Nodular preservation of trilobite fossils from the Bokkeveld Group, Eastern Cape Province, South Africa

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Introduction

Invertebrate fossils and fossiliferous nodules within the Bokkeveld Group (Cape Supergroup) were recorded in the Cederberg area from the early nineteenth century (Rogers 1937; Cooper 1982; Theron 1972; MacRae 1999). These fossils have since been collected and described from various other localities within the Cape Fold Belt (Johnson 1976; MacRae 1999; Oosthuizen 1984).

The preservation of fossils within the Bokkeveld varies greatly. In general, specimens are better preserved within nodules compared with the surrounding shales, which reflects the early diagenetic origin of these nodules (Theron & Johnson 1991). Some nodules have been known to contain very well preserved invertebrate fossils (Theron 1972; Oosthuizen 1984), many of which are described as type specimens. Although preservation of fossil material as moulds predominates (Oosthuizen 1984), some original skeletal material in the form of phosphatic inarticulate brachiopods is preserved (Almond 2005). Rare preservation of skeletal carbonate is known from accumulations of shelly debris (*op cit.*). Studies on the original mineralogy of trilobite exoskeletons have shown that these are usually composed of calcite (Wilmot & Fallick). Fresh fossil samples often display pyritic encrustations (Theron 1999). Within the Bokkeveld the composition of trilobite fossil material specifically has not been studied. Also, very little attention has been paid to the nodular structures themselves and to possible reasons for better preservation of fossils within them compared to within the surrounding shales. The following short note aims to highlight some macro- and micro-structural and mineralogical differences between trilobite material found within shales and nodules.

The lower Bokkeveld shales were deposited on a storm-influenced clastic shoreline controlled by cyclical eustatic sea-level fluctuations (Cooper 1982; Broquet 1992; Cotter 2000). These lithologies were subjected to advanced stages of diagenesis grading into low grade metamorphism (de Swardt & Rowsell 1974). Nodular structures within them are considered to be early diagenetic in origin (Theron 1972).

Materials and methods

Nodules were collected from the Gydo Formation, within the Ceres Sub-group, at various localities in the Cockscomb/Steytlerville area. Where possible, nodules were collected in situ and their GPS locations were taken (see Browning 2009). Some limitations of this study should be noted from the outset. In the absence of equipment needed for detailed chemical and isotope analysis, it was decided to adopt a different approach to nodule examination. Limited chemical analysis in the form of XRD (X-ray diffraction) was carried out on the central regions of both nodules and shale. However the majority of the work entailed petrographic analysis of thin sections, together with careful observations and photography of macro-structural features and field observations.

Results

Macro-structure

The nodules are clearly more resistant to weathering than the surrounding shales in which they occur. They are typically spheroidal, ranging from oblate to prolate in form, and range in size from 30–130 mm (long axis). Nodule shape is controlled by that of the enclosed organic remains in 40% of nodules, while the shapes of the remaining nodules are not influenced by enclosed organic remains (Browning 2009). Nodular cross-sections usually reveal a series of colouration zones which mimic their roughly circular to elliptical shape. These colouration zones indicate that the nodules are weathered and vary from burnt orange to deep purple-maroon. Fossil material within nodules varies but is usually dark grey in colour (Fig. 1). Fossil material within shales also varies but is typically burnt orange in colour and often associated with the growth of fine mica (sericite?) crystals.

X-ray diffraction (XRD)

The XRD results obtained from the analysis of nodules and host shales are presented in Table 1. On average the shales contained higher percentages of sericite compared to the nodules. The average nodule contains more quartz than the average shale does. The feldspar median percentages of shales and nodules are very similar.

The results obtained from the XRD analysis of selected nodules in the Western Cape (Cederberg) by Almond (1996), are shown in Table 2. Differences were noted in the chemistry of the nodules from the Western and Eastern Cape localities (Tables 1 & 2). These variances may be real or they may be an artefact of the degree of weathering. The most noticeable difference between Eastern and

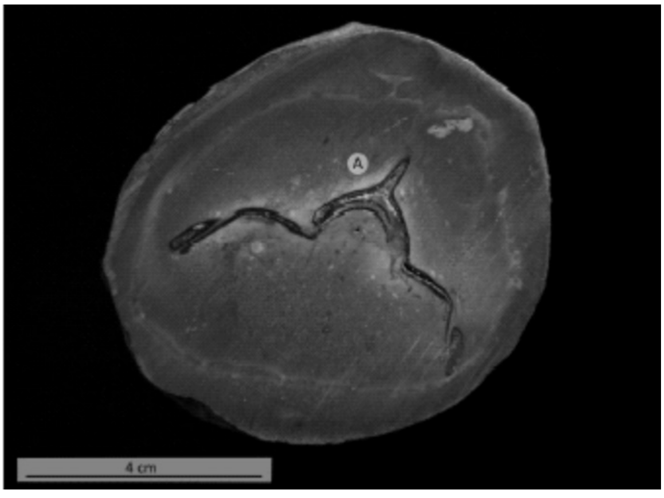

Figure 1. Macro-photograph of a transversely sliced surface of a nodule showing a cross-section through a trilobite carapace (A).

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Table 1. Preliminary XRD results showing the percentage of dominant minerals found within shales and nodules.

Sample no.	Seriate	Quartz	Chlorite	Feldspar
Nodule (5)	30	28	36	5
Nodule (017)	39	33	17	12
Nodule (03H)	12	63	26	n/d
Nodule median %	30	33	26	8.5
Shale 2	39	28	22	11
Shale 3	52	20	10	10
Shale median %	45.5	24	20	10.5

Western Cape nodules is the apatite content. Apatite is the dominant mineral recorded in the Western Cape nodules, while the Eastern Cape nodules did not contain any apatite (at least not within the detectable limits of the analysis). When the combined percentage of mica found within the Eastern and Western Cape samples is compared, the Eastern Cape nodules have higher percentages of mica. This suggests a greater degree of weathering in these nodules. The nodules of the Eastern Cape are enriched in quartz with respect to the Western Cape samples. A slightly higher percentage of quartz was recorded in Western Cape nodules containing trilobite remains, compared with the quartz content of the nodules that did not contain trilobite fragments. The Eastern Cape nodules contained an unidentified feldspar. The Western Cape samples contained feldspar that has been identified as plagioclase. Plagioclase has been identified in some Bokkeveld shales (de Swart & Rowsell, 1976). A high percentage of calcite was present in one Western Cape sample identified as a 'carbonate nodule'. Calcite was not identified in XRD analyses of the Eastern Cape samples.

Petrography

The minerals contained within trilobite carapaces in shales and nodules differ. Within nodules, quartz, together with some minor opaque minerals, is the only replacement mineral (Fig. 2). Within shales, the trilobite carapace material was composed of equal proportions of quartz, hematite and biotite (Fig. 3). Opaque minerals were also present as minor constituents. Hematite was found in the central portions of the carapace, while quartz and biotite dominate the outer portions of the carapace. Fossils found within nodules are generally more deformed towards the nodule margins than they are in the centre of the nodule.

Discussion

The colour zoning within nodules probably results from varying levels of oxidation of opaque and iron minerals within the nodule matrix. It appears that the presence of quartz within both the nodule structure and as a replacement of the trilobite carapace within the nodule, makes these structures more resistant to weathering than surrounding shales. These results could be clarified by the investigation of a wider variety of faunal groups as well as a more extensive chemical analysis of a range of nodules.

There are clearly differences in the nature of minerals which replace fossil material in the shales and within nodules. As previously stated, most fossil material within the Bokkeveld is preserved as moulds and casts. The direct replacement of trilobite carapaces by quartz is therefore unlikely. Quartz and other replacement minerals were more probably deposited later in the diagenetic process, as a secondary infilling of a mould. The presence of a gap in the axial ring and furrow regions of the carapace where the cuticle is thickest (Fig. 2) further supports

Table 2. XRD results for Western Cape nodules (Almond 2006).

Sample	Calcite	Apatite	Mica	Smectite	Quartz	Chlorite	Plagioclase
Orbiculoidea	n/d	59	9	5	24	4	n/d
Metaconularia	n/d	68	5	n/d	21	5	n/d
Shelly remains	n/d	58	10	10	19	3	n/d
Trilobite concretion	n/d	55	7	2	29	6	n/d
'Carbonate' nodule	68	n/d	8	n/d	9	13	3
Median %	68	59	7.5	5	22.5	5	3

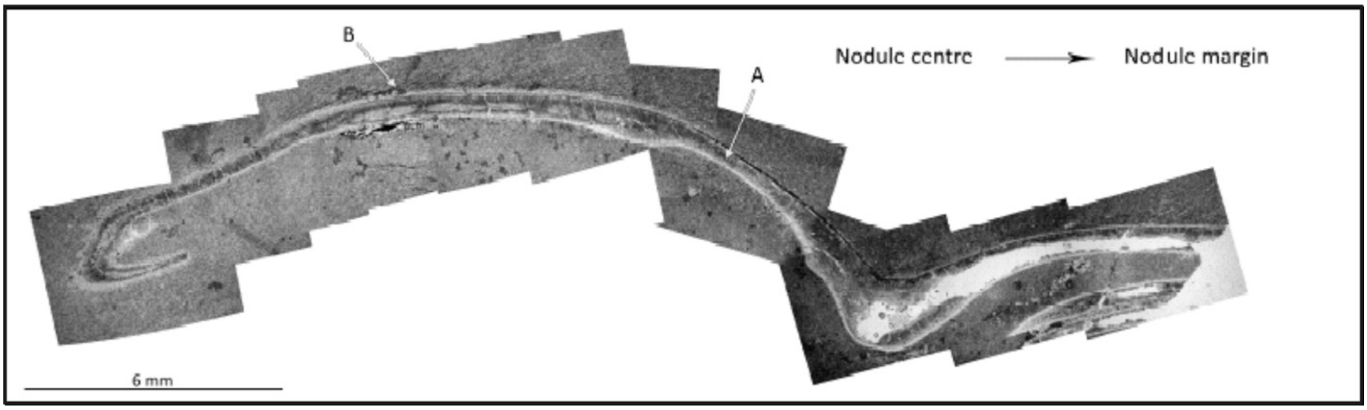

Figure 2. A photomicrograph composite composed of various images of a transverse section through a single thoracic tergite of a trilobite within a nodule. Quartz is the dominant replacement mineral (A). The images were taken under plane polarized light. Note the excellent preservation of the carapace and the formation of cleavage near the upper surface of the fossil (B).

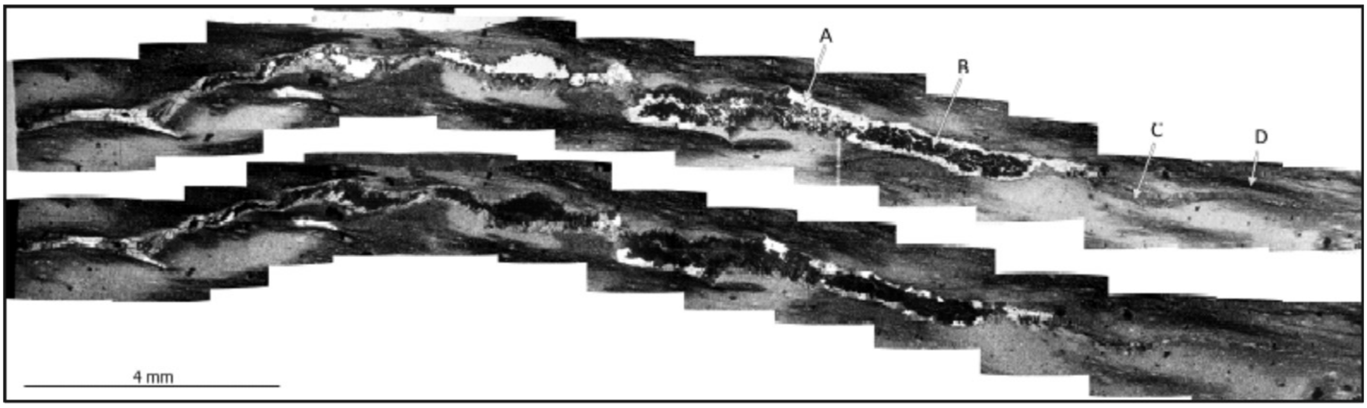

Figure 3. A photo-composite image composed of photomicrographs taken of a longitudinal section through successive thoracic tergites of a trilobite carapace within shale. The upper composite was taken under plane polarized light while the lower one was taken under cross-polarized light. The general shape of the carapace can still be seen although deformation is evident. Minerals within the carapace include quartz (A), hematite (B) and biotite (C). Minor amounts of other white micas are found in association with biotite. Biotite seems to develop preferentially at the thinner margins of the fossil. Hematite is mostly found in the central portions of the carapace and generally shows a close association with quartz. Cleavage can clearly be seen in the shale matrix surrounding the carapace (D). Cleavage intensity varies as do colouration zones within the shale.

this idea. Within the shales, the predominance of biotite in the outer regions of the carapace, suggests that this mineral initially coated the surfaces of the empty mould. This initial coating could then have been followed by the infilling of the remaining empty spaces by quartz and later haematite although these observations need to be confirmed by more extensive studies. The increase in deformation towards the nodule margins compared with the central regions implies nodule growth during compaction and supports the early diagenetic origin.

Nodules from the Cockscomb area are predominantly composed of quartz while nodules from some Western Cape localities (Almond 1996) within the same formation are mainly composed of apatite. The reasons for this variation along strike are not known. It is interesting to note, however, that similar compositional variations have been documented for nodules located in the Armorican Massif of France (Becq-Giraudon *et al.* 1992; Loi & Dabard 2002). The analysis of these 'French nodules' recorded variations in bulk quartz composition of between 40 and 85% and the quartz percentages presented were directly proportional to the apatite content within the nodules. Given this variation, the difference in bulk mineral composition between the Cockscomb and Western Cape nodules may simply reflect a natural variation and not imply vastly different diagenetic or depositional environments of formation.

Conclusion

Although preservation of invertebrate fossiliferous material is better within nodular structures, material within the shales of the Bokkeveld are not as deformed or poorly preserved as would be expected for lithologies subjected to the known levels of diagenesis and metamorphism. The reason for this appears to be mineralogical, with variations in both mineralogy and overall nodule composition being the main contributing factors. The composition of nodules analysed from the Western and Eastern Cape varied significantly. These findings need to be clarified with more detailed analysis of general as well as isotope chemistry.

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