EXPLODED *PLAGIOSTOMA* SHELLS: MACROFOSSIL CONFIRMATION OF DISPLACIVE CEMENTS IN LIMESTONES AND CONCRETIONS OF THE BLUE LIAS FORMATION (LOWER JURASSIC) AROUND LYME REGIS, DORSET, U.K.

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Andrew, C., Howe. P. and Paul, C.R.C. 2016. Exploded *Plagiostoma* shells: macrofossil confirmation of displacive cements in limestones and concretions from the Blue Lias Formation around Lyme Regis. *Geoscience in South-West England*, **14**, 52–58.

Nearly 70 years ago Peter Kent drew attention to 'crazy' *Plagiostoma* shells in the Blue Lias Formation (Lower Jurassic), which were cracked and the pieces separated by limestone growth. Such 'exploded' shells result from displacive cement growth, which arises when microspar growth continues after total occlusion of pores, thus effectively increasing pore volume. Growth of displacive cements in the Blue Lias has been demonstrated using SEM, but the commonest suggestive evidence from limestones is acid insoluble residue values <20%. 'Exploded' shells can be distinguished from those damaged by compaction because the pieces maintain their relative orientations and the shell profile remains a smooth curve. Compaction damage reorientates shell pieces or displaces them across small faults. Cracks opened perpendicular to their sides. Thus, crack orientation relative to the hinge line can be used to detect any preferred stretching direction. Point counts were used to quantify the amount of stretching. Proportion of cracks on photographs ranges from 6–25%. Kent also recorded 'crazy' *Plagiostoma* shells from the top of the Planorbis Zone in Nottinghamshire. They are common and well developed at this horizon in Devon, but also occur at other horizons.

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Keywords: Exploded bivalves, point counting, limestone diagenesis, Blue Lias rhythms, Lower Jurassic

INTRODUCTION

Plagiostoma gigantea Sowerby, 1812, is one of the commonest bivalves in the Blue Lias Formation near Lyme Regis, Dorset, U.K. Occasionally, examples occur in the limestone beds that are cracked and which appear to have been pulled apart. They resemble the surface of some muffins that early in cooking form a hard crust, but as the heat penetrates the mixture the dough continues to rise, thus cracking the brittle surface crust. We believe that these 'exploded' *Plagiostoma* shells are macroscopic (and therefore obvious) evidence for the growth of displacive cements in the limestone beds that contain them. Displacive cements arise when diagenetic minerals do not just passively fill the pore spaces, but continue to grow when the pores are completely occluded, thus forcing the host sediment to expand. Arzani (2006) used electron microscopy (EM) to demonstrate the presence of displacive cements in the limestones of the Blue Lias Formation. He showed (e.g., Arzani, 2006, fig. 8a, p. 100) that calcite microspar crystals in the centres of the limestone beds were surrounded by 'clay cages': that is rims of clay minerals compacted by the growth of the microspar crystals. Arzani (2006, p. 100) also cited the presence of ostracod carapaces that had been pushed apart by the calcite crystal growth. In other words microscopic scale analogues of the 'exploded' *Plagiostoma* shells we describe here.

Neither our observations nor interpretations are entirely new. Kent (1957) drew attention to what he called 'crazy *Plagiostoma*' shells. It is worth quoting Kent's comment in full because he recognized the key features that distinguish 'exploded' *Plagiostoma* shells from those damaged by other means, particularly crushing. He wrote:

> "Positive evidence of dilation of the original sediment associated with limestone deposition is provided by the occurrence of *Plagiostoma gigantea* specimens which have become "crazy" (i.e. like the superficial appearance of a septarian nodule) through separation of the pieces of the fractured shell by normal limestone while retaining their original relative orientation; this has been observed in the highest part of the *planorbis* zone in Nottinghamshire, and is known elsewhere." (Kent, 1957, p. 429).

It is clear from the above that Kent recognized that the 'exploded' *Plagiostoma* shells resulted from growth of displacive cement, that 'exploded' shells could be distinguished from crushed shells by the fact that the shells were not distorted merely 'pulled' apart, and that 'exploded' shells were more common at certain stratigraphic horizons. Interestingly, they are common near the top of the Planorbis Zone in Devon as well as Nottinghamshire.

Arzani (2006) used EM to demonstrate his 'clay cages', but the most common evidence that suggests the possibility of displacive cement growth comes from very low acid insoluble residue (AIR) values. For example, Hallam (1960, fig. 2, p. 11) gives five values below 10% and another 14 below 20% from Blue Lias limestones. Similarly, Arzani (2004, p. 263) gives three values for the centres of Blue Lias limestone nodules between 15.5% and 18.2% and Paul *et al*. (2008, p. 265) give three values for limestones and concretions of between 13.5% and 18.5%. All these values imply that, after diagenetic cement growth, the limestones and concretions contain >80% and in rare cases >90% carbonate. Such values are too high to result from passive fill of pore spaces even in freshly deposited clay. In the past AIR