Read at the Annual Conference of the Ussher Society, January 1993

CHERT FORMATION IN THE PORTLAND LIMESTONE FORMATION (UPPER JURASSIC) OF THE DORSET COAST; A PRELIMINARY INVESTIGATION

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Gorman, I., Hart, M. B., and Williams, C. L., 1993. Chert formation in the Portland Limestone Formation (Upper Jurassic) of the Dorset coast; a preliminary investigation. *Proceedings of the Ussher Society* **8,** 181-185.

Preliminary findings are described of the post- and syn-depositional diagenetic events in the chert-bearing beds of the Portland Limestone Formation. Central to this investigation is the JSM6100 scanning electron microscope with LINK dispersive X-ray analytical capability.

Chertification was not homogeneous and a distinct silica banding and zonation can be seen in chert nodules and beds. Previous authors have attributed the silica source to the abundant sponge spicules within the rock. These spicules are now found to be calcitic. If earlier assumptions are true, therefore, the initial spicules must have undergone solution of silica and subsequent replacement by secondary calcite.

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INTRODUCTION

The Portland Beds (Arkell 1933; 1947) or the Portland Group (Townson 1971; 1975) are a distinctive and well known part of the Upper Jurassic succession (Figure 1) in Dorset. The Group is well exposed (Figure 2) on the Purbeck Coast (Chapmans Pool to Durlston Head) and the Isle of Portland.

Most published works use the nomenclature of Arkell (1933; 1947) (Figure 1). Subsequently, Townson (1971; 1975) proposed a radical alteration of the lithostratigraphical nomenclature and, in substantial outcrops, this appears to be quite practicable. In smaller, isolated, sections it is more difficult to identify individual members. The cherts and diagenetic features described below are, therefore, from the Upper Chert Series and Lower Chert Series of Arkell (1933, 1947), the Dancing Ledge Member and the Dungy Head Member of Townson (1971; 1975). They form part of the Portland Limestone Formation of Townson (1971; 1975) (Figure 1).

The Portland Limestone Formation (Townson 1971; 1975) was deposited during a regressive period towards the end of the Jurassic. The palaeoenvironment was a shallow-marine carbonate shelf, affected by minor transgressions. The chert nodules are thought to be the result of early diagenetic alterations in a sulphate reduction zone, just a few cms beneath the sediment surface. The more continuous bands would have developed along redox boundaries and reflect localised to basin-wide hiatuses in sedimentation.

LOCALITIES INVESTIGATED

As part of a larger project IG has visited the majority of the localities on the Purbeck Coast and the Isle of Portland. Much of the material described herein comes from the Nicodemus's Knob [SY 698 732] (Figure 3) and East Weare Cliff [SY 701 735] sections on the Isle of Portland. Additional samples come from Freshwater Bay [SY 691 701] and Broadcroft Quarry [SY 700 720]. The Portland Limestone Formation contains an abundance of nodular and banded cherts. The chert-rich, fine-grained limestones are rich in sponge spicules which, in many cases, appear to have been replaced by carbonate. Townson (1971; 1975) assumed that these spicules were the source of the silica. The process of solution and concentration of replaced silica would adequately account for the uneven chert bands and nodular cherts, which often show concentric rings of fluctuating silica content (Figure 4). Many nodules also show a sharp join between the dark chert nodule and a lighter siliceous halo surrounding, or linking the cherts along a continuous band. This is probably due to the burrowing activities of Thalassinoides-type crustaceans or other taxa. The initial deposition of silica would have been in the burrow void (Clayton, 1986), with decreasing concentrations of silica away from the centre and mixing with the $CaCO_3$ sediment.

The banding is considered to be the result of the fluctuating abundance of silica-rich pore fluids that are caused

Arkell 1933 and 1947			Townson 1971 and 1975		
PURBECK BEDS (part)		(Lower Purbeck)	Lulworth Formation	PURBECK GROUP (part)	
PORTLAND BEDS	PORTLAND STONE	Freestone Series	Winspit Member	PORTLAND LIMESTONE FORMATION	PORTLAND GROUP
		Upper Chert Series	Dancing Ledge Member		
		Lower Chert Series	Dungy Head Member		
		Basal Shell Bed			
	PORTLAND SAND			PORTLAND SAND FORMATION	

Figure 1: Current lithostratigraphical nomenclature of the Portland group.

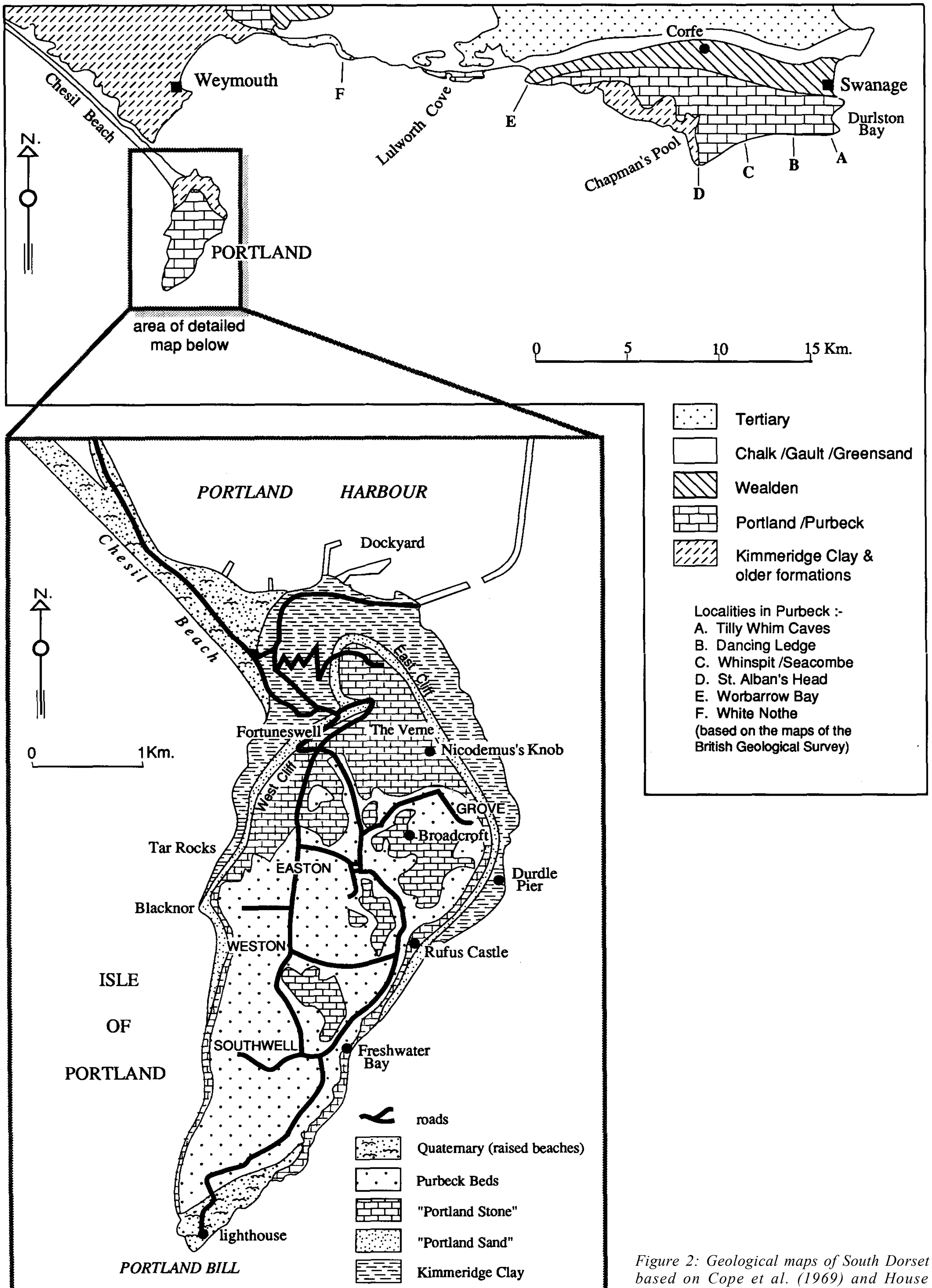

Figure 2: Geological maps of South Dorset based on Cope et al. (1969) and House (1989) showing sample localities.

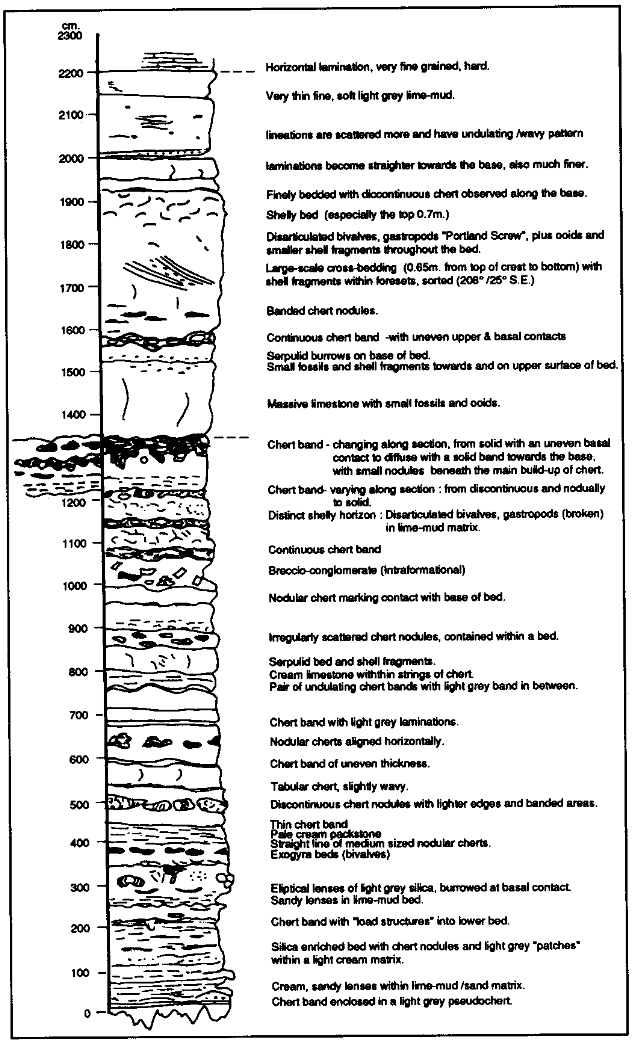

Figure 3. *Geological succession of the Portland Group at East Weare Cliff (SY 701 735] and, especially, Nicodemus's knob (SY 698 732]. The banded cherts, seen in figures 4, 5, 6, were taken from 500cm level.*

by periods of non-deposition and an oscillatory redox boundary that forces silica into solution in a sulphate-reducing environment. This leads to increased silica solubility in the pore fluids. Relatively long periods of non-deposition lead to a build up of silica and flat-topped bedded cherts are produced. The basal layer can vary in character from planar to undulating, depending on the amount of down filtering of silica into burrow systems. These features often appear as blobs of chert suspended below the main bed of chert by a thin ribbon of lighter coloured chert.

Previous authors (e.g. Townson, 1971; 1975) attribute the silica source to the abundant sponge spicules within the binding matrix, with the assumption that they are (or were) siliceous in composition. When tested by microprobe analysis the spicules are shown to be calcareous, indicating that early diagenetic processes caused solution of the silica and that redeposition occurred within the surrounding silica-rich matrix.

The cherts in the moderately dolomitic Lower Cherty Series formed *in situ* by replacement of the original lime mud. The cherty limestones are rich in sponge spicules, which in many cases have been replaced. The solution and concentration of replaced silica accounted for the unevenness of the chert bands and nodularity of the majority of the beds. Many nodules also show a sharp contact between the dark chert and a lighter siliceous halo surrounding or linking a bed of nodules.

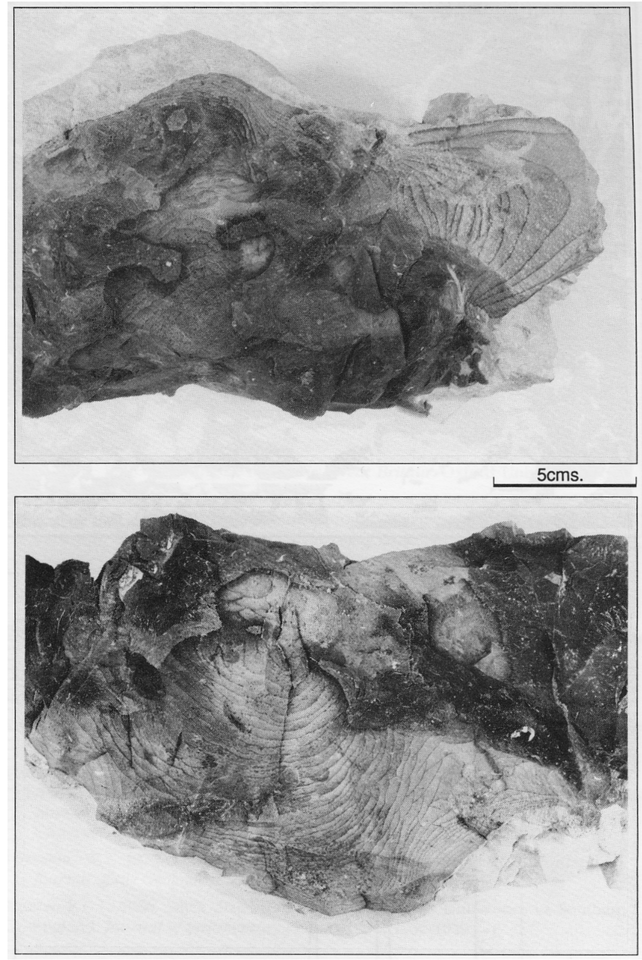

Figure 4: Hand specimens of banded cherts from East Weare Cliff and Nicodemus's Knob (taken from the chert horizon at 500 cms in Figure 3).

SEM INVESTIGATION

Most of the rocks are too fine-grained for conventional microscope work and it has been necessary to use the scanning electron microscope (JSM 5300 and JSM 6100) for both petrological work and analysis of geochemical composition (Link dispersive X-ray analysis).

Limestone samples consist of very small (<10μm) crystal grains with some scattered larger grains throughout. In most cases, no biogenic origin can be ascertained, although some highly corroded coccoliths have been tentatively recognised.

Chert samples appear as a mosaic of interlocking sponge spicules interbedded with smaller silica grains and larger masses of chert of unidentifiable origin. The spicules and silica grains occur in corroded pockets of the homogeneous chert matrix. Figure 5 shows a sponge, in the foreground, thought to belong to a demosponge taxon, with trigonal or tetragonal branching rays; some examples only have two rays arranged in a wishbone pattern but there is evidence of corrosion or dissolution of the third ray. These spicules, which appear to be the dominant matrix, have pitted, irregular surfaces, suggesting alteration has occurred.

Using the microprobe on the JSM 6100 the .spicule shown in Figure 5 has been analysed. The tip of the spicule (A) is altered and deformed, while point (B) is the best preserved part of the spicule. Location (C) is a typical area of groundmass. While it was initially assumed that the spicules were composed of silica, thereby providing an adequate source for the cherts (Townson, 1971; Wilson, 1966), these spicules are seen to be calcite, with only a small increase in Si content towards the distorted tip

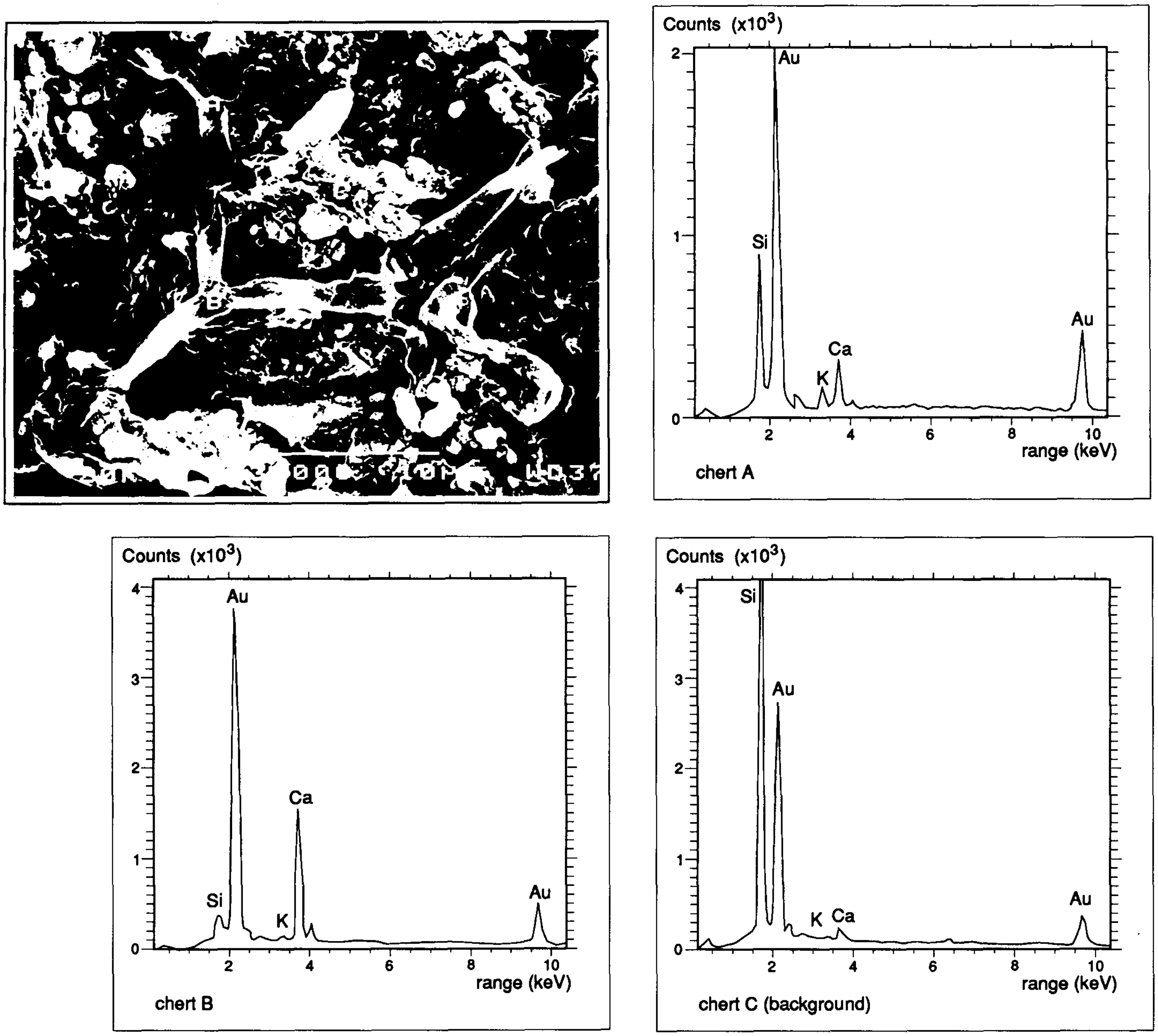

Figure 5: *Sponge spicule showing locations of analyses A to C. Note that the Au peaks in the spectra are due to the gold coating on the specimen. Specimens for analysis are now coated in carbon to aviod interference with the silica peak.*

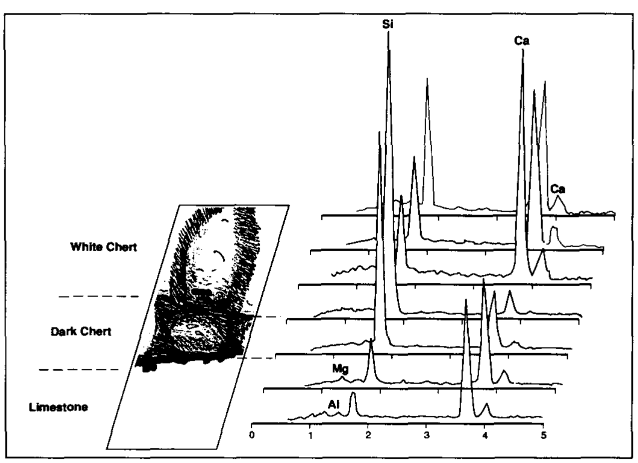

Figure 6 Geochemical data from seven points across a limestone/dark chert/pale chert boundary. Length of specimen is approximately 6 cms. Note the lack of magnesium and the marked reduction in calcium in the dark chert.

(at A). The surrounding groundmass is dominantly Si, with only minor traces of calcite. This indicates that the initial silica has been dissolved out and the resulting cavities replaced by secondary calcite. Townson (1971) defined the source as being *Rhaxella* and *Pachstrella* spicules. *Rhaxella* spicules are hollow, siliceous tetraxons, with rays 1 to 2 mm long. They are closely associated with silicification and cherty horizons, especially in coarser grade carbonate facies. Spicules of both types are susceptible to solution of silica and can occur together, but only *Pachstrella* spicules are observed as casts or voids. If the spicules observed are related to *Pachstrella* and the initial silica was dissolved and replaced by calcite, then this would explain the silica excess in the groundmass.

If the spicules were initially calcite, then the silica source remains a mystery. Jones (1984) described calcareous sponge spicules as being formed of individual crystals of magnesium calcite, which also contain other impurities; the structure is not homogeneous, the central axial region being composed of relatively impure calcite, the purity varying from inside to outside. This does not fit with the spicules observed, because if the spicule was originally calcite, then under high magnification it would be possible to observe the individual crystals. No such crystals have been observed and no magnesium has been detected in the analyses (Figure 5).

Another option is that the silica dissolved in, and filtered down from, a higher horizon, but this is unlikely since there is no evidence of this in the outcrop. All the evidence leads to the conclusion that most (if not all) of the chert was formed *in situ.*

The banded cherts have recently been investigated using polished slabs covering the chert/limestone boundaries. Preliminary work (Figure 6) shows that the variations across such boundaries can be resolved and the chertification fronts linking the darker nodules clearly identified (shown in Figure 4). The initial samples were covered in gold (Figure 5; A, B and C), with the possible distortion of the silica peak. All later investigations have been completed on carbon-covered samples (Figure 6), to improve the quality of the results.

DISCUSSION

The most common banded cherts appear to be the result of widespread low intensity sulphate reduction within the sediment. Local porosity and permeability variations, mostly due to burrows and bioturbation, produced mixing of the upward-diffusing sulphide and downward mixing of oxygen. This process produces the nodular form of the cherts in the Dancing Ledge Member. Less marked permeability variations produced more regular tabular bodies and early stage compaction joints produced obliquely bedded cherts (a common feature on the Isle of Portland).

Chert tends to form at any important change in the sediment fabric and burrowed sediment is not an absolute necessity. The contrast of porosity and permeability between the burrows and the sediment is not a significant reason for modification of the pattern of silicification, although when present the majority of the silica precipitated would appear to remain within the burrows.

Chert bands also represent cycles of deposition. Each break in sedimentation causes a prolonged gap with a stationary redox boundary below the sediment, which would lead to the development of a chert bed. Laterally, well developed continuous beds may record basin-wide hiatuses in sedimentation, while smaller, discontinuous bands may have formed beneath local washout beds or in a sheltered environment (Clayton, 1986).

SUMMARY

Chert bands are the product of chemical segregation of silica which was originally dissolved in the pore waters of the sediment and derived from the dissolution of the siliceous sponge spicules, the original carbonate having been dissolved from the chert areas concurrent with the precipitation of silica.

ACKNOWLEDGEMENTS

I.G. is grateful to Dr S. A. Caswell for his advice and for the assistance given by the staff of the Plymouth Electron Microscope Centre (Mr B. Lakey, Dr R. Moate and Mrs J. Green); also Mr J. Abraham who prepared the figures.

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