocks. The warm, humid conditions that prevailed during Westphalian times would have favoured further leaching of mobile elements, with the corresponding enrichment in less mobile elements.

Amalgamated proximal turbidites from the Bude Formation, from Heath Bridge Quarry and Brembridge Farm, differ little from the distal turbidites in chemical composition (Fig. 1b). The sample from Heath Bridge Quarry has high Si and low Be, Ca, Cu, Pb, Th and Zr, but that from Brembridge Farm has no distinctive features. The distinction between the distal and proximal turbidites thus rests more on the sedimentology than on the materials of which the sediments are constituted.

The fine micaceous sandstone from North Creedy (Fig. 1b) has lower Si content than the turbidites, and correspondingly higher values of most other elements, notably Mg, Al, Ti, V, Mn, Ga, Rb, Ba, and Th, reflecting a higher proportion of phyllosilicates and lower proportion of quartz.

Distal turbidites from the Crackington Formation south of the Crediton Trough show similar patterns to those of the Bude Formation to the north (Fig. lc). The main differences are that the mobile elements Mg, Ca and Mn are less depleted, a feature that may suggest the presence of carbonate cement. The concentrations of the other mobile elements, Na and Sr, however, are similar to those in the Bude Formation. Si, Zr, La and Ce are lower, and values of the ratio Y/Zr are higher. The Crackington Formation turbidites may thus contain rather less of the coarser (quartz) and denser (e.g. zircon) phases that are so abundant in the Bude Formation, with correspondingly more of the finer, less dense phases (such as clays).

The Sherwood sample (Fig. 1d), is a micaceous sandstone. Unlike the micaceous sandstone sample from the Bude Formation (Fig. 1b), it is strongly depleted in Ca and Mn compared with its associated distal turbidites.

The distal turbidite from the Upton Pyne borehole (Fig. 1d) comes from a unit that lies beneath Permian red beds. Compared with the other turbidites it is enriched in Mg, Ca, Mn and Sr. It is likely that these mobile elements were precipitated, largely as carbonate, from the saline groundwaters that permeated the red beds in Permian and post-Permian times. The concentration of Na is particularly low; it may have been leached by the same groundwaters, or by recent weathering.

The plot of V against Rb shows a moderately good positive correlation (Fig. 2a), indicating that clay minerals (in particular illite) are the hosts for these elements. Boron is also hosted by clay minerals in some detrital sediments, while in others tourmaline is the principal carrier. Figs. 2b and c show that in the samples from the Bude Formation B correlates well with Zr (representing resistate minerals), suggesting that tourmaline is the principal host, whereas in the samples from the Crackington Formation there is a better correlation with Rb, representing clays.

The plot of MgO/SiO_2 against Y/Zr shows that, although the two

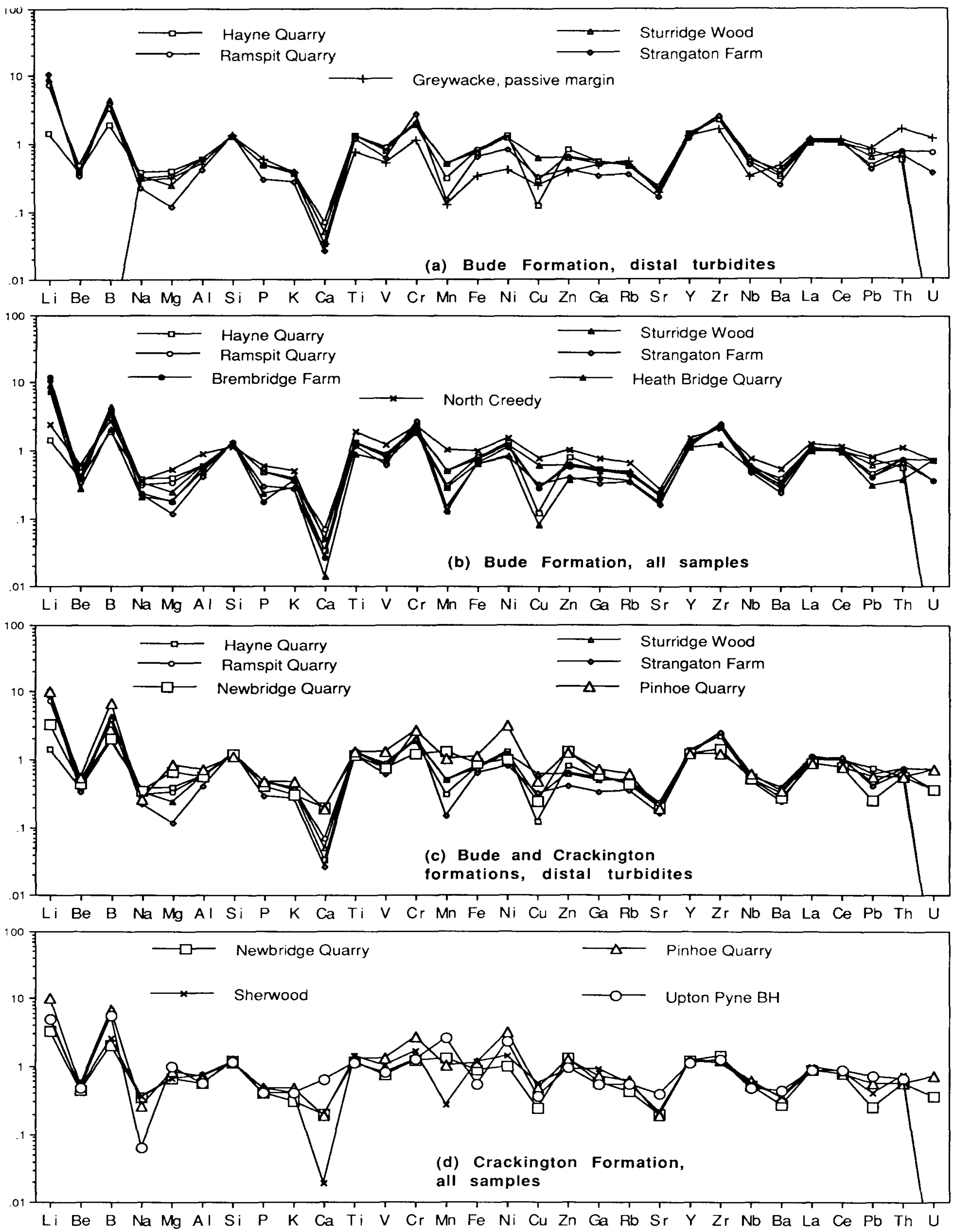

Figure 1. Normalised multi-element diagrams: (a) distal turbidites from the Bude Formation (small open symbols) compared with typical greywacke from passive margin setting (data from Bhatia and Crook, 1986) (represented by crosses); (b) distal turbidites from the Bude Formation (small open symbols) compared with amalgamated proximal turbidites from the Bude Formation (small closed symbols) and micaceous sandstone (crosses); (c) distal turbidites from the Crackington Formation (large open symbols) compared with distal turbidites from the Bude Formation (small open symbols); (d) distal turbidites from the Crackington Formation (large open symbols) compared with micaceous sandstone from the Crackington Formation (crosses) and distal turbidite altered by Permian groundwaters (large open circles).

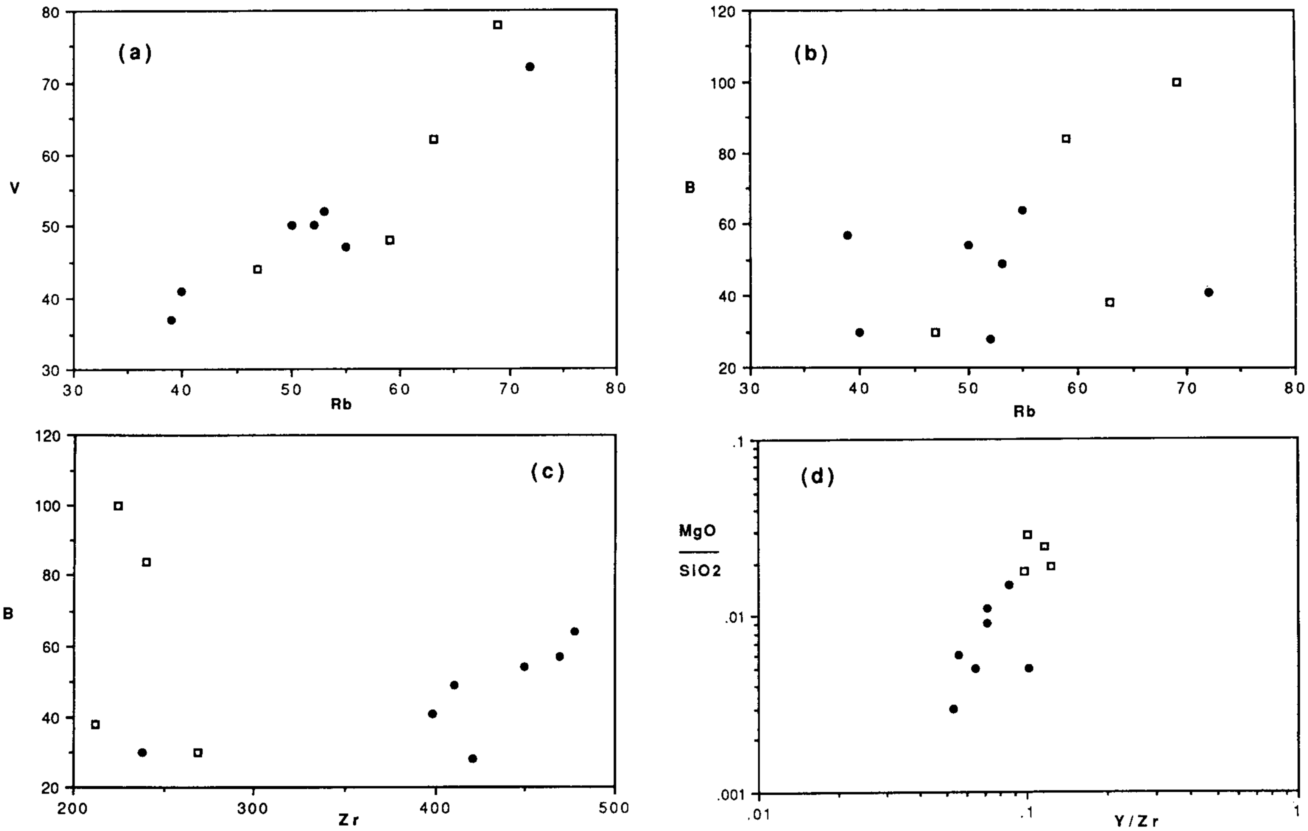

Figure 2. Scatter diagrams: filled circles, Bude Formation; open squares, Crackingtion Formation.

formations are very similar chemically, it is possible to discriminate between them, using carefully selected parameters, and there may therefore be certain differences in provenance and/or conditions of deposition.

References

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