CORRESPONDENCE

Genesis of the graphite deposit at Seathwaite in Borrowdale, Cumbria

SIR – a recent paper by Weis, Friedman & Gleason (1981) provided welcome confirmation of the organic origin for the carbon which constitutes the graphite deposit near Seathwaite in Borrowdale, Cumbria. In a study of the $^{13}C/^{12}C$ isotope ratios for a number of graphite deposits, they concluded that the isotopically light Seathwaite graphite could only be derived from organic matter and had no opportunity to react with carbonate rocks during mobilization and redeposition. It has been established that graphite can be an abiogenic product of deep crustal metamorphism (Glassley, 1982), and a magmatic source for the carbon in the Seathwaite graphite was proposed by Strens (1965). The graphite occurs in veins intimately associated with the Steel Fell Diabase, an intrusion in the Borrowdale Volcanic Series. Lower Palaeozoic mudstones underlie the volcanics and in the past have been considered a source for the graphite (Marr, 1916), a view now supported by the work of Weis, Friedman & Gleason. However, the reasons for the graphite mineralization have never been clear. A genetic association with the diabase intrusion is suggested by K/Ar dating of the intrusion and vein alteration at 382 Ma and 376 Ma respectively by Mitchell & Ineson (1975), and by the absence of graphite in veins remote from the diabase.

Bitumens derived from organic-rich sedimentary rocks are commonly present in and about igneous intrusions (e.g. Osborne, 1923), the intrusive bodies providing a heat source for mobilization and/or a channel for fluid migration. The volume of graphite present at Seathwaite, once sufficient to support a mining industry, is considerably greater than that normally associated with a single intrusion, and emphasizes the importance of the diabase as a channel for fluids mobilized by other means. A similar problem arises in some intrusion-related ore deposits, for example lead and zinc sulphide veins at Blackcraig (Kirkcudbright) and Strontian (Argyll), each far larger than would be expected if their genesis were related solely to adjacent dykes. Both examples are also spatially related to Caledonian granites, which provided a high geothermal gradient over a wider area and allowed wider scavenging by mineralizing fluids through deep-seated fractures. Granites remain a source of high heat flow long after intrusion (Brown *et al.* 1980). Granite intrusion is a likely mechanism for the mobilization of organic carbon compounds in the Borrowdale region. The Eskdale Granite which underlies the area is now dated at 429 ± 9 Ma (Caradoc) by Rundle (1979) and must have affected the organic matter in pre-existing mudstones. Granites can drive hydrocarbon minerals from source rocks through which they intrude (e.g. Mueller, 1960). The Seathwaite graphite however derived from mobilization at a later date in accord with the isotopic data of Mitchell & Ineson (1975), the 'end Silurian event' of Rundle (1979) which includes the intrusion of the Steel Fell Diabase and the Skiddaw and Shap granites. Organic matter might have mobilized afresh from the mudstone sequence or remobilized from existing Caradoc mobilizates.

A possibly analogous deposit is that of Shungite, once mined from the region north of Petrozavodsk in the Karelian ASSR. Varietes of Shungite include an epigenetic deposit containing up to 98.8% carbon (Sudovikov, 1937; Marmo, 1953), with some X-ray lines characteristic of graphite (Rankama, 1948). The deposit formed by the intrusion of diabases through Lower Proterozoic carbonaceous pelites, a relationship confirmed by the similarity of the $^{13}C/^{12}C$ ratios for the Shungite and the pelites (Rankama, 1948). Shungite is found both within diabase and adjacent to it, as is the Seathwaite graphite. Precise details of the deposit are not available to the writer, but Nalivkin (1973) recorded that the Upper Karelian pelite/psammite/diabase formation is intruded by Rapikivi Granites (1400–1600 Ma), whose heat would have contributed to the genesis of the organic matter.

Carbonaceous minerals are thought to develop during metamorphism to minerals of higher carbon content (King, Goodspeed & Montgomery, 1963). Although aspects of this continuous development sequence are incompatible with organic geochemical studies (e.g. Jacob, 1967), the general concept holds true. Metamorphism by burial and magmatic intrusion is responsible for much graphite, but time may also be an important factor in the formation of high-carbon minerals like anthraxolite and graphite (Breger, 1963). However, Ordovician dolerite intrusions which cut Lower Palaeozoic mudstones in the Welsh Basin at Llanelwedd contain bitumens but not graphite. The derivation of graphite from similar mudstones in Cumbria was the result of the higher heat flow which affected the region due to granitic intrusion, and which is still evident now (Brown *et al.* 1980).

Geol. Mag. **119** (5), *1982, pp. 511–512. Printed in Great Britain.*

https://doi.org/10.1017/S0016756800026868 Published online by Cambridge University Press

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8th March 1982

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https://doi.org/10.1017/S0016756800026868 Published online by Cambridge University Press