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ANTONINO IETTO (*) & FABIO IETTO (*)

AGE AND HISTORY OF THE WEATHERING OF GRANITOIDS IN SOUTHERN CALABRIA (ITALY)

ABSTRACT: IETTO A. & IETTO F., *Age and history of the weathering of granitoids in southern Calabria (Italy)*. (IT ISSN 1724-4757, 2004).

The main outcrops of granitoid rock in the Italian peninsula are to be found in Calabria or, to be more precise, in Southern Calabria. The literature which, up to now, has studied the weathering process of these rocks, even though limited to the Serre mountains, has always implicitly or explicitly stated that these occurred in an environment with a «Mediterranean climate» and, consequently, during the Pleistocene, taking into account the climatic variations of this period. This assumption is the basis from which the various stages of maturity of these processes have been studied area by area, adopting the classic methods of analysis or proposing some new techniques.

Our recent studies enable us to state that the beginning of the weathering process in Calabrian granitoids dates back at least to the pre-Tortonian and that the present outcrops of granitic alterithes are the erosive residual of more ancient mantles. Consequently, the degree of maturity that can now be observed in different outcrops depends essentially on the extent of the superficial erosive processes.

The stratigrafic columns do not show the degree of maturity that the weathering has reached but the immaturity of the deepest levels of the more ancient mantles that progressively emerge. The areas with more mature alterith outcrops are, however, those which are more protected from the erosive stripping. In the two principal mountain chains of southern Calabria it can be observed that:

a) on the promontory of Mt. Poro, between Vibo Valentia and Tropea, the granitoids are covered by Tortonian transgressive sediments made up of very fossiliferous sandstones and calcarenites. The basic conglomerate elements are all in an advanced phase of spheroidal weathering;
b) in the Serre mountains, the granitoids do not have a sedimentary covering and so it can be supposed that their continental outcrops have never been interrupted from the Miocene to today. Also here, the weathering mantles are the thickest to be found in the whole of Calabria (up to 40-45 m). The Pleistocene uplift of the mountain chain has been estimated to be of about 0,6-0,8mm/year on average. At the same time an intensity of 800-1000 tn/km^2 is estimated for the erosive stripping.

Therefore, the weathering of Calabrian granitoids was already mature in the Miocene.

KEY WORDS: Weathering; Granitoids; Grus; Miocene, Calabria (Italy).

(*) *Dipartimento di Scienze della Terra, University of Calabria.*
e-mail: iettoa@unical.it

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Nella Calabria ed in particolare nella Calabria meridionale (M.te Poro e Montagne delle Serre) si hanno i maggiori affioramenti di rocce granitoidi di tutta l'Italia peninsulare. La letteratura che fin'ora ha studiato i processi di weathering di queste rocce, sia pure limitata ai rilievi delle Serre, ha sempre sottinteso o affermato che l'alterazione si sia sviluppata in ambiente con «clima mediterraneo» e di conseguenza entro un intervallo temporale racchiuso nel Pleistocene, pur con le sue variazioni climatiche. Con questa assunzione di base sono stati cercati e studiati, finora, i vari stadi di maturità dei processi adottando le metodiche classiche di analisi o proponendone di nuove.

Nostri recenti studi consentono di affermare invece che l'inizio dei processi di *weathering* dei granitoidi calabresi va riportato al minimo a tempi pre-tortoniani e che gli attuali affioramenti delle alteriti granitiche sono il residuo erosivo delle più antiche coperture. Di conseguenza, il grado di maturità che attualmente si rileva sui diversi affioramenti dipende essenzialmente dalla profondità alla quale si spingono i processi erosivi superficiali.

Nelle colonne stratigrafiche di analisi non è la maturità del *weathering* che cresce ma è l'immaturità del *weathering* che via via emerge. Le aree con affioramenti di alteriti più mature sono quindi le aree più protette dal denudamento erosivo. Nei due sistemi montuosi principali della Calabria meridionale (M.te Poro e Montagne delle Serre) si rileva:

a) Nel promontorio del M.te Poro, tra Vibo Valentia, Tropea e Joppolo i granitoidi sono sormontati da una trasgressione miocenica di calcari e arenarie riccamente fossiliferi (*Pecten*, *Ostrea*, *Clipeaster*, *Cancer*, *Terebratula*, etc.). Il conglomerato di base, bene affiorante oggi a livello mare e quindi di recentissima emersione, ha esclusivamente clasti formati da grossi blocchi arrotondati di granitoidi quasi tutti già in fase avanzata di zonazione concentrica per weathering. In altre zone della stessa area la trasgressione miocenica sormonta protoliti granitici fortemente disgregati e ossidati o perfino regoliti granitiche poco elaborate, spesse fino a 8-10 m.
b) Nelle montagne delle Serre i granitoidi sono ricoperti dalla trasgressione neogenica fino alle quote dei 700 m. Alle quote più alte e fino alla sommità dei 1400 m non hanno coperture sedimentarie per cui si suppone, in accordo con la letteratura, che la loro continentalità non si sia mai interrotta dal Miocene a oggi. Nelle Serre, inoltre, le coltri di weathering (grus) raggiungono gli spessori maggiori di tutta la Calabria (fino a 40-45 m). Il sollevamento pleistocenico del sistema montuoso viene stimato dell'ordine medio di 0,6-0,8 mm/anno cui si associa, oggi, una intensità del denudamento erosivo di un ordine non inferiore a 1000 tn/km^2.

In definitiva resta accertato che il weathering dei granitoidi calabresi è già ben maturo nel Miocene e che il suo inizio resta collocato, come limite cronologico ultimo, al Tortoniano e, come limite cronologico più antico, alla loro prima emersione dopo la messa in posto dell'Arco Calabro.

TERMINI CHIAVE: Weathering; Granitoidi; Grus; Miocene, Calabria.

INTRODUCTION

The largest outcroppings of granitoid rocks in the whole of Italy are found in Calabria, and in particular in the south of Calabria (Monte Poro and the Serra Mountains). The consensus in the recent geological literature is that these rocks constitute the highest tectonic units of the orogene Arco Calabro (Amodio Morelli & *alii*, 1976), covered in places by post-orogene Miocene transgressive sediments (Nicotera, 1959).

Between the Tyrrhenian and the Ionic sea, the granitoids are constantly found from the Poro promontory, the Mesima valley and the Serra Mountains as far as the Catanzaro coast at Soverato and, in all these places, they form the basic outcropping element of different stratigraphic sequences. The granite substratum and transgressive sediments are particularly well exposed at Mount Poro (from Vibo Valentia to Briatico, Tropea, Joppolo) along the Mesima valley and the Serre Mountains up until 700m above sea level. Above this and up to 1400 m. the granitoids of the Serre are without sedimentary cover, and for this reason they might have emerged since the late Miocene (Ghisetti, 1980).

In the more widespread and exposed outcroppings, and especially in the Serra above 700 m, the granitoids are found in a greatly altered state, even to the extent of being decomposed into highly compacted sand (angle of attrition from 35-36 to 40-42 degrees) mixed, to a greater or lesser extent, with silt and clay. These altered formations, whose similarity in structure to their mother rock origin become more recognisable at depth, are attributed to subaereal weathering processes and are termed saprolite or «grus» (Migon & Thomas, 2002). Their different aspects «geo-technical, geomorphic, mineralogical and geo-chemical» have been the subject of studies in southern Calabria over the last 40 years (Ietto 1969, 1976; Guzzetta, 1974; Moresi, 1987; Mongelli & Moresi, 1987; Mongelli, 1993; Calcaterra & *alii*, 1993; Mongelli & *alii*, 1996; Lepera & Sorriso-Valvo, 2000; Ietto & *alii*, 2002).

As regards the mineralogical and geo-chemical aspects of weathering in particular, the literature has always held, implicitly or explicitly, that alteration has developed in an environment with a Mediterranean climate, and consequently within the Pleistocene time span, albeit with its climatic variations. Based on this assumption, the various stages of maturity have been identified and studied area by area, not only through the use of classic analytical methods, but also through new techniques, proposed by the researchers.

DATA ON WEATHERING MANTLES

In the following section, the most relevant results of our research will be explained, with particular reference to the principal theme in question. The data has been collected through different means: field analysis, drillings, geophysical and hydrological investigations, tunnelling, laboratory analysis, direct geo-mechanics utilising the Schmitt hammer and scissometer.

As indicated earlier, the granitoids in southern Calabria are generally found in two principal conditions:

– granitoids underlying transgressive Miocene sediments, the most notable outcroppings of which are found on the Tyrrenian slopes of Monte Poro;
– granitoids of the Serre mountains above 700 m a.s.l., which according to the relevant literature, have been emerging since the Miocene age.

The next section will deal with the two conditions separately.

The Serre Mountains

Data from boreholes made in 3 zones considered to be representative of the whole area: Cardinale, Fabrizia, Lacina (stations 1, 2, 3 of fig. 1) indicate that the maximum thickness of the layers of decomposed granitoids are in the order of 40-45 m. These values are taken between ground level and the depth at which the drilling found a first significant interval (at least 3-4 m) with the rock having a RQD of at least 25%. The columns in fig. 2 are measured

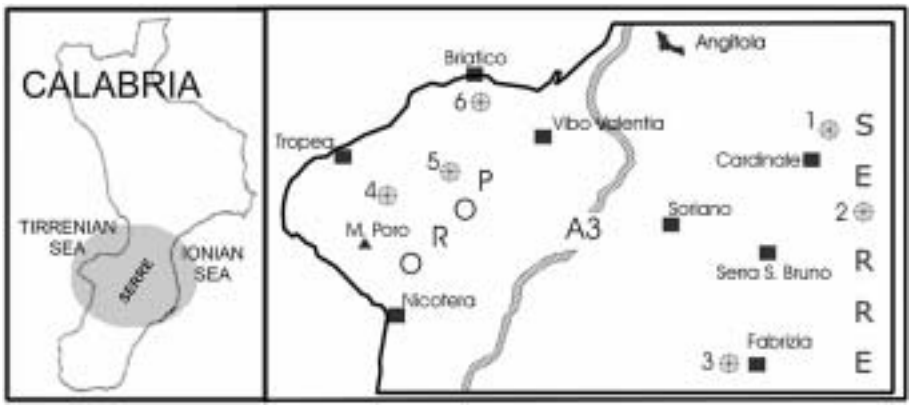

FIG. 1 - Study area and quoted localities (⊕).

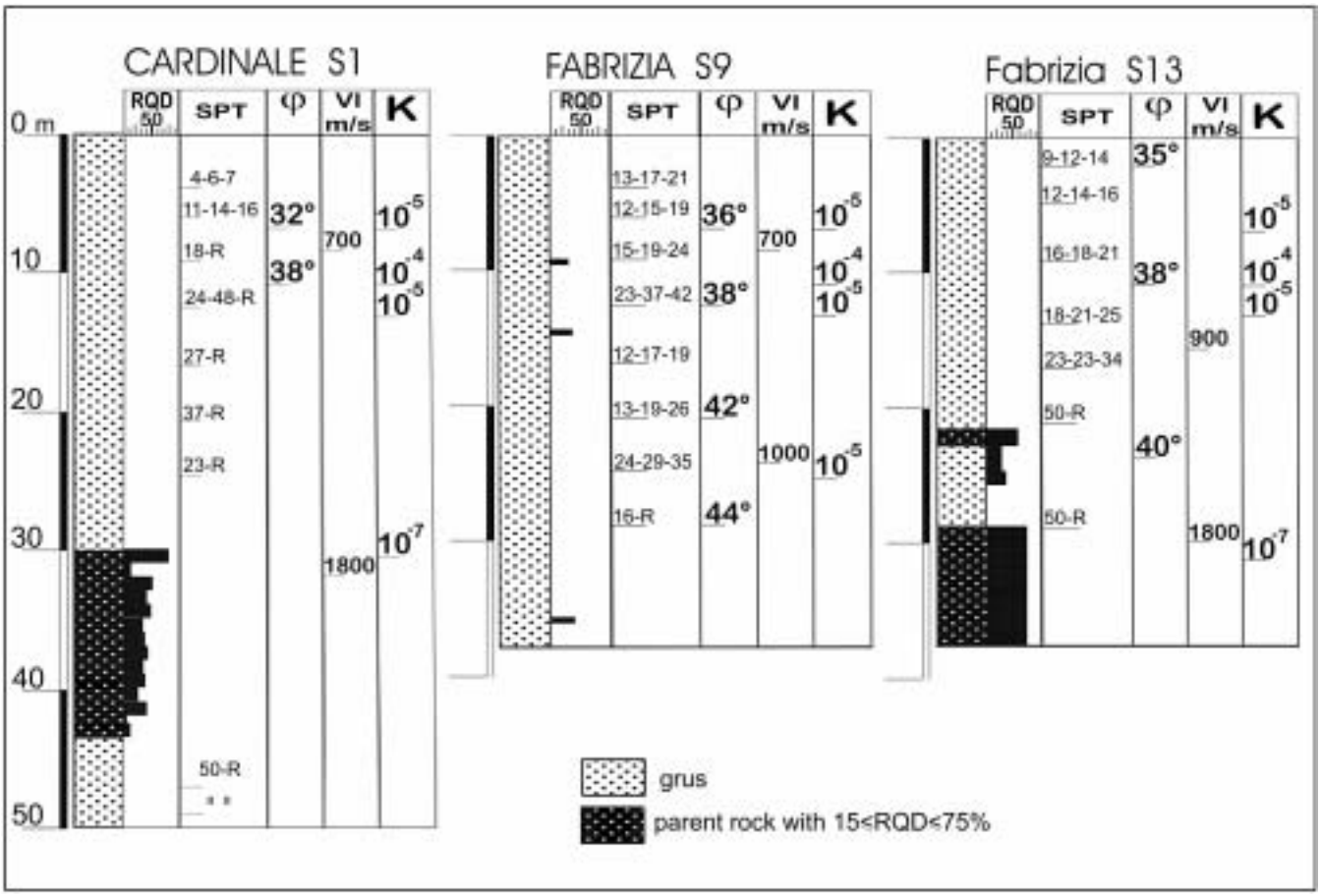

FIG. 2 - Some stratigraphical columns of weathering mantles of the Serre granitoids.

without the thickness of the soils, they go through the same saprolite and do not show evidence of landslides or colluvial contributions.

In the set of columns examined (over 50) the altered mantles have a minimum thickness of 13-14 m even at points very close to those with maximum thickness and with the same ground level (fig. 3). The same interval between minimum and maximum thickness is generally also found by different measurements obtained in the field at exposed sections through the use of the Schmitt hammer. In this survey, rebound echo measurements of a value of not more than 15 were assumed to correspond to grus, in other words to belong to the IV-VI groups in the 1979 IAEG classification (Lee & De Freitas, 1989).

The data from the measurements reported above agree with seismic refraction investigations, which point out a velocity of at least 900-1000 m/sec as representative of the saprolite, in different stages of disaggregation. This limit in seismic velocity is confirmed by bore measurements of the permeability, which usually have values of $K>10^{-5}$, for as long as one remains in the grus ($V_L<1000$ m/sec) permeable due to porosity. The value for K, however, changes rapidly to become $K<10^{-5}$ when speeds increase to over 1500m/sec and where the uniformly porous rock changes to one of mixed permeability deriving from porosity and fissures.

The change with increasing depth between saprolite and rock is, as one would expect, not sudden but gradual. This, however, takes place within quite a narrow range as is clearly shown by the jumps in seismic velocity as well as by the observations in the field. Nevertheless, the physical limits show substantial convergence through a number of different evaluations, and therefore it can be assumed that the estimate of thicknesses proposed for the saprolite of the granitoids is representative. Finally, the digging of a 4 kilometre tunnel across the high ground of the Serre, at a maximum distance of approximately 200m from the surface confirms both the evidence obtained in the field and the measurements derived from the equipment (Calcaterra & *alii*, 1993).

Monte Poro

The only data available, as regards the granitoids on Monte Poro, come from observations made in the field

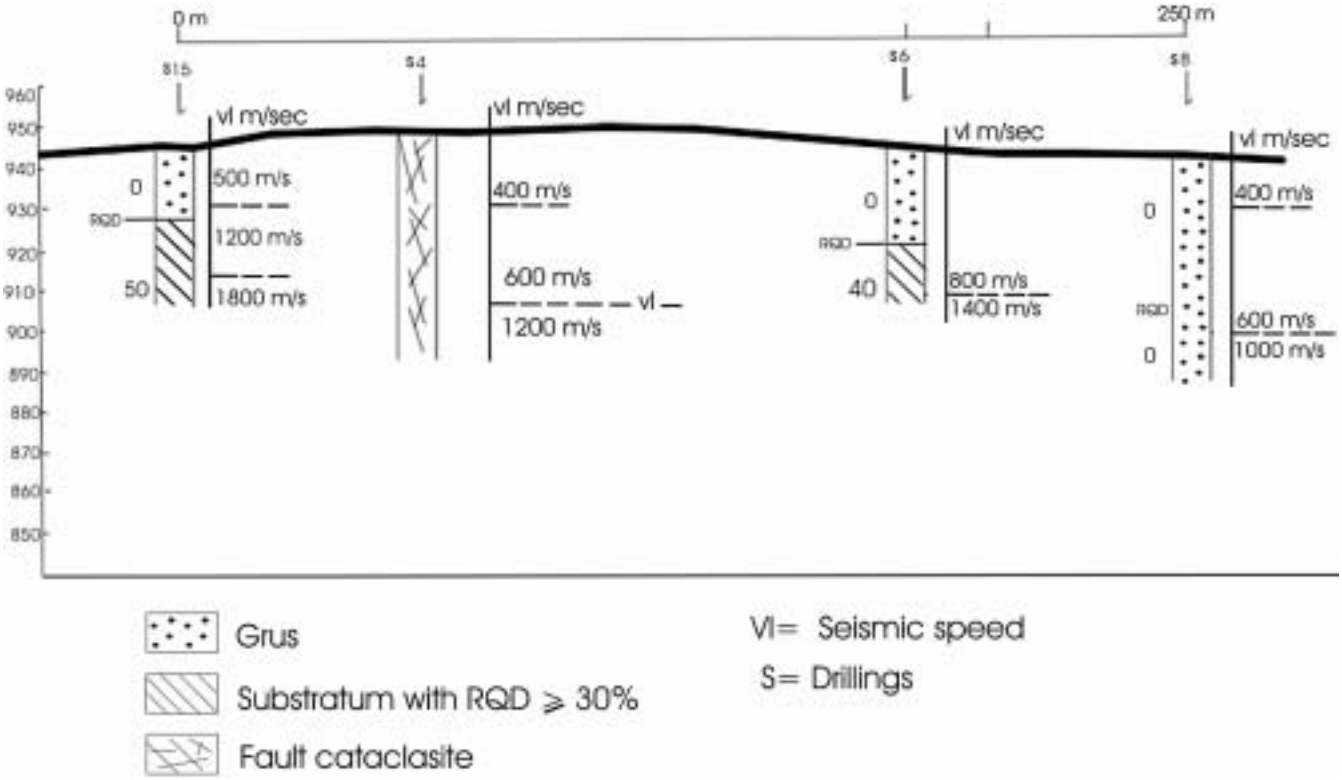

FIG. 3 - Fabrizia: Neotectonic control of the variation of the weathering thickness for brought closer points (section in scale).

and Schmitt hammer measurements. Here, however, as regards the work in hand, the granitoids sealed by Miocene transgression show the importance of geology in the field compared to other investigative methods. The following data, in fact, all come from a detailed analysis of the outcropping sections of granitoids along the better preserved transgressive surfaces.

As is well known, in the advance of a transgression, erosive and depositional events can be represented by two extremes:

– the demolition of rocky cliffs, in which case the initial sedimentary deposit can be conglomerates of varying coarseness up to megabreccia (Ietto & *alii*, 2003);
– the gradual advance of the sea over areas with an ageing morphology, in which case we have fine marine sediments directly superimposed on mature and soft continental deposits (alterites, aeolian deposits, lagoon and lacustrine silts, etc.).

In the Monte Poro region, numerous, diverse transgressive geological situations are found. However, as far as the present research is concerned, three can be considered the most representative: Torre Ruffa, Vallone Ciappetta and Briatico (stations 4, 5, 6 of fig. 1).

Torre Ruffa

At Torre Ruffa (fig. 4) diverse granitoid rocks (rich in quartz and muscovite) are covered directly by monogranular white miocenic sand with Clypeaster. The granitoid substratum is highly tectonized with little oxidisation along the fracture surfaces; there is, however, some evidence of initial disaggregation in the signs of crystallisation in the constituent minerals. The values given by the Schmitt hammer are between 10 and 25.

Vallone Ciappetta

Between the villages of Zungri and Papaglionti in a new outcrop, Miocene transgression, represented here by the tortonian formations of slightly clayey grey sand, directly overlies a granitoid alterite, which is reddish in colour, highly oxidised and rich in biotite mica (fig. 5).

The alterite outcrops for a thickness of between 7 and 15m and in the lower portion it is evidently a granitoid saprolite which is rich in femic, amphibolite and biotite elements («anphibolitic granodiorites» in Nicotera, 1959). The crumbling is virtually complete; in the portions lying immediately under the marine sediments, for example, every trace of the original mineralogical texture has been lost and the texture now resembles «regolith in situ» (Migon & Lidmar-Bergstrom, 2001).

FIG. 4 - Transgressive miocenic conglomerates and sands on highly fracturedand middly altered granitoids (γ) - values of rebound to the Schmitt hammer up to 20-25.

Briatico

Along the cliff coast of Briatico there is a spectacular outcrop where Miocene calcarenites, rich in fossils (the largest and most frequent are Clypeaster, Cidaris, Pecten and Ostrea), directly surmount granitoid rocks crossed by metr-wide bands of white quartz.

At the foot of the calcarenites there are lenses of conglomerates with a carbonate matrix and round clasts (up to 2 m in diameter) composed entirely of granodiorite which is very similar to the substratum. The conglomerate lenses outcrop up to 4 m in thickness and 50 m in length and, for this reason, they can be considered sedimentary pockets conserved within the irregular morphology of the submerged area.

All the larger clasts of the transgressive conglomerates show spectacular signs of spheroidal weathering (fig. 6) as well as spheroidal exfoliation. As regards these clasts, which are always clearly rounded, it is possible to infer that they were originally isolated boulders and/or corestones in the external layers of continental granitoids.

The height of the outcrop in question is no greater than 1 m a.s.l.. Therefore, considering the actual phase of tectonic uplift, it is possible to hypothesise very short emergence times, even when taking into consideration eustatic quaternary variations in sea level.

AGE OF WEATHERING

From the data so far provided, it can be affirmed that the age of weathering of the granitoids in southern Calabria can be located at the very least to the Miocene, that is to say, before the Tortonian transgression.

As far as the granitoids of Monte Poro are concerned, the data is clear and unequivocal.

Consequently, the same claim can also be made for the granitoids of the Serre, where there is an absence of marine sedimentary cover. The reasons for this assertion are the lithological uniformity and the physical continuity with the granitoids of Monte Poro. This is also valid for the unitary assemblage of the tectonic frame from the Miocene till the present time, which is the same for both the Serre and Monte Poro.

TECTONICS AND WEATHERING

The neotectonic processes of the Pleistocene, with their considerable degree of uplift, mean that the Calabrian relief is in a phase characterised more by erosional denudation, a stripping phase, rather than a growth phase of alterites and continental sediments; we can also refer to this as an «etching phase». As regards the south of Calabria and the Serre mountains in particular, in fact, Brogan & *alii* (1975) proposed rates of Quaternary uplift of 0.8/1.3 mm per year, according to the local differences in dislocations. Ghisetti (1980) suggested 0.06/1.5 mm per year and finally for Westaway (1993) the average was 1mm per year ± 0.02 mm.

On the other hand, Migon & Thomas (2002) hypothesise a rate for the deepening of alteration in any homogeneous plutonic body, varying from 5 to 20 m/Ma according to whether the phenomena develop under hot or cold climates, semiarid or wet climates.

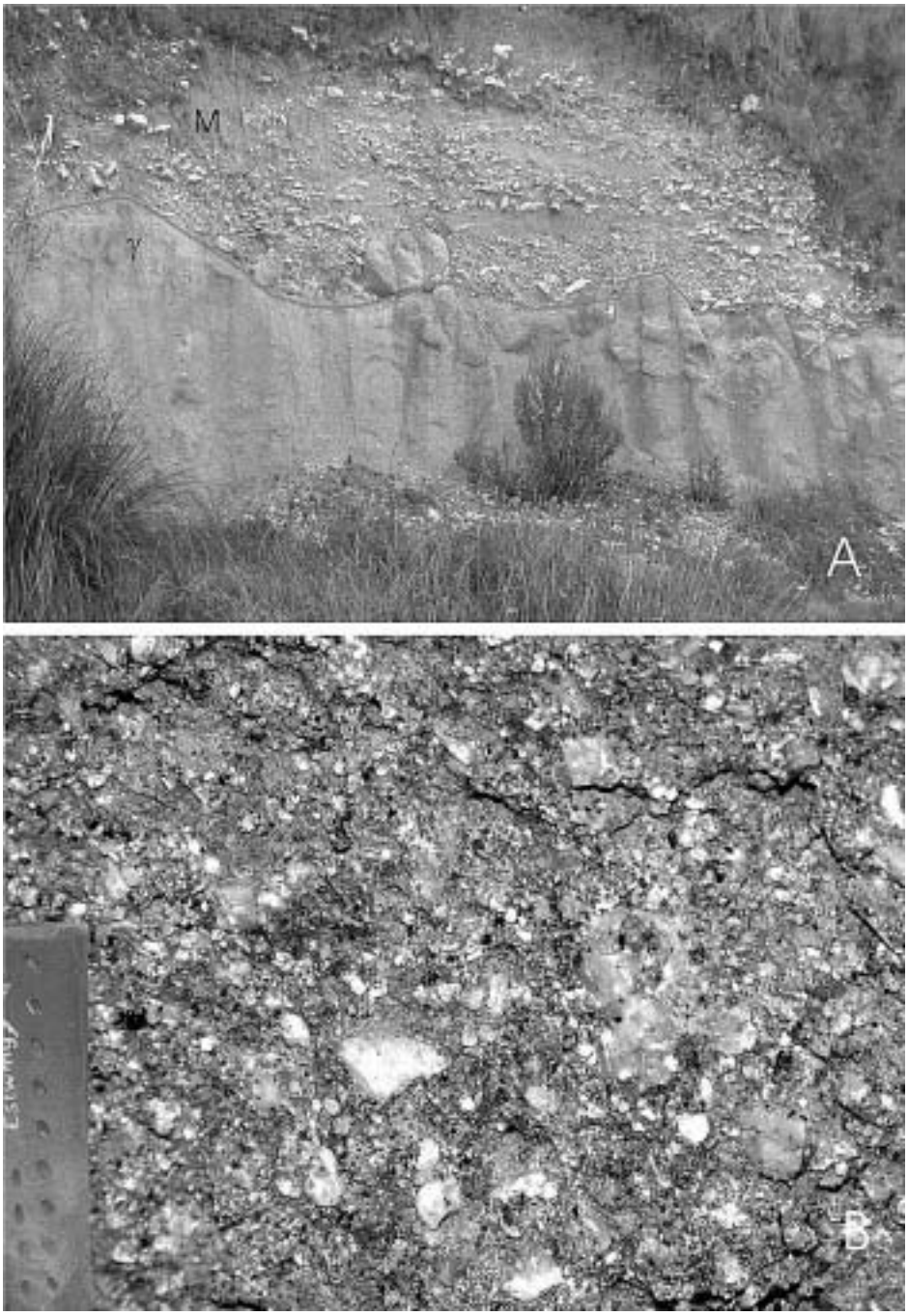

FIG. 5 - A) Pebbles and sands of the miocenic transgression (M) on a granitoid, strongly oxidized regolith (γ). B) Particular of the regolith.

With this in mind, it is clear that in southern Calabria, with reference to the Pleistocene, the balance between etching and stripping will tend to favour the latter. This has also been confirmed by our recent studies on the intensity of erosion (Ietto & *alii*, work in progress). The findings estimate values in the order of 1000-1200 tn/sqK of soil eroded from the Serre mountains overall.

Therefore, it is likely that the layers of weathering which are currently being studied on the granitoids are none other that the remains of the old covers in phase of erosion in the Pleistocene. The level of erosion between different points is determined by the degree of tectonic uplift and the morphological conditions in the area. In other words, areas with less erosive energy conserve thicker alteration layers, while areas with vigorous erosion are nearly or completely lacking in them (fig. 7). The greater or lesser maturity of the alterites outcropping today should, therefore, be seen not as the final or advanced stage of an ongoing process, but more as the

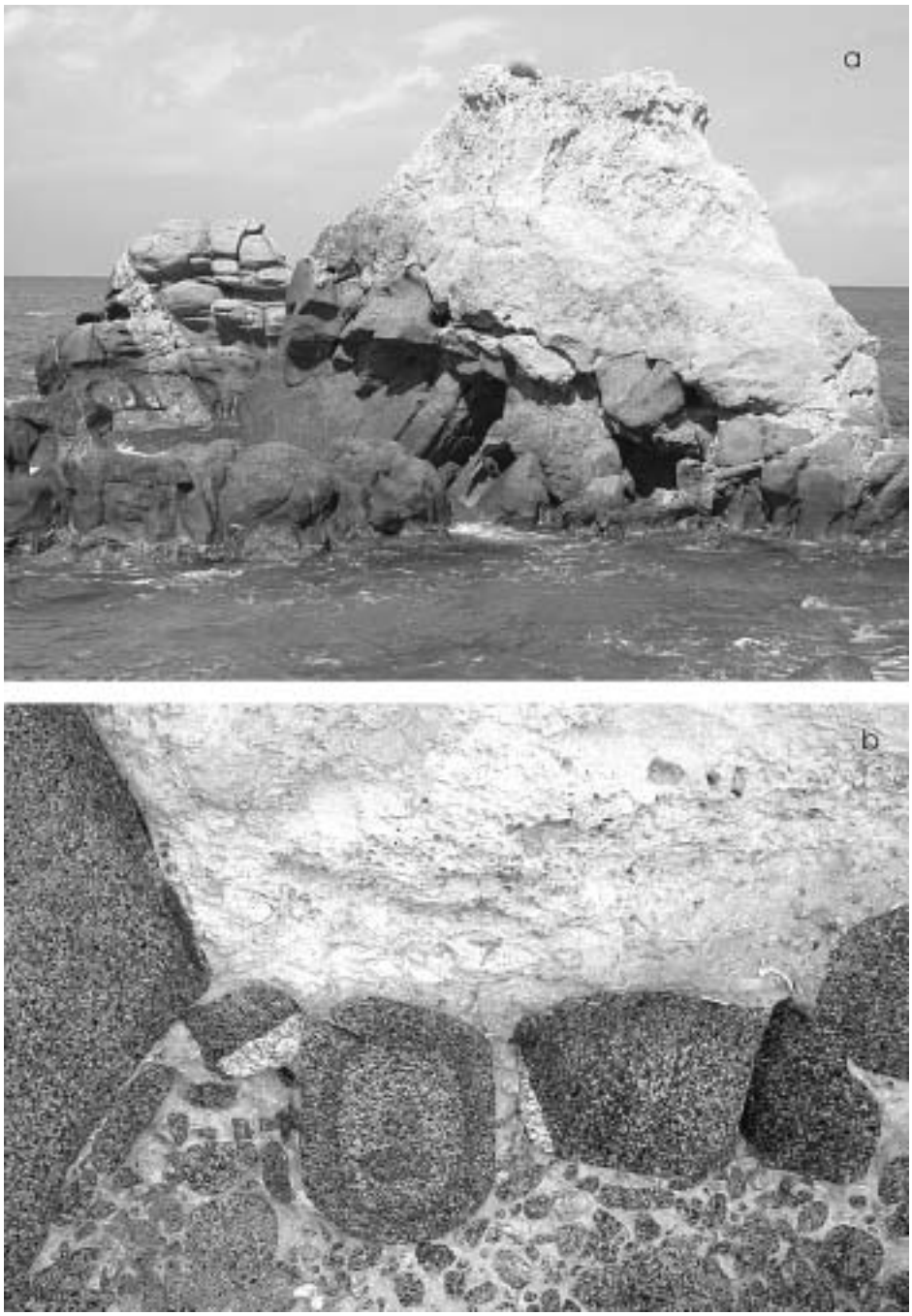

FIG. 6 - a) The miocenic transgression on the granitoids of the Briatico cliff. b) Spheroidal wheatering in the bulks of the miocenic transgressive conglomerate. At the top the miocenic calcarenite rich in macrofossils.

greater or lesser erosion of pre-Quaternary weathering mantles. These have their own maturity and have developed in continental and climatic conditions still to be ascertained.

DISCUSSION

Thanks to this research work we can now define the chronological minimum limit for the weathering of granitoids in Calabria and can place it at least in the Miocene prior to the Tortonian.

As regards this conclusion, transgression and the outcrops at Fosso Ciappetta and Briatico are the determining elements. This result leads to the possibility that the alternating layers which outcrop today could be remaining portions saved from erosion of the older and thicker covers formed essentially before the uplifting of the relief in the Quaternary. However, these conclusions pose certain

FIG. 7 - Immature Saprolite (Class IV-V-IAEG) in outcrop. The corestones to the Schmidt hammer gives values up to 20-25.

problems both for geology in general, and for the criteria used for the study of alterites in Calabria in particular.

As regards general geology and with the rate of weathering put forward by Migon & Thomas (2002), the problem arises of fixing a time frame for the late placement of the granitoids in the Arco Calabro orogene and their consequent early emergence. Hence, the time between the Eocene (the closure of Tethys) and the Tortonian (marine transgression onto the granitoids) remains open.

In the light of the new information, as far as the criteria used for the study of alterites is concerned, there is a need to make a fundamental consideration; that is to what extent the weathering sections outcropping today are the remaining portions of much older and larger columns dating from before the Pleistocene (therefore referable to other environmental contexts), or whether these are effectively the maximum expression of an alterating process, which has developed and evolved entirely in the Quaternary age and in a Mediterranean climate.

We are of the opinion that, regarding the outcrops which are still exposed, it is not so much the maturity of weathering that is increasing, but rather the immaturity of the weathering which progressively crops out as the stripping of the relief proceeds.

This may well be the case for southern Calabria as for all the areas in Calabria where granitoids outcrop, albeit to a less extent for example in the Sila or Aspromonte. Indeed, the uplifting of different parts of Calabria is comparable to the description proposed for the Serre mountains with its balance of stripping and etching.

This does not exclude the possibility that in the Pleistocene, the Mediterranean climate was able to impose, on the already decomposed plutonic rock, its own processes of alteration, especially in the higher and more inland areas (Sila, Serra, Aspromonte). Nevertheless, these effects were certainly of a lesser degree than in those areas with more severe climates such as those which have succeeded each other from the Palaeogene to the present time and for much longer and severe periods: from glacial to tropical.

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