THE SURFACE TEXTURES OF QUARTZ GRAINS FROM A RHAETIAN BONE-BED, BLUE ANCHOR BAY, SOMERSET.

by

D.D.J. Antia and J.H. Sykes

Summary

The surface textures of detrital quartz grains in a Rhaetian bone-bed at Blue Anchor Bay, Somerset, have been investigated using a scanning electron microscope. The results show that there is a systematic change from the base to the top of the bed in the nature of the textures displayed by the quartz grains. Those from the basal clay-rich parts of the bed feature solution pits, while grains from the upper clay-poor parts of the bed display well developed euhedral overgrowths. The differences are attributed to *in-situ* diagenesis.

Introduction

Quartz grains in Rhaetian bone-beds are usually abraded and well rounded. They have been recorded from many localities, ranging across England and Wales, including Barnstone (Nottinghamshire), Barrow-upon Soar (Leicestershire), Westbury (Gloucestershire), Chilcompton (Somerset) and Lavernock (Glamorgan). Further examples including locality details have been presented by Sykes (1977). Rare bipyramidal quartz crystals have been recorded from Rhaetian bone-beds (Kent, 1970, p.365) at a number of localities including Barnstone (Duffin, 1978, pers. com.) and Blue Anchor Bay (Antia, 1979a, pl.18, fig.f). Such crystals arise as the result of quartz overgrowths around an original quartz nucleus. They have been recorded from a number of bone-beds including those of the Silurian in Britain (Antia & Whitaker, 1978, pp.121, 123-127; Antia, 1979a, pp.115, 169) and bone-beds in the Devonian of the U.S.A. (Wells, 1944, p.283).

In Silurian bone-beds (e.g. the Ludlow Bone-Bed) some of the euhedral crystals predate the formation of the deposit and bear surface abrasion features (Antia & Whitaker, 1978, pp.132, 133, 135, 136). Others have no abrasion features and nucleate around quartz grains, suggesting that they have grown in the bone-bed after its deposition. At the present time there are no adequate descriptions of euhedral quartz crystals from a Rhaetian bone-bed and consequently it is not known if they were reworked from a previous sediment or whether they have grown *in-situ* in the bone-bed. Reworked grains should be identified by their abraded surfaces.

Conversely, if the quartz euhedra were precipitated in the sediment after it was deposited, then a complete continuum ranging from original quartz grains and silica coated quartz nuclei through to perfect euhedral quartz crystals could be expected to occur, in which quartz euhedra increase in abundance towards the more porous base or top of the deposit. If, however, the relative abundances of the various diagenetic quartz morphotypes remain constant throughout the deposit then they could either have been derived from an older deposit (cf. Wilson, 1979) or have formed as diagenetic precipitates within the bone-bed. This study seeks to determine which of the explanations is most applicable to the quartz euhedra in the bone-bed under review.

Stratigraphy

Exposures of the Rhaetian beds at Blue Anchor Bay have been described by Richardson (1911, p.17) and also by Elliot (1953) and Macfayden (1970, p.225). Richardson recorded three bone-beds: 'Basal Bone-bed' (no. 33), 'The Clough' (no. 27) and 'The Bone-bed' (no. 15) near the top of the Westbury beds.

In a recent investigation into the nature of British Rhaetian bone-beds (Sykes, 1977), a large number of quartz crystals were noticed in part of the uppermost bone-bed (Richardson's bed 15) at Blue Anchor Bay (ST 042432). This bone-bed is 0.28 m thick and has been divided into five distinct parts (Table 1) (Sykes, 1977, p.231). Samples from parts 'a, c, d, & e' were disaggregated in acetic acid, washed and dried. The finer particles were removed by washing the grains in petroleum spirit and the coarser fraction (above 250 microns) separated by sieving. Several random samples were taken from each part and examined under a binocular microscope. The number of grains in each sample were counted in respect to their possession or lack of crystal faces also with regards to the amount of crystalline pyrite present. In each part of the bed averages of the relative contents were calculated over the various samples and the amounts expressed in percentages (table 2).

Scanning electron microscope (S.E.M.) analysis

Fifty quartz grains were randomly selected from each part of the bed listed in Table 2. These grains were then mounted on the S.E.M. stubs with either silver dug (parts d & e) or Pritt (parts a & c) and gold splatter coated to a thickness of 350 Å. The grains were then examined on a Cambridge 600 S.E.M.. After examination the grains were removed from the stubs and cleaned using first acetone and then hydrogen peroxide. The majority of the grains are now deposited with the Ludlow Museum; specimen nos. SHRCM G05501-4.

Most of the external surfaces of the quartz grains were covered by diagenetic overgrowths which appear to have been precipitated on more rounded quartz nuclei. Some of the grains are affected by silica solution which has removed the primary abrasive features and caused pitting. The exoscopic features of the grains are described as follows.

1. Primary crystal overgrowths, pl.23, figs.1,2 & 3

Many of the quartz grains observed from parts 'd' and 'e' possess euhedral crystal faces. These vary in shape from compact grains to elongate, bipyramidal, euhedral crystals, some of which have prism faces. Some of the compact grains have crystal faces without a clear crystallographic orientation, while some of the more euhedral grains have prism faces which are poorly defined or are smothered by bulbous overgrowth.

The quartz grains show three stages of diagenetic overgrowth around an original, compact spheroidal quartz grain (text-fig. 1, fig.A).

a Silica sheet layering on the external surface of the grain (pl. 23, fig.7, text-fig.1, fig.B). These sheets are in optical continuity with the host quartz grain.

b Polarisation of quartz growth to produce a c-axis aligned along the quartz grain and to allow development of pyramidal crystal faces at either end of the grain (pl. 23, fig.3, text-fig.1, fig.C).

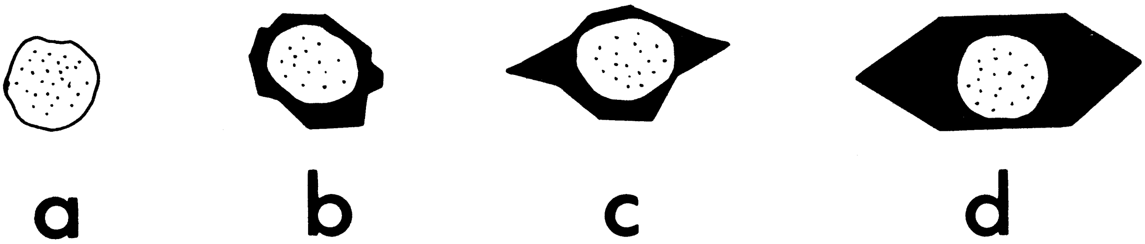
c Enlargement of the pyramidal faces until the pyramid diameter equals or exceeds the grain diameter. This is followed by development and growth of the prism faces (text-fig.1, fig.D).

Table 1. Description of bone-bed, parts 'a' to 'e'

Part	Thickness	Description
e	up to 120 mm	A massive, calcareous sandstone, enriched in vertebrate remains.
d	50 mm	A calcareous sandstone, enriched in vertebrate remains and containing thin layers of black shale limestone.
c	70 mm	Alternating layers of black shales and sandstones with vertebrate remains.
b	up to 30 mm	A layer of 'beef' calcite ($CaCo_3$).
a	18 mm	A calcareous, sandy bone-bed containing shell and silt laminae.

Table 2. Distribution of crystalline pyrite and quartz crystal faces in the coarse fraction of the bone-bed

Part	Without crystal faces	With crystal faces	Crystalline pyrite
e	23%	74%	3%
d	33%	62%	5%
c	73%	19%	8%
a	94%	0%	6%



Text-fig. 1. Deduced stages in the development of quartz euhedra

Fig. a. Original quartz grain (shape unknown).

Fig. b. Quartz grain coated with silica sheets producing crystal faces on the grain's surface (most common in parts 'a' and 'c').

Fig. c. Polarisation of crystal growth and the development of crystal faces (most common in parts 'd' and 'e').

Fig. d. Development of prism faces connecting the pyramid faces (most common in parts 'd' and 'e').

2. Secondary crystal overgrowths (pl.23, figs.6 & 8)

On one quartz grain from part 'e', a small euhedral crystal growth was observed encrusting a primary overgrowth crystal face (pl. 23, fig.8). On another grain from the same part of the bed a more complex pattern of secondary crystal overgrowth was observed (pl.23, fig.6). On some grains the growth of silica sheets appears to post-date the development of euhedral crystal faces within the bone-bed (pl.23, figs.4,7 & 9).

3. Diagenetic solution (pl.23, fig.5)

Silica solution features are present throughout the bone-bed though they are most pronounced at its base, in part 'a'. A thin section of this part (Sykes, 1977, pl.16, fig.5) shows that most of the silica solution features appear to be related to the growth of the calcite matrix during 'late' diagenesis.

Typical examples of pitting due to silica solution within the bone-bed are illustrated in pl.23, fig.5.

Discussion

The association of pyrite, apatite and black shale has been noted in bone-beds throughout the geological record and may indicate the presence of high negative Eh (-200 to -300) and a pH of 6 to 8 in the sediment pore waters during diagenesis (Baturin, 1971, p.61; Burnett, 1977, p.820-821; Antia, 1979a, pp.107, 124). If this sediment was also undersaturated with respect to Ca^{2+} and CO_3^{2-} ions, then diagenetic gypsum and/or quartz may have precipitated within the sediment (Burnett, 1977, p.821; Briskin and Schreiber, 1978, pp.47-48; Antia, 1979b, p.M1, M3).

Observations (Sykes, 1977, p.232) show that the mean grain size of the sand fraction of the bone-bed increases upwards. This trend, coupled with a decrease in its clay and limestone content towards its top (Sykes, 1977, p.231), shows that the initial post-depositional porosity of the bone-bed also probably increased towards its top. The increase in porosity coincides with a change in quartz grain shape (Table 2) and a decrease in the incidence of solution features.

A possible explanation is that silica was removed from some of the quartz grains and clay minerals in the bone-bed by upward percolating pore waters and concentrated in the upper porous layers of the bone-bed beneath the overlying impervious clays. In this context it is interesting to note that clay minerals may actually enhance solutions of quartz (see Blatt, Middleton & Murray, 1972; Pettijohn *et al.*, 1972) and that the presence of a clay mineral matrix will inhibit growth of cement. The pore water solutions may then have become supersaturated with respect to silica and precipitated as silica sheets in the lower porosity layers of the bone-bed (parts 'a' and 'c') and quartz crystals in the higher porosity layers (parts 'd' and 'e'). Silica may also have been derived from the impermeable clays overlying and underlying the bone-bed.

Elsewhere in the geological column similar relationships appear to occur between porosity and quartz crystal growth. For example, the Ludlow Bone-Bed at Netherton (King & Lewis, 1912) grades upwards from vertebrate rich clays to a vertebrate sand (Antia, 1979b). These vertebrate sands had a higher initial porosity than the vertebrate rich clays and the contain diagenetic, euhedral, quartz crystals. Such crystals are not present in the lower porosity clays.

Conclusions

The quartz grains in a Rhaetian bone-bed at Blue Anchor Bay, Somerset, have diagenetic quartz overgrowths. These overgrowths are restricted to silica sheets in the lower porosity, vertebrate rich clays and limestones but form euhedral crystal overgrowths in the higher porosity, vertebrate rich quartz sands of the upper layers of the bone-bed.

Acknowledgements

D.D.J.A. thanks N.E.R.C. for its financial support, and Prof. B.E. Leake for the use of facilities at Glasgow University. We thank Mr. M. Ghummed (Mobil Oil) for critically reading the manuscript.

References

ANTIA, D.D.J. 1979a. Bone-beds: A review of their classification, occurrence, genesis, diagenesis, geochemistry, palaeoecology, weathering and microbiotas. *Mercian Geol.*, vol.7, pp.93-174.

ANTIA, D.D.J. 1979b. Authigenic gypsum in marine sediments - a comment. *Marine Geol.*, vol.32, pp.M1-M4.

ANTIA, D.D.J. & WHITAKER, J.H. McD. 1978. A scanning electron microscope study of the genesis of the Upper Silurian Ludlow Bone-Bed. In W.B. Whalley (ed.) *Scanning Electron Microscopy in the study of sediments.* Geo. Abstracts Ltd., Norwich, pp.119-136.

BATURIN, G.N. 1971. Stages of phosphorite formation on the sea floor. *Nat. Phys. Sci.*, vol.232, pp.61-62.

BLATT, H., MIDDLETON, G. & MURRAY, R. 1972. *Origin of sedimentary rocks.* Prentice Hall, New Jersey, 634 p.

BRISKIN, M. & SCHREIBER, B.C. 1978. Authigenic gypsum in marine sediments. *Marine Geol.*, vol.28, pp.37-49.

BURNETT, W.C. 1977. Geochemistry and the origin of phosphorite deposits from off Peru and Chile. *Bull. Geol. Soc. Amer.*, vol.88, pp.813-823.

ELLIOT, G.F. 1953. The conditions of formation of the Lower Rhaetic at Blue Anchor Bay, Somerset, and the Western European Rhaetic generally. *Proc. geol Soc. Lond.*, vol.64, pp.32-35.

KENT, P.E. 1970. Problems of the Rhaetic in the Midlands, *Mercian Geol.*, vol.3, pp.361-373.

KING, W.W. & LEWIS, W.J. 1912. The uppermost Silurian and Old Red Sandstone of South Staffordshire. *Geol. Mag.*, vol.49, pp.437-443, 484-491.

MACFAYDEN, W.A. 1970. *Geological highlights of the West country*, 296 p.

PETTIJOHN, F.J., POTTER, P.E. & SIEVER, R. 1972. *Sand and Sandstone.* Springer-Verlag, New York, 618 p.

RICHARDSON, L. 1911. On the Rhaetic and contiguous deposits of West, Mid. and East Somerset. *Q. Jl geol. Soc. Lond.* vol.67, pp.1-72.

SYKES, J.H. 1977. British Rhaetic Bone-beds. *Mercian Geol.*, vol.6, pp.197-240.

WELLS, J.W. 1944. Middle Devonian Bone-beds of Ohio. *Bull. Geol. Soc. Am.*, vol.55, pp.273-302.

WILSON, P. 1979. Surface features of quartz and grains from the Brassington Formation. *Mercian Geol.*, vol.7, pp.19-30.

D.D.J. Antia,
Exploration Department,
BP Petroleum Development Ltd.,
Farburn Industrial Estate,
Dyce,
Aberdeen, AB2 OP8,
Scotland.

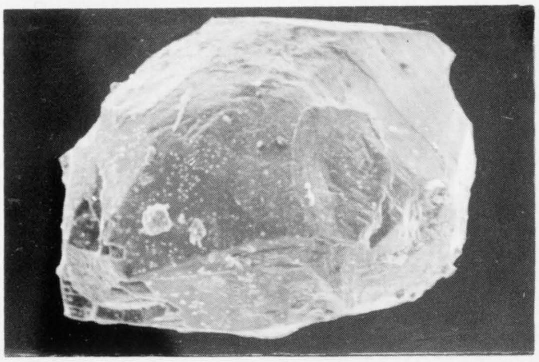
J.H. Sykes
138 Harlaxton Drive,
Lenton Sands,
Nottingham,
Notts.

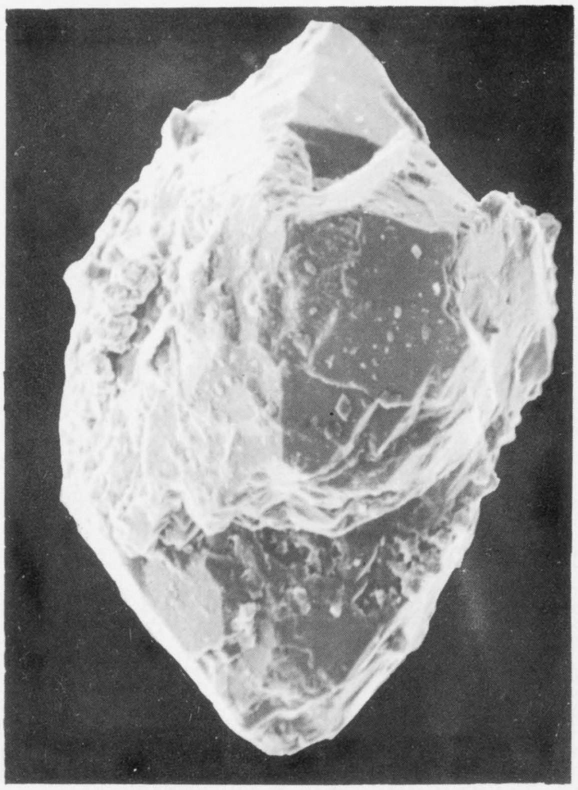
Explanation for Plate 23

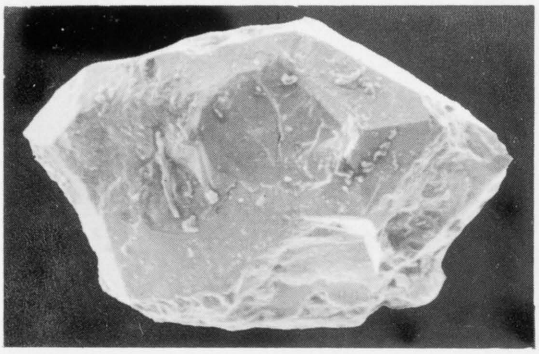
1 - 9 Quartz grains and surfaces from a Rhaetian Bone-Bed at Blue Anchor Bay

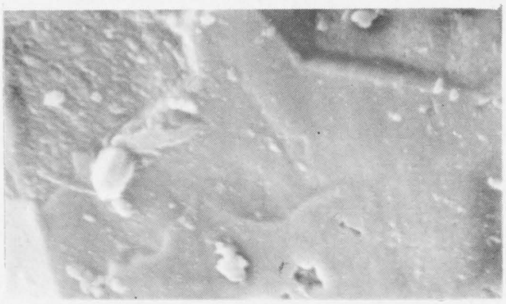
1. Angular, compact, high sphericity grain (x 150).
2. Modified, compact grain, showing the development of crystal faces (x 80).
3. Compact grain completely enclosed within a quartz overgrowth (x 80).
4. Silica sheeted surface (x 600).
5. Silica surface showing solution pits (x 600).
6. Quartz overgrowth on a grain (x 500).
7. Silica sheeting on a grain surface (x 600).
8. Quartz overgrowth on a grain surface (x 1000).
9. Silica sheeting on a grain surface - note the various angles of the sheet faces (x 700).

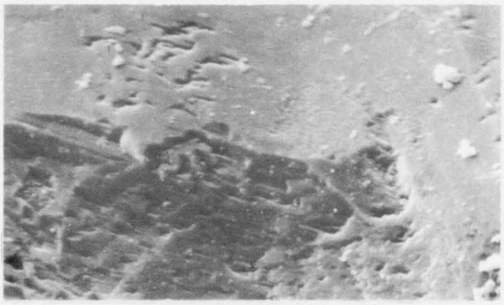
Plate 23

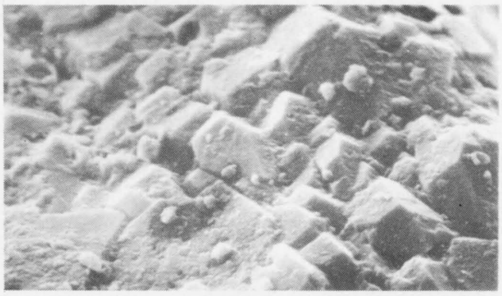

1

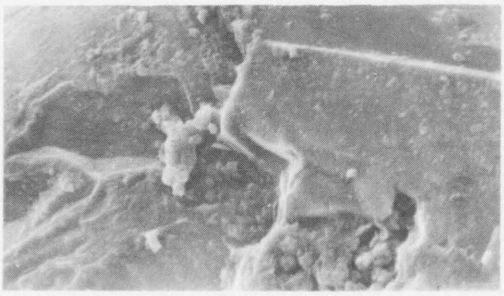

2

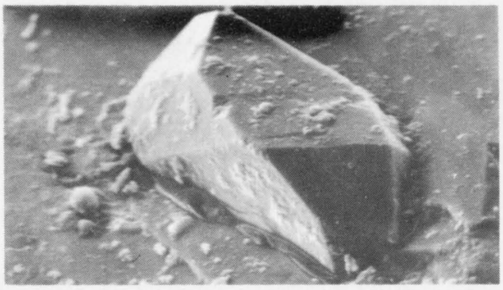

3

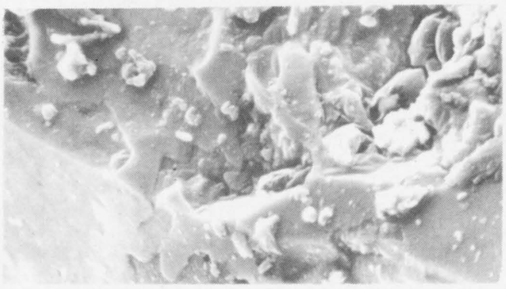

4


5


6


7


8


9

Antia & Sykes—surface textures of quartz grains.