Geogr. Fis. Dinam. Quat.
39 (2016). 121-128, 9 figg.
DOI 10.4461/GFDQ.2016.39.11

SIMONA CAFARO (*,**), ERWAN GUEGUEN (*,***), MARIO PARISE (****) & MARCELLO SCHIATTARELLA (*****)

MORPHOMETRIC ANALYSIS OF KARST FEATURES OF THE ALBURNI MTS, SOUTHERN APENNINES, ITALY

ABSTRACT: CAFARO S., GUEGUEN E., PARISE M. & SCHIATTARELLA M., *Morphometric analysis of karst features of the Alburni Mts, Southern Apennines, Italy.* (IT ISSN 0391-9839, 2016)

With more than 250 caves, the Alburni Mts represent one of the most important karst areas of southern Italy. The backbone of this ridge is constituted of Mesozoic-Cenozoic limestone with limited outcrops of Miocene siliciclastic formations and internal shale units, often trapped in elongated downthrown structures. NW-SE- and NE-SW-trending faults with a clear morphological expression are responsible for the genesis of a squared framework of flat-topped ridges and flat-bottomed valleys at the top of the massif.

In an approximate way, the Alburni Mts can be described as a roughly NW-SE-trending monocline, dipping toward the SW, covering an area of about 350 km^2. The fault system has partially disrupted an ancient flat landscape, as testified by the widespread fragments of the southern Apennines late Pliocene - early Pleistocene summit palaeosurface.

This work aims at understanding the role played by tectonic structures on karst development based upon a morphometric analysis. We also try to constrain the age of the karst phenomena using the relationships among morpholineaments, land surfaces, and other morphotectonic markers.

New data, besides confirming the role of the map-scale faults as a controlling factor of the surface and hypogean karst development, also highlight the strong influence of the small-scale faults and pervasive jointing. Further, the presence of different levels of hypogean karst seems to trace the arrangement in several orders of land surfaces, thus suggesting a discontinuous lowering of the (relative) erosion base level due to a multi-phase tectonic uplift.

KEY WORDS: Karst geomorphometry, Palaeosurfaces, Alburni Mts, Southern Italy.

(*) *CNR-IMAA, C.da S. Loja, I-85050 Tito Scalo (PZ), Italy.*
(**) *Gruppo Speleo-Alpinistico Vallo di Diano.*
(***) *Gruppo Speleologico Valle del Melandro.*
(****) *CNR-IRPI, Bari, Via Amendola, 122 I-70126 Bari, Italy.*
(*****) *Dipartimento delle Culture Europee e del Mediterraneo (DiCEM), Università della Basilicata, I-75100 Matera, Italy.*

We sincerely thanks Maurizio del Monte and Jo De Waele for their accurate revision of the manuscript. This study was financially supported by Basilicata University RIL 2015 granted to M. Schiattarella.

RIASSUNTO: CAFARO S., GUEGUEN E., PARISE M. & SCHIATTARELLA M., *Analisi morfometrica delle forme carsiche dei Monti Alburni (Appennino meridionale, Italia).* (IT ISSN 0391-9839, 2016)

I Monti Alburni rappresentano una delle aree carsiche più importanti dell'Italia meridionale. L'ossatura geologica della dorsale è costituita da calcari meso-cenozoici di mare basso, il cui ambito deposizionale è riconducibile alla Piattaforma Campano-Lucana, una delle grandi unità paleogeografiche del margine apulo-africano. Lembi di modesta estensione di unità silicoclastiche mioceniche e di terreni a dominante argillosa di provenienza interna si ritrovano a tetto delle successioni carbonatiche, spesso conservati in stretti corridoi morfologici assimilabili a strutture di tipo graben. L'intera dorsale è in effetti attraversata da famiglie di faglie, anche plurichilometriche, con orientazione NO-SE e NE-SO e chiara espressione morfologica. Queste sono responsabili dello stile morfostrutturale generale della sommità del massiccio, con dorsali minori a sommità spianata e depressioni allungate a fondo piatto o poco ondulato laddove ospitano le unità terrigene. Più in generale, l'intera morfostruttura positiva è controllata da linee perimetrali con gli stessi andamenti sopra ricordati, a costituire un'ampia monoclinale (circa 350 km^2) immergente verso SO di pochi gradi (5-10°). Il sistema di faglie ha disarticolato un ampio lembo di paleosuperficie sommitale di età tardo-pliocenica.

Nel presente lavoro vengono illustrati i risultati di un'analisi morfometrica sul carsismo ipogeo ed epigeo, che ha consentito – unitamente a considerazioni geomorfologiche di più ampio respiro – di mettere in luce i controlli esercitati dalle strutture tettoniche alle diverse scale e di porre vincoli sulla cronologia degli eventi. I dati mostrano che il controllo strutturale è stato esercitato in maniera diffusa anche dal sistema di frattura alla mesoscala, soprattutto sulle forme ipogee. I diversi livelli carsici, infine, sono messi in relazione alle variazioni del livello di base dell'erosione suggerite dall'analisi della distribuzione altimetrica delle paleosuperfici erosionali. Appare probabile che l'abbassamento costante ma discontinuo del livello di base relativo sia il risultato di un sollevamento legato a tettonica polifasica.

TERMINI CHIAVE: Geomorfometria carsica, Paleosuperfici, Monti Alburni, Italia meridionale.

INTRODUCTION

The Alburni Mts constitute an impressive carbonate massif, which occupies about 350 km^2 in the axial zone of the southern Italian Apennines (fig. 1) and is bordered by pronounced scarps ranging in the northern sector, from about 600 m a.s.l. to about 1600 m a.s.l. (the highest elevation of 1742 m a.s.l. is reached at Mt. Alburno). The ridge is surrounded by two major rivers (Calore and Tanagro) and the entire area is included in the National Park of Cilento, Vallo di Diano and Alburni (an UNESCO-supported Geopark). With more than 250 registered caves, the massif is one of the most important kast areas of southern Italy. Many speleological explorations have been carried out here since early '60s (Del Vecchio & *alii,* 2013), but an updated dataset of morphology and architecture of karst caves is still incomplete. Also the surficial features have only been qualitatively described (Brancaccio & *alii*, 1983).

The aim of this work is to reconstruct the morphotectonic evolution of the Alburni carbonate massif combining both surface and underground observations. To this

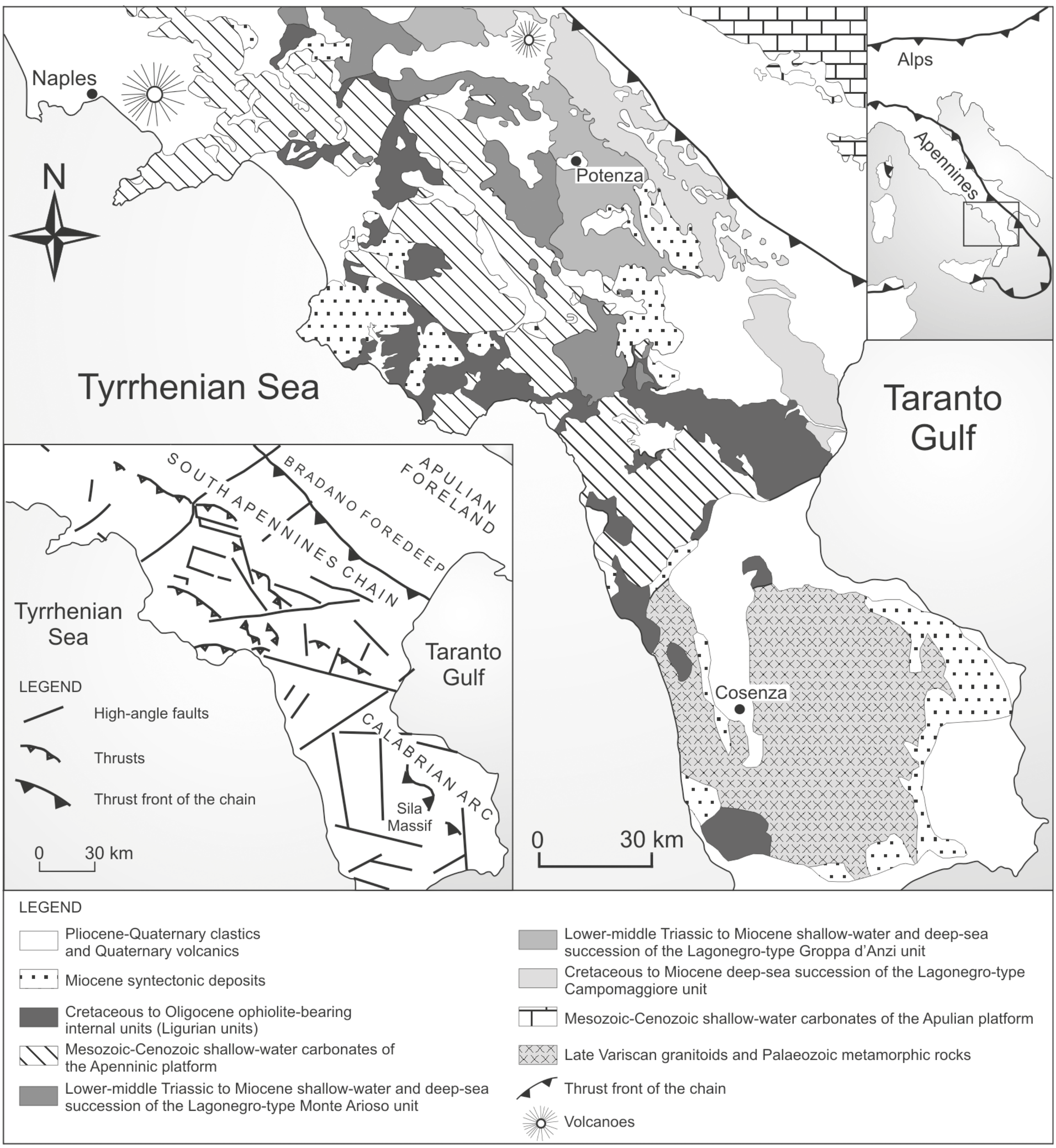

FIG. 1 - Geological sketch map of the southern Apennines. The Alburni Mts are represented in the box. The corresponding structural sketch map reporting the main tectonic features is shown in the inset on the bottom left, regional localization in the inset on the top right (after Martino & *alii,* 2009).

scope, geomorphological mapping of land surface and tectonic lineaments, structural analysis of fault and fracture populations, and morphometric analyses of karst elements have been performed on both mountain- and mesoscopic scales. In fact, such geomorphological features may assume a significant role in assessing the morphological history of a region if related to former erosion base-levels. Further, the full comprehension of the structural control exerted by the multiscale brittle deformation can reveal timing and modalities of karst development and, together with the suggestions from some morphometric indices, may indicate the state of morphological maturity of the relief.

GEOLOGICAL SETTING

The study area is located in the axial zone of the southern Apennines (fig. 1), a north-east verging fold-and-thrust belt derived from the Neogene deformation of the African-Apulian palaeomargin (Patacca & Scandone, 2007, and references therein), tectonically exhumed by low-angle extension and later shaped by regional-scale erosional flat palaeosurfaces, and finally displaced in minor morphostructural blocks by Quaternary high-angle faulting (Schiattarella & *alii*, 2006, and references therein). As a consequence, the orogenic belt was strongly uplifted and fragmented, showing a rough chess pattern of flat-topped ridges and squared intermontane basins, filled by late Pliocene to Holocene marine and continental deposits (Giano & *alii*, 2014).

In a simplified view, the Alburni Mts are a huge NW-SE-trending and SW-dipping monocline made of an about 1500 m thick Mesozoic-Cenozoic succession, mainly formed by shallow-water limestone of the Alburni-Cervati tectonic unit, originating by the palaeogeographic domain of the Campania-Lucania platform (D'Argenio, 1974; D'Argenio & *alii*, 1975; Patacca & Scandone, 2007). The carbonate rocks are locally unconformably covered by Miocene siliciclastic units or tectonically overlain by shaly units of the internal domains, often trapped in elongated half-graben basins.

The massif is largely affected by NW-SE and NE-SW trending faults, but several different sets are also present. Its north-eastern margin coincides with a N120°-striking fault slope, representing the morphological expression of the Alburni Line fault system (Gioia & *alii*, 2011), whereas it is limited to the north-east by a complex fault system linking the Alburni Mts to the Maddalena Mts ridge.

From a geomorphological point of view, unlike the other carbonate massifs of central and southern Apennines, the Alburni Mts show a large plateau at the top of the ridge – although moderately displaced by many faults with moderate offsets – densely pitted by epikarst landforms, in particular dolines (Brancaccio & *alii*, 1983).

STRUCTURAL AND RELICT GEOMORPHOLOGICAL FEATURES

Morpholineaments and fracture system

The morpholineament analysis allowed us, in a previous work (Cafaro & *alii*, 2015), to recognize linear topographic features with a tectonic significance (fig. 2). On the basis of the major tectonic boundaries and of some other characteristics, such as the attitude of the beds and the length of the morpholineaments, the carbonate massif was subdivided into three distinct morphostructural units by Cafaro & *alii* (2015): West-Alburni Block (WAB), East-Alburni Block (EAB), and Mt. Forloso Block (MFB). WAB and EAB are separated by a set of NE-SW trending structures that assume the role of kinematic release. On the northern border, the "Alburni Line", a N120°-striking high-angle listric fault (Gioia & *alii*, 2011), represents the tectonic boundary between the MFB and the other two blocks of the Alburni Mts. Cafaro & *alii* (2015) have compared the tectonic lineaments with morphological expression from the three blocks by using the method proposed by Gioia & Schiattarella (2010) and tested by Gueguen & *alii* (2012), stressing the similarity among the fault orientations, mainly represented by N55°-65° and N120°-130° azimuthal ranges. The massif is also crossed by map-scale and mesoscale N30°±10° and N150°±10°-striking fault sets, surveyed in the field both at the surface and within the caves.

Underground data by Santangelo & Santo (1997) revealed the existence of an E-W trend, maybe representing the oldest brittle deformation, whereas the presence of both N-S and E-W trending faults and fractures has been recorded at the surface in this work (fig. 3). In particular, N-S-striking planes are the most statistically represented. These orientation data have been collected in 8 sample sites, equally distributed in the whole area of the two Alburni morphostructural blocks. For each station, minor faults and fractures inside an area of 1 sq. m have been measured, collecting about 1800 orientation data.

Part of the tectonic structures above listed are responsible for the origin of NW-SE trending troughs in which the Miocene terrigenous deposits are preserved and where the most of the ponors of the massif are located (Santo, 1988).

Palaeosurfaces

The massif top landscape is dominated by remnants of flat or gently undulated erosional land surfaces, generated during periods of base level stability and organized in several orders located at different altitudes. Such geomorphic elements have been investigated through field survey, map analysis, and photo-aerial interpretation (Cafaro & *alii*, 2015). Four orders of palaeosurfaces have been recognized (fig. 2) on the basis of their altitudinal arrangement, geomorphological characteristics, and relationships with different fault sets, in agreement with the regional morphostructural framework (Schiattarella & *alii*, 2003, 2013). The highest land surface S1, in fact, is placed at altitudes higher than 1,100 m a.s.l. and represents the morphological relict of a regional low-relief landscape located at the top of many positive morphostructures, such as the Marzano massif and the Maddalena Mts (respectively to the north and the east of the study area). The S1 surface unconformably cuts both tilted Mesozoic limestones, upper Miocene terrigenous units, and lower-middle Pliocene marine sediments, indicating an age of its genesis not older than the late Pliocene – early Pleistocene transition, as also proved by apatite

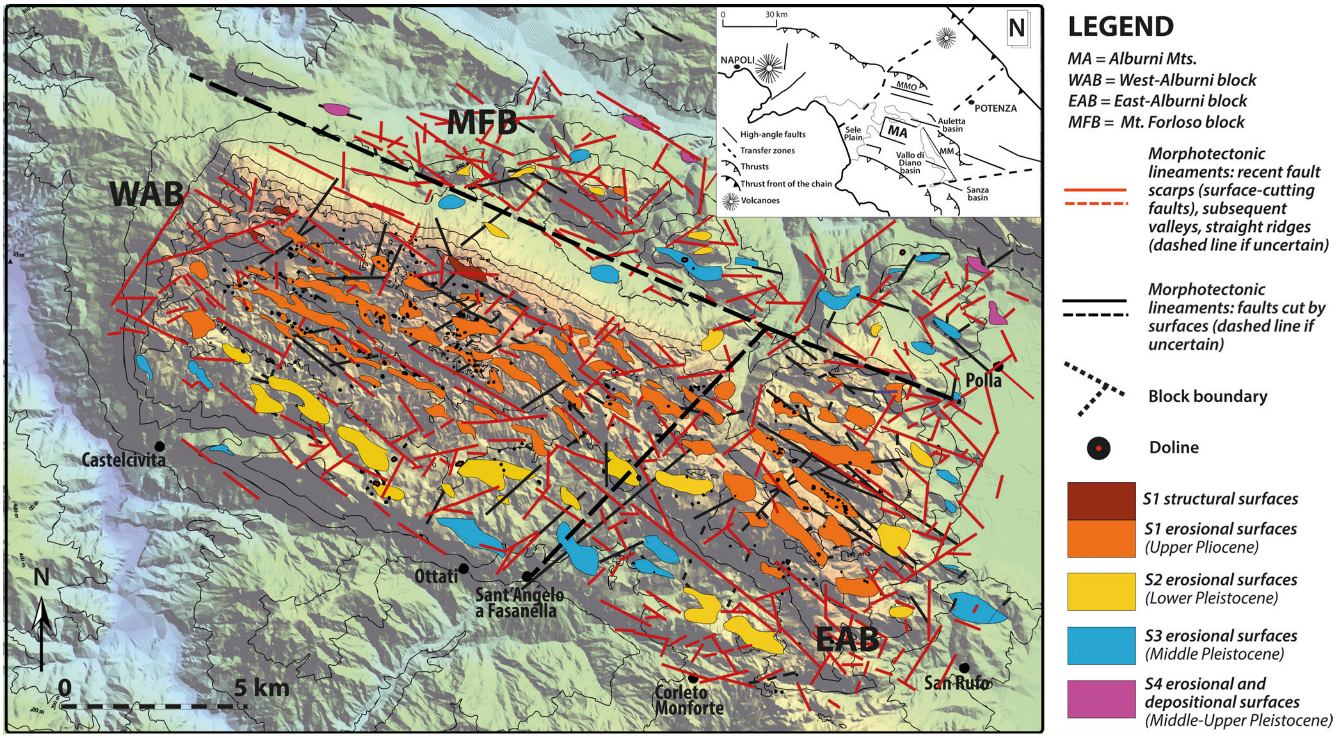

FIG. 2 - Morphostructural map showing several orders of erosional land surfaces and morpholineaments of the Alburni Mts (in the inset structural map of the southern Apennines).

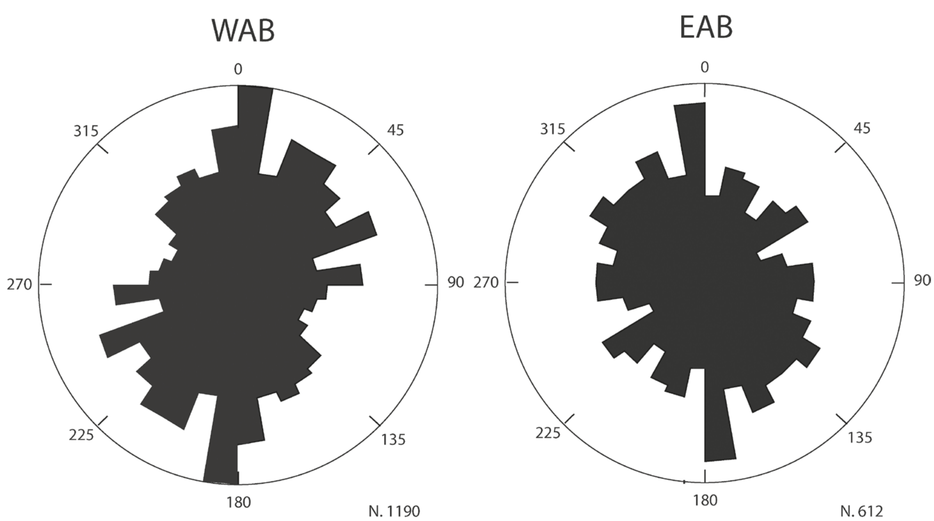

FIG. 3 - Rose diagrams of Azimuthal orientation of faults and fractures in the surface outcrops from WAB and EAB.

fission track data (Schiattarella & *alii*, 2013). E-W and N-S trending faults are truncated by such erosional surfaces and therefore they have to be slightly older than the late Pliocene. The tectonic deactivation of the S1 palaeosurface and also of the younger orders of land surfaces, instead, occurred during the Pleistocene. The previous faulting of an ancient surface older than the S1 land surface, whose presence is locally testified by the highest remnants of a planation landscape, did not produce great offsets, contrarily to what observed for the S1 palaeosurface. In the entire massif, in fact, the latter is correlated to several hundred meters high fault scarp or fault-related slopes with a regularized, sometimes convex, profile.

The S2 surfaces, distributed at about 1,000 m a.s.l., have been shaped starting from the inherited S1 palaeolandscape. In the MFB, within the Petina low, remnants of an erosional landscape correlated to the S2 land surfaces have been carved in both the upper Miocene terrigenous deposits and the lower Pleistocene (Gelasian?-Calabrian) slope deposits (Gioia & *alii*, 2011). Most of the N70°- and N150°-trending tectonic lineaments are cut by the S2 palaeosurfaces, thus appearing early Pleistocene in age (probably older than the Calabrian). The N120°-trending faults displaced the oldest palaeosurfaces and are morphological-

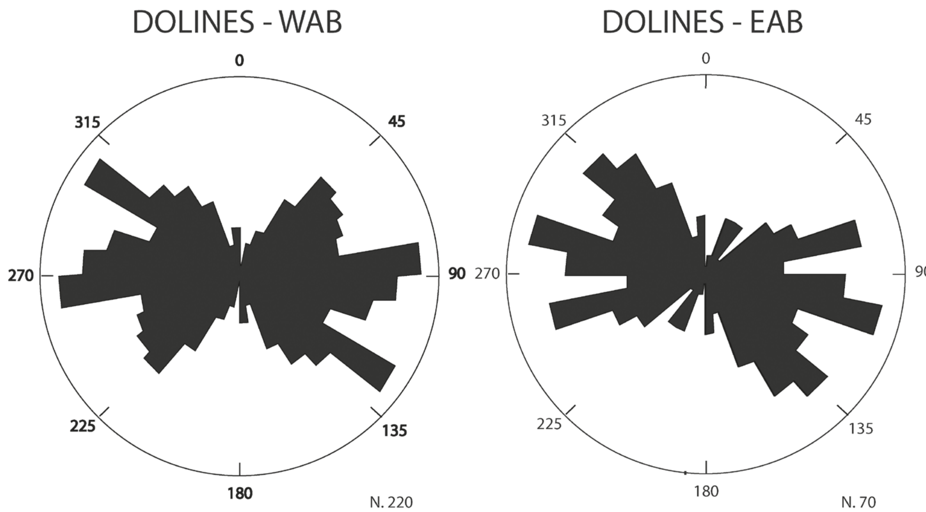

FIG. 4 - Rose diagrams regarding the analysis of the major axis orientations of dolines into WAB and EAB.

ly expressed by fault line scarps, thus suggesting a rather old activity. The Alburni line (Gioia & *alii*, 2011) has the same orientation and bounds the massif as a high-angle master fault, but it shows a younger activity and it is partly responsible for the fast uplift of the whole carbonate ridge.

The S3 erosional surfaces cut the mid-Pleistocene continental deposits, the Miocene terrigenous units, and the Mesozoic limestone, mainly inside the Mt. Forloso block. Their tectonic displacement occurred along the N120°-130° trending lineaments. Finally, the S4 erosional surfaces are arranged at the average altitude of about 400 m a.s.l. in the northern sector of the MFB and are suspended on the present-day valley floors.

GEOMORPHOMETRY

Epigean karst

The Alburni Mts landscape offers the possibility to perform statistical analysis on dolines, the main surface karst features that characterize the S1 palaeosurface. It is well known that karst landforms, both epigean and hypogean, are more or less controlled by geological structures (Lauritzen, 1989; Palmer, 1991; Klimchouk & Ford, 2000; Sebela, 2003; Basso & *alii*, 2013; Parise, 2014; Pepe & Parise, 2014).

The morphometric parameters of 220 dolines mapped inside the WAB and 70 dolines inside the EAB allowed us to make a quantitative analysis and to provide information on structural controls on their genesis and evolution. Such parameters have been proposed by several authors during the first half of the last century (i.e. Gortani, 1908; Cramer, 1941; Segre, 1948) and partly revised in Bondesan & *alii* (1992) and Sauro (2003, 2005). To determine possible structural controls we used the eccentricity parameter (ratio between maximum and minimum axis). The different eccentricity degrees enabled us to divide the surveyed dolines in different classes (Brunamonte & *alii*, 1994). The analysis of the whole population of dolines in the WAB showed that most of them have a shape varying from elliptical (58%) to ellipsoidal (32%). Inside the EAB there are sub-circular (37%), ellipsoidal (44%), and elliptical dolines (18%). In both the morphostructural blocks we carried out the analysis of the major axis orientations, represented in the rose diagrams of figure 4. The diagrams showed the existence of three preferential trends in both sectors: N90°-100°, N115°-135°, and N50°-60°. The first trend follows a fracture set observed in the field, whereas the other two trends are in agreement with the main morpholineaments of the Alburni massif. Therefore, it seems clear that the development of dolines has been originally influenced by one of the oldest tectonic features (i.e. the E-W-striking faults) and only later by the other ones.

In order to determine a relative chronology of the epigean elements, the shape parameter was defined for part of the features, computing the ratio between average diameter length and the depth of dolines with a diameter up to 30 m (fig. 5), since the major ones are the oldest. This has revealed a appreciable difference in morphology and size between the dolines inside the two morphostructural blocks. In the western side (WAB) the dolines have greater dimensions and mostly show bowl (39%), conical (37%) and flat-bottomed (24%) morphology, whilst in eastern area (EAB) the dolines show less than 10 m-long major axes and their concentration is shifted in the cylindrical and conical classes. Inside the same carbonate massif, this morphological diversity could be related to the maturity degree of the two subareas: in the WAB, in fact, the relevant presence of flat-bottomed dolines and their greater size might suggest a longer exposure time to karst shaping than in the eastern area, where other forms prevail. In other words, the exhumation processes (i.e. the erosion of terrigenous covers) seems to be started before in the western area.

In the north-western portion of the summit palaeosurface (S1), at about 1450 m a.s.l. we recognized a particular karst landform identified as roofless cave or unroofed cave (Mihevc & *alii*, 1998; Knez & Slabe, 2001), partially transformed by surface processes (fig. 6). Along the walls of the roofless caves, sub-horizontal grooves are clearly visible in the entire area in which this karst system extends, testifying a phase of water table stationing. It can be interpreted as a past karst level genetically linked to the most ancient erosion base level, and other examples of notch-like landforms can

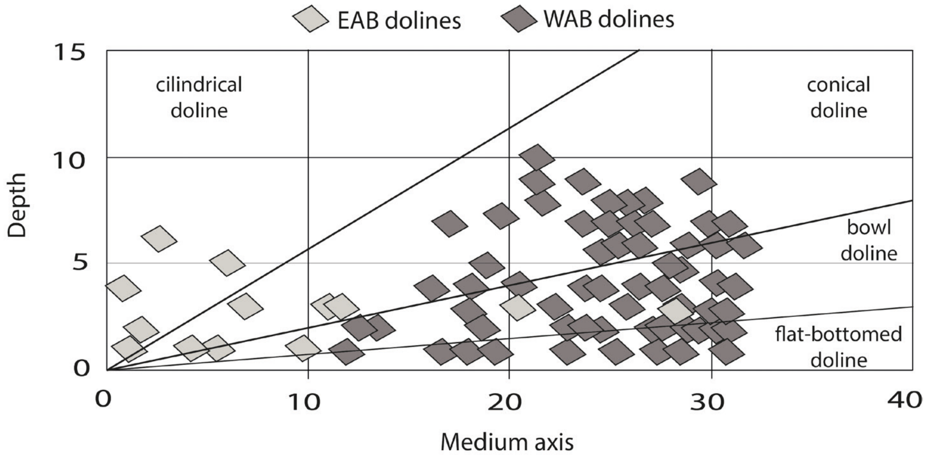

FIG. 5 - Shape diagram of dolines computing the ratio between average diameters length and the depth of dolines.

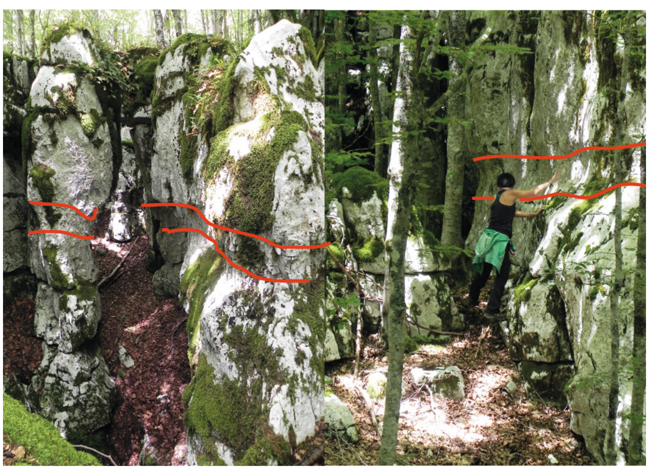

FIG. 6 - Roofless cave in the WAB. Red lines indicate the notches along their walls.

FIG. 7 - Example of notch-like landform recognized in the Rifugio Panormo area, at about 1400 m a.s.l., not far from the roofless cave of figure 6.

be recognized in the area at the same altitude (fig. 7). Further, horizontal karst caves with a small extension (called Grotta Palombello and Grotta Malacera) have been carved in the sub-horizontal beds of the WAB (at about 1450-1475 m a.s.l.), here affected by intense fracturing (fig. 8).

Hypogean karst

The Alburni Mts are well known for the presence of intense hypogean karst phenomena. Until now, the speleologists have recorded more than 250 karst cavities, archived into the Campania speleological cadastre (Del Vecchio, 2005). The geological structure defines the network of lithological discontinuities (bedding planes, tectonic joints, and faults), which represent the potential ways for the underground water flow and have mainly a passive role (Dreybrodt & Siemers, 2000; Klimchouk & Ford, 2000). The hydrological setting is the main factor having an active role, which can abruptly change during the evolution of a cave as a consequence of morphological and/or climate modifications (Piccini, 2011).

Many studies showed a clear correlation between cave

FIG. 8 - Grotta Malacera and Grotta Palombello located at 1450 m a.s.l.

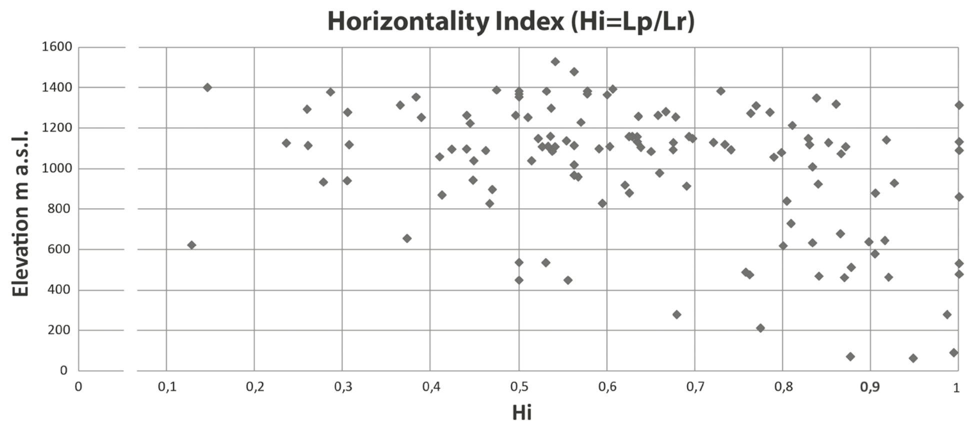

FIG. 9 - Horizontality index (Hi) calculated for the caves of the Alburni Mts (after Cafaro & *alii*, 2015).

passages and the fracture system (Deike 1969; Hauselmann & *alii*, 1999; Sauro & Zampieri, 2001; Gueguen & *alii*, 2012). The analysis of the planimetric arrangement of the cave passages can easily permit us to recognize the role of vertical or subvertical mechanical discontinuities, such as fractures or faults. Klimchouk & Ford (2000) indicate four indices as the most indicative to characterize the amplitude of karst development. The morphometric analysis of caves was made by acquiring in the field dimensional parameters concerning vertical or horizontal development, following the procedure defined by Piccini (2011). Data about the horizontality index (Hi) have been used to get some morphometric information. This index is expressed by the ratio between total length of the plan view (all cave passages) and the real development of the cave (Hi = Lp / Lr) and theoretically ranges from 1 to zero. If compared to geological field data, it can help us to understand the different effects on the genesis and evolution of karst caves produced by structural control.

The statistical analysis performed on the karst caves of the Alburni Mts (Cafaro & *alii*, 2015) showed that Hi values (fig. 9) are mostly comprised between 0.5 and 1, so indicating the presence of caves with a horizontal pattern at different elevations. This suggests that different karst levels could have been related to base level changes over the time. The most important caves that could be correlated to uplift stages (i.e. to a sensitive lowering of the base level of erosion) are Grotta del Falco (EAB), Grava del Fumo (WAB), and Inghiottitoio III dei Piani di Santa Maria (WAB).

FINAL REMARKS

The development of the hypogean and epigean karst features of the massif has been driven by different tectonic structures at different scales. The azimuthal analysis of the tectonic morpholineaments of the Alburni Mts showed the existence of several sets of brittle structures, which allowed us to divide the massif in three morphostructural blocks (Cafaro & *alii*, 2015). Such data, besides confirming the role of the map-scale faults as a control factor of the surface and hypogean karst development, also highlight the strong influence of the small-scale faults and pervasive jointing. The analysis of the brittle deformation actually showed the presence of less evident N-S and E-W trending faults and fractures, the oldest of the area. These structural elements have controlled the development of the epigean karst. Further, a different maturity degree has been highlighted by the doline-shape analysis.

Two relevant karst features have been observed at the same altitudes (roofless caves and sub-horizontal caves) as an evidence of an ancient base level. The Alburni Mts hypogean karst system is characterized by some active caves with a prevailing horizontal pattern at different altitudes that could be associated to several phases of uplift or to base level changes.

The recognition of four orders of palaeosurfaces, to which the karst levels are related, and the cross-cut relationships between karst and tectonic features enabled us to reconstruct the uplift stages of the carbonate massif during Pliocene-Pleistocene times. As a matter of fact, the presence of different levels of hypogean karst seems to trace the arrangement in several orders of land surfaces, so suggesting a discontinuous lowering of the (relative) erosion base level due to a multi-phase tectonic uplift.

REFERENCES

BASSO A., BRUNO E., PARISE M. & PEPE M. (2013) - *Morphometric analysis of sinkholes in a karst coastal area of southern Apulia (Italy).* Environmental Earth Sciences, 70 (6), 2545-2559.

BELISARIO F., DEL MONTE M., FREDI P., FUNICIELLO R., LUPIA PALMIERI E. & SALVINI F. (1999) - *Azimuthal analysis of stream orientations to define regional tectonic lines*. Zeitschrift für Geomorphologie, Suppl.-Bd, 118, 41-63.

BONDESAN A., MENEGHEL M. & SAURO U. (1992) – *Morphometric analysis of dolines.* International Journal of Speleology, 21, 1-55.

BRANCACCIO L., CINQUE A. & SGROSSO I. (1983) – *Brevi considerazioni sul carsismo e il paleocarsismo dell'Appennino Campano-Lucano*. Notiziario Sezionale Napoli, CAI, 1, 49-50.

BRUNAMONTE F., PRESTININZI A. & ROMAGNOLI C. (1994) - *Geomorfologia e caratteri geotecnici dei depositi di terre rosse nelle aree carsiche degli Aurunci orientali (Lazio meridionale, Italia).* Geologica Romana, 30, 465-478.

Cafaro S., Gueguen E., Parise M. & Schiattarella M. (2015) - *Relazioni tra assetto morfostrutturale e carsismo ipogeo dei Monti Alburni (Campania): risultati preliminari*. In: De Nitto L., Maurano F., Parise M. (a cura di), Atti XXII Congresso Nazionale di Speleologia – Euro Speleo Forum 2015 "Condividere i dati", 30/05/2015 - 02/06/2015, Pertosa - Auletta (SA), Memorie dell'Istituto Italiano di Speleologia, Serie II, 29, 289-294.

Cramer H. (1941) - *Die Systematik der Karstdolinen*. Neues Jahrhbuch f*ü*r Mineralogie Geologie und Pälaontologie, 85, 293-382.

D'Argenio B. (1974) - *Le piattaforme carbonatiche periadriatiche. Una rassegna di problemi nel quadro geodinamico mesozoico dell'area mediterranea*. Memorie Società Geologica Italiana, 13 (2), 137–160.

D'Argenio B., Pescatore T. & Scandone P. (1975) – *Structural pattern of the Campania-Lucania Apennines.* In: Ogniben L., Parrotto M., Praturlon A. (eds). Structural model of Italy, Maps and explanatory notes, CNR – Quaderni della Ricerca Scientifica, 90, 313-327.

Deike G. H. (1969) - *Relations of jointing to orientation of solution cavities of Central Pennsylvania.* American Journal of Science, 267, 1230-1248.

Del Vecchio U. (2005) – *Il Catasto delle Grotte della Campania*. In: Grotte e speleologia della Campania. Atlante delle cavità naturali. Ed. Elio SellinoEditore. 549-563.

Del Vecchio U., Lo Mastro F., Maurano F., Parise M. & Santo A. (2013) - *The Alburni Massif, the most important karst area of southern Italy: history of cave explorations and recent developments.* In: Filippi M. & Bosak P. (eds.), Proceedings 16th International Congress of Speleology, Brno, 21-28 July 2013, 1, 41-46.

Dreybrodt W. & Siemers J. (2000) - *Cave evolution on two-dimensional networks of primary fractures in limestone*, In: Klimchouk A.B., Ford D.C., Palmer A.N., Dreybrodt W. (eds.), Speleogenesis, National Speleological Society. Evolution of Karst Aquifers. National Speleological Society, Huntsville, Alabama, 201-211.

Giano S.I., Gioia D. & Schiattarella M. (2014) - *Morphotectonic evolution of connected intermontane basins from the southern Apennines, Italy: the legacy of the pre-existing structurally controlled landscape.* Rendiconti Accademia Nazionale dei Lincei., 25, suppl. 2, 241-252.

Gioia D. & Schiattarella M. (2010) - *An alternative method of azimuthal data analysis to improve the study of relationships between tectonics and drainage networks: examples from southern Italy.* Zeitschrift für Geomorphologie, 54 (2), 225-241.

Gioia D., Schiattarella M., Mattei M. & Nico G. (2011) – *Quantitative morphotectonics of the Pliocene to Quaternary Auletta basin, southern Italy.* Geomorphology, 134, 326-343.

Gortani M. (1908) – *Appunti per una classificazione delle doline.* Mondo sotterraneo, 4 (6), 115-116.

Gueguen E., Cafaro S., Schiattarella M. & Parise M. (2012) - *A new methodology for the analysis of morpho-structural data of karstic caves in the Alburni Mountains of southern Italy.* Rendiconti online della Società Geologica Italiana , 21, 614-616.

Häuselmann P., Jeannin P.Y. & Bitterli T. (1999) - *Relationships between karst and tectonics: case-study of the cave system Northof Lake Thun (Bern, Switzerland*). Geodinamica Acta, 12, 6, 377-387.

Klimchouk A. & Ford D. (2000) - *Lithologic and structural controls of dissolutional cave development.* In: Klimchouk A.B., Ford D.C., Palmer A.N., Dreybrodt W. (eds.), Speleogenesis. Evolution of Karst Aquifers, National Speleological Society, Huntsville, Alabama, 54-64.

Knez M. & Slabe T. (2001) - *Unroofed caves are an important feature of karst surfaces: examples from the classical Karst*. Zeitschrift für Geomorphologie , 42-46.

Lauritzen S.E. (1989) - *Fracture control of caves in marble in Norway.* Cave Science, 16 (3), 114.

Martino C., Nico G., Schiattarella M. (2009) - *Quantitative analysis of InSAR digital elevation models for identification of areas with different tectonic activities in southern Italy.* Earth Surface Processes and Landforms 34, 3-15.

Mihevc A., Slabe T. & Šebela S. (1998) - *Denuded caves*. Acta Carsologica 27 (1), 165-174.

Palmer A.N. (1991) – *Origin and morphology of limestone caves*. Geological Society of America Bulletin, 103, 1-25.

Parise M. (2014) - *No limits, no boundaries: a view of karst as the typical transboundary environment*. In: Kukuric N., Stevanovic Z. & Kresic N. (Eds.), Proc. Int. Conf. and Field Seminar "Karst without boundaries", 11-15 June 2014, Trebinje – Dubrovnik (Bosnia & Herzegovina – Croatia), 392-397.

Patacca E. & Scandone P. (2007) – *Geology of the Southern Apennines*. Bollettino della Società Geologica Italiana (Italian Journal of Geosciences), Special Issue No. 7, 75-119.

Pepe M. & Parise M. (2014) – *Structural control on development of karst landscape in the Salento Peninsula (Apulia, SE Italy*). Acta Carsologica 43 (1), 101-114.

Piccini L. (2011) - *Recent developments on morphometric analysis of karst caves.* Acta Carsologica, 40 (1), 43-52.

Santangelo N. & Santo A. (1997) - *Endokarst processes in the Alburni massif (Campania, Southern Italy): evolution of ponors and hydrogeological implications*. Zeitschrift für Geomorphologie, 41 (2), 229-247.

Santo A. (1988) - *Alcune osservazioni sul carsismo ipogeo dei Monti Alburni.* L'Appennino Meridionale, Annuario del CAI, Sez. di Napoli, 71-88.

Sauro U. (2003) – *Aspetti evolutivi del paesaggio carsico nei gessi in Italia*. In: Madonia G., Forti P. (eds.), Le aree carsiche gessose d'Italia. Memorie dell'Istituto Italiano di Speleologia 2, 14, 41-45.

Sauro U. (2005) – *Closed depressions*. In: Culver D.C. & White W.B. (eds.), Encyclopedia of Caves. Elsevier, Amsterdam, 108-127.

Sauro U. & Zampieri D. (2001) - *Evidence of recent surface faulting and surface rupture in the Fore-Alps of Veneto and Trentino (NE Italy).* Geomorphology, 40, 169-184.

Sebela S. (2003) - *The use of structural geological terms and their importance for karst caves.* Acta Carsologica, 32, 53-64.

Segre A.G. (1948) - *I fenomeni carsici e la speleologia nel Lazio*. Pubblicazione Istituto di Geografia dell'Università di Roma, 239 pp.

Schiattarella M., Di Leo P., Beneduce P. & Giano S.I. (2003) - *Quaternary uplift vs tectonic loading: a case-study from the Lucanian Apennine, southern Italy.* Quaternary International, 101-102, 239-251.

Schiattarella M., Di Leo P., Beneduce P., Giano S.I. & Martino C. (2006) – *Tectonically driven exhumation of a young orogen: An example from the southern Apennines, Italy.* In: Willett S.D., Hovius N., Brandon M.T. & Fisher D.M. (eds.), Tectonics, climate, and landscape evolution, Geological Society of America Special Paper 398, Penrose Conference Series, 371-385.

Schiattarella M., Giano S.I., Gioia D., Martino C. & Nico G. (2013) – *Age and statistical properties of the summit palaeosurface of southern Italy.* Geografia Fisica e Dinamica Quaternaria, 36, 289-302.

Wise D.U., Funiciello R., Parotto M., Salvini F. (1985) - *Topographic lineament swarms: clues to their origin from domain analysis of Italy.* Geological Society of America Bulletin, 96, 952-967.

(Ms. received 1 June 2016; accepted 30 November 2016)