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ACRITARCH FINDINGS IN EARLY PALEOZOIC, LOW-GRADE METASEDIMENTS OF SARDINIA (ITALY): A REVIEW

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ABSTRACT

Acritarchs were found in the weakly metamorphosed deposits of the Hercynian belt of Sardinia (Italy). Silurian assemblages has been described from the Outer Zone of the Sardinian chain since 1979. From the same zone, recently, Early Tremadocian acritarchs associated with graptolites have also been found. In the Nappe Zone of Central Sardinia the palynomorphs were found in Late Cambrian to Arenigian, terrigenous formations. The preservation of acritarchs in metamorphosed and strongly deformed rocks such as the Sardinian Paleozoic metasediments is discussed. The most important geological implications of the palynological datings are also briefly examined.

Keywords: Palynology, Early Paleozoic, Hercynian, Metasediments, Low-grade, Sardinia.

RESUMEN

Se analizan los datos sobre acritarcos procedentes de los materiales hercínicos de Cerdeña (Italia), y se discute su modo de preservación en las rocas intensamente deformadas y metamorfizadas del Paleozoico sardo. Las asociaciones silúricas han sido documentadas en la Zona externa de la Cadena sarda desde 1979, en donde se localizan también los descubrimientos recientes de acritarcos del Tremadoc inferior asociados con graptolitos. En la Zona de Mantos de Cerdeña central, los palinomorfos se registran en formaciones terrígenas entre el Cámbrico tardío y el Arenig. Finalmente, se examinan las implicaciones geológicas más importantes de las dataciones palinológicas.

Palabras clave: Palinología, Paleozoico Inferior, Hercínico, Metasedimentos, Bajo Grado, Cerdeña.

GEOLOGICAL OUTLINES

Three parallel NW-SE trending belts have been recognized in the Sardinian sector of the Hercynian chain, each with its own particular grade of metamorphism, tectonic structure and stratigraphic sequence.

The first belt, or Outer Zone, lies in South-West Sardinia, in the Iglesiente-Sulcis region (Carmignani *et al.*, 1986a, with bibliography). This zone has very low grade anchimetamorphism and a complete stratigraphical sequence ranging from the Early Cambrian to Late Devonian (Naud, 1979; Minzoni, 1981, with bibliography).

The sequence of the Outer Zone is characterized by a terrigenous Early Cambrian formation (Bithia Formation), that becomes upwards gradually enriched in carbonatic layers (Nebida Formation). This latter formation passes to limestones and dolostones of the Early- (Gonnesa Formation) and Middle Cambrian (Nodular Limestone of the Cabitza Formation), which in turn are followed by a pelitic-siltitic sequence (Cabitza Schists), unconformably covered by coarse clastic deposits of Ordovician age ("Puddinga" auct.). The "Puddinga" gradually passes upwards into weakly carbonatic siltites and argillites with a rich Caradocian fauna, followed by biocalcarenites with Ashgillian fossils (Leone *et al.*, 1991). The Silurian is represented by black graptolitic shales containing, towards the top, lenses of *Orthoceras* bearing limestones. The Silurian sequence passes into a Devonian formation mostly comprised of fossiliferous "griotte" limestone (Gnoli *et al.*, 1990).

The Outer Zone sequence is tectonically covered by the Arburese allochthonous Unit, whose sequence is similar to that of the Units of Central Sardinia.

The second belt, or Nappe Zone, is found in Central and South-Eastern Sardinia (Barca *et al.*, 1986; Carmignani *et al.*, 1986b; with bibliography). In this zone, a low grade metamorphism affects a stratigraphic sequence ranging from the Late Cambrian to Early Carboniferous. The Nappe Zone contains several tectonic units that form the Gennargentu, Sarcidano, Gerrei, and Sarrabus allochtonous complexes.

The stratigraphic sequence varies little in the different complexes. As an example, the Meana Sardo Nappe sequence (Sarcidano region) begins at the base with a terrigenous, turbiditic Cambrian-Ordovician formation (Solanas Sandstone), followed by a volcanic and volcanoclastic complex (Mt. Corte Cerbos Volcanites, Manixeddu and Serra Tonnai Formations), which are followed by the mainly terrigenous, dark deposits of the Bruncu su Pizzu Formation (Caradoc-Ashgill?). The Silurian is represented by lydites, graptolitic black schists and *Orthoceras* bearing metalimestones, sometimes associated with basic metavolcanites. The sequence ends in the Gerrei Units with a Devonian-Dinantian formation which is characterized by "griotte" limestones and pas-

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ses upwards into Tournasian metasandstones and metaconglomerates.

The third belt, or Axial (or Inner) Zone, is found in Northern Sardinia (Elter *et al.*, 1986, with bibliography) and has a high grade metamorphism, prograding northeastwards.

STATE OF PRESERVATION OF THE ACRITARCHS

The state of preservation of the Sardinian acritarchs has been studied in detail in the Solanas Sandstone Formation of the Nappe Zone (Di Milia, 1988). Here, the most productive lithologies were the most fine-grained, dark-gray to black, metapelitic or metapelitic-siltitic, which corresponds to the hemipelagic layers of the turbiditic sequences. By far the majority of the samples collected in these lithotypes were more or less fossiliferous; in practice, only the weathered samples were totally barren, as a result of surface oxidization of the rock. However, few of the fossiliferous samples could be used for paleontological and stratigraphical studies, since most of the microfossils had been stretched and shattered by tectonic deformations until they were no longer identifiable. Even the best preserved specimens were in a poor state of preservation, dark gray to black in colour, very flattened, with thinned out and often truncated processes, or even reduced to a mosaic of minute graphitic fragments. Only a very small percentage of the samples could undergo the usual palynological preparation techniques. In most cases the palynomorphs were studied using thin sections cut parallel to the main rock foliation, since during standard palynological treatment, broken palynomorphs disperse into small particles.

Most of the scholars dealing with the state of preservation of palynomorphs in metamorphosed rocks, have almost exclusively focused their attention on thermal alteration. As an example, this approach led Smith & Saunders (1970) to sustain that organic-walled microfossils may resist metamorphism only up to the green schists facies; Hayes *et al.* (1983, p. 134) emphasize that any level of greenschist facies metamorphism destroys any molecular or structural organic chemical record and that at or beyond the upper greenschist facies the investigation only deals with graphite; Cramer & Diez (1975) conclude that organic-walled microfossils are destroyed at relatively low temperatures. According to these authors (Cramer & Diez, 1975, text-Fig. 1, p. 894), at about 160° C smoothening out of the sculptural elements, separation of processes from the body and other similar damage make species identification difficult; at about 165° C, serious shearing and fracturization starts to such an extent that at about 200° C identification becomes difficult even on the genus level; between 250° C and 300° C an increasing mosaic shattering occurs. The same authors maintain that spores and pollen identification is restricted to lower temperatures, up to a little more than 150°.

Our experience in Sardinia suggests that the temperature values proposed by Cramer & Diez (1975) as maximum values for the preservation of identifiable palynomorphs are probably too low. As an example, fully identifiable species of acritarchs were obtained by Di Milia (1988, 1991) from 10 metapelitic rock samples (metargillites to argillitic metasiltites) collected from the Solanas Sandstone Formation of Central Sardinia (Fig. 1, Riu Araxisi and Riu di S. Giorgio), whose metamorphism temperature has been estimated by P. Sassi (personal communication) to be about 350-370° C. This temperature and a metamorphic thermal gradient of about 50°/Km were estimated by Sassi (methods in Sassi,

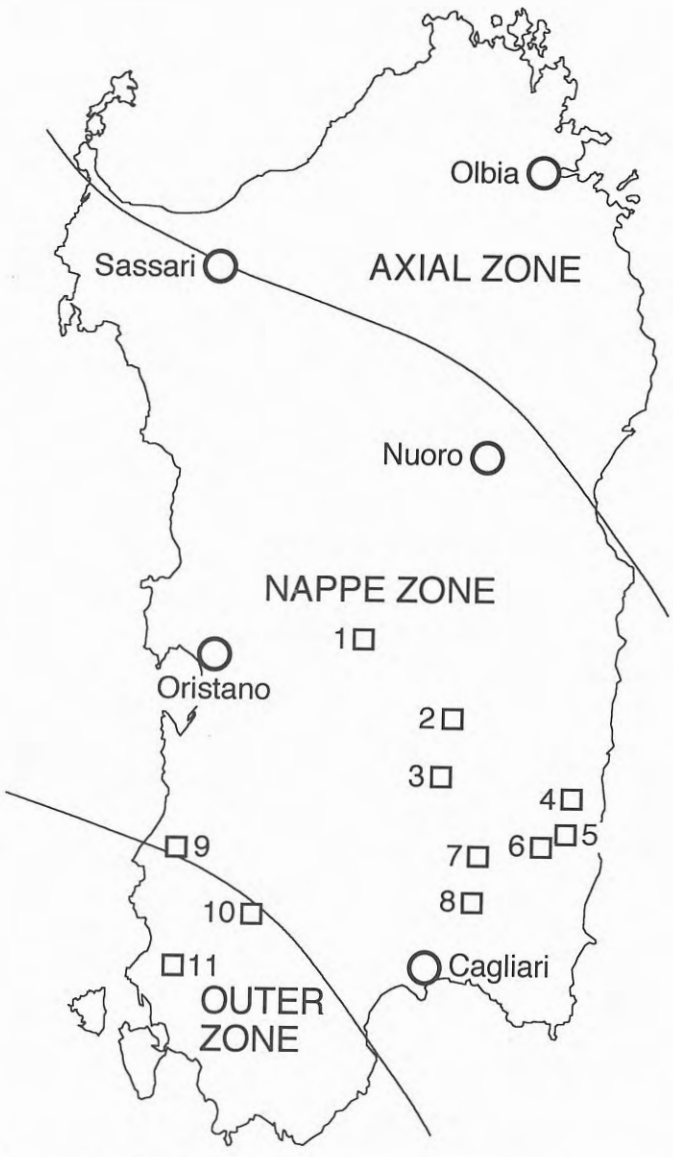

Figure 1. Map of Sardinia showing the approximate boundaries between main tectonic Zones and the location of the fossiliferous (acritarchs) outcrops. 1. Riu Araxisi, Sarcidano region. 2. Lago Medio del Flumendosa, Sarcidano region. 3. Bruncu Maresosus, near the Mulargia Lake, Gerrei region. 4. Riu di S. Giorgio, Quirra region. 5. Bruncu s'Arrettori, Quirra region. 6. Lower Flumendosa Valley, Gerrei region. 7. South of S. Nicoló Gerrei, Sarrabus region. 8. Punta Serpeddì and Bruncu Lacoi, Sarrabus region. 9. Is Arenas section, Arburese region. 10. Domusnovas, Iglesiente region. 11. Gonnesa, Sulcis region. Further information (age, tectonic setting) in the text.

1972; Sassi & Scolari, 1974; Guidotti & Sassi, 1976, 1986; Sassi, 1987) from these 10 rock samples, on the base of illite crystallinity (I.C. = 1.98 ± 0.11 mm, according to Kubler, 1968), mineral assemblage (muscovite, chlorite, albite, quartz ± epidote) and muscovite b_0 value (8.991 ± 0.007 Å). The above measurements were referred to neoblastic phyllosilicates since thin sections revealed that clastic micas are very scarce to missing in all the samples studied.

But, since metamorphic rocks are also mainly strongly deformed rocks, more attention should be paid to the effects of tectonic stresses on palynomorph preservation. Some authors (among others, Burmann, 1968, 1969, 1970; Kalvacheva, 1978; Tongiorgi *et al.*, 1984; Kalvacheva *et al.*, 1986) have pointed out the importance of tectonic deformations, along with thermal alteration, in the processes which lead to palynomorph mosaic-like fracturization until they become destroyed. Since 1978, Kalvacheva has described acritarchs which have become completely crumbled after multiple rock folding.

Di Milia (1988) has studied in detail the relationships between rock deformation and acritarch preservation in the weakly metamorphosed Solanas Sandstone Formation of Central Sardinia (Fig. 1, Riu Araxisi). This formation contains intensely fractured and deformed acritarchs, which become totally unrecognizable wherever a more intense tectonization is present. Only 20 % of the treated samples from Central Sardinia provided identifiable microfossils; both metamorphism and deformations are responsible for the destruction of the palynomorphs of most of the "barren" samples.

From strain measurements carried out on fossiliferous thin sections, Di Milia (1988) deduces that total shortening of the palynomorphs along the z axis of the deformation ellipsoid is about 60-70 % of the original diameter. In thin sections cut on the schistosity plane, elongation along x varies from 30 % to 60 % and from 20 % to 40 % along y. These acritarchs were first compressed and partly broken by compaction of the clayey sediment, before being graphitized down to a fragile mosaic of crystals, reoriented along the schistosity planes and flattened again orthogonally to the latter until they were totally fractured. In Central Sardinia, acritarchs are always destroyed near the fold hinges because of the complete transposition of the material in this part of the folds. Along the fold limbs, they are mostly reduced to a flat, graphite fragment cloud, stretched out along the mineralogical lineation, but in some cases they are still identifiable. Large and thick walled specimens with long processes are in any case fragmented, while thin walled spheromorphs, devoid of processes, may have more easily avoided fracturization.

As a conclusion, let us emphasize that in polymetamorphic and polyphased rocks, palynomorphs play a passive rôle during multiple deformations: they are excellent "strain markers" because, after graphitization, no further recrystallization take place in the pressure shadows between the fragments produced by their flattening and crushing during deformation. Thus, in the case of multiple deformations producing superimposed, pervasive schistosities, the consequent reorientation of the graphite crystals along the schistosity planes evolving into shear planes, produces repeated dispersal of the graphite fragments of organic origin along the extension lineation x and, to a lesser extent, also along the y axis. In such polyphased rocks, the organic walled microfossils may become destroyed even if the metamorphism temperature is rather low. Consequently, any assessment of the state of preservation of the acritarchs should consider, along with thermal alteration, the mechanical deformation deriving from diagenetic compaction and tectonic stresses, especially if the latter are accompanied by metamorphic recrystallization.

These observations on the state of preservation of the acritarchs in the Central Sardinian Solanas Sandstone Formation are also valid for other acritarch assemblages in Southwestern and Southeastern Sardinia.

ACRITARCH FINDINGS AND GEOLOGICAL IMPLICATIONS

The acritarch assemblages found in Sardinia could be assigned to the Late Cambrian, Tremadoc, Arenig and Silurian.

From as early as 1979 Silurian acritarchs have been described in the Outer Zone (Del Rio *et al.*, 1980; Domusnovas, Iglesiente region, Fig. 1). Acritarchs associated with *Dictyonema flabelliforme* (= *Rhabdinopora flabelliformis* (Eichwald, 1840)) have also been found recently in the same Zone (Fig. 1, Gonnesa, Sulcis region), i.e. in the upper part of the Cabitza Formation (Barca *et al.*, 1987; Pillola & Gutierrez-Marco, 1988). This is an important discovery as it permits the age of the Sardinian Phase ("eo-Caledonian" tectonic phase auct.) to be put forward to the Early Ordovician, since the Sardinian Unconformity is located at the top of the Cabitza Schists.

In the Nappe Zone acritarchs have been mainly found in the Cambro-Ordovician clastic formations. The findings from the Solanas Sandstone Formation were particularly abundant and significant. The above formation is a mainly arenaceous complex, typically occurring in the lower part of many Hercynian tectonic units of Central Sardinia and especially at the base of the Meana Sardo Unit, the topmost of the Sarcidano Units. Identical formations were also recognized in the Gerrei and Sarrabus Units. In the latter zone they are named San Vito Sandstone Formation. An identical formation has also been described in the Arburese Unit ("Postgotlandiano" auct.), lying allochthonously over the sequences of the Iglesiente-Sulcis region (Outer Zone).

The age of the above mentioned formations has until now been a matter for debate since few macrofossils could be found in them (medusoid casts and ichnofossils in the San Vito Sandstone: Debrenne & Naud, 1981) and no univocal conclusions were possible. New, more decisive evidence has been provided by the palynoflora (acritarchs) found in the San Vito Sandstone Formation of the Sarrabus region (Fig. 1, Punta Serpeddì and Bruncu Lacoi-Dolianova: Barca *et al.*, 1982a; Fig. 1, south of S. Nicolò Gerrei: Barca *et al.*, 1989); in the "Postgotlandiano" of the Arburese Unit, Arburese region (Fig. 1; is Arenas section: Barca *et al.*, 1982b; Pittau, 1985); in the Solanas Sandstone of the Meana Sardo

Unit of the Sarcidano and Quirra regions (Fig. 1, Riu Araxisi; Lago Medio del Flumendosa; Riu di S. Giorgio: Tongiorgi *et al.*, 1982; Tongiorgi *et al.*, 1984; Albani *et al.*, 1985; Albani, 1989; Di Milia, 1988, 1991; Di Milia & Tongiorgi, 1991; Di Milia & Tongiorgi, 1993); in the Solanas-like sandstone of the Bruncu Nieddo Unit, Quirra region (Fig. 1, Bruncu s'Arrettori: Di Milia *in* Gattiglio & Oggiano, 1991); in the Solanas/San Vito-like sandstone of the Bruncu Maresusus Unit, Gerrei region (Fig. 1, south of Mulargia Lake: Barca *et al.*, 1984); and in the Cuili Biringoni Formation of the Arcu de su Bentu Unit and in the Nuxi Formation of the Brecca Unit, Gerrei region (Fig. 1, lower Flumendosa Valley: Naud & Pittau, 1985).

These findings permit sandstone complexes such as the Solanas Sandstone to be assigned to an interval ranging from the Late Cambrian to the Arenig. These complexes will thus correspond to the upper part (Cabitza Schists) of the Cabitza Formation of the Iglesiente-Sulcis region. The slight unconformity at the top of sandstone complexes such as the Solanas Sandstone (Sarrabese Unconformity) thus corresponds to the Sardinian Unconformity of Southwestern Sardinia. The Sardinian Phase would thus now fall exactly at the end of the Arenig. Consequently, an age can also be found for the Ordovician magmatism of Sardinia (between the Early Llanvirn and the Caradoc).

A SHORT DESCRIPTION OF THE ACRITARCH ASSEMBLAGES

Late Cambrian assemblages

The oldest microflora found in Sardinia are of Late Cambrian age. The richest assemblages have been found in the Solanas Sandstone Formation (Meana Sardo Unit), in the Riu Araxisi valley, near Meana Sardo, Sarcidano region (Fig. 1) and in the Riu di San Giorgio valley, near Salto di Quirra (Fig. 1) in the Nappe Zone of Central Sardinia (Albani *et al.*, 1985; Di Milia, 1988, 1991).

These microflora are characterized by the presence of two or three species of *Timofeevia*, such as *Timofeevia phosphoritica* Vanguestaine, 1978, *T. lancarae* (Cramer & Diez) Vanguestaine, 1978, *T. pentagonalis* (Vanguestaine) Vanguestaine, 1978, associated with *Leiofusa stoumonensis* Vanguestaine, 1973, *Vulcanisphaera turbata* Martin, 1981 and several species of the genus *Stelliferidium*. Such assemblages are referred to the Late Cambrian (more precisely to an interval probably ranging between the *Agnostus pisiformis* (?) or *Olenus* trilobite Zone and the *Parabolina spinulosa* trilobite Zone (Di Milia, 1991) because of the frequent occurrence of *Stelliferidium* species, including *S. cortinulum* (Deunff) Deunff, Górka & Rauscher, 1974 which only appears near the base of the *Olenus* trilobite Zone (see Tongiorgi *in* Bagnoli *et al.*, 1988; Albani *et al.*, 1991). This age is confirmed by the presence of species of the genus *Leiofusa* and the absence of *Eliasum* and other forms typical of the Middle Cambrian.

In the San Vito Sandstone (a turbiditic formation very similar to the Solanas Sandstone and belonging to the Sarrabus Unit of the Nappe Zone), two Acritarch assemblages were found (Barca *et al.*, 1982a) in two closely spaced outcrops of Central-West Sarrabus: A1 and A2 (Fig. 1, Punta Serpeddì and Bruncu Lacoi - Dolianova, respectively). The A1 assemblage consists of some forms identified only at the generic level and referred to stratigraphically widely distributed genera, and consequently of no chronological significance. The above quoted authors define this assemblage "a Cambrian-type assemblage"; with the data available, it cannot be assigned to a more specific chronological unit. The A2 assemblage contains *Timofeevia lancarae* (Cramer & Diez) Vanguestaine, 1978, *Granomarginata* sp. cf. *G. squamacea* Volkova, 1968 (= *Annulum squamaceum* (Volkova) Martin, 1984), *Leiosphaeridia fumiana* Vanguestaine, 1974, *L. papillata* (Staplin) Downie & Sarjeant, 1964, *Vulcanisphaera fermosa* Fombella, 1977, as well as various species of *Micrhystridium*. The A2 assemblage can be referred definitely to the Late Cambrian (Barca *et al.*, 1982a) or even to the latest Cambrian (Barca *et al.*, 1984).

An assemblage containing *Timofeevia pentagonalis* (Vanguestaine), Vanguestaine, 1978, *T. phosphoritica* Vanguestaine, 1978, *"Priscogalea"* spp. was recognized by Naud & Pittau (1985) in the arenaceous (turbiditic) Cuili Biringoni Formation of the Arcu de su Bentu Unit (Nappe Zone of Central-Eastern Sardinia, Gerrei region), in the lower Flumendosa Valley (Fig. 1). The above authors attributed it to Middle Cambrian - early Late Cambrian.

Tremadoc assemblages

The Acritarch assemblages of Tremadoc age have been found in various outcrops of Central and Southern Sardinia.

In the Solanas Sandstone of Riu Araxisi (Fig. 1) in the Sarcidano region (Meana Sardo Unit, Nappe Zone of Central Sardinia), rich, typically Tremadocian microflora were found (Albani *et al.*, 1985; Di Milia, 1988; Di Milia & Tongiorgi, 1991; Di Milia & Tongiorgi, 1993), containing numerous Diacrodian species (*Acanthodiacrodium complanatum* (Deunff) Vavrdová, 1965, *A. formosum* Górka, 1967, *A. partiale* Timofeev, 1959, *A. scytotomilleii* Martin, 1973, *Dasydiacrodium caudatum* Vanguestaine, 1973, *D. tremadocum* (Górka) *emend.* Tongiorgi, 1988, *D. tumidum* (Deunff) Tongiorgi, 1988, etc.) associated with numerous species of *Cymatiogalea* and *Stelliferidium* (such as *Stelliferidium furcatum* (Deunff) *emend.* Deunff, Górka & Rauscher, 1974, *S. glabrum* (Martin) *emend.* Tongiorgi, 1988, *S. simplex* (Deunff) *emend.* Deunff, Górka & Rauscher, 1974, etc.) together with *Polygonium* and *Veryhachium* species. These microflora are attributed to a non-basal Early Tremadoc (Di Milia, 1988; Di Milia & Tongiorgi, 1991; Di Milia & Tongiorgi, 1993).

The Solanas-like sandstones of the Bruncu Nieddo Unit (Bruncu s'Arrettori, Nappe Zone, Quirra region, Fig. 5: Di Milia *in* Gattiglio & Oggiano, 1991) recently yielded a typical Tremadocian microflora, with *Cymatiogalea, Polygonium* and *Stelliferidium* species, associated with *Vulcanisphaera britannica* Rasul, 1976 (Di Milia, unpublished data).

Further Tremadocian assemblages have been found in the arenaceous, turbiditic complexes of Central Sardinia (Nappe Zone), similar to the Solanas or San Vito Sandstone: south of Mulargia Lake, Bruncu Maresurus area, Gerrei region (Fig. 1: Barca *et al.*, 1984) and near S. Nicolò Gerrei (Fig. 7: Barca *et al.*, 1989). The sandstone of the Mulargia Lake yielded numerous *Acanthodiacrodium* (*A.* cf. *A. achrasii* Martin, 1972 (= *A. achrasii* Martin, 1973), *A. complanatum* (Deunff) Vavrdová, 1965, *A. simplex* Combaz, 1967, etc.), together with *Goniosphaeridium* (= *Polygonium*) species, among which *G. dentatum* (Timofeev) Rauscher, 1973 (= *P. dentatum* (Timofeev) Albani, 1989), *Micrhystridium*, etc. The composition of this assemblage allows an age attribution to the lower part of the Late Tremadoc (Barca *et al.*, 1984). The sandstone investigated near S. Nicolò Gerrei are attributed to the Early Tremadoc, based on various species of *Acanthodiacrodium, Cymatiogalea cuvillierii* (Deunff) Deunff, 1964, *Goniosphaeridium dentatum* (Timofeev) Rauscher, 1974 (= *Polygonium dentatum* (Timofeev) Albani, 1989) and *Stelliferidium pseudoornatum* Pittau 1985 (= *Stelliferidium glabrum* (Martin) Tongiorgi, 1988).

The terrigenous Nuxi Formation of the Brecca Unit (Nappe Zone of Central Sardinia) of the lower Flumendosa Valley, Gerrei region (Fig. 1) yielded (Naud & Pittau, 1985) a microflora comprising *Acanthodiacrodium angustum* (Downie) Combaz, 1967, *Cymatiogalea* sp. cf. *C. multarea* (Deunff) Combaz, 1967 (= *C. multarea* (Deunff) Eisenack, Cramer & Diez, 1973), *Dactylofusa velifera* Cocchio, 1981, as well as several species of *Goniosphaeridium* (= *Polygonium*) and *Stelliferidium* (including *S. simplex*) and *Vulcanisphaera tuberata* (Downie) Eisenack, Cramer & Diez, 1973. This assemblage also seems to be Tremadocian in age, even if Naud & Pittau cautiously prefer to indicate a "Tremadoc-Arenig age".

The turbiditic formation of South-West Sardinia called "Postgotlandiano", belonging to the Arburese Unit, allochthonous over the Outer Zone in the Arburese region, Southern Sardinia (Is Arenas section, Fig. 1: Pittau, 1985) yielded four Tremadocian assemblages. All these assemblages contain, among others, *Acanthodiacrodium* and *Stelliferidium* species. Samples 1074 and 1075 also contain fragments of *Vulcanisphaera africana* Deunff, 1961 and *V. britannica* Rasul, 1976. The palynoflora from Is Arenas are referred by Pittau (1985) partly to the earliest Tremadoc (sample 1079, which also contains *Cymatiogalea cuvillieri* and various species of *Impluviculus*) and partly to a generic Tremadoc.

In some samples from Riu Araxisi section and Is Arenas section, the presence of Cambrian species (e.g. *Leiofusa stoumonensis* Vanguestaine, 1973, *Timofeevia phosphoritica* Vanguestaine, 1978, *Trunculumarium* sp., *Veryhachium dumontii* Vanguestaine, 1973) together with definitely Tremadocian species, indicates the occurrence of reworking phenomena (Pittau, 1985; Di Milia, 1988; Di Milia & Tongiorgi, 1991; Di Milia & Tongiorgi, 1993).

South-West of Gonnesa (Fig. 1), in the Sulcis region (Outer zone, South-Western Sardinia), in the upper layers of the Cabitza Formation, whose Early Tremadocian age is defined by the presence of *Rhabdinopora flabelliformis*, an acritarch assemblage was found by Barca *et al.* (1987). This assemblage is characterized by the presence of *Acanthodiacrodium angustum* (Downie) Combaz, 1967 and other species of the same genus, associated with *Cymatiogalea cuvillierii* (Deunff) Deunff, 1964 and *Dactylofusa squama* (Deunff) Combaz, Lange & Pansart, 1967 (= *Dactylofusa squama* (Deunff) Rauscher, 1974).

Arenig assemblages

In the Solanas Sandstone of Riu Araxisi (Fig. 1) in the Sarcidano region (Meana Sardo Unit, Nappe Zone of Central Sardinia) Tongiorgi *et al.* (1984) recognized a very rich acritarch assemblage right at the top of the formation, near the contact with the overlying Monte Corte Cerbos Formation. This assemblage is attributed to the Arenig because it contains *Striatotheca quieta* (Martin) Rauscher, 1974, *Pirea* cf. *P. dubia* Vavrdová, 1972 and various species of the genus *Coryphidium* such as *C. miladae* Cramer & Diez, 1976 and *C. tadla* Cramer & Diez, 1976, associated with *Goniosphaeridium* cf. *G. pungens* (Timofeev) (= *Polygonium pungens* (Timofeev) Albani, 1989) and *Solisphaeridium solidispinosum* Cramer & Diez, 1977. The Arenigian age (probably a little older than the Late Arenig, according to Di Milia, 1988) of this assemblage is confirmed by further, numerous species.

Some acritarch assemblages from the Solanas Sandstone of the Lago Medio del Flumendosa (Meana Sardo Unit, Nappe Zone of Central Sardinia, Sarcidano region; Fig. 1) described by Albani *et al.* (1985) and by Albani (1989) are also characterized by the presence of *Striatotheca* and *Coryphidium*. Their Arenigian age is confirmed by the presence, among others, of species such as *Marrocanium simplex* Cramer, Kanes, Diez & Christopher, 1974, *Stephanodiacrodium stephanum* (Vavrdová) Vavrdová, 1986 and *Tetraniveum arenigum* (Vavrdová) Vavrdová, 1982 (= *Vavrdovella areniga* (Vavrdová) Loeblich & Tappan, 1976).

In the Arburese allochthonous Unit (Postgotlandiano of Is Arenas area, South-Western Sardinia) two microflora (samples 1078 and 1076; Fig. 1, loc. 9) were described by Barca *et al.* (1982b) and by Pittau (1985), consisting of a mixed assemblage which contains both Tremadocian and Arenigian species. The species which are never quoted before the Arenig comprise *Petaloferidium florigerum* Vavrdová, 1972 (= *Petaloferidium florigerum* (Vavrdová) Fensome, Graham, Barss, Freeman & Hill, 1990), *Veryhachium downiei* Stockmans & Willière, 1962 and *V. trisulcum* (Deunff) Deunff, 1959. Tremadocian species comprise, among other, different species of the genera *Acanthodiacrodium* and *Stelliferidium* (including *S. cortinulum* and *S. simplex*) and *Vulcanisphaera tuberata* (Downie) Eisenack, Cramer & Diez, 1973, occasionally associated with *Arbusculidium rommelaerei* Martin, 1981. Pittau suggests an age at the Tremadoc-Arenig boundary, but reworking cannot be excluded.

Silurian assemblages

Acritarch assemblages of Late Llandovery - Early Wenlock age were found in samples from various parts of the Iglesiente (Outer Zone; Fig. 1, loc. 10), Iglesiente region, South-West Sardinia (Del Rio *et al.*, 1980). The assemblage consists mainly of Acanthomorphs, together with species of the genera *Micrhystridium, Multiplicisphaeridium* and *Baltisphaeridium*, as well as many species of the genus *Leiofusa* (including *L. bernesgae* Cramer, 1964, which is the most significant from a chronological point of view). The assemblage also contains *Eupoikilofusa striatifera* (Cramer) Cramer, 1970 (= *Dactylofusa striatifera* (Cramer) Fensome, Graham, Barss, Freeman & Hill, 1990) and *E. cantabrica* (Cramer) Cramer, 1970 (= *Dactylofusa cantabrica* (Cramer) Fensome, Graham, Barss, Freeman & Hill, 1990). *Domasia* and *Deunffia* (?) are poorly represented; *Neoveryhachium carminae* (Cramer) Cramer, 1970 is, on the contrary, well represented along with many species of the genus *Veryhachium*.

CONCLUSIONS

In the above review, there is a summary of the results of recent palynological research into weakly-metamorphosed Paleozoic rocks of Sardinia. New stratigraphic knowledge of this sector of the Hercynian belt has been provided by palynology. This also represents an important contribution to the new Geological Map of Italy 1:50.000, now in progress.

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