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Dating and differentiation of geological units in highly deformed and metamorphosed rocks – Can palynology help? Examples from the Ossa-Morena Zone (W Portugal)

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Abstract: Macrofossils and most mineralized microfossils are often absent in metasediments and commonly unrecognizable in deformed rocks. Conversely, organic-walled microfossils such as spores/pollen, acritarchs and chitinozoans (i.e. palynomorphs) can preserve their characteristics even in high-grade metamorphic conditions (Hanel *et al.*, 1999; Bernard *et al.*, 2007). They are frequently the only preserved fossils in metamorphic rocks and thus valuable for obtaining sedimentation ages and paleoenvironmental data. Here we discuss some geological variables involved in palynomorph preservation and destruction in deformed metasediments by compiling data from the literature and by presenting data from Devonian and Carboniferous metasediment samples from the Ossa-Morena Zone (W Portugal).

Keywords: palynomorphs, metasediments, Ossa-Morena Zone, organic matter preservation, deformation, mineralization.

Due to the solubility of the mineral substances that make up most macrofossils and microfossils, they are very frequently absent from or dramatically modified in sedimentary rocks that have been subjected to metamorphism. The main variables involved are temperature and pressure which are often associated with deformation and fluid circulation. Palynomorphs have sizes from a few micrometers (small acritarchs) up to a few hundreds of nanometres (larger chitinozoans and megaspores). The wall is composed of different organic substances, according to its nature. It is usually very resistant to abrasion and breakage, and can maintain its overall shape over a wide range of temperatures and pressures, showing a gradual and irreversible darkening with temperature (Yule *et al.*, 1998, 1999, 2000). Palynomorphs are found in rocks from the Precambrian (first acritarchs) up to recent. They are usually obtained by maceration of sedimentary rocks (HCl + HF attacks) and mounting of the organic residue in a microscopy slide. They can also be observed in thin sections, but this is done only when the organic wall has been replaced by mineral substances or when fragmentation precludes taxonomic identification in an organic residue observation.

Geological setting

Along the Porto-Coimbra-Tomar shear zone (Western Ossa-Morena Zone, Iberian Massif) several tectonostratigraphic units crop out to form a metamorphic belt. These range from very-low to high metamorphic grade. The Albergaria-a-Velha Unit comprises Devonian and Carboniferous, dispersed black and grey shale outcrops in an area from Espinho to Albergaria-a-Velha (Chaminé *et al.*, 2003, 2007) and southwards in an area from Mealhada to Tomar (Gama Pereira, 1987; Chaminé *et al.*, 2003, 2007). The metamorphic grade of the unit is very-low to low: high anchizone to epizone (Chaminé *et al.*, 2003; Vázquez *et al.*, 2007) with estimated temperatures higher than 200 ºC and pressures up to 2 kbar (Illite crystallinity data from Vázquez *et al.*, 2007). It is densely imbricated in the Late Proterozoic (Beetsma, 1995) black-greenish phyllites of the Arada Unit which are lithologically very similar, having a slightly higher metamorphic grade. Despite the strong deformation, considerable metamorphic grade and common mineralization, the Albergaria-a-Velha unit provides diverse and moderately well preserved palynological assemblages which allow the determination of sedimentation ages, paleoenvironmental assessment and cartographic differentiation from the Arada Unit. The several geological variables in play are discussed and examples of palynomorph preservation are presented.

Studied variables

Sedimentation and diagenetic factors

Due to their size and hydrodynamic characteristics, palynomorphs tend to be concentrated in pelitic sediments (Traverse, 2007). Coarser grained rocks may provide palynomorphs but usually in a much lower quantity and quality. Carbonates rarely provide good palynological assemblages (Wicander and Wright, 1983) due to the alkalinity of their sedimentation setting and usually low concentration of organic matter (Gehman, 1962; Traverse, 2007). Anoxic and dysoxic environments in both sedimentation and diagenesis favor organic matter preservation and, therefore, of palynomorphs (Tiwari *et al.*, 1994; Traverse, 2007). An extensive discussion with examples of the effects of physical variables during deposition and diagenesis is given in Tiwari *et al.* (1994).

Temperature and pressure

With increasing temperature and pressure, palynomorphs progressively and irreversibly change colour and lose transparency. The effect of lithostatic pressure has been shown to retard organic maturation, but its effect is drastically reduced over 1 kbar (Sengupta, 1975; Sajgo *et al.*, 1986).

For the most mature and metamorphosed spores, little differentiation can be made as they reach a black and normal-light-opaque stage. They become more brittle and are thus more easily broken due to deformation, but their overall shape is frequently preserved and a taxonomic identification is possible using strong oxidizing agents or SEM observation (Traverse, 2007).

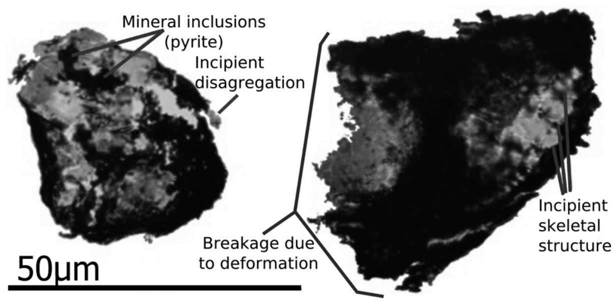

Figure 1. Example of partially destroyed thin-walled acritarchs from a (?) Silurian/Early Devonian highly deformed metasediment located in the Albergaria-a-Velha Unit.

Acritarchs respond differently and thin-walled ones may remain translucent up to low-grade metamorphic conditions, after which they start to disaggregate (especially when associated with deformation), frequently producing skeletal structures with relicts of their original ornamentation (Fig. 1). Thick-walled acritarchs become dark in a similar way to spores and are destroyed in the same way as thin walled acritarchs.

Chitinozoans are probably the most resistant palynomorphs. They may be partially preserved as graphitized particles in mylonitic gneisses with estimated peak temperatures between 300 and 500 ºC (Hanel *et al.*, 1999). In all of these cases palynomorphs still provide useful paleoenvironmental data and in some cases crude stratigraphical bracketing.

Compaction and deformation

Compaction due to lithostatic pressure, especially in shales, causes flattening and consequent folding of the wall of palynomorphs (Clayton, 1972). Due to their elastic wall, the overall shape and ornamentation is usually preserved. Sedimentary rocks and their fossil contents preserve most of their characteristics when subjected to gentle folding and minor faulting. Other deformation features such as penetrative foliation, grain boundary sliding, closely packed folding and bedding-parallel shear movement may destroy the entire macrofossil content and a significant part of the millimetre-sized microfossils. Due to their minute size and organic wall, palynomorphs may be preserved even in metasediments with millimetre scale foliation and closely packed kink folds. This is frequently observed in the Albergaria-a-Velha unit (Fig.2).

Fluid circulation and mineralization

It is widely known among palynologists and organic petrologists that oxidation (positive Eh values), resulting either from weathering or diagenesis or metamorphism, alters or destroys organic-matter (Tiwari *et al.*, 1994). Metasediments that have extensive mineralization or veining with oxides are almost invariably barren. On the other hand, exceptionally well preserved palynomorphs can be found in pisolitic ironstones, in both matrix and pisoliths (Vavrdová, 1999). Sulphide mineralization, when restricted to veins or not completely replacing the host rock, has a milder effect. Palynomorphs frequently have pyrite crystals growing inside of the wall or attached to the processes, but are generally preserved (Fig.1).

Silicification in early diagenesis stages can actually increase the fossilization potential of palynomorphs, preserving them in their original 3D form, as observed in the Rhynie chert. Silicification (either extensive or veining) in late diagenesis and during metamorphism usually decreases the preservation quality, but is not usually a determining factor, except when there is a significant replacement of the host rock by silica. We have sampled Upper Devonian black shales with millimetrical quartz veins and thick (ca. 50 cm) quartz + complex carbonates ± pyrite ± chalcopyrite ± dickite/kaolinite (Chaminé, 2000; Chaminé *et al.*, 2003) which were equally fossiliferous as were samples from the same locality with no mineralization, although more undissolved minerals remained after HF attack (Fig. 3)

Discussion and conclusions

It is difficult or even impossible to determine well defined limits of physical variables under which palynomorphs are preserved. In the case of the Albergaria-a-Velha Unit sediments exposed to temperatures higher than 200 ºC and pressures up to 2 kbar provide diversified and moderately preserved palynomorphs that allow stratigraphical positioning to the stage level and good paleoenvironmental determination. Strong deformation and some types of mineralization have a limited detrimental effect on the quality of the assemblages. The more deformed and heated, the worse the quality of the microfossils but, in some cases at least, palynomorphs may be preserved in mylonitic gneisses exposed to temperatures of between 300 and 500 ºC, still providing useful sedimentary and stratigraphical information (Hanel *et al.*, 1999).

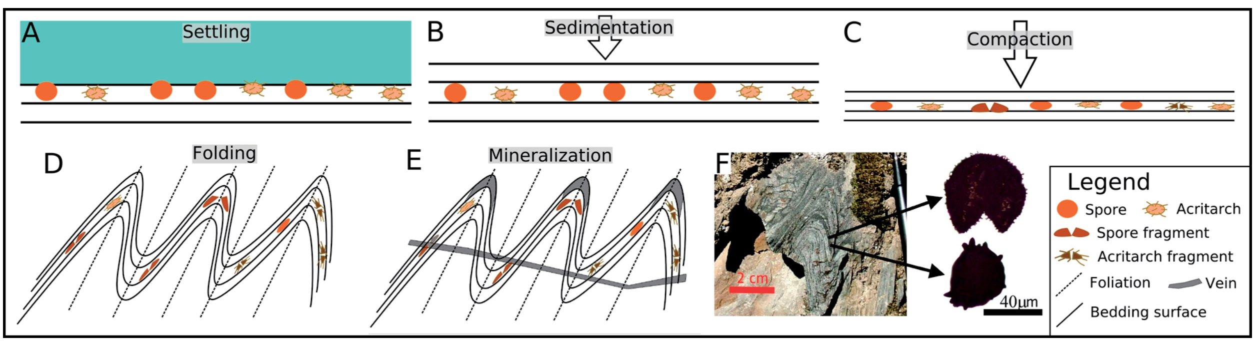

Figure 2. Schematic illustration of a hypothetical sequence of palynomorph destruction/preservation and an actual case of a deformed and metamorphosed rock that provided both acritarchs and spores. (A) Sedimentation of palynomorphs in a marine setting, (B) sedimentation of overlying strata, (C) compaction due to overburden and destruction of some of the palynomorphs, (D) folding and associated foliation with further destruction of palynomorphs, (E) mineralization during or posterior to deformation with minor effect on palynomorphs, (F) actual case of deformed and mineralized rock that provided moderately preserved palynomorphs.

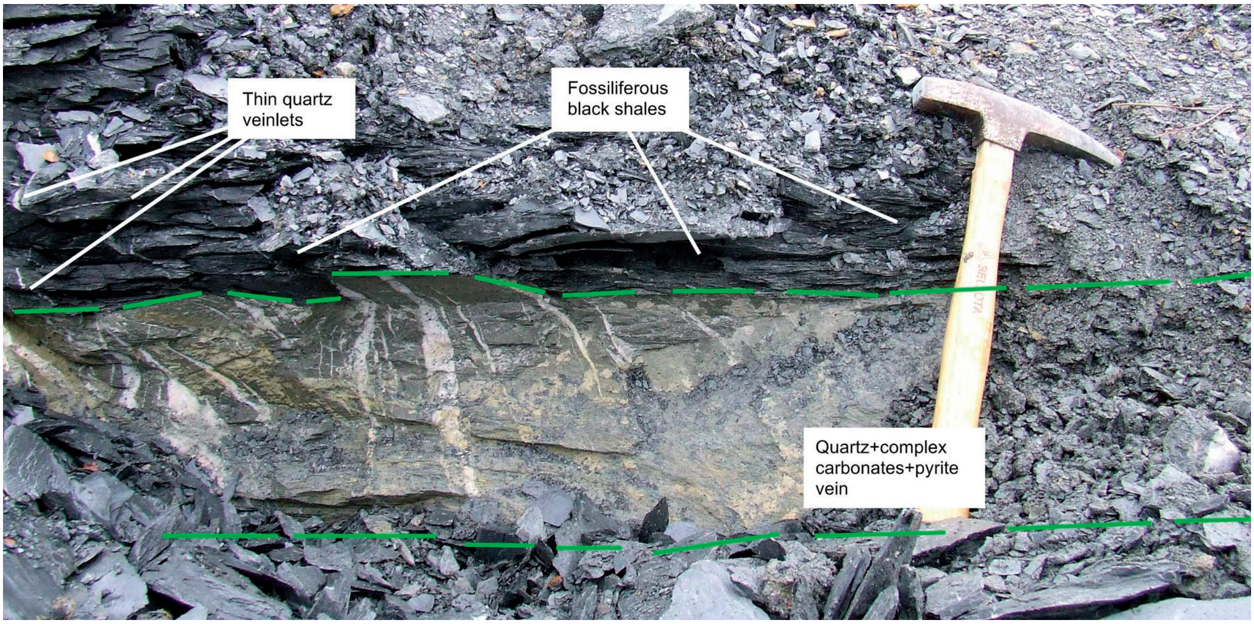

Figure 3. Fossiliferous black shale samples affected by mineralization.

The potential of many metasedimentary units around the world is probably greater than currently considered by many palynologists and geologists. Although laborious and sometimes unsuccessful, palynological processing of metasediments can provide information that would otherwise be unattainable.

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