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The Carboniferous-Permian succession of the Pisani Mountains (Tuscany, Italy): preliminary data from the De Stefani collection (Natural History Museum of Florence)

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ABSTRACT

The De Stefani collection represents a very important historical, museological and scientific heritage of the Natural History Museum of Florence. The collection counts approximately 1.000 specimens (total samples: 1012, for a total number of specimens: 982) of a fossil macroflora collected by Carlo De Stefani at the end of the 19th century in the Upper Paleozoic, graphite-rich metapelites and metasandstones of the San Lorenzo Schists Formation in the Pisani Mountains. The fossil species together with the geology and stratigraphy of this area of Tuscany, are described in the monograph «Flore carbonifere e permiane della Toscana». The San Lorenzo Schists Formation as a whole, was referred by previous authors to a fluvial-lacustrine environment. The museological reorganisation and a general overview of this collection is the first stage of a project aimed at carrying out a detailed stratigrapic and paleoenvironmental study. A new 1:10.000 scale geological survey of the San Lorenzo Schists in the Valle del Guappero type-area (see enclosed geological map) has been accomplished, during which the classical fossil localities were precisely positioned on the map; new localities characterized by the occurrence of marine fossils were also found. Many of the correspondent specimens figured in De Stefani's monograph have been found in the collection (i.e. n° 51 specimens/85 figures). The results of our studies indicate a relevant taxonomic diversity, mostly among ferns and sphenophytes, and point to an intertropical humid climate. These preliminary data improve the knowledge of the paleoenvironmental scenario of Tuscany during the Late Carboniferous.

KEY WORDS: *Northern Apennines, Tuscan Metamorphic Units, Late Carboniferous, stratigraphy, macrofloras.*

RIASSUNTO

Analisi delle successioni carbonifero-permiane dei Monti Pisani (Toscana, Italia): dati preliminari dalla collezione De Stefani (Museo di Storia Naturale di Firenze).

La collezione De Stefani, conservata presso il Museo di Storia Naturale di Firenze (Sezione di Geologia e Paleontologia), possiede un grande valore museale, ma anche geologico e paleontologico. Essa comprende infatti numerosi reperti fossili vegetali (982 esemplari su un totale di 1012 campioni) di età tardo paleozoica provenienti dall'area dei Monti Pisani (Valle del Guappero, Lucca) che furono studiati, e in parte raccolti, dal geologo e naturalista Carlo De Stefani sul finire dell'Ottocento, tra il 1889 e il 1900. I risultati dello studio paleobotanico e biostratigrafico effettuato dall'autore furono poi pubblicati nella monografia «Flore carbonifere e permiane della Toscana». In particolare, i macrofossili vegetali della collezione De Stefani, provengono dalla formazione degli Scisti di San Lorenzo affiorante sui Monti Pisani che finora è stata attribuita interamente ad un ambiente continentale in clima intertropicale umido. Questa formazione fa parte delle successioni paleozoico-terziarie metamorfiche appartenenti alle unità più profonde dell'edificio tettonico appenninico (Unità Metamorfiche Toscane), esposte in larga parte in finestra tettonica lungo la Dorsale Metamorfica Medio-Toscana (allineamento Alpi Apuane-Monti Pisani-Iano-Monticiano Roccastrada-Monte Leoni). La riorganizzazione della collezione, effettuata anche con strumenti informatici, ha consentito da un lato, di rivalorizzare e far emergere il potenziale storico-museale di questa raccolta, dall'altro, di approfondire alcune analisi in ambito paleobotanico e biostratigrafico. In particolare, i dati paleofloristici in nostro possesso hanno rivelato una diversità tassonomica piuttosto elevata che si mantiene più o meno invariata lungo l'intera successione. È stato inoltre effettuato un rilevamento di campagna che ha portato alla stesura di una carta geologica alla scala 1:10.000 della Valle del Guappero (Lucca), ovvero dell'area in cui si trovano gli affioramenti tipici degli Scisti di San Lorenzo. Durante tale rilevamento è stata localizzata con esattezza la maggior parte delle località fossilifere storiche, e ne sono state individuate alcune nuove. Tra quest'ultime è da sottolineare la località fossilifera di Montuolo (località mai citata dai precedenti autori), nella quale sono state rinvenute anche alcune associazioni fossili di invertebrati marini (crinoidi, briozoi, brachiopodi?, bivalvi). Il rilevamento effettuato, il locale rinvenimento di fossili marini e l'analisi della composizione floristica delle differenti località fossilifere all'interno della collezione hanno consentito di proporre con maggior dettaglio lo scenario paleoambientale dell'area di sedimentazione degli Scisti di San Lorenzo durante il tardo Carbonifero.

TERMINI CHIAVE: *Appennino settentrionale, Unità Metamorfiche Toscane, Carbonifero Superiore, stratigrafia, macroflore.*

INTRODUCTION

The Paleozoic rocks of Tuscany represent the key to reconstruct the paleogeographic, paleoenvironmental and tectonic evolution of the southern part of the Variscan belt (BAGNOLI *et alii*, 1979; TONGIORGI & BAGNOLI, 1981; VAI & COCOZZA, 1986; CONTI *et alii*, 1991; PANDELI *et alii*, 1994; VAI & MARTINI, 2001 and references therein) and are in general characterized by scarce fossiliferous formations, mostly because of the Variscan and/or Alpine tectono-metamorphic overprints. The Carboniferous-Lower Permian formations represent an exception since they include fossil plants such as the assemblage of the San Lorenzo Schists Formation outcropping in the Pisani Mountains, in the Valle del Guappero area (figs. 1, 2).

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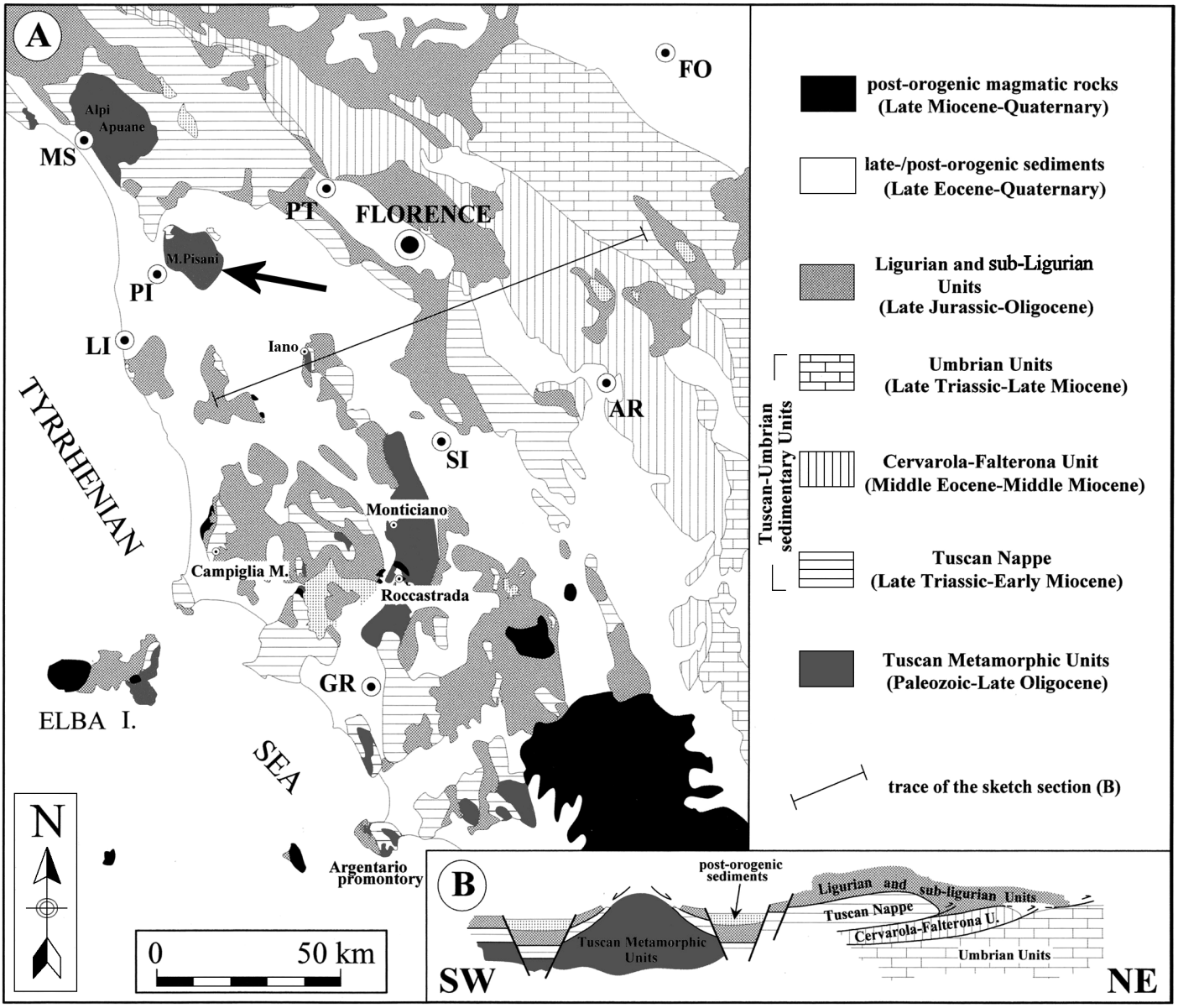

Fig. 1 - Geological sketch map (A) and cross-section (B) of the Northern Apennines. Arrow indicates the location of the Pisani Mountains. *– Carta (A) e sezione (B) geologica schematica dell'Appennino Settentrionale. La freccia indica l'ubicazione dei Monti Pisani.*

This formation was referred by RAU & TONGIORGI (1974) to a continental paleoenvironment.

The San Lorenzo Schists (= SLS) succession yielded many fossils, collected by Carlo De Stefani, that are today kept in the Natural History Museums of Florence and Pisa (Calci).

Carlo De Stefani (Padua, 1851-Florence, 1924) (fig. 3) was a prominent researcher in the outline of geological-stratigraphical and paleontological studies of Italy at the end of the 19th century. In his multiform and wide-ranging scientific activity he published more than 400 papers on various miscellaneous topics. De Stefani's studies ranged from geology to paleobotany and malacology, but his interests focused also on sociological and political problems. Between the years 1889-1901, the author collected and studied the SLS fossil plant assemblages (DE STEFANI, 1890; 1891a, b, c; 1894; 1901).

De Stefani was in contact with some other geologists and naturalists exploring the same area such as Zygmunt De Bosniascki and Mario Canavari (DE BOSNIASCKI, 1881, 1891, 1894; CANAVARI, 1891, 1892).

De Bosniascki (Krosno, Poland, 1837-San Giuliano Terme, Pisa, 1921) gathered a conspicuous collection that he kept in his private villa «Il Belvedere» at Monte Castellare near San Giuliano Terme (ARCANGELI, 1895; STEFANINI, 1934; TRATZI, 1999). Canavari discovered two new fossiliferous areas (Villa Massagli and Monte Vignale) yielding flora and continental fauna (pelecypods and insects). Many of the specimens collected by these two authors were also studied by De Stefani and are kept in the Pisa Museum (Calci). Some specimens of a Late Paleozoic flora collected in the Pisani Mountains, were brought to Poland by J. Grzybowski, and are today kept in Cracow (pers. comm. Dorota Laptosz).

In 1901 De Stefani summarized his paleobotanical and stratigraphical study of the Pisani Mountains in the monograph «Flore carbonifere e permiane della Toscana» which also includes the analysis of the coeval paleoflori-

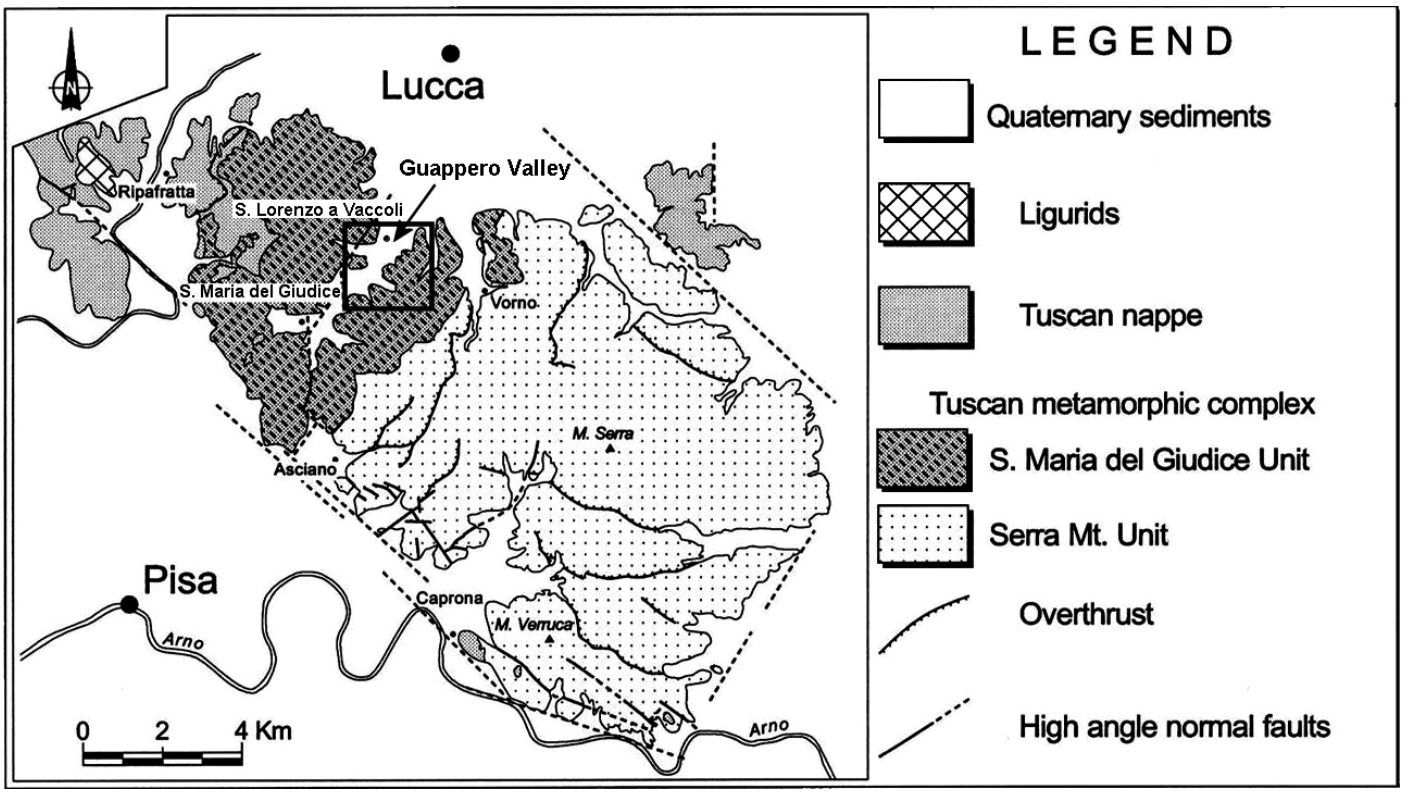

Fig. 2 - Structural sketch of the Pisani Mountains (redrawn from RAU & TONGIORGI, 1974; TONGIORGI *et alii*, 1977) and location of the studied area (squared area), in the Valle del Guappero.
– Schema strutturale dei Monti Pisani (modificato da RAU & TONGIORGI, 1974; TONGIORGI et alii, *1977) e ubicazione dell'area studiata, la Valle del Guappero (area riquadrata).*

stic associations of the graphitic metasediments of Iano (fig. 1) (SAVI & MENEGHINI, 1851).

De Stefani's paleobotanical treatise (DE STEFANI, 1901) describes and figures more than 60 species with the indication of the sampling sites. In the same monograph, the author ascribed the SLS to a generic Permo-Carboniferous age and the Iano metasediments to the lowermost part of the Upper Carboniferous.

To improve the paleoenvironmental-paleogeographic knowledge of the Late Carboniferous-Permian in the Tuscan sector of Gondwana, we performed the reorganisation and a preliminary study of the De Stefani collection (Natural History Museum of Florence) together with a geological survey in the Valle del Guappero area.

In this paper we show an outline of the De Stefani collection and a new 1:10.000 geological map of the SLS outcrops in Valle del Guappero type-area (fig. 5) which shows the precise locations of the historical and new fossil sites.

GEOGRAPHICAL AND GEOLOGICAL SETTING OF THE PISANI MOUNTAINS

The Pisani Mountains are located along the so-called Middle-Tuscan Ridge, a regional morpho-structural high extending from the Apuan Alps to the Leoni Mountain (fig. 1). They form a natural barrier between the Plio-Quaternary Pisa and Lucca plains (fig. 2). In the structural framework of the Northern Apennines, the Pisani Mountains represent a relatively wide tectonic window of

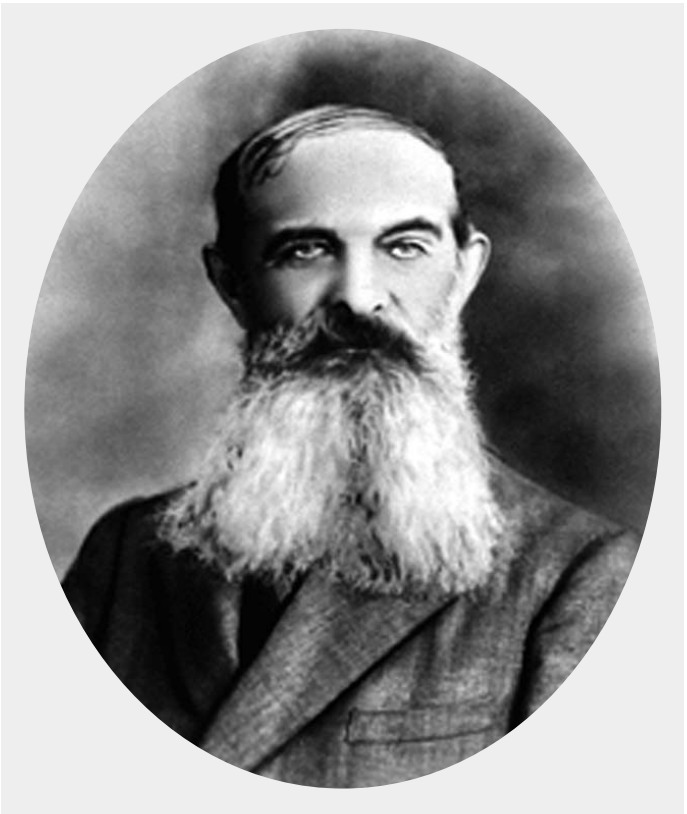

Fig. 3 - Carlo De Stefani (1851-1924).
– Carlo De Stefani (1851-1924).

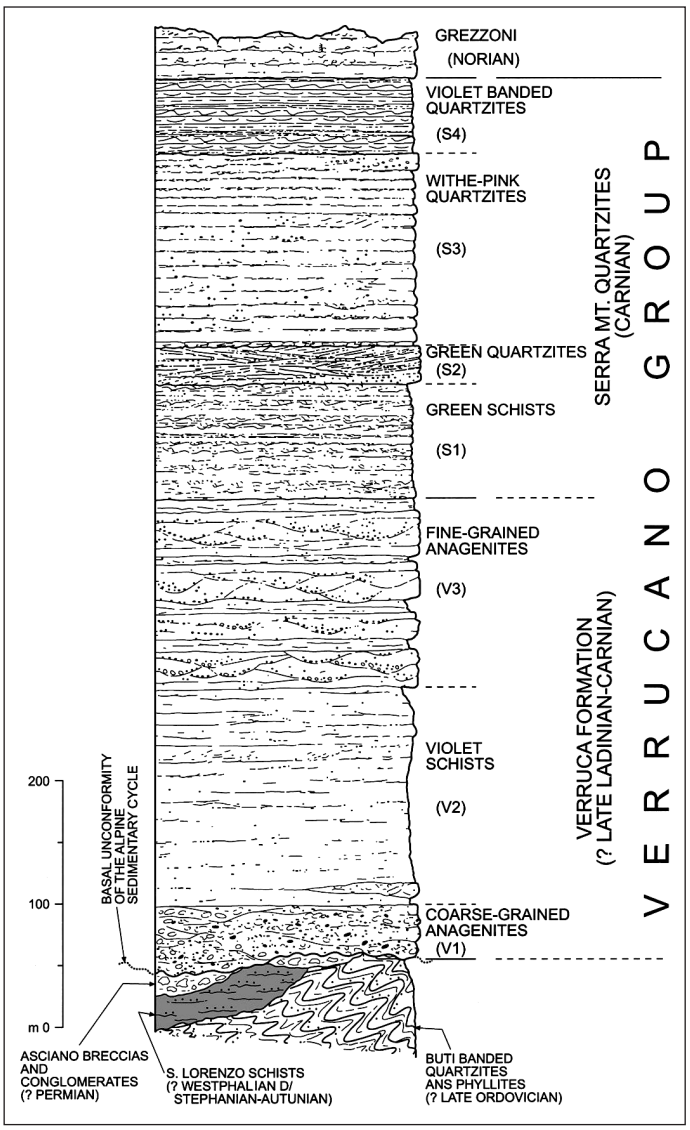

Fig. 4 - Stratigraphic column of the Paleozoic-Carnian succession of the Pisani Mountains (redrawn from RAU & TONGIORGI, 1974).
– Colonna stratigrafica della successione Paleozoico-Carnica dei Monti Pisani (da RAU & TONGIORGI, 1974, modificato).

the deepest Tuscan Metamorphic Units that are buried below the non-metamorphic Tuscan Nappe and the overlying sub-Ligurian and Ligurian Units. This morphological-structural elevation is bounded by mainly NW-SE and NE-SW-trending high-angle normal faults systems linked to the Neogene-Quaternary extensional tectonics (for more details see RAU & TONGIORGI, 1974; PANDELI *et alii*, 2004 and references therein). In particular the Pisani Mountains inlier is made up of the superposition of two epimetamorphic units: the Monte Serra Unit and the overlying Santa Maria del Giudice Unit (fig. 2) (RAU & TONGIORGI, 1974). Both units include siliciclastic Paleozoic formations which are unconformably overlain by an Alpine, passive margin-type sedimentary sequence ranging from the syn-rift, Middle/Upper Triassic continental to coastal Verrucano sediments to the Mesozoic pelagic carbonates and cherts (fig. 4) (RAU & TONGIORGI, 1974; TONGIORGI *et alii*, 1977). The youngest formations of this sequence, i.e. the Late Cretaceus to Tertiary pelagic shales and carbonates, and the Late Oligocene foredeep siliciclastics (Pseudomacigno), are preserved only in the upper part of the Santa Maria del Giudice Unit succession.

These successions were affected by polyphased tectono-metamophism, essentially in the greenschist facies, with peak conditions of T = 400 °C and P = 0.8-0.9 GPa during the Apenninic tectogenesis (FRANCESCHELLI *et alii*, 1986, 2004; CONTI *et alii*, 1991; CAROSI *et alii*, 1993, 1995) which occurred in the 27 to 10 Ma time interval (radiometric ages from the Apuan Alps Core: KLIGFIELD *et alii*, 1986).

Fig. 4 shows the reconstructed stratigraphic column of the Paleozoic to Norian units of the Pisani Mountains (RAU & TONGIORGI, 1974).

As to the Paleozoic section, three formations, which are separated by unconformity surfaces, can be distinguished (from the oldest):

1) The Buti Banded Quartzites and Phyllites (?Ordovician) consist of grey, medium- to fine-grained, quartz-albite metasandstones interbedded with grey-violet and greenish-grey phyllites and metasiltstones. These latter typically include millimetric hematite-rich bands. These unfossiliferous rocks, containing relics of pre-Alpine schistosity (Sudetic event of the Variscan Orogeny), are correlated to the Caradocian transgressive deposits of central Sardinia (PANDELI *et alii*, 1994). The 275±12 Ma (Rb/Sr, whole rock) isochron data obtained from these metasiliciclastics by BORSI *et alii* (1967), can be interpreted as the cooling age for the Permian magmatism.

2) The SLS (?Westphalian D/Stephanian-Autunian) consist of grey to black, organic matter-rich phyllites and metasiltstones, and well stratified, grey quartzitic metasandstones. Metaconglomerates, characterized by abundant whitish quartz clasts, are intercalated in the upper part of the formation. The abundant fossil content of the metapelitic and sometimes also of the metasandstone lithotypes is well known (see RAU & TONGIORGI, 1974 and references therein) and includes plant remains (essentially ferns: DE STEFANI, 1901), limnic pelecypods (*Anthracosia*: CANAVARI, 1891), insects (Blattinariae: CANAVARI, 1892), lamellibranchia and crustaceans (Estherie: RAU & TONGIORGI, 1974). All of the fossil sites of the SLS are located in the Valle del Guappero (Lucca), i.e. the Santa Maria del Giudice area: Valentona, Monte Togi, Traina/Colletto, Monte Vignale and Sasso Campanaro, on the eastern side of the valley, Villa Massagli and Montuolo, on the western side of the valley (fig. 5).

The ?Westfalian D/Stephanian-Autunian age of the SLS was defined by TREVISAN (1955) through the biostratigraphic study of the fossil plants of the De Stefani collection (Natural History Museum of Florence) together with those that are kept at the Natural History Museum of Pisa (Calci), and later by RAU & TONGIORGI (1974) also with the supplement of litostratigraphical data. Tab. 1 shows the biostratigraphical scheme proposed by TREVISAN (1955) and the subsequent revision performed by RAU & TONGIORGI (1974) for the different fossil localities.

The sedimentary characteristics and the fossil content of the SLS suggested to RAU & TONGIORGI (1974, 1976) a continental, fluvial-lacustrine depositional paleoenvironment in an area dominated by a wet intertropical- or equatorial-type climate.

The basal unconformity surface that separates the SLS from the underlying Buti Banded Quartzites and

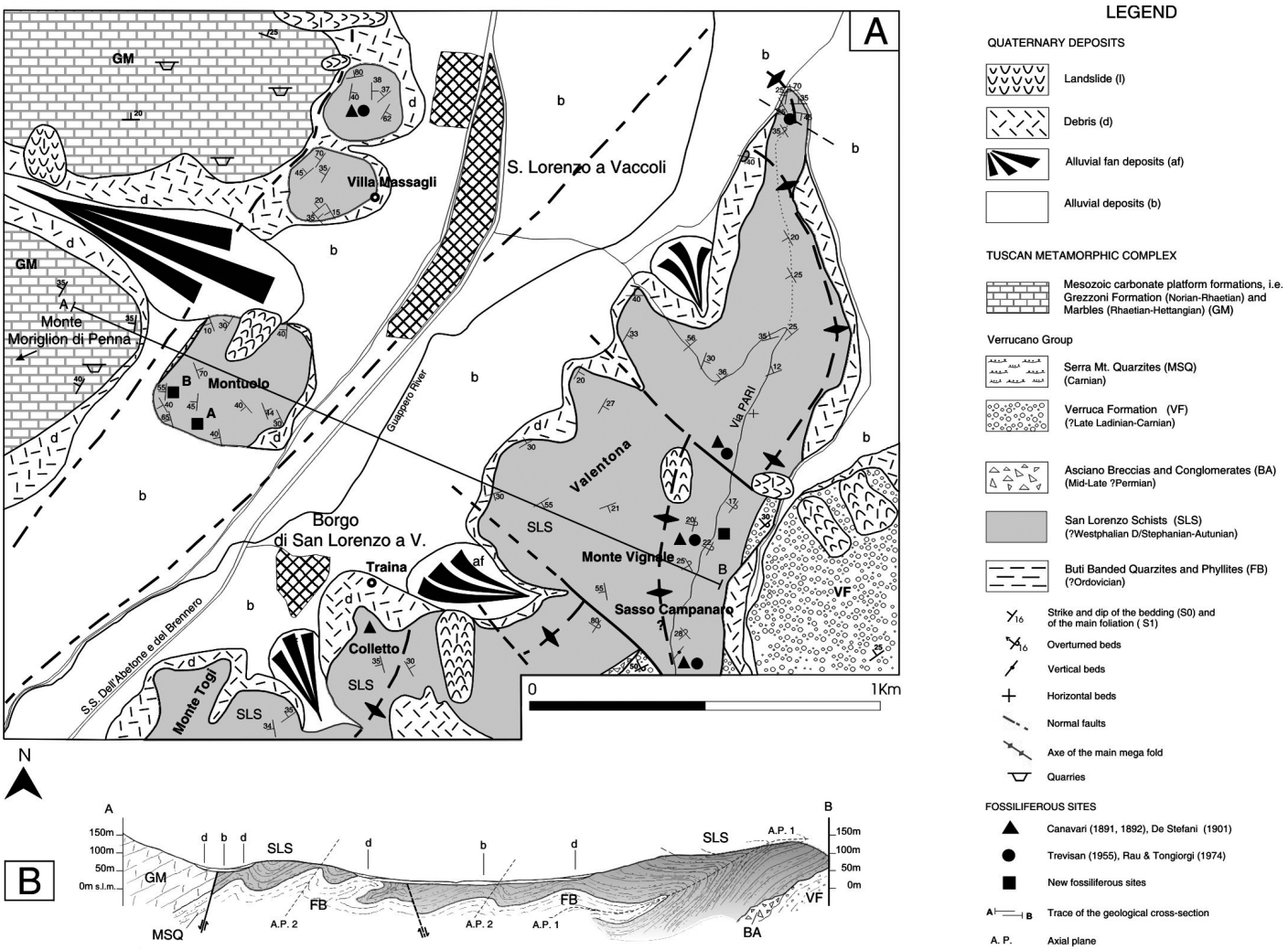

Fig. 5 - Geological map (A) of the San Lorenzo a Vaccoli area, in the Valle del Guappero and geological cross section (B).
– Carta (A) e sezione (B) geologica dell'area di S. Lorenzo a Vaccoli nella Valle del Guappero.

Phyllites is related to the Asturian event of the Variscan Orogeny (BAGNOLI *et alii*, 1979; PANDELI *et alii*, 1994).

3) The Asciano Breccias and Conglomerates (?middle/?Late Permian). These red beds are composed of poorly-bedded, massive and polymictic metarudites that are characterized by a low textural and compositional maturity. The clasts are angular to subrounded and are generally represented by phyllites, quartzites and metasandstones (including the Buti Banded Quartzites and Phyllites-like lithotypes) and minor quartz pebbles. The hematite-rich, phyllitic matrix often prevails over the clasts. Intercalations of polymictic metasandstone and violet phyllites can be locally present. These unfossiliferous deposits represent continental fanglomerates in a sub-arid intertropical climate (RAU & TONGIORGI, 1974) and are linked to the middle Permian Saalian block faulting event that caused the rejuvenation of the Variscan landscape (BAGNOLI *et alii*, 1979; PANDELI *et alii*, 1994; PANDELI, 2002).

All the three above mentioned units are unconformably overlain by Triassic syn-rift Verrucano sediments (i.e. the fluvial Verruca Formation and the overlying neritic-deltaic Monte Serra Quartzite: RAU & TONGIORGI, 1974; TONGIORGI *et alii*, 1977).

THE SAN LORENZO SCHISTS OF THE VALLE DEL GUAPPERO

GEOLOGICAL DATA

A 1:10.000 scale geological survey was performed by the authors (fig. 5) to refine the stratigraphical and structural frame of the SLS in their type-area (Villa Massagli-San Lorenzo a Vaccoli-Via Pari area) already mapped by RAU & TONGIORGI (1974) at 1:25.000 scale. During the survey, Prof. M. Tongiorgi kindly gave us further valuable suggestions and field data. Fig. 5 shows the location of traditional (historical) and new fossil sites.

In the studied area, the SLS have a relatively wide exposure compared to the stratigraphically overlying formations. In fact, the ?Permian Asciano Breccias and Conglomerates and the basal Verruca Formation of the Triassic Verrucano Group are only exposed in the south-easternmost areas. To the northwest, the SLS are instead in lateral tectonic contact through a high-angle normal fault with the Norian and Hettangian carbonate platform rocks (i.e. the Grezzoni Fm. and the Marbles Fm.).

Quaternary fluvial and colluvial deposits are present in the plains and at the base of the reliefs respectively.

In agreement with RAU & TONGIORGI (1974), two main lithofacies are recognizable within the SLS:

TABLE 1

Chronological ordering of the main fossil sites of the SLS formation according to TREVISAN (1955) and RAU & TONGIORGI (1974). TREVISAN (1955) indicated for each fossil locality the index fossils.

– Collocazione stratigrafica dei principali siti fossiliferi della formazione degli Scisti di San Lorenzo secondo TREVISAN (1955) e RAU & TONGIORGI (1974). Nello schema di TREVISAN (1955) sono indicati, per ogni località fossilifera, anche i fossili guida.

L. Trevisan (1955) Biostratigraphy	**A. Rau & M. Tongiorgi** (1974) Lithostratigraphy
Via Pari and Sasso Campanaro: *Walchia piniformis, Callipteris conferta* AUTUNIAN (Lower Permian)	Sasso Campanaro: AUTUNIAN (Lower Permian)
Monte Vignale: *Taeniopteris multinervis* STEPHANIAN **B** and **C**	Monte Vignale: AUTUNIAN (probable)
Monte Togi: *Sphenophyllum oblongifolium, Pecopteris arborescens, Acitheca isomorpha* STEPHANIAN **A**	Traina: ? STEPHANIAN **B** and STEPHANIAN **C**
Villa Massagli: Lepidodendrids flora WESTPHALIAN **D**	Villa Massagli: STEPHANIAN **A** and **B**

a) *A mainly pelitic and pelitic-arenaceous lithofacies*, which crops out in the Villa Massagli-Montuolo and the Monte Togi-Traina/Colletto-Valentona areas, consists of dominant grey to black, graphite rich phyllites and metasiltstones with local intercalations of grey metasandstones. Coarse-grained metasandstone and fine-grained quarzitic meta- microconglomerate beds are rarely present.

b) *A mainly arenaceous-pelitic lithofacies*, cropping out in the Sasso Campanaro-Via Pari area is made of decimeters to meters-thick beds of coarse- to fine-grained metasandstones, locally characterized by plane-parallel laminations and cross-beddings and graphite-rich metapelitic intercalations, sometimes including carbon concentrations. Withish-grey, quartz pebble metaconglomerate beds, often with erosional bases, also occur. These lithotypes are generally organized in metric fining- and thinning-upward cycles which can be referred to the filling of fluvial channels. Locally, horizons of red-violet metapelites are also present.

During the survey, new fossil sites were identified (fig. 5). They generally yielded unidentifiable plant fragments, but in the Montuolo area, marine faunas (?brachiopoda, bryozoa, bivalves and crinoids: see PANDELI *et alii*, 2008, this volume) were also found.

On the basis of our survey, the reconstructed stratigraphic and structural setting of the San Lorenzo a Vaccoli area, and the stratigraphic position of the fossiliferous sites within the SLS succession is as it follows: Villa Massagli outcrops (lowermost part), Montuolo outcrops (lower part), Valentona-Monte Togi-Traina/Colletto outcrops (middle part), Monte Vignale-Via Pari outcrops (upper part), Sasso Campanaro outcrops (uppermost part).

The SLS succession shows a total apparent thickness that exceeds 250 m (300-350 m according to RAU & TONGIORGI, 1974).

The SLS show a polyphased deformation evolution linked to the Apenninic tectogenesis, which is similar to that of the other formations of the Pisani Mountains and more in general of the other Tuscan Metamorphic Units (CONTI *et alii*, 1991; CAROSI *et alii*, 1993, 1995; PANDELI *et alii*, 2004).

Particularly, the D1 event is recognizable at the mesoscale as the very pervasive, continuous metamorphic foliation (S1=quartz+sericite±chlorite+graphite or hematite) which is generally parallel to the bedding. In spite of the lack of outcrops of D1 folds in the studied area, S1 is the axial plane foliation of NE-vergent isoclinal folds recognized in the Pisani Mountains inlier (CAROSI *et alii*, 1995) and at regional scale in the Tuscan Metamorphic Units (CARMIGNANI & KLIGFIELD, 1990; CONTI *et alii*, 1991; CORSI *et alii*, 2001).

In our opinion, the east-vergent, mega-overturned anticline reconstructed in the Via Pari area (fig. 5) could be referred to a D1 structure.

Metric to decametric, often asymmetric to overturned, east-vergent D2 folds that deform S1, were also locally observed in the field. They are generally close to tight folds, characterized by a mainly NNE-SSW to a NW-SE axial strike and a western axial plane dip. Their axial plane foliation is a millimetric- to centimetric-spaced zonal to discrete (S2=sericite+opaques) crenulation cleavage. A following gentle to open folding can also be recognizable at places.

Finally, a mainly NW-SE and NE-SW-trending high angle normal faulting dissected the poly-folded metamorphic assemblage. These brittle structures can be related to the Pliocene- Quaternary extension of the chain.

PRELIMINARY DATA FROM THE DE STEFANI COLLECTION

The De Stefani collection consists of nearly 1.000 fossil specimens; more precisely, 1012 are the samples detected in the collection and 982 is the total number of specimens. They come from known and, in a lesser way, from unknown localities. It has to be underscored that some samples yield more than one specimen, but also that a relevant number of parts and their counterparts have been identified and thus counted as one specimen or individual.

Most of the specimens are represented by adpressions, with many counterparts. They are imprints of plants, or their parts, that are devoid of organic material. No permineralized specimens are present in the collection.

DE STEFANI's monograph (1901) was the starting point of our analysis: in the text the author describes and illustrates more than 60 species including new species and new nomenclatural combinations. The new species are mainly ferns and sphenopsids; putative pteridosperms are also present and, to a smaller extent, lycopods, cycads and other gymnosperms.

During the museological reorganisation of the collection, we have found most of the species listed in De Stefani's paleobotanical treatise. Many of the collection specimens that are illustrated in the enclosed iconographic

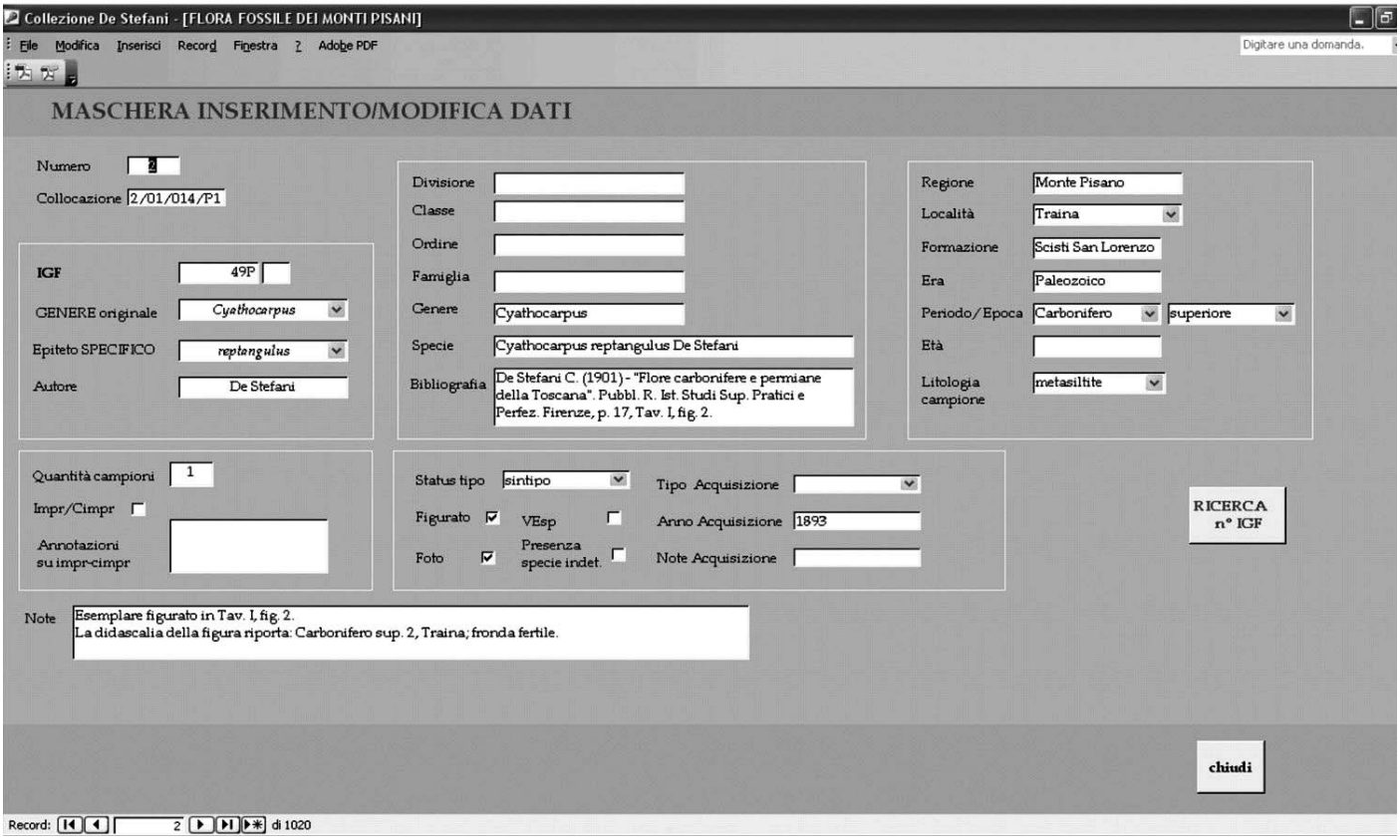

Fig. 6 - The research *form* of the database: it contains 27 *fields* and allows to research specimens by number of IGF (= acronym of Istituto Geologico Fiorentino). The database allows also to make researches by means of other criteria (e.g. search by genus, species, locality, etc...). – *La* maschera *di ricerca del database: contiene 27* campi *e consente di cercare gli esemplari per numero di IGF (= acronimo di Istituto Geologico Fiorentino). Il database consente anche di fare ricerche con altri criteri (ad esempio ricerca per genere, specie, località, ecc...).*

tables (51 specimens/85 figures) were also identified. Since the author indicates the sampling site of all these specimens, the matching of the fossil with the figure allowed us to know their provenience, even when not indicated on the museum label.

The overview of the entire collection has been facilitated and supported by the implementation of a database (Microsoft ACCESS). The database has been a very useful tool for data processing and the subsequent analysis of the macroflora. It contains museological, taxonomic, geographic, historical and geological- lithological information in accord with the main standard requirements for paleontological collections (fig. 6).

During the reorganisation of the De Stefani collection, 104 specimens collected by the geologist A. Fucini, were also detected and considered in the present study; a note of DE STEFANI (1901) attests their provenance from the Monte Vignale area. Finally, 28% of the specimens come from unknown localities and they have not been considered in the present paper.

In the collection, fern foliage genera are the most represented together with sphenopsids, to a lesser extent. More precisely, according to De Stefani, 83% of the specimens of the collection belong to pteridophytes, whereas gymnosperms reach 8%. Moreover, about 9% of the specimens are unidentified (fig. 7a, tab. 2, pl. 1). It also has to be outlined that arborescent lycopods (i.e. the genera *Lepidodendron*, *Sigillaria*, *Stigmaria*) are very scarce. Only one specimen of the collection comes from Villa Massagli, an area where the historical authors refer to have found some specimens of lepidodendrids (DE BOSNIASCKI, 1894; DE STEFANI, 1901).

It has to be underscored that the author's classification is very outdated and that many taxonomic collocations should be revised, particularly among pteridophytes (e.g. the ferns *i.s. sensu* De Stefani). To give an example, form-genera like *Alethopteris*, *Neuropteris*, *Odontopteris* are supposed to belong to Medullosales in more recent literature (CLEAL, 1991; TAYLOR & TAYLOR, 1993), the form-genus *Callipteris*, reviewed by KERP & HAUBOLD (1988), is now related to Peltaspermales. However, the number of these form-genera in the De Stefani collection is low and do not affect our results.

Moreover, a general nomenclatural revision of the whole monograph would be desirable together with a revision of the most important genera of the collection, as we can infer from recent literature, like the study of *Acitheca* performed by ZODROW *et alii* (2006). *Acitheca*, in fact, represents one of the most important genera of the collection.

Even if a general revision of the nomenclature would be necessary, it is not the object of this paper.

Table 2 contains the list of the species detected in the De Stefani collection, with indication of their frequency; furthermore the correspondence between the names used by DE STEFANI (1901) and those used by DOUBINGER *et alii* (1995) is also shown (see Discussion).

The museological reorganisation has also provided the occasion for the identification of the lithological fea-

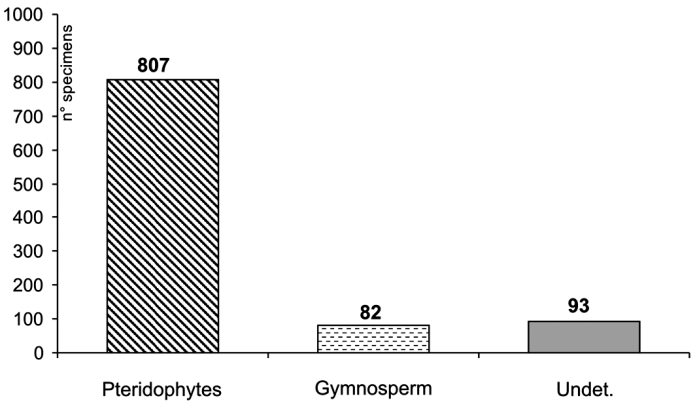

Fig. 7a - Main taxonomic groups of the De Stefani collection.
– I principali gruppi tassonomici presenti nella collezione De Stefani.

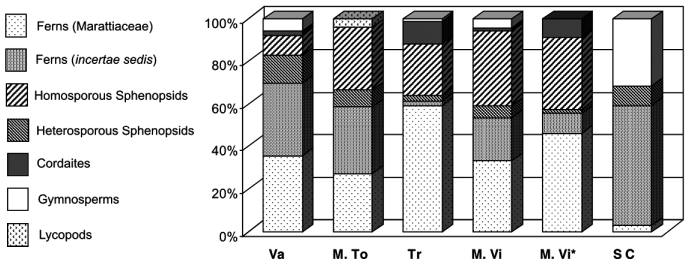

Fig. 7b - Percentages of the taxonomical groups of the fossil sites identified in the De Stefani collection. Va: Valentona; M. To: Monte Togi; Tr: Traina; M. Vi: Monte Vignale; M. Vi*: Monte Vignale (collected by Fucini); SC: Sasso Campanaro.
– Rapporti percentuali dei gruppi tassonomici delle località fossilifere della collezione De Stefani. Va: Valentona; M. To: Monte Togi; Tr: Traina; M. Vi: Monte Vignale; M. Vi: Monte Vignale (collected by Fucini); SC: Sasso Campanaro.*

tures of all the specimens (i.e. the host-rock) of the collection. The lithological data represent a new additional information that updates the geological and paleontological relevance of the collection specimens.

The lithology of the host-rock was fitted into three main categories: metarenites, metasiltstones and phyllites. Furthermore their identification supported our effort to focus on, and thus take in proper consideration the relevance of taphonomical factors. In fact the analysis of the substratum allowed to better characterize the floristic data extrapolated from the De Stefani collection database, taking into account the possible bias introduced by taphonomical processes. Thus, the results regarding the lithological composition of the entire collection show that more than half of the samples are phyllites (58%), whereas metasiltstones are represented by 28% and metarenites by 14% of the samples. These results may be attributed to the sampling methodology and to fossilization processes. In fact, phyllites represent certainly a good lithology for fossilization mainly because of their fine-grained composition. Moreover phyllites are generally easy to cleave and they often yield specimens that are aesthetically appreciable.

Fossils from all the fossiliferous localities (Monte Togi, Traina/Colletto, Valentona, Sasso Campanaro, Monte Vignale and Villa Massagli) quoted by DE STEFANI (1901) and by the other previously mentioned authors (DE BOSNIASCKI, 1891, 1894; CANAVARI, 1891, 1892) are well represented in the collection.

In the new geological map (fig. 5) these toponyms have been correctly located, in spite of errors and omissions that are present in the old maps of the Santa Maria del Giudice area. This is the case of Sasso Campanaro, whose exact position was uncertain: some general indications (DE STEFANI, 1901; DE BOSNIASCKI, 1894) locate this toponym at the top of the Valentona area. Moreover, during the field survey, it was also possible to identify Traina, a fossil site often cited (CANAVARI, 1892; DE BOSNIASCKI, 1894; DE STEFANI, 1891a, 1891c, 1894, 1901), but lacking in all of the consulted maps. More precisely, the toponym Traina corresponds to an old house located in the Colletto area (for this reason, this area will be indicated in the present paper as Traina/Colletto) (fig. 5).

Before discussing the results concerning the distribution of the fossil specimens collected by De Stefani, it is necessary to make some considerations about the sampling methodology and the self-consistency (i.e. the completeness) of the collection analysed: more precisely, we do not know the sampling methodology used in collecting the material and we also ignore the relations between the collections kept in Florence and in Pisa.

However, in this paper we have taken as a working hypothesis that the De Stefani collection of Florence is indeed representative of the original frequency of the various fossil taxa.

DISCUSSION

The study of the fossil macroflora of the De Stefani collection not only brings up to date the museological relevance of this historical and scientific heritage, but also offers new geological and paleontological informations for both paleoenvironmental and paleogeographic reconstructions.

The reorganisation of the De Stefani collection has lead to exactly detect the number of specimens (982) and the total number of the genera and species present (tab. 2). The new data acquired on the lithological composition of the collection specimens and the identification of the fossil plant assemblages for each fossil site (fig. 7b) point out that a relevant biological diversity characterizes the entire succession of the SLS in the Valle del Guappero area.

All the collected data show that in most of the fossil localities ferns, sphenopsids and gymnosperms (cordaites and conifers) were present (fig. 7b).

The only exception is represented by the fossil site of Monte Togi where the presence of gymnosperms is not testified and a very low percentage of specimens of *Sigillaria* was collected.

Fern foliage genera, including putative pteridosperms previously mentioned, classified by DE STEFANI (1901) as ferns *i.s.*, are present in all the floristic assemblages. Their percentage values range from a minimum of 53-55% for Monte Vignale to a maximum of 70% for Valentona. Intermediate values, of approximately 60%, are recorded for Traina/Colletto, Monte Togi and Sasso Campanaro.

Since these fossils are well represented in all of the lithological categories of the host-rock (i.e. metasandstones, metapelites and phyllites), we can assume that

TABLE 2

List of the species of the De Stefani collection (Museum of Natural History, Geology and Paleontology Section) according to the classification of the author.

The taxa detected in each fossil site are compared with those of the Saint-Étienne basin (DOUBINGER *et alii*, 1995). Symbols: +: detected in the collection; X: present in DOUBINGER *et alii*, 1995. The new species established by DE STEFANI (1901) are highlighted in grey.

– Elenco delle specie della collezione De Stefani (Museo di Storia Naturale, Sezione di Geologia e Paleontologia) secondo la classificazione dell'autore.

I taxa di ogni località fossilifera sono messi a confronto con quelli del bacino di Saint-Étienne (DOUBINGER et alii*, 1995). Simboli: +: identificato nella collezione; X: presente in DOUBINGER* et alii *(1995). Le nuove specie istituite da DE STEFANI (1901) sono evidenziate in grigio.*

Nomenclature according to De Stefani (1901)	**Nomenclature according to Doubinger *et alii*(1995)**	VILLA MASSAGLI	VALENTONA	MONTE TOGI	TRAINA	MONTEVIGNALE	MONTE VIGNALE (Coll. Fucini)	SASSO CAMPANARO	SAINT-ÉTIENNE (DOUBINGER *ET ALII*, 1995)
LOWER VASCULAR PLANTS:									
MARATTIACEAE									
Acitheca isomorpha De Stefani			+	+	+	+			
Acitheca polymorpha (Brongniart) De Stefani	*Pecopteris polymorpha* Brongniart,1834				+	+	+		x
Callipteridium connatum Roemer					+	+			
Crossotheca pinnatifida (von Gutbier) De Stefani			+	+	+		+		
Cyathocarpus daubreei (Zeiller) De Stefani	*Pecopteris daubreii* Zeiller, 1888		+		+	+			x
Cyathocarpus pectinatus De Stefani					+				
Cyathocarpus pillae De Stefani			+						
Cyathocarpus reptangulus De Stefani			+	+	+	+	+		
Dactylotheca canavarii De Stefani					+				
Diplazites unitus (Brongniart) De Stefani	*Pecopteris unita* Brongniart, 1836		+	+	+	+	+		x
Eremopteris lucensis De Stefani					+			+	
Goniopteris foeminaeformis (Schlotheim) De Stefani	*Pecopteris foeminaeformis* Schlotheim ex Sterzel, 1881			+					x
Pecopteris sp.			+						
Pecopteris ? ristorii De Stefani					+				
Sphenopteris pisana De Stefani				+	+				
Sphenopteris sp.				+					
FERNS INCERTAE SEDIS									
Alethopteris grandini (Brongniart) De Stefani						+			
Aphlebia cfr. *elongata*						+			
Aphlebia savii De Stefani				+	+		+		
Callipteris conferta (Sternberg) De Stefani	*Autunia conferta* (Sternberg) Kerp, 1988		+	+		+	+	+	x
Cyclopteris sp.					+				
Lesleya cocchii De Stefani			+			+			
Neurodontopteris auriculata (Brongniart) De Stefani	*Neuropteris osmundae* (Artis) Kidston, 1890		+	+	+	+	+	+	x
Neurodontopteris sp.						+			
Nevropteris zeilleri De Lima						+		+	
Odontopteris (Mixoneura) subcrenulata (Rost) De Stefani			+			+			
Taeniopteris bosniackii De Stefani					+				
Taeniopteris multinervis Weiss						+			
HOMOSPOROUS SPHENOPSIDS									
Aspasia amplectens De Stefani			+					+	
Calamites cistii Brongniart	*Calamites cistii* Brongniart,1828				+				x
Calamites leioderma von Gutbier			+	+	+	+	+	+	
Calamites suckowii Brongniart	*Calamites suckowii* Brongniart, 1828				+				x
Calamites sp.					+	+			
Equisetum fucini De Stefani			+						
Hydatica capillacea (Lindley & Hutton) De Stefani				+	+	+			
HETEROSPOROUS SPHENOPSIDS									
Annularia cometa De Stefani					+	+			
Asterophyllites equisetiformis (Schlotheim) De Stefani	*Asterophyllites equisetiformis* (Sternberg) Brongniart, 1828		+	+	+	+	+		x
Sphenophyllum oblongifolium (Germar & Kaulfuss) De Stefani	*Sphenophyllum oblongifolium* (Germar & Kaulfuss) Unger, 1850		+	+	+	+	+		x
Sphenophyllum sp.			+	+					
Sphenophyllostachys sp.									
LYCOPODS									
LEPIDODENDRACEAE									
Lepidodendron sp.		+							
SIGILLARIACEAE									
Sigillaria sp.				+					
GYMNOSPERMS:									
CORDAITES									
Aspidiopsis coniferoides					+				
Cordaites borassifolius (Sternberg) De Stefani	*Cordaites borassifolius* (Sternberg) Unger 1850		+		+	+	+		x
Cordaites principalis (Germar) De Stefani	*Cordaites principalis* Germar, 1848				+				x
CYCADS									
Noeggerathia ? pillae De Stefani								+	
CONIFERS									
Czekanowskia sp.					+				
Walchia eutassaefolia Brongniart						+			
Walchia piniformis (Schlotheim) De Stefani	*Walchia piniformis* Sternberg, 1825		+		+	+		+	x
Walchia sp.					+			+	
Indet.			-	2	31	1	4	-	
TOTAL OF THE COLLECTION SPECIMENS FOR EACH FOSSIL SITE		**1**	**53**	**53**	**444**	**124**	**108**	**32**	

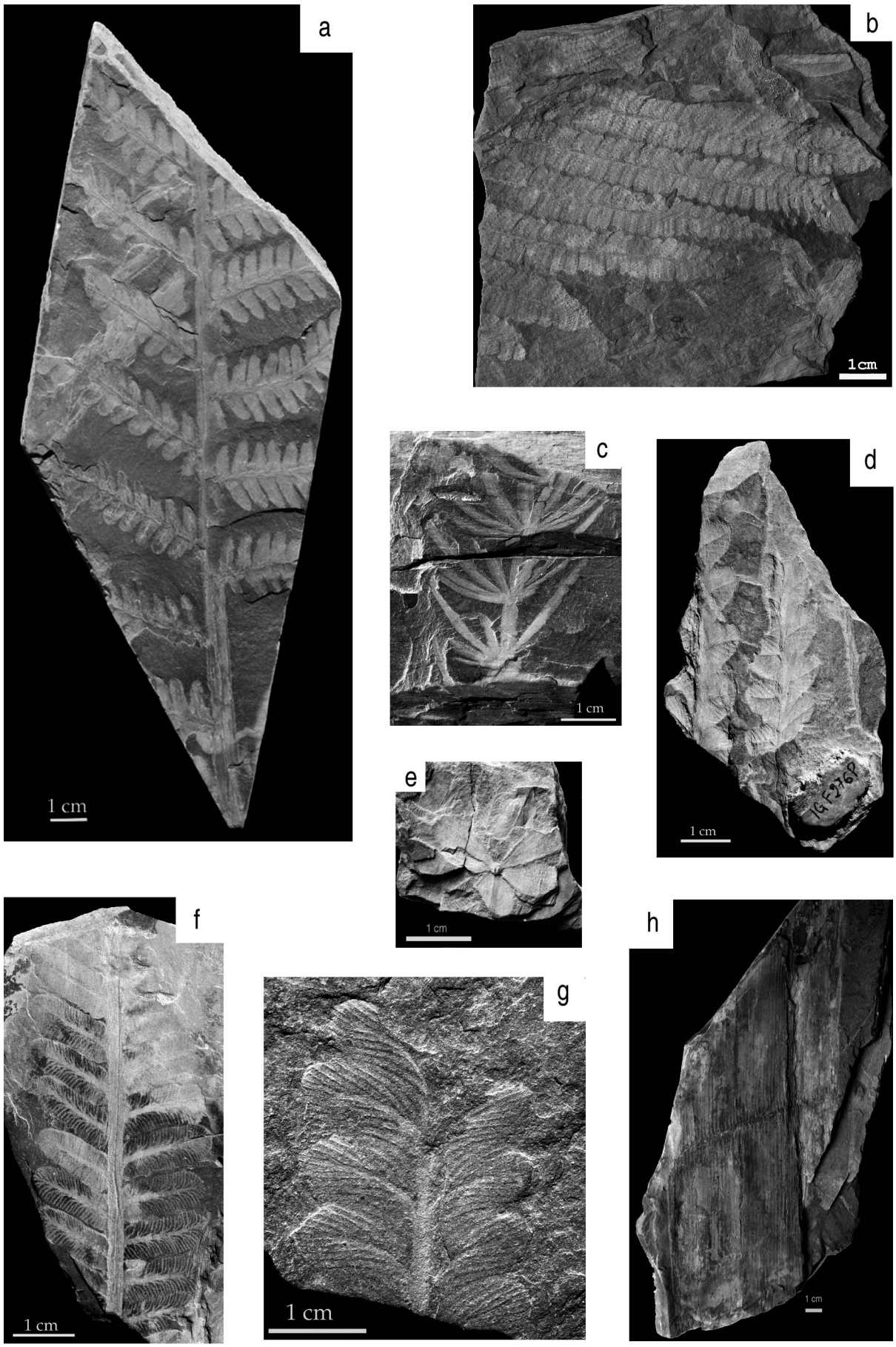

Plate 1.

ferns were a conspicuous element of the paleofloristic scenario of the Valle del Guappero area. Sphenopsids (mostly represented by *Calamites*, *Sphenophyllum*, *Asterophyllites*) have an average percentage of 26% with the highest values (41%) for Monte Vignale and the lowest (9%) for Sasso Campanaro.

Gymnosperms (cordaites and conifers) are absent or poorly represented in the fossil record with an average value of 8%. The cordaites collected at Traina/Colletto show the highest rates reaching a value of 11% of the total fossil plants, whereas they decrease to 2% in the Valentona and Monte Vignale collections. They represent 9% of the specimens collected by Fucini in the Monte Vignale area.

Conifers show relevant values (31%) among the Sasso Campanaro fossils. The high percentage recorded for this group of plants in this site, where metasandstones are the predominant lithology, may be a consequence of taphonomical processes and/or an indication of their increase in the environment. Taking in consideration taphonomical problems, it has to be outlined that conifers fossilize better than ferns and may be more resistant to decay and thus result over-represented in metasandstones. This is mainly due to their adaptations to arid environments which involve the presence of a thickened and sometimes wax-protected cuticule and the typical reduced area of their leaves. On the contrary, ferns may be under-represented. As a consequence, the predominancy of metarenites has to be taken in careful consideration since it could lead to a misrepresentation of the original taxa composition. Few specimens related to the genus *Sigillaria* come from the fossil location Monte Togi, whereas only one specimen of *Lepidodendon* sp. comes from Villa Massagli. Regarding this topic, we decided to consult the database of the coeval paleoflora collection kept at the Museum of Pisa (Calci). Also the Pisa collection has a quite low number of specimens of lycopods: only 2% of the taxa are, in fact, related to lepidodendrid (54/2017 specimens) and sigillarian (13/2017 specimens) species. Unfortunately, their provenance is unknown.

The paucity of arborescent lycopods (lepidodendrids) brings us to suppose that this group of plants might have been in a declining trend; alternatively, we can suppose that ecological conditions necessary for their growth were absent in the Late Carboniferous paleoenvironment of the Pisani Mountains area.

Selection operated by the collectors may also give reason of the scarce number of these plants.

Furthermore, for each of the fossil sites of the studied area (Valle del Guappero), we have taken in consideration the floristic ratio (= number of taxa/number of specimens), which gives an idea of the biological diversity, and the predominant lithology of the collection specimens (tab. 3). The fossils referred to Valentona, Monte Togi and Sasso Campanaro areas show the highest values of the floristic ratio. As to the quite high floristic ratio pertaining to the collection of Sasso Campanaro, we can hypothesize that the floristic/biological diversity might have been higher since metarenites constitute the worst substratum, within the considered lithologies, for fossilization processes. However, the sampling methods may strongly affect this kind of data.

TABLE 3

The floristic ratio and the predominant lithology (with the corresponding percentage) of each fossil location of the Valle del Guappero area.

– Il quoziente floristico e la litologia predominante (con i valori percentuali corrispondenti) di ciascuna delle località fossilifere della Valle del Guappero.

Fossil locations	n° specimens	n° taxa	Floristic Ratio	Predominant lithology
Villa Massagli	1	1	_	phyllite
Valentona	53	19	0,36	phyllites (95%)
Monte Togi	51	16	0,31	phyllites (88%)
Traina/Colletto	413	36	0,09	phyllites (46%), metasiltstones (48%)
Monte Vignale	123	25	0,20	phyllites (75%)
Monte Vignale (FUCINI collection)	104	11	0,11	phyllites (69%)
Sasso Campanaro	32	9	0,28	metarenites (82%)

The floristic ratio sensibly decreases in the Monte Vignale collection and shows the lowest value in the Traina/Colletto one. Traina/Colletto is the fossil site that yielded the greatest amount of specimens.

The collected data suggest that most of the SLS sedimentation area was characterized by a quite high environmental stability, a hot-humid intertropical climate and a continuous siliciclastic input, as already supposed by RAU & TONGIORGI (1974, 1976).

Moreover, the new findings of a marine fossil fauna assemblage in the lower part of the formation (Montuolo outcrops) indicate a vertical evolution from a coastal plain to neritic environment which passed upwards, with a regressive trend, to the fluvial and at times marshy environment which characterizes the middle (Valentona, Monte Togi, Traina/Colletto areas) and the upper (Monte Vignale, Via Pari, and Sasso Campanaro areas) part of the formation.

The evident increase of the siliciclastic input in the upper part (e.g. Sasso Campanaro) of this regressive-type

Plate 1 - Some of the most representative fossil specimens of the De Stefani collection (Museum of Natural History, Geology and Paleontology Section, University of Florence): *a*) *Crossotheca pinnatifida* (VON GUTBIER) DE STEFANI (IGF 400 P); *b*) *Cyathocarpus daubreei* (ZEILLER) DE STEFANI (IGF 41 P); *c*) *Aterophyllites equisetiformis* (SCHLOTHEIM) DE STEFANI (IGF 130 P, 140 P); *d*) *Callipteris conferta* (STERNBERG) DE STEFANI (IGF 276 P); *e*) *Sphenophyllum oblongifolium* (GERMAR & KAULFUSS) DE STEFANI (IGF 796 P); *f*) *Acitheca isomorpha* DE STEFANI (IGF 750 P); *g*) *Callipteris conferta* (STERNBERG) DE STEFANI (IGF 290 P); *h*) *Calamites* sp. (IGF 143 P).
– Alcuni degli esemplari più rappresentativi della collezione De Stefani (Museo di Storia Naturale, Sezione di Geologia e Paleontologia, Università di Firenze): a) Crossotheca pinnatifida *(VON GUTBIER) DE STEFANI (IGF 400 P);* b) Cyathocarpus daubreei *(ZEILLER) DE STEFANI (IGF 41 P);* c) Aterophyllites equisetiformis *(SCHLOTHEIM) DE STEFANI (IGF 130 P, 140 P);* d) Callipteris conferta *(STERNBERG) DE STEFANI (IGF 276 P);* e) Sphenophyllum oblongifolium *(GERMAR & KAULFUSS) DE STEFANI (IGF 796 P);* f) Acitheca isomorpha *DE STEFANI (IGF 750 P);* g) Callipteris conferta *(STERNBERG) DE STEFANI (IGF 290 P);* h) Calamites *sp. (IGF 143 P).*

succession is probably related to the onset of the uplifting phenomena linked to the Saalian extensional phase of the Variscan orogeny and/or to possible consequent climatic changes (see the local red beds horizons).

Thus, the paleoenvironmental scenario of the most part (i.e. the middle-upper part) of the SLS area can be imagined as a relatively wide alluvial floodplain characterized by temporary marshy depressions that were mainly inhabited by plants of wet environments such as ferns and sphenopsids.

A meso-hygrophilus flora, represented by ferns, putative pteridosperms and gymnosperms, found in the uppermost part of the SLS formation, can be referred to more marginal areas like bordering highlands and reliefs, where the soil was less humid.

Moreover in our analysis we attempted to compare the species of the collection with those discovered and studied in other Upper Carboniferous-Lower Permian sedimentary basins of Italy and France. As it regards the comparison with the Saint-Étienne basin (DOUBINGER *et alii*, 1995), one of the most important coal basins of France (Massif Central) and considered the type-locality for the Stephanian biostratigraphy, it was necessary to find the possible correspondence between the names used by DE STEFANI (1901) and those used by DOUBINGER *et alii* (1995). As shown in tab. 2, almost one third (i.e. 13/35) of the fossils of the De Stefani collection can be successfully compared with those of Saint-Étienne. No comparison was possible for the most part of the new species established by De Stefani.

As it regards the Italian area, more problems arose in attempting the correlation of the paleofloristic data of the SLS with coeval formations cropping out in Tuscany. The Late Carboniferous Iano Schists and Sandstones, studied by SAVI & MENEGHINI (1851) and later by VAI & FRANCAVILLA (1974), and the Rio Marina Formation (cropping out in the eastern Elba Island) could offer a solid basis for biostratigraphic correlations since both sequences are related to marine and/or transitional environments. In particular the lithologic-sedimentologic features and the fossil content (pelecypods, brachiopods, bryozoans, crinoids, foraminifera and plant remains) of the Rio Marina Formation suggest a Late Carboniferous-Early Permian age and a littoral-deltaic to neritic depositional environment (DE STEFANI, 1914; BODECHTEL, 1964; KAHLER & KAHLER, 1969; VAI, 1978). Nevertheless, besides a conspicuous number of fossil fauna descriptions, the fossil floras cited by DE STEFANI (1914) (*Asterophyllites* sp., *Annularia stellata* and *Calamites suckowii*) are so scanty, that it is difficult to propose a consistent comparison; neither excavation sites have been recently set up in the Elba Island. On the other hand, the comparison with the floristic data reported from VAI & FRANCAVILLA (1974) regarding the Iano Schists and Sandstones also failed, primarily because of the low number of specimens collected by the authors.

Furthermore, the correlations with the macrofloristic data of the Permian-Carboniferous San Giorgio basin in Sardinia (COCOZZA, 1967; DEL RIO & PITTAU, 2000) are hampered by the low number of plant species. In any case, we tried a comparison between the genera of the De Stefani collection and those of the San Giorgio basin referred by COCOZZA (1967). The comparison was successful for half of the genera reported from the Sardinian area (i.e. the following genera: *Annularia*, *Asterophyllites*, *Calamites*, *Callipteridium*, *Cordaites*, *Pecopteris*, *Walchia*). Microfloristic data reported by DEL RIO & PITTAU (2000) for Sardinia cannot be compared with our material because of the lack of micro-paleontologic studies in the Pisani Mountains area. Some unsuccessful attempts in collecting micro-paleontological data in this area were performed by Prof. M. Tongiorgi (pers. comm.).

CONCLUSIONS

Our preliminary analysis of the paleoflora of the SLS permits to outline some biostratigraphical considerations.

Although the floristic framework of the collection specimens shows Stephanian similarities (see tab. 2 and DOUBINGER, 1956; DOUBINGER *et alii*, 1995; CLEAL, 1991), our data cannot confirm nor contrast the «Autunian age» of the upper part of the SLS (i.e. Sasso Campanaro area) mainly as a consequence of the scarce number of specimens detected in the De Stefani collection for this fossiliferous site (Sasso Campanaro: 32 specimens) and the interference of the taphonomical processes previously discussed. The «Autunian age» of this part of the formation was suggested by TREVISAN (1955), on the basis of the occurrence of *Walchia piniformis* and *Callipteris conferta*, and by RAU & TONGIORGI (1974, 1976) on the basis of lithostratigraphical considerations.

Same difficulties arise in comparing our results concerning the other fossiliferous localities with the biostratigraphical scheme proposed by TREVISAN (1955), because of the lack of some fossil sites cited by the author and the different fossils identified (tab. 1). To give an example, for most of the localities quoted by Trevisan the index fossil are not consistent with our data and some important fossil localities (e.g. the locality Traina/Colletto) have not been taken in consideration by this author.

Moreover, the analysis of the macrofloristic framework related to Villa Massagli is not possible since only one specimen, coming from this fossil location, was found in the De Stefani collection. TREVISAN (1955) on the basis of the presence of Lepidodendrid specimens, ascribed this part of the formation to the Westphalian D.

Finally, since the major drawbacks of the De Stefani's collection concern nomenclatural problems, the ignorance of the sampling methodology and the stratigraphical reliability of the specimens, a complete revision of this material would be desirable. In particular, further investigations and studies should focus on a nomenclatural revision of the new species, particularly the new combinations proposed by DE STEFANI (1901). Dedicated field campaigns should also be necessary for collecting macro- and micro-paleontological data in a more systematic way.

The examination of the De Stefani collection underlines it's museological, historical and geo-paleontological relevance. Since almost all of the species described, and all of the fossil sites cited by DE STEFANI (1901) have been detected in the collection, we can state that the loss of information through time has been very low.

The study and the analysis of this Upper Paleozoic macroflora of the SLS and the new geological survey of the Valle del Guappero type-area offer new data for the paleoenvironmental reconstruction of the Tuscan domain during the Late Carboniferous-Permian.

The relevant biological diversity showed by the fossil macroflora within most of the fossil sites of the Valle del

Guappero area testifies the existence of a probably high environmental stability. We cannot however surely state the presence of deposits related to the Westphalian D at the base of the succession (Villa Massagli), nor the «Autunian age» of its uppermost part (Sasso Campanaro area). The former uncertainty is related to difficulties in comparing the results of our study with the biostratigraphical hypotesis of TREVISAN (1955) and to the extreme paucity of specimens, the latter uncertainty is principally due to taphonomical processes (and also to the small number of specimens).

From a paleoenvironmental point of view, the litostratigraphic and paleontologic data (i.e. the finding of marine invertebrates at Montuolo) of the SLS lead us to define a depositional environment evolving from a coastal plain/neritic environment to a continental fluvial (with local marshy depressions) environment. Furthermore, the increase of the siliciclastic input in the upper part of the formation could be related to the onset of the extensional block faulting due to the Saalian phase at the end of the Variscan orogeny which rejuvened the Upper Paleozoic landscape.

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