Preliminary report on the diagenesis of the Lower New Red Sandstone deposits from the Colebrooke Borehole, Devon

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Introduction

The South West Water Authority's Colebrooke Borehole (SS 75670157) (Fig. 1) penetrated 181m of the Lower New Red Sandstone sedimentary rocks of the undeformed, gently dipping Crediton Trough succession, whose age falls somewhere within range from the Stephanian to the Lower Permian (Laming 1965; Edmonds and others 1968), resting unconformably on deformed Culm Measures. The Knowle Sandstones which form the upper 85m of the core, consist of interbedded £me-grained to coarse-grained red sandstones with thin red mudstone units. The underlying Bow Conglomerates consist of poorly sorted red breccias and conglomerates, interbedded with occasional thin mudstone or coarse-grained sandstone units.

The breccias and conglomerates of the Lower New Red of Devon are generally considered to be marginal alluvial fan deposits (Laming 1966; Henson 1971), laid down in a semi-arid environment, with local aeolian and fluvial sandstones. Edmonds and others (1968) suggest that the Knowle Sandstones are shallow water deposits peripheral to the alluvial fan.

Diagenesis

Compaction

Compactional effects due to lithostatic loading are strongly developed within these rocks. Detrital biotite and Culm shale fragments have suffered intense ductile deformation, being squeezed between competent quartz and feldspar clasts (Fig. 2a) reducing the initial porosity and permeability. The large scale ductile deformation would have reduced the effect of pressure solution between the competent quartz clasts, suggesting this to be an unlikely source of silica for quartz precipitation within these rocks.

Diagenetic minerals

Clay Minerals

X-ray diffraction analyses of oriented clay separations (<5 µm) reveals three major clay minerals: illite, kaolinite and a 'swelling' clay, predominantly montmorillonite, but in some samples the diffraction patterns show a regular mixed layer illite/montmorillonite. The distinction between detrital, mechanically inwashed and authigenic clay is based primarily upon SEM and thin section observations of the clay morphology and its relationships to detrital grains and other authigenic developments. For an account of the criteria used see Wilson and Pittman (1977).

Illite is the main detrital clay mineral together with small quantities of mixed layer illite/smectite. Illite also occurs as tangential coats around the detrital grains formed by mechanical inwashing soon after deposition (Crone 1969). Authigenic illite occurs as a replacement product of K-feldspar and as a neoformed mineral within the pore spaces. It characteristically occurs as large plates with irregular edges frequently aggregating to form an 'open book' or 'sheaf type morphology (Fig. 2b), the books attaining lengths of 600 µm. This illite morphology is clearly distinguishable from the kaolinite books described below. Although Hancock and Taylor (1978) considered similar illite books to be pseudomorphs after kaolinite, there is no direct evidence of this here, with none of the intermediate stages of kaolinite alteration being present which were shown by Hancock and Taylor.

Kaolinite occurs in varying amounts throughout the borehole and is entirely authigenic in origin. It forms pseudohexagonal plates, characteristically, but not necessarily, arranged in books (Fig. 2c). Kaolinite occurs as a pore filling and is not necessarily spatially associated with grain decomposition.

The 'swelling' clays consist of montmorillonite with minor mixed layer illite/montmorillonite, which locally becomes dominant, showing diffraction patterns characteristic of allevardite.

These clays correspond to an intricate 'mesh' morphology (Figs. 2c and 2d) occurring in all the samples studied. The mesh exhibits morphological variations from a regular mesh size of approximately 1 µam in size (Fig. 2c) to an irregular mesh with pores up to 10 lam in size (Fig. 2d). The clay surfaces may be smooth or have irregular frilled projections which closely resemble the mixed layer illite/montmorillonite described by Wilson and Pittman (1977).

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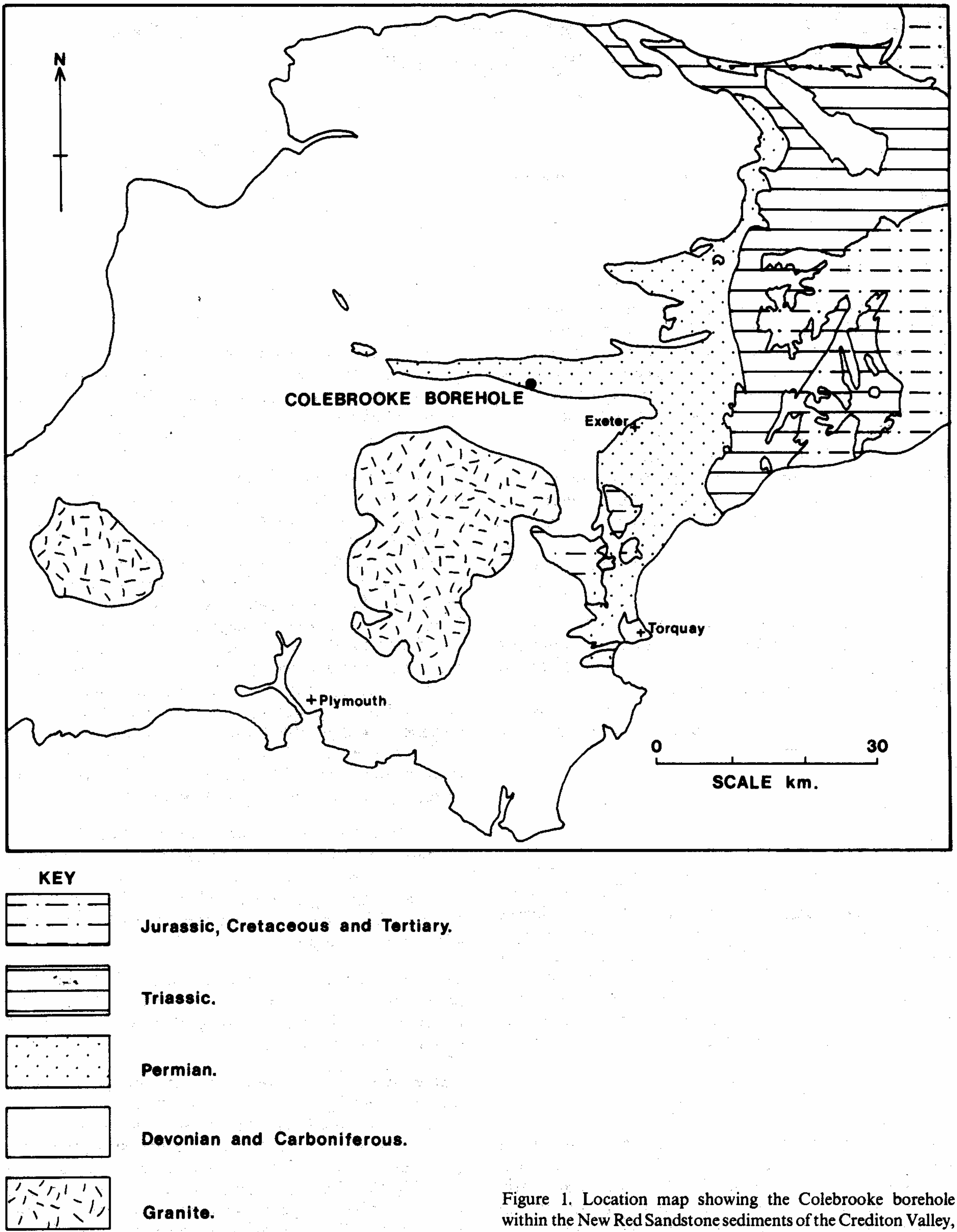

Figure 1. Location map showing the Colebrooke borehole within the New Red Sandstone sediments of the Crediton Valley, forming a westward extension of the main basin in Devon.

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Figure 2c. SEM photographs of pseudohexagonal kaolinite plates aggregating to form `books' overlying a regular, smooth textured, montmorillonite(?) mesh. Scale bar = 5 µm.

Figure 2a. Photomicrograph showing detrital biotite and slate clasts deformed around two quartz grains during compaction. Scale bar = 5 µm.

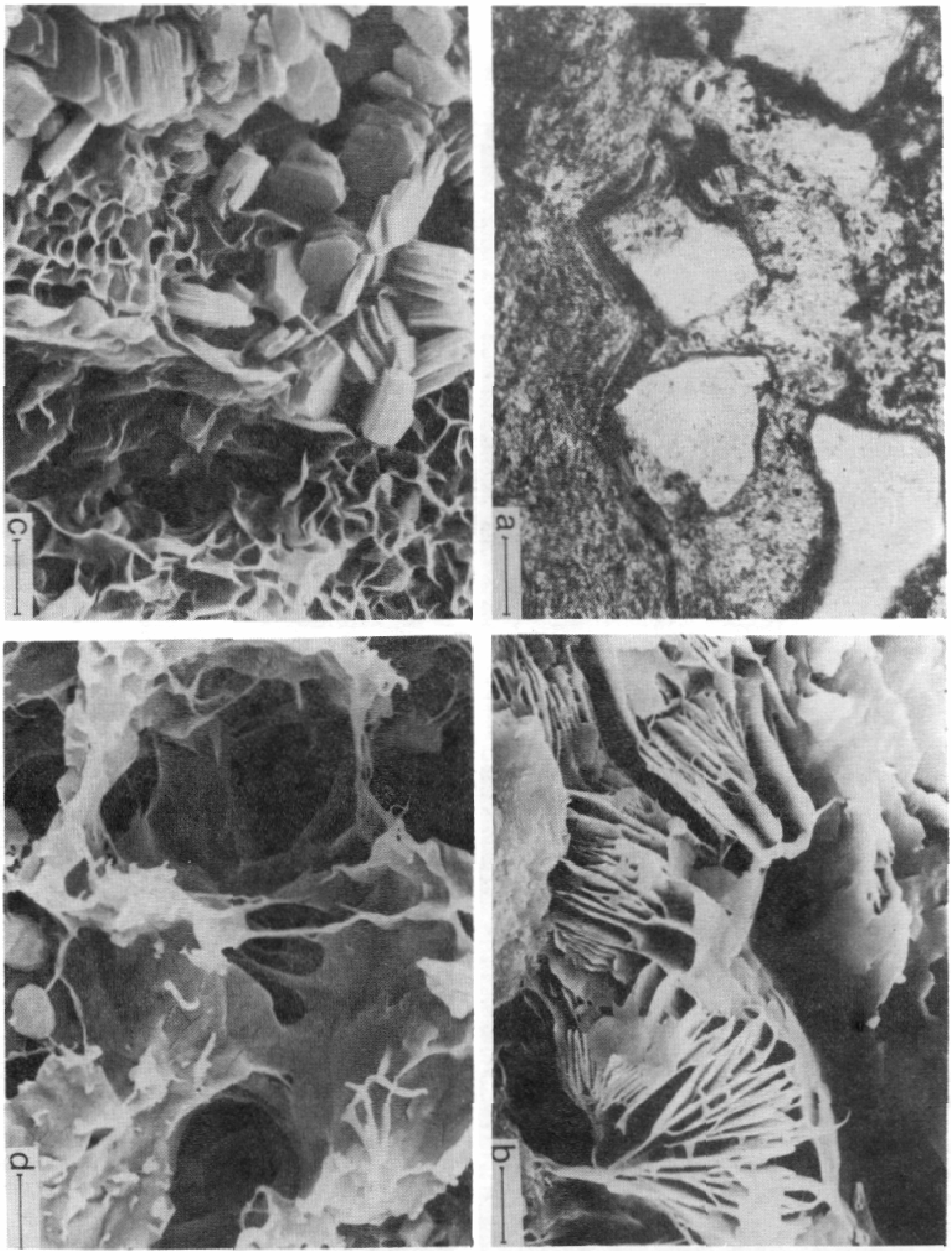

Figure 2d. SEM photograph of an irregular pore filling `mesh' (montmorillonite or mixed layer illite/montmorillonite). This will have a marked effect upon the permeability of the sediment. Small quartz crystals are seen growing off the clay (bottom centre of photograph). Scale bar = 5 µm.

Figure 2b. SEM photograph showing authigenic illite forming an `open book' growing into open pore space. Scale bar = 5 µm.

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Figure 3b. SEM photograph of an authigenic, discrete quartz crystal growing on a substrate of mechanically inwashed clay. Scale bar = 1 µm.

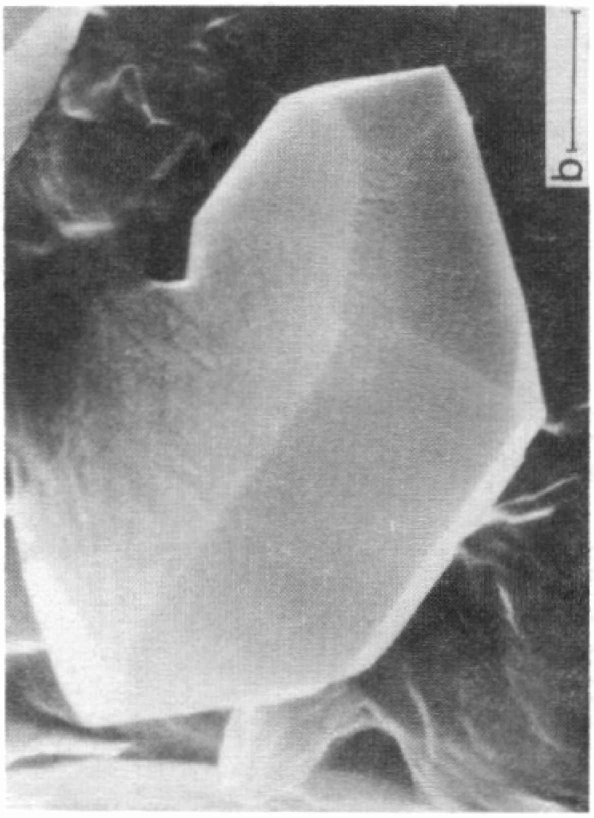
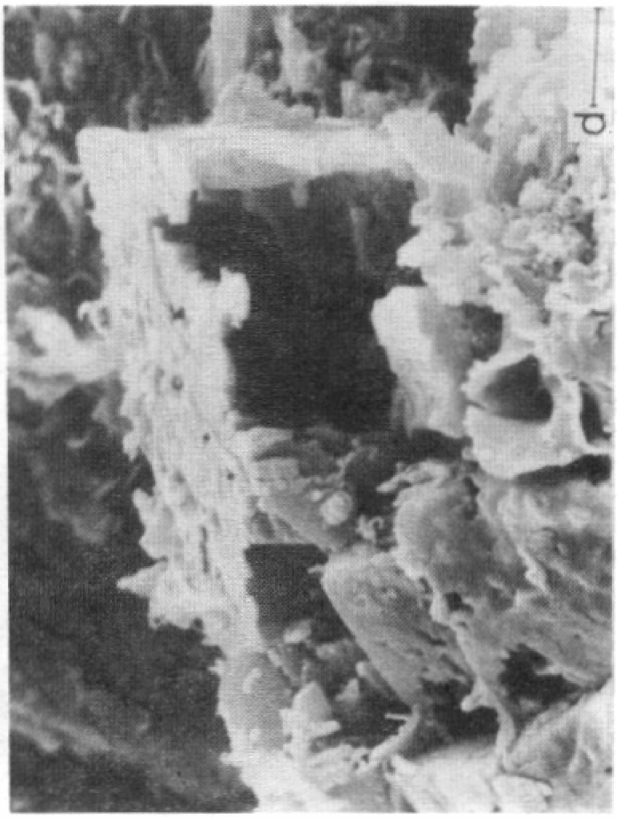


Figure 3a. SEM photograph of detrital rock fragments with feldspar and quartz overgrowths, the overgrowths having various crystallographic orientations dependent upon their hosts. Scale bar = 25 µm.

Figure 3d. SEM photograph of a dolomite crystal showing the effects of internal dissolution leaving a relatively unaltered outer ‘skin’. Scale bar = 5 µm.



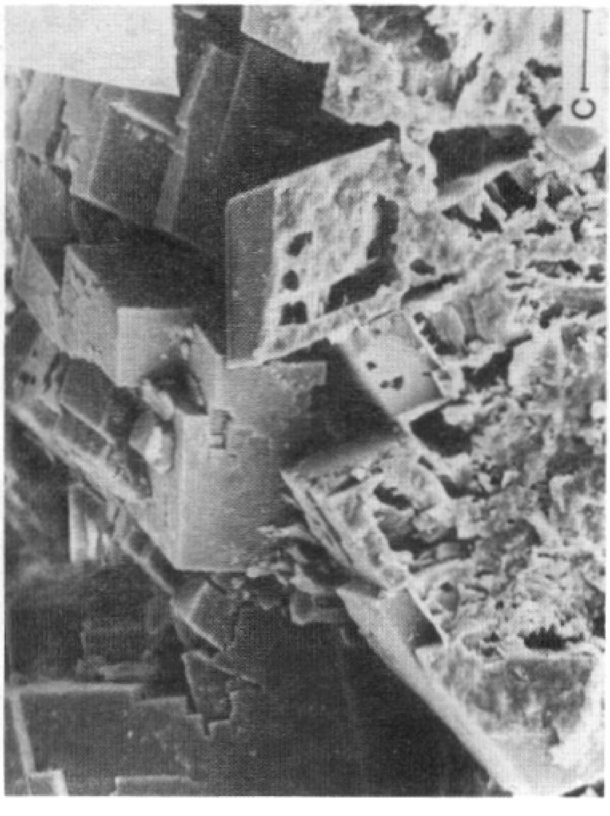


Figure 3c. SEM photograph showing dolomite cement formed by the coalescence of individual rhombic crystals. Scale bar= 14 µm.

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Diagenetic quartz

Diagenetic quartz occurs in all the samples studied, taking two different forms:

(a) oriented overgrowths developed on pre-existing host grains. These may develop upon mono- or poly-crystalline quartz grains and rock fragments. In the latter two cases several overgrowths (quartz and feldspar in the case of rock fragments) may be present on the same grain with different crystallographic orientations controlled by their host (Fig. 3a).

(b) Discrete quartz crystals with dimensions of 3-4 µm, but exceptionally attaining lengths of 100 µm are seen to have grown on various substrates including dolomite, detrital grain surfaces ~and mechanically inwashed clay (Fig. 3b).

Diagenetic feldspar

As with the quartz described above, diagenetic feldspar occurs as oriented overgrowths (Na- and K- hearing feldspars) and discrete crystals (K-bearing feldspars).

Most of the feldspar grains appear to have suffered dissolution rather than diagenetic growth, overgrowths appearing in only 20% of the samples, although the coatings of mechanically inwashed clay on the grains have been partly responsible for inhibiting overgrowth development. There has been less diagenetic feldspar development here than in many other parts of the New Red Sandstone in Devon, as the small delicate adularia habit crystals so common in pore spaces elsewhere, in some cases to the extent of forming a complete pore-filling cement, are present here in very small numbers. Both potassium and sodium feldspar overgrowths are present, although the latter are more uncommon and have suffered some dissolution (Fig. 4d).

Dolomite

Dolomite occurs in all but one of the samples forming a blocky cement due to the coalescence of individual rhombic crystals(Fig. 3c) with dimensions of 40-50 µm. Characteristically they show complex internal dissolution textures, in some cases leaving a fragile, outer unaffected layer (Figs. 3d and 4a).

Calcite

Calcite cement is sporadically developed and cementation is never complete. Where present it usually forms-large (up to 2mm) isolate crystals, but may occur as small crystal clusters upon a detrital or authigenic substrate (Fig. 4c). The calcite cement is "aggressive" towards detrital quartz and feldspar clasts.

Barytes

Barytes crystals were found in only one of the samples studied, occurring as clusters of moderately well formed tabular crystals approximately 20 µm in length (Fig. 5a).

Dissolution and Replacement

The chemically immature sediments have suffered alteration of both the unstable primary grain components and of early diagenetic minerals during the diagenetic history.

The detrital grains showing the most intense dissolution are the alkali feldspars, which in many cases have been almost completely removed with some of the resulting voids being filled by such later minerals as dolomite, kaolinite, quartz or calcite. Commonly, feldspar grains show partial internal dissolution within a less affected crust, in which characteristic skeletal textures can be identified, K-feldspars showing a parallel needle-like texture (Fig. 5b), whilst Na-feldspars show a blocky, columnar texture (Fig. 5c). This relationship between the feldspar mineralogy and dissolution texture is consistent Within this borehole, but not elsewhere in Devon, where the K-feldspars may also show a blocky dissolution texture.

The K-feldspars have also suffered illite alteration which in the case of volcanic clasts may leave resistant quartz and biotite crystals preserved within a ground mass of illite.

Fe-Mg minerals are rare within these deposits, possibly because they have been diagenetically removed. Certainly where present they have undergone dissolution. Such alteration was suggested by Walker (1967) to be a major contributor of iron involved in the reddening of desert sands.

Calcite and dolomite cements are aggressive towards detrital quartz, feldspar and volcanic fragments. The dolomite itself has subsequently undergone dissolution, the textures being described above.

Discussion and Conclusions

The Lower New Red Sandstone Bow Conglomerates and Knowle Sandstones of the Crediton Valley have similar diagenetic histories despite their differences in sediment type (grain size, sorting, roundness, pore size, and depositional environment). This diagenetic similarity probably relates to similar primary mineralogies and post depositional histories.

The breakdown of the unstable detrital components released Na, K, Al, Si, Fe and Mg to the interstitial waters aiding the development of various authigenic minerals (quartz, feldspars, various clay minerals and haematite). Carbonate cements, however, are more likely to have resulted from the external supply of ions within the ground-water system.

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Figure 4b. SEM photograph of a large calcite crystal growing into open pore space and partially enveloping `mesh' clays. Scale bar = 5 µm.

Figure 4d. SEM photograph of an authigenic quartz crystal enclosing an earlier Na-feldspar crystal showing preferrential internal dissolution. Scale bar = 5 µm.

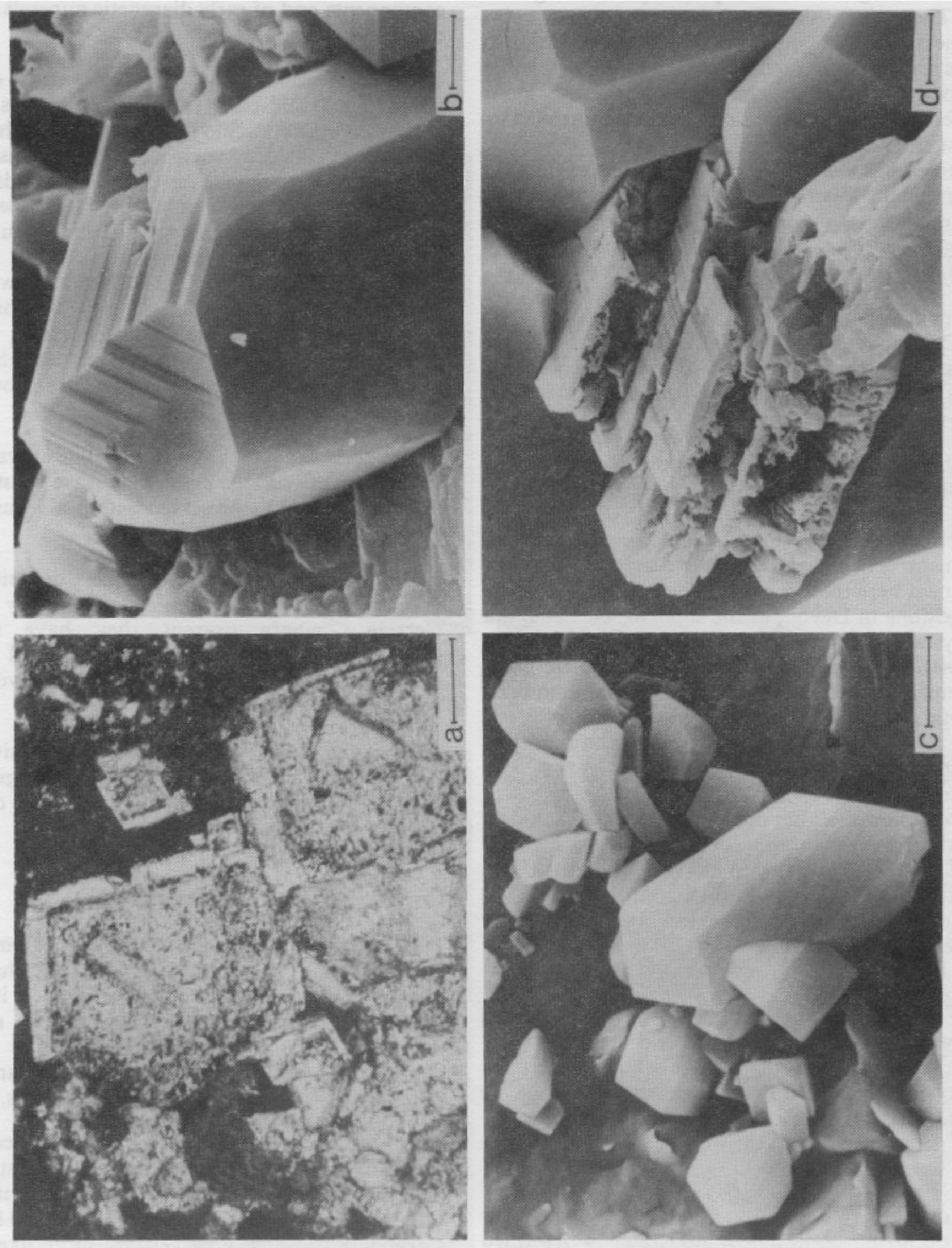

Figure 4a. Photomicrograph of dolomite crystals growing into open pore space, showing unaltered outer 'skins' surrounding internal areas affected by dissolution. The two largest crystals also have clear areas near their centres, possibly resulting from the replacement of detrital grains. Scale bar = 150 µm.

Figure 4c. SEM photograph showing a cluster of small authigenic calcite crystals growing upon a dolomite substrate. Scale bar = 3 µm.

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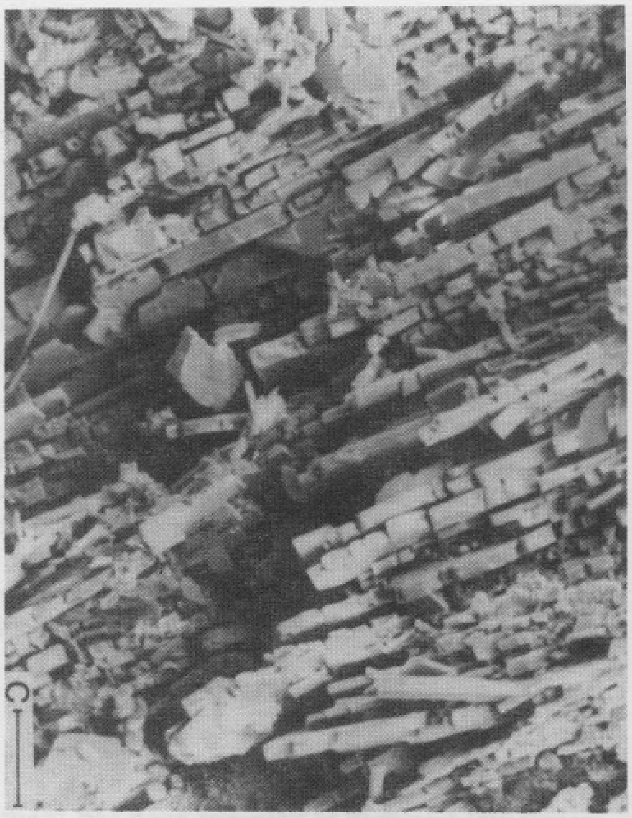
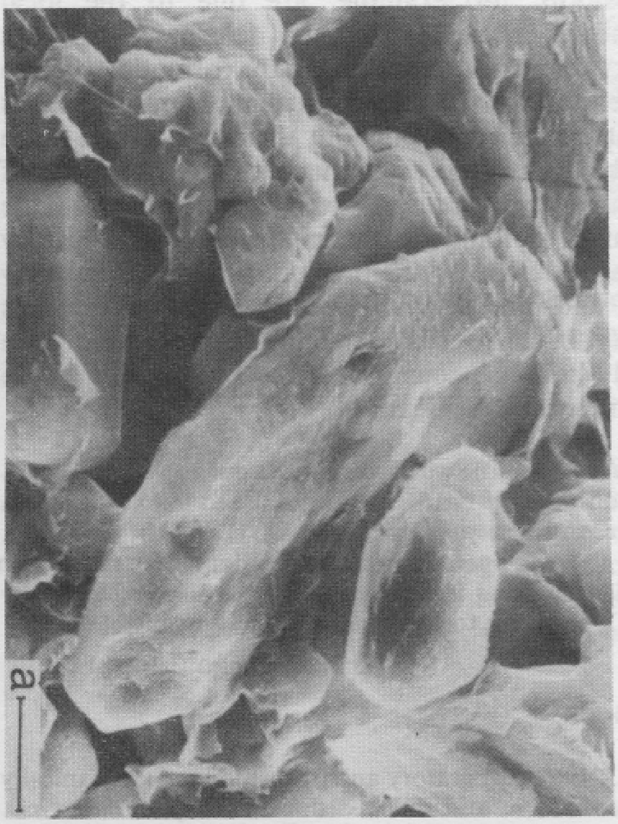
Figure 5c. SEM photograph of a detrital sodium feldspar with a columnar dissolution texture. Scale bar = 10 µm.

Figure 5a. SEM photograph of authigenic barytes crystals with slightly pitted surfaces. Scale bar = 5 µm.





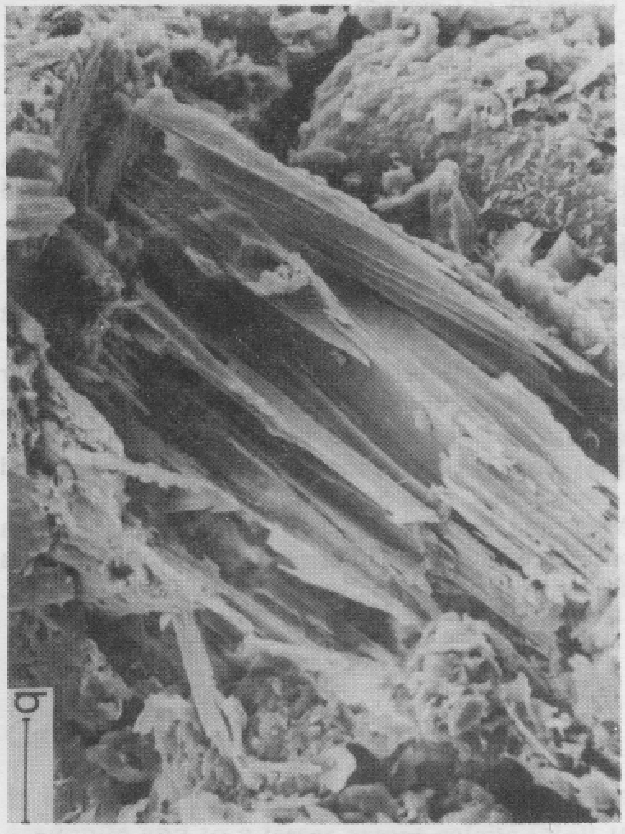


Figure 5b. SEM photograph showing a detrital feldspar with a delicate needle-like dissolution texture. Scale bar = 20 µtn.

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Variations in the abundance of authigenic minerals relate to differences in local interstitial environments as well as to large scale changes in pore water chemistry. The local concentrations of illite associated with K-feldspar decomposition, for example, are due to the local environment, controlled by the feldspar, with the retention of potassium resulting in the formation of illite as opposed to kaolinite. The consistent temporal changes in cementation seen throughout the borehole are more likely to be due to large scale changes in the chemistry of the ground water. This can be seen, for example, with the formation of dolomite early in the diagenetic history which was followed by the precipitation of various clay minerals and the dissolution of the dolomite. This uniformity of large scale changes in turn implies a chemically homogeneous ground water system with no marked internal stratification.

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