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General palaeontology (Biostratigraphy)

First record of Devonian orthoceratid-bearing limestones in southern Calabria (Italy)

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Abstract

Lower to Middle Devonian orthoceratid-bearing nodular limestones in Calabria are described here for the first time, along the Fiumara Assi section. The succession is tectonically inverted and has been dated by conodonts. The lower beds are Lochkovian–Lower Pragian, because they provided *Icriodus* cf. *steinachensis* and *Pelekysgnathus serratus*, which occur in the delta-sulcatus Zones. Upwards appear *Polygnathus* cf. *dehiscens*, corresponding to the dehiscens-gronbergi Zones, and *Ozarkodina* cf. *steinhornensis miae* of the dehiscens-inversus Zones, both indicating a topmost Pragian–Lower Emsian age. The Eifelian (or younger) age for the top of the succession is demonstrated by *Polygnathus linguiformis linguiformis*. This succession, as well as similar coeval deposits of the southern Variscan Chain (southwestern Sardinia, eastern Pyrenees), Betic–Rifian Maláguides-Ghomarides and southern Alps, made part of a western embayment of the Palaeotethys. ***To cite this article: P. Navas-Parejo et al., C. R. Palevol 8 (2009).***

Résumé

Présence de calcaires à orthoceratidés du Dévonien en Calabre méridionale (Italie). Le Dévonien inférieur et moyen à faciès de calcaires noduleux à orthoceratidés a été trouvé pour la première fois en Calabre, dans la coupe de la Fiumara Assi. La succession est renversée (tectonique varisque) et a été datée par des conodontes. La base de la succession est Lochkovien–Pragien inférieur, datée par *Icriodus* cf. *steinachensis* et *Pelekysgnathus* gr. *serratus*, appartenant aux zones delta-sulcatus. Les niveaux successifs, à *Polygnathus* cf. *dehiscens*, correspondant aux zones dehiscens-gronbergi et *Ozarkodina* cf. *steinhornensis miae* des zones dehiscens-inversus, indiquent un âge Pragien–Emsien. L'âge Eifelien (ou éventuellement plus jeune) de la partie supérieure de la coupe est démontrée par *Polygnathus linguiformis linguiformis*. Cette succession, comporte des dépôts comparables à ceux de la Chaîne varisque méridionale (Sardaigne sudoccidentale, Pyrénées orientales), des Malaguides-Ghomarides béticorifaines et des Alpes méridionales et faisait partie de la terminaison occidentale de la Paléotethys. ***Pour citer cet article : P. Navas-Parejo et al., C. R. Palevol 8 (2009).***

Keywords: Stratigraphy; Conodonts; Palaeozoic; Stilo Unit; Calabria–Peloritani Terrane; Italy

Mots clés : Stratigraphie ; Conodontes ; Paléozoïque ; Unité de Stilo ; Terrane Calabro-Péloritain ; Italie

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1. Introduction

Orthoceratid limestones are typical facies of the Silurian and Early Devonian North-Gondwanic margins. In the Mediterranean Alpine Belts of southern Europe and North Africa these facies have been widely recognised: from the Pyrenees [12,28] to the Alps [29,30], from the Gibraltar Arc [23,27] to the northern Apennines [8,34], and also in Sardinia [15,16]. However, until now, such facies had never been seen in Calabria. In this article the presence of Lower to Middle Devonian orthoceratid-bearing limestones is reported for the first time in the basement of the Stilo Unit of southern Calabria. This is also the first record of Lowermost Devonian deposits, well dated by conodonts, in the Calabria–Peloritani Terrane (CPT). This opens new perspectives to the understanding of the complex Palaeozoic history of the perimediterranean Alpine areas.

2. Geological setting and previous studies on Calabrian Palaeozoic successions

The Calabria–Peloritani Arc, or Terrane [4], is an arc-shaped orogenic belt connecting the Apennine and the Maghrebian Chain. It is characterised by Alpine continental crust nappes which thrust over H-P ophiolite-bearing thrust sheets, these latter originating from the central-western Tethys. In the CPT, two sectors, characterised by different nappe architecture and Alpine tectonic evolution, have been recognised [3,4]. The southern sector of the CPT is formed only by continental crust nappes and slices, which override the Maghrebian Monte Soro Unit. The highest tectonic unit of this sector is the Stilo Unit. The nappe stack was established, and underwent a very rapid exhumation and erosion, in the Aquitanian–Early Burdigalian. This orogenic evolution is testified to the Aquitanian terrains involved in the nappe stack, and to the Burdigalian Stilo-Capo d'Orlando Formation (Fm.), sealing the nappes (Fig. 1A) [5].

The nappes are characterised by pre-Triassic basements, made up of both metamorphic and plutonic rocks, and by Meso-Cenozoic covers. In these basements, fossiliferous beds are very scarce, and the knowledge of the stratigraphic features of the successions is scanty and poorly defined. Consequently, different tectonosedimentary reconstructions have been proposed for these fragments of the Variscan orogeny involved in the Alpine Chains. In particular, the location of the CPT basements in the Variscan Chains of the central-western Mediterranean area is subject of debate [1,32].

In the 1970s, studies on the pre-Alpine basements of the CPT showed the only presence of Middle-Upper Devonian dacryoconarids and conodonts in metacalcareous lenses of both Stilo and Longi-Taormina Units [2,9,14,20]. Later, successions starting in the Cambro-Ordovician and ending with Carboniferous Culm facies were recognised in the Sila, Stilo and Longi-Taormina Units [6,7,21,22]. However, only Cambro-Ordovician and Middle-Upper Devonian layers have been dated by means of a very few specimens of acritarchs and conodonts, respectively. Consequently, the reconstructed successions and their ages are questionable because they are based mainly on facies similarities and/or field characters of volcanics occurring in them (see discussion in Spalletta and Vai [32]).

3. Stratigraphy of the Stilo Unit

The Stilo Unit is the highest thrust-sheet of the Calabrian nappe stack and crops out only in southern Calabria. It consists of both a pre-Alpine basement and a Meso-Cenozoic cover, this latter severely reduced by erosion (Fig. 1A). The basement is made up of Variscan metamorphites in which a gradual transition from amphibolite facies to greenschist facies is recognisable [3]. The low-grade metamorphites consist mainly of phyllites and metarenites, with minor metabasites, metalimestones and black cherts. The metamorphites are intruded upon by Late-Variscan calc-alkaline plutonic rocks. The sedimentary cover starts with continental redbeds a few metres thick, followed by Upper Triassic?–Lower Jurassic? dolostones and limestones. The succession continues up to the Jurassic–Cretaceous boundary with platform facies, consisting of limestones and calcareous breccias, with frequent lacunae marked by bauxitic clay layers. Upper Cretaceous–Eocene marine rocks have never been documented. The Earliest Oligocene is represented by marsh marls, marly limestones and algal limestones, followed by a layer of red clays and by Upper Rupelian–Chattian calcarenites and calcareous breccias with *Lepidocyclina*, rich in metamorphic and granitoid clasts fed by the underlying basement. The succession ends with a few metres of Aquitanian turbiditic sandstones. Alpine metamorphism is lacking, and the whole succession is unconformably covered by the Stilo-Capo d'Orlando Fm.

The Palaeozoic low-grade metamorphic succession widely outcrops in the Stilo-Bivongi area, along the Fiumara (stream) Stilaro and its tributaries, Pardalá and Crocco, where it constitutes the so-called Bivongi series [7,21], in which six main lithostratigraphic units have been distinguished. The lowest layers are represented by

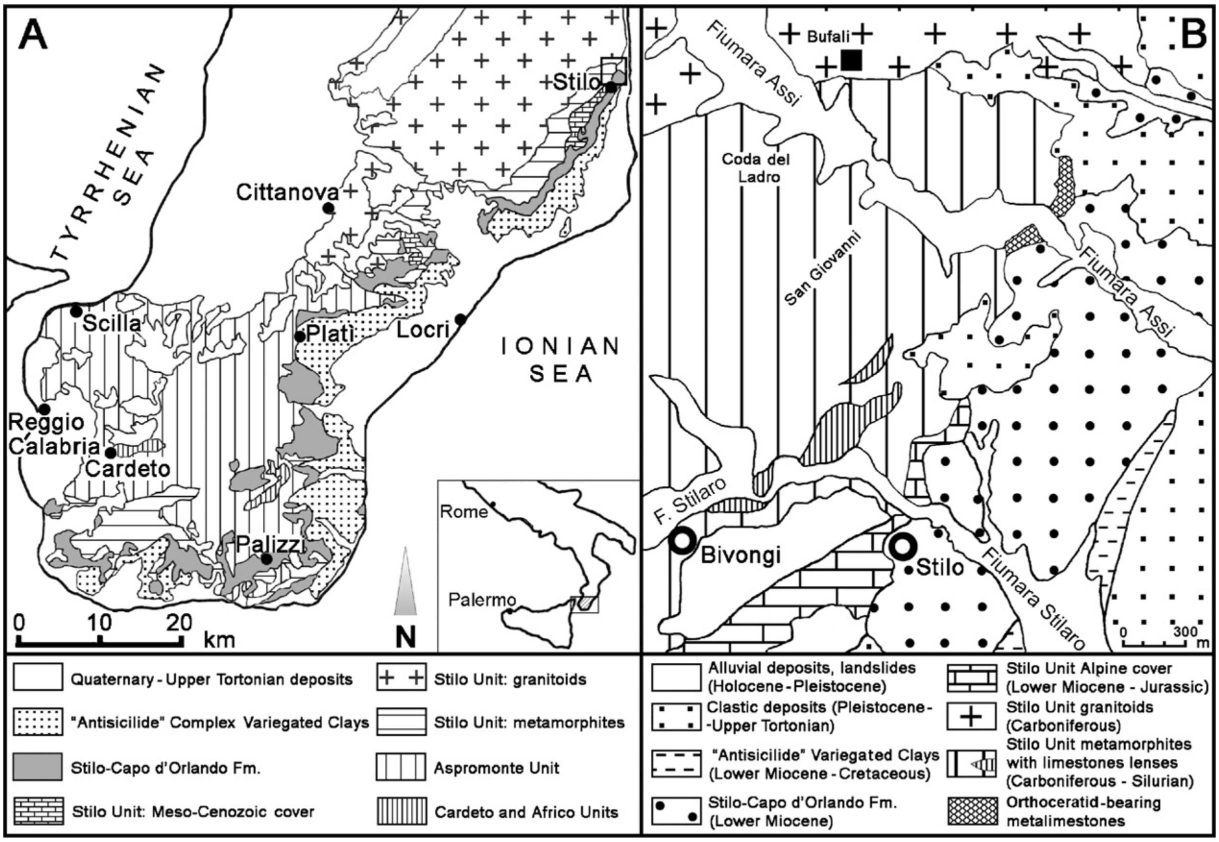

Fig. 1. **A**. Geological sketch map of the southern Calabria. **B**. Geological map of the area around the Fiumara Assi and Fiumara Stilaro.
Fig. 1. **A**. Schéma géologique de la Calabre méridionale. **B**. Carte géologique aux environs des rivières Stilaro et Assi.

several hundred metres of low-grade silvery phyllites and grey metarenites with intercalated lenses of metabasites, that Bouillin et al. [7] attributed to the Cambro-Ordovician. Its top is marked by a thin and laterally discontinuous horizon of black metapelites with some associated metalimestone lenses, with less than 10 m of total thickness and both considered to be of Silurian age. These rocks are followed by grey metapelites, alternating with thin- and fine-grained metarenite beds, more than 200 m thick, locally including greenish quartzites and, towards its top, thin-bedded limestones with some dacryoconarids, indicating a Devonian age [2]. Upwards, several strongly folded and laterally discontinuous limestone lenses, a few metres to several tens of metres thick and showing nodular structure and reddish colours (*griotte* facies), have provided Late Famennian conodonts [9,21] and constitute the only well-dated horizon, until now, in this succession. These limestones are topped by few metres of thin-bedded cherts, considered to be Early Carboniferous in age. Finally, the succession ends with more than 100 m of dark slates alternating with turbiditic sandstones, sometimes bearing plant remains and showing the classical Carboniferous Culm facies [7].

4. The Fiumara Assi section

4.1. Lithological succession

The Stilo Unit widely crops out on both sides of the Fiumara Assi (Topographic Map of Italy 1:50,000, sheet 584 Badolato; Fig. 1B), but it is particularly well exposed on the left versant (latitude N 38° 30′ 06″; longitude E 16° 28′ 57″), where the studied succession was measured (Fig. 2). Palaeozoic terrains consist of silvery metapelites and metarenites dipping towards southeast, followed by well-developed orthoceratid-bearing nodular limestones, unconformably overlain by the Stilo-Capo d'Orlando Fm. Limestones are affected by folds with hectometre wavelength and show a well-developed foliation. Structural and biostratigraphic data (see below) demonstrate that the study succession is overturned. This latter, divided in eight lithologic intervals (a to h on Fig. 2), is described below.

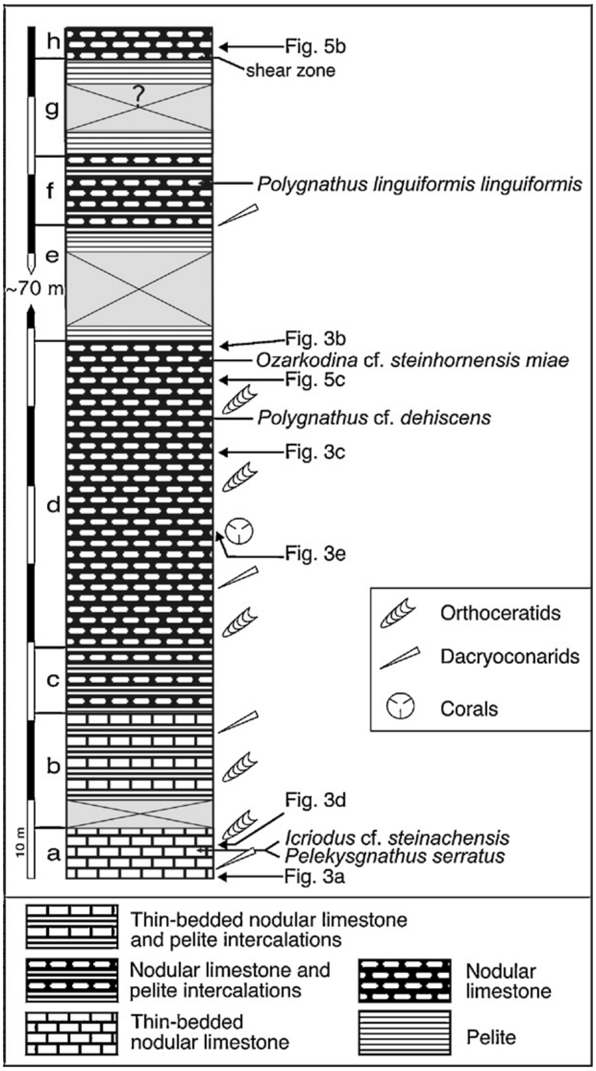

Fig. 2. Measured stratigraphic column along the Fiumara Assi. The characters a–h indicate the lithologic intervals described in the text.
Fig. 2. Colonne stratigraphique mesurée dans la Fiumara Assi. Les lettres a–h indiquent les intervalles lithologiques décrits dans le texte.

The lowermost part of the succession, lying directly under the basal conglomerates of the Stilo-Capo d'Orlando Fm. (interval a on Fig. 2; Fig. 3a), is formed by 7 m of thin- to medium-bedded, parallel-laminated and partly nodular limestones, alternating with yellowish and greyish-black fine-grained limestones, with some orthoceratids. This carbonate layer is followed by a more pelitic interval (13 m thick, partially covered at its base), formed by an alternance of thin-bedded calcareous slates, with aligned calcareous nodules, and centimetre- to decimetre-thick dark-grey limestone beds, locally with nodular structure (interval b on Fig. 2). Upwards, the succession gradually becomes more calcareous, forming an alternance (9 m) of upwardly thickening, thin- to medium-bedded limestones with progressively thinner intercalations of black pelites (interval c on Fig. 2). Interval c is followed by 40 m of limestones with very rare centimetre-thick grey to yellowish metapelites (interval d on Fig. 2). Limestones are predominantly nodular (Fig. 3b) and contain abundant orthoceratids (Fig. 3c and d) and some isolated bivalves and corals (Fig. 3e). In thin section, microfacies are essentially mudstones or wackestones with pelagic microfossils and bioclasts (dacryoconarids, orthoceratids, crinoids, and rare trilobites).

The upper part of the succession, nearly 75 m thick and partially covered, consists mainly of grey to black metapelites (intervals e and g on Fig. 2) alternating with two nodular limestone intervals (intervals f and h on Fig. 2). The limestones of the interval f (6 m) gradually change to the under- and overlying metapelites and are medium- to thin-bedded. The limestones of the interval h (Fig. 2) are strongly affected by folds with metre to decimetre wavelength, and show a sharp cleavage (see below) and a strongly sheared contact with the metapelites.

4.2. Conodont biostratigraphy

Scarce and poorly preserved conodont elements have been found in 18 of 44 limestone samples analysed (Fig. 4). Most of these can be classified only at the generic level because of strong deformation. The most abundant elements belong to *Pseudooneotodus beckmanni* Bischoff and Sannemann and *Belodella* sp. Ethington.

The oldest association (interval a on Fig. 2; Fig. 3a) is formed by *Icriodus* cf. *steinachensis* Al Rawi (Fig. 4, 1) and *Pelekysgnathus serratus* Jentzsch (Fig. 4, 4), which occurred in the delta-sulcatus Zones of the Lochkovian–Lower Pragian. Specimen 1 on Fig. 4 of *I.* cf. *steinachensis* is badly preserved but it shows a spindle-shaped outline very similar to that of the eta morphotype of the species [18]. The angle of its lateral process with the main axis of the spindle is slightly less than 90° and denticles are rounded. The different subspecies of *Pelekysgnathus* belonging to the *serratus* group are distinguished mainly on the basis of the size and position of denticles of the posterior end of blade, which are not preserved in the specimens found. Consequently, there are no indisputable criteria to assign them to any of the subspecies defined within this group.

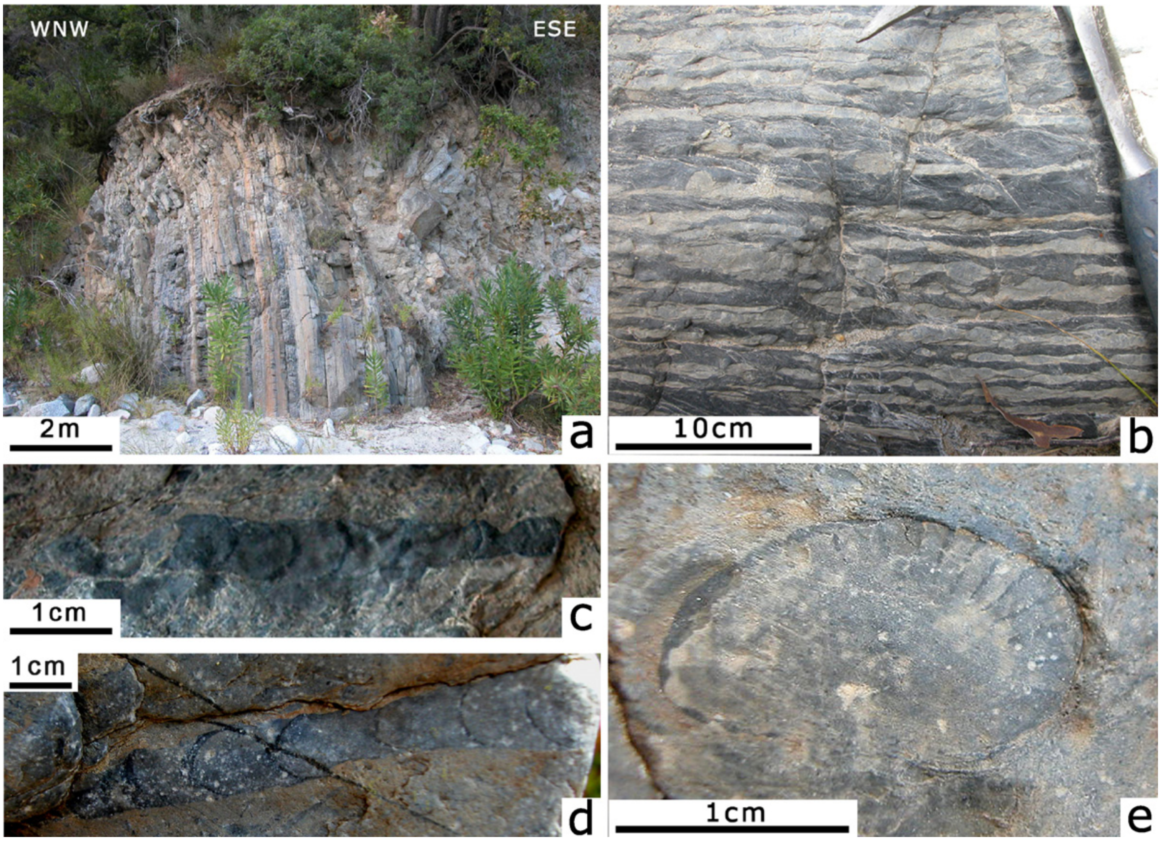

Fig. 3. **a**: unconformity of the reversed stratigraphic base of the succession below the Stilo-Capo d'Orlando Fm; **b**: nodular limestones of the upper part of the interval d; **c, d**: orthoceratid sections; **e**: flattened isolated coral. For location of photographs see Fig. 2.

Fig. 3. **a** : discordance de la succession renversée au-dessous de la Fm. Stilo-Capo d'Orlando Fm ; **b** : calcaires noduleux de la partie supérieure de l'intervalle d ; **c, d** : sections d'orthocératidés ; **e** : coraliaire isolé écrasé. Pour la localisation des photographies voir la Fig. 2.

Geometrically below the former, younger conodont associations have been found. First, several specimens of *Polygnathus* cf. *dehiscens* Philip and Jackson (Fig. 4, 3) appear in the interval d (Fig. 2). Despite its bad preservation, the specimen on Fig. 4 shows a large basal cavity and its carina does not reach the posterior end. This species belongs to the dehiscens-gronbergi Zones, indicating the topmost part of the Pragian and the Lower Emsian [25,36]. One specimen of *Ozarkodina* cf. *steinhornensis miae*, which belongs to the dehiscens-inversus Zones [18], has been found few metres upwards (interval d). Although its anterior half is broken, typical asymmetrical oval lobes are visible (Fig. 4, 2).

The youngest conodont association has been identified in the interval f (Fig. 2) located at the geometric base of the outcrop. This association is characterised by *Polygnathus linguiformis linguiformis* Hinde, a species occurring from the Eifelian to the Lower Frasnian [24].

The vertical distribution of the conodonts recorded in the limestone beds indicates that the studied stratigraphic succession has been tectonically reversed, as described below.

4.3. Structural analysis

Structural investigations of the Fiumara Assi outcrop reveal that the orthoceratid-bearing limestones are involved mainly by a mesoscale asymmetric fold system with axial planar cleavage (Fig. 5). This folding, post-Devonian in age, is responsible for deformation of the bedding (S_0), still well preserved, as well as of orthoceratids (about 50 forms/m^2) or rare corals (Fig. 3e), which appear strongly flattened on S_0 (Fig. 5c). In these folds (Fig. 5a and b), bedding (S_0) is characterised by attitudes for which the poles appear to be distributed around a large NNW–SSE circle (Fig. 5d). Folds display an axial trend moderately plunging towards northeast (Fig. 5d) and axial surfaces steeply inclined southeastwards. These northwest-verging folds are responsible for the general NE–SW strike of the bedding characterised

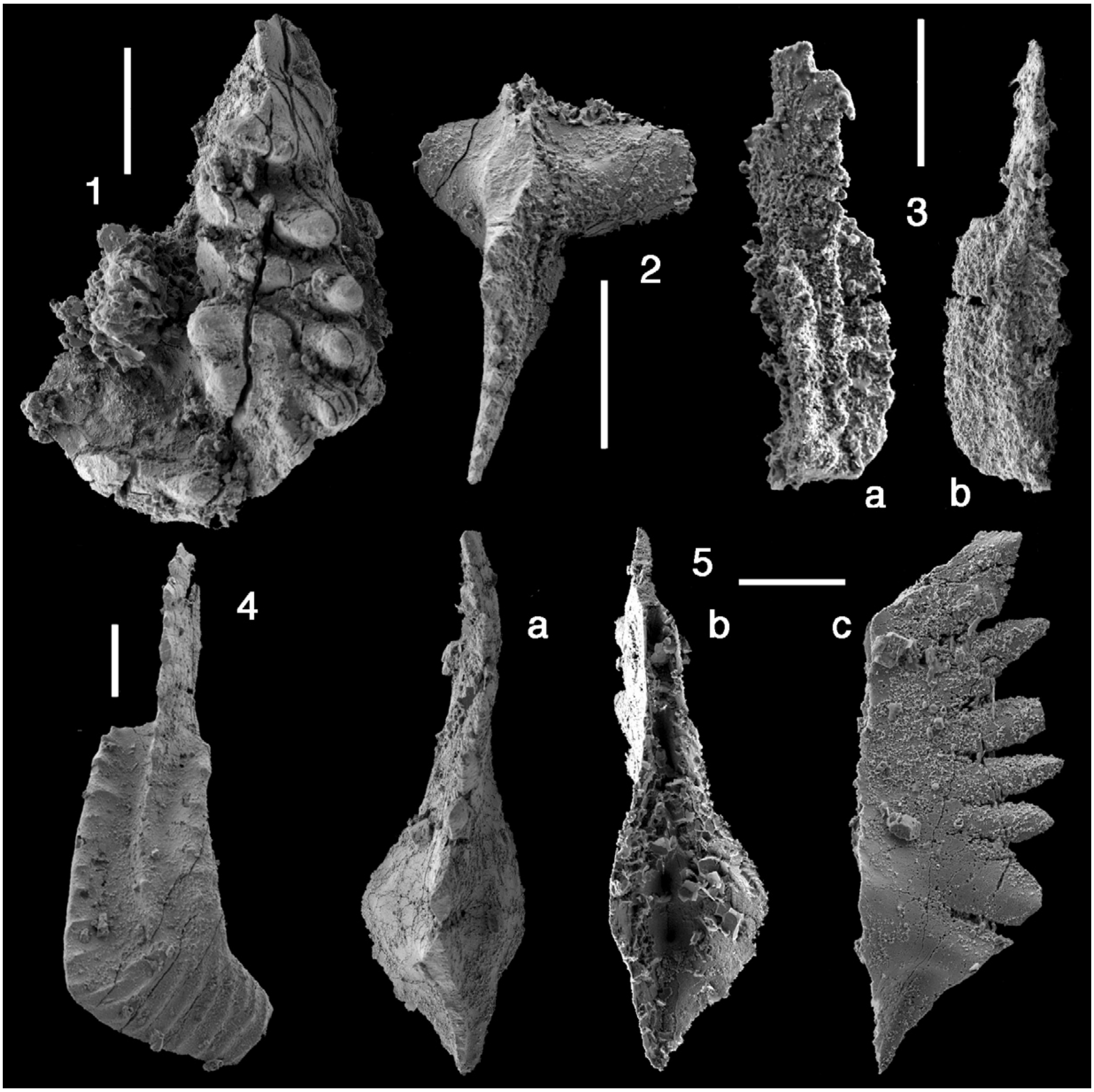

Fig. 4. **1**. *Icriodus* cf. *steinachensis* Al Rawi eta morphotype, I element (73-4). **2**. *Ozarkodina* cf. *steinhornensis miae* Bultynck, Pa element (221/86-1). **3**. *Polygnathus* cf. *dehiscens* Philip and Jackson, Pa element (82-3); **a**: upper view; **b**: lower view. **4**. *Polygnathus linguiformis linguiformis* Hinde. Pa element (216-1). **5**. *Pelekysgnathus serratus* Jentzsch, Pa element (73-1); **a**: upper view; **b**: lower view; **c**: lateral view. Scale bars: 200 μm.

Fig. 4. **1**. *Icriodus* cf. *steinachensis* Al Rawi eta morphotype, élément I (73-4). **2.** *Ozarkodina* cf. *steinhornensis miae* Bultynck, élément Pa (221/86-1). **3**. *Polygnathus* cf. *dehiscens* Philip et Jackson, élément Pa (82-3) ; **a** : vue supérieure ; **b** : vue inférieure. **4**. *Polygnathus linguiformis linguiformis* Hinde, élément Pa (216-1). **5**. *Pelekysgnathus serratus* Jentzsch, élément Pa (73-1) ; **a** : vue supérieure ; **b** : vue inférieure ; **c** : vue latérale. Échelles : 200 μm.

by vertical to steeply inclined southeast-wards attitudes, which dominate in most of the basement outcrops of the Stilo area.

The limestone beds of the Fiumara Assi are involved mainly by a northwest-verging asymmetric syncline with a hectometre wavelength. Folding is accompanied by a centimetre to millimetre spaced axial planar cleavage dipping southeastwards (Fig. 5d). The analysis of the relationships between cleavage and bedding in this syncline has allowed us to identify the normal and inverted fold limbs. In the stratigraphic succession analysed (intervals a to h on Fig. 2) S_0 is steeper than cleavage and it cross-cuts cleavage, defining angles β (*sensu* [26]) of 35–40° (Fig. 5c). Consequently, the Assi

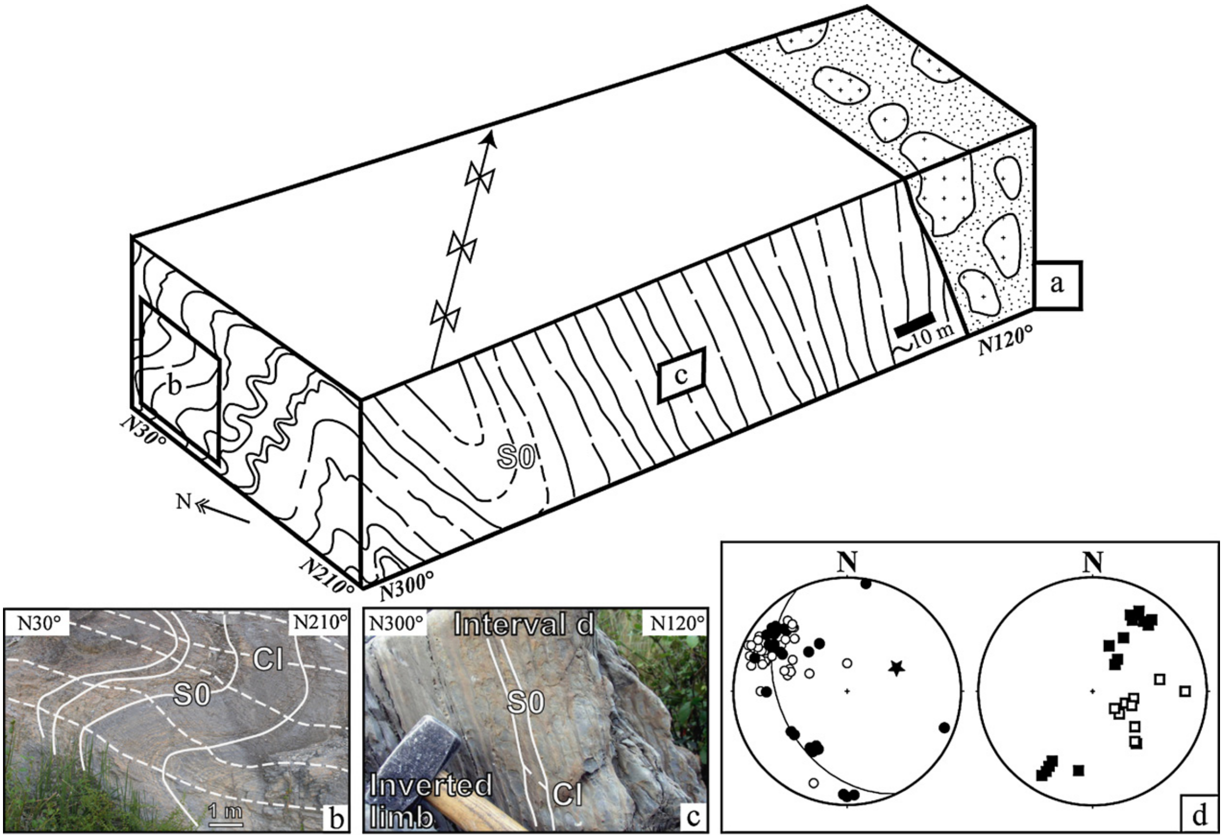

Fig. 5. **a**: block diagram showing the syncline of the Fiumara Assi outcrop (the scale bar is approximate); **b**: minor folds occurring on syncline normal limb; **c**: relationship between bedding (S_0) and cleavage (Cl) on the syncline inverted limb; **d**: orientation data (equal-area projections, lower hemisphere) of mesoscale fabrics. *Planar fabrics* (on the left): poles to bedding (S_0) distributed along π-circle of π-diagram (*sensu* [26]) (symbol: solid circle: 28 data), poles to cleavage (Cl) (symbol: empty circle: 39 data). The mean π axis is 64/50 (symbol: solid star). *Linear fabrics* (on the right): *L: S_0/Cl* intersection lineation (symbol: solid square: 19 data), movement s*triae* (symbol: empty square: 14 data).

Fig. 5. **a** : schéma montrant le synclinal de l'affleurement de la Fiumara Assi (la barre d'échelle est approximative) ; **b** : plis mineurs dans le flanc normal du synclinal ; **c** : relation entre la stratification (S_0) et le clivage (Cl) dans le flanc renversé du synclinal ; **d** : stéréogrammes (projection équivalente de Schmidt, hémisphère inférieur) des fabriques à mésoéchelle. *Fabriques planaires* (à gauche) : pôles de la stratification (S_0) distribués selon un cercle π du diagramme π (*sensu* [26]) (symbole : cercle plein : 28 données), pôles du clivage (Cl) (symbole : cercle vide : 39 données). L'axe moyen est 64/50 (symbole : étoile solide). *Fabriques linéaires* (à droite) : *L : S_0/Cl* linéation d'intersection (symbole : carré solide : 19 données), stries de mouvement (symbole : carré vide : 14 données).

section constitutes the subvertical inverted limb (Fig. 5a and c) of the syncline. Along the fold normal limb, being strongly affected by cleavage and by several minor folds with metre to decimetre wavelengths, deformation has hindered a reliable stratigraphic reconstruction (Fig. 5a and b).

The intersection lineation (S_0/Cl) lies subparallel to fold hinges, and plunges both towards the northeast and southwest, defining two clusters on the equal area projection (Fig. 5d). Fine-spaced lineation plunging southeast-wards has been recognised (Fig. 5d). These linear fabrics could represent movement *striae* parallel to the slip direction associated with simple flexural slip folds (*sensu* [26]), because they lie on bedding and are arranged subperpendicular to the fold axis.

In the rare decimetre-thick metapelites, alternating with the limestones, a cleavage consisting of a fine-spaced foliation, showing sericite + quartz + chlorite ± plagioclase ± carbonate ± opaque mineral assemblage, is present. In the metapelites, P–T conditions reached the field of low metamorphism with low pressure (b_0 of the K-white micas = 8.994 [10]). In the limestones, however, the thermobaric conditions seem not to have exceeded those near the limit of the diagenesis, as still observed in the analogous limestones exposed at Pietrapennata on the southern slope of the Aspromonte Massif [14].

It is noteworthy that NE–SW trending upright folds with hectometre wavelength (up to 400 m) have been recognised along the Ionian slope of the Serre Massif, south of Fiumara Assi, and illustrated on a geological sketch map [7]. This fold system, to which the northwest-verging folds recognised in the Fiumara Assi outcrop can be inferred, appears arranged parallel to the boundary between the Upper Carboniferous plutons and the metamorphites of the Stilo Unit exposed only a few kilometres away from the study area.

5. Concluding remarks

Lower to Middle Devonian orthoceratid-bearing nodular limestones have been firstly recognised in the CPT. These rocks belong to the Stilo Unit basement and are well exposed along the Fiumara Assi, where they are involved by an hectometre asymmetric syncline. Their age ranges between the Lochkovian–Lower Pragian and the Eifelian.

As many other Palaeozoic and younger cephalopod limestones, the orthoceratid limestones of the Fiumara Assi were deposited under pelagic conditions, with rare presence of shallow-water organisms. These conditions are typical of outer-shelf environments of moderate depth and of pelagic plateaus with condensed sedimentation [17,19], which usually occur in the distal zone of continental margins. In adjoining deeper areas, coeval Silurian–Devonian deposits were predominantly ampelitic (black shales), shaly and/or turbiditic. These are the most common lithologies of the CPT Palaeozoic successions, although they have been strongly modified by the Variscan metamorphism and orogenesis ([4], and references therein).

A similar lithological and facies spectrum is also found in Silurian–Devonian successions of other Mediterranean areas. In particular, the succession studied resembles those of SW Sardinia (Mason Porcus Fm.) [11,16,25], eastern Pyrenees [28], and other sites of the southern Variscan Chain [13]. Equivalent coeval facies are also present in the Maláguide-Ghomaride Units of the Gibraltar Arc [23,27], testifying to a common palaeogeographic origin for most of these domains. Equivalent deposits in the Alps [29,30] are interpreted as being related to the rifting and later drifting of North-Gondwanic fragments, leading finally to the opening of the Palaeotethys Ocean during Silurian–Devonian [35]. A derivation from the northern Palaeotethyan margin has been proposed for most of these western Mediterranean Palaeozoic successions [33]. In summary, the Calabrian Palaeozoic terrains and their equivalents in the western Mediterranean Alpine belts formed the western embayment of the Palaeotethys, opposite to Variscan regions of the Iberian Massif and of the Moroccan Meseta, which were rather related to the Rheic Ocean and its North-Gondwanic palaeomargin [31]. This latter was completely subducted during the Devonian–Early Carboniferous, whereas subduction of the westernmost Palaeotethys accounted later [33]. The deciphering of stratigraphic evolution of the Alpine-Mediterranean Palaeozoic successions is thus essential for understanding the Silurian–Devonian opening of the westernmost Palaeotethys and its later closing.

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