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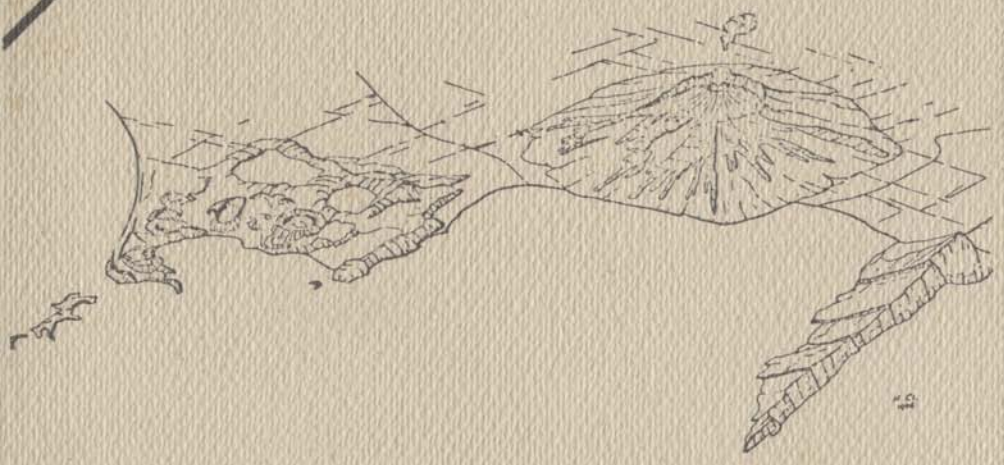

PROCESSI PALEOCARSICI E NEOCARSICI
E LORO IMPORTANZA ECONOMICA NELL'ITALIA MERIDIONALE

ISTITUTO DI GEOLOGIA E GEOFISICA DELL'UNIVERSITÀ DI NAPOLI
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2. geology and geomorphology

2.1 Structural framework of Southern Apennines

Southern Apennines represent a section of the Neogene orogenic belt normally considered as the result of deformation of the southern "African" margin of the Tethys.

The genaral structure of this chain is that of a pile of nappes, whose tectonic transport decreases from the geometrically higher to the lower ones, reaching the autoctony in the foredeep and foreland (Apulia).

Different lithological nature, influence of paleotectonic, tectogenetic and neotectonic phases and differential behaviour of the rocks during the deformation are the characters and processes whose interaction - together with climatic conditions and related variations - allow to determine the main morphological units.

Barring Calabria Arc, where plutonites and metamotphites with related sedimentary cover autcrop, Southern Apennines east of the tectonic line Anzio-Ancona consist of:

- carbonate neritic sediments;
- calcareous-siliceous and marly basinal sediments;
- arenaceous-clayey sediments with flysch facies.

The age of these sediments ranges from middle Triassic to middle-upper Tertiary. Individual thickness of the sequences can be over 5 Km, that of the whole chain reaches about 10-15 Km.

2.2 Structural-Stratigraphic Units

Southern Apennines are therefore a nappes pile, whose sediments can be grouped in structural-stratigraphic units. This term inidicates (D'Argenio and Scandone, 1969) great geological bodies, continuous or broken, deriving from preexisting paleogeographic units. Their lithological distinctive features, mechanical homogeneous behaviour at large scale and geometrical relationships with the adjacent units, allow to trace their boundaries.

These structural-stratigraphic units may have preserved the stratigraphic connection with their basement (i.e. Apulia) or have been displaced (i.e. Apennines); in some cases, they may also be undeformed.

The structural-stratigraphic units of the Southern Apennines, north of Calabrian crystalline rocks, can be divided as follows (D'Argenio, Pescatore, Scandone, 1973; Ippolito, D'Argenio, Pescatore and Scandone, 1975):

- Foreland and foretrough unit;
- External units of the chain;
- Internal units of the chain.

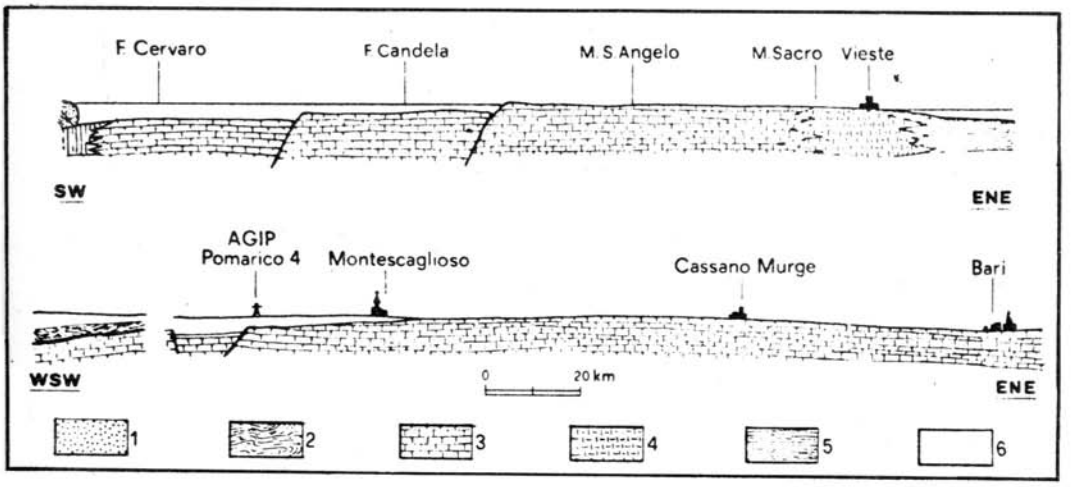

Fig. 2 - Stratigraphic and tectonic relationships among structural-stratigraphic units (see also Tab. III) 1. Irpinian Units; Frido Flysch and Cilento Units; 3,5 Murge-Gargano Unit: 3. back-reef lagoon facies, 4. reef-complex facies, 5. reef-scarp and basin facies; 6. Bradano Unit and sediments of intra-apenninic troughs. (Da D'Argenio et al., 1973).

Foreland and Foretrough Units.

a) Murge-Gargano Unit. This unit outcrops in the area between Gargano and Murge. The sequence begins with evaporites (Carnian) crossed by drilling at Foresta Umbra and outcropping at Punta delle Pietre Nere. to which follow shelf carbonate platform deposits of Jurassic Cretaceous and Tertiary age. Reefoidal and basinal facies of the upper Jurassic are known to occur in eastern Gargano.

Thickness of this unit ranges from about 4.000 meters in Gargano area to over 6.000 meters in Salento area. The cretaceous system itself reaches over 3.000 meters in the Murge area (Ricchetti, 1975).

b) Bradanic Unit and Deposits of intrapenninic basins. This unit consists of the sediments of Bradanic Foretrough and intrapenninic basins and its sequence, which ranges from Pliocene to Calabrian, is formed of terrigenous deposits with facies varying from littoral to bathyal.

Allochthonous sediments coming from the Apennines are intercalated in the normal sequence in the inner part of the trough. Thickness is over 3.000 meters.

External Units of the Chain

a) Altavilla Unit. This unit outcrops either along the apenninic front or in the inner areas (Altavilla, Irpinia). At its base we often find evaporitic sediments ("gessoso-solfifera" formation), followed upwards by clastic. The age renges from upper Tortonian to middle Pliocene. Thickness varies strongly from place to place, with a maximum of a few hundred meters, and the facies vary from littoral to bathyal.

The Altavilla Unit (which is formed of sediments settled in a series of basins fitted on nappes) has been affected by the last thrusting movements of middle Pliocene.

b) Frosolone Unit. The upper part (upper Cretaceous-Miocene) of this unit outcrops north of the Matese area. The lower part, on the contrary, is known because it has been crossed by the "Frosolone I" well, drilled by AGIP (Pieri, 1966).

From down up the unit is made of cherty dolomites (Triassic-Liassic?), shales and radiolarites with volcanic intercalations (Jurassic), graded calcareous sandstones, calcilutites and marlstones (Cretaceous-lower Tertiary), calcarenites, siltstones and sandstones (lower and middle Miocene). The paleogeographic area in which this unit was formed is the Molise Basin, which was located between Apulian and Abruzzi-Campania carbonate platform.

c) - Matese-Mt. Maggiore Unit. This unit outcrops in the following localities: Mt. Maggiore, Mt. Camposauro. In Lucania it outcrops in the tectonic window of Mt. Alpi.

The sequence consists of dolomites (upper Triassic-lower Liassic) and limestones (middle Liassic-upper Cretaceous). Sediments of the lower Tertiary are generally absent and the Miocenic sediments, which are usually transgressive on the top of the Cretaceous, consist of limestones, marls and terrigenous clastics (Catenacci, De Castro, Sgrosso, 1963; Selli, 1957).

Thickness is over 3.000 meters. The carbonates show mainly a backreef facies. In the western Matese we also find parts of the outer margin of the former paleogeographic body (Abruzzi-Campania carbonate platform), whose facies are in correlation with those of the Frosolone Unit.

The Miocenic terrigenous clastics consist mainly of turbidites and the facies is bathyal.

d) - Mt. Croce Unit. - The unit outcrops in the Picentini Mts. and represents the lowest known unit of the tectonic window of Campagna (Scandone and Sgrosso, 1974; Turco, 1976).

The sequence, whose thickness is of several hundred meters, consists of: white, some times cherty. dolomites; gray limestones and shales; cherty white dolomites (Carnian-Norian). Follow massive limestones and breccias (upper Jurassic) that overlie unconformably Triassic sediments and in turn are overlain, unconformably again, by the Eocenic sediments. The latter consists of calcirudites and calcarenites of Aquitanian age, passing to marls and sandstones of Serravallian-Tortonian age. This sequence, whose charaters are those of a margin of platform can be interpretated as derived from the inner edge of the Abruzzi-Campania carbonate platform.

e) - Irpinian Units. - The sequence of these units is made of terrigenous and deep sea deposits: it outcrops along a belt, about 50 Km wide, ranging from southern Lucania to the Daunia (Pescatore, 1976).

From the east to the west we can distinguish three types of sequences:

- a sequence of marls and calcarenites (Mt. Faeto flysch). some of which are 500 meters thick and range from the lower Serravallian to the lower Tortonian.
- a mainly marly-calcareous sequence (Langhian) overlain by an arkosic formation of Serravallian age (Serra Palazzo formation); the top of the sequence consists of Tortonian marls. The thickness of the whole sequence is over 1.500 meters.
- a terrigenous sequence consisting of conglomerates, arkosic sandstones and graywackes. which ranges from Langhian to lower Tortonian age (Castelvetere flysch, Caiazzo sandstones, Gorgoglione flysch). Thickness is over 1.500 meters.

The Castelvetere formation presents wildflysch characters and encloses calcareous blocks of various size (from a few cubic meters to many thousands) carried out from the front of the Campano-Lucanian carbonate platform.

In the Langhian time, therefore, the area of sedimentation of Irpinian Units (Irpinian Basin) was partly coinciding with the Lagonegro Basin of Mesozoic and lower Tertiary ages.

The outer margin of the Irpinian Basin consisted of the Abruzzi-Campania carbonate platform not yet translated. The inner margin, on the contrary, consisted of stratigraphic-structural units resulting both from the breaking down of the Campano-Lucanian carbonate platform and the more internal allochtonous sheets.

f) - Lagonegro Units - In these units, widely outcropping in western Lucania and in the tectonic window of Campagna (Giffoni Vallepiana, Campagna), we may recognize two units in tectonic contact. The paleogeographic unit from which they derive is the Lagonegro Basin, that was located between the Abruzzi-Campania - Mt. Alpi carbonate platform and the Campano-Lucania carbonate platform (Scandone, 1972). The Basin was formed in the upper Triassic and reached the maximum depth in Jurassic age.

Lower Lagonegro Unit; from down up we may distinguish:

Limestones with cherty interbeds and nodules (calcari con liste e noduli di selce), cherty calcilutites (500 meters);

"Scisti silicei", radiolarites and siliceous shales (70 meters);

"Galestri", shales and cherty limestones (400 meters);

Pecorone schists, green and red shales and calcarenites (70 to 80 m.).

The age of the sequence ranges from Carnian to upper Cretaceous.

Upper Lagonegro Unit; from down up we find:

Mt. Facito formation consisting of shales, siltstones, sandstones and conglomerates with some reefoidal limestones, probably diabases and pillow breccias too (200 meters);

Limestones with cherty interbeds and nodules (calcari con liste e noduli di selce), cherty calcilutites and dolomites with interbedded dolorudites (an average of 250 meters);

"Scisti silicei", radiolarites and siliceous shales with graded calcarenites and calcirudites interbeds (an average of 250 meters);

"Galestri", shales and more or less siliceous limestones with calcirudites and graded calcarenites interbeds (several hundred mts.);

"Flysch rosso" (red flysch) consisting of red and green shales, calcarenites and sandstones (about 200 meters);

"Flysch Numidico" (Numidico flysch), given by turbiditic quartz-sandstones (about 200 meters).

The age of the sequence ranges from Anisian to Aquitanian.

g) - Mt. Foraporta and Maddalena Mts. Unit - The unit outcrops in the Lagonegro area along the Noce River valley. At the Mt. Foraporta we can see three thrust-sheets, whose sequence from down up is made of white and gray fish bearing dolomites (upper Triassic-lower Liassic), followed by black marly limestones (lower to middle Jurassic). Thickness is of about 450 meters; facies are neritic in dolomites and pelagic in black limestones (Scandone, 1972). The sediments of the Mt. Foraporta were derived from the outer margin of the Campano-Lucania carbonate platform.

In the Maddalena Mts. the sequence shows Norian dolomites overlain by reefoidal or perireefoidal limestones (Jurassic), calcirudites and calcarenites with fossil fragments and macroforaminiphera (upper Cretaceous-Eocene and lower Miocene)

h) - Alburno-Cervati Unit. - It outcrops in Campania (Avella-Partenio Mts., Lattari Mts., Picentini Mts., Alburno-Cervati Mts., Marzano Mt.), in western Lucania (Mt. Coccovello, Lauria Mts.) and in northern Calabria (Mt. Pollino and Coastal Chain north of Sangineto Line).

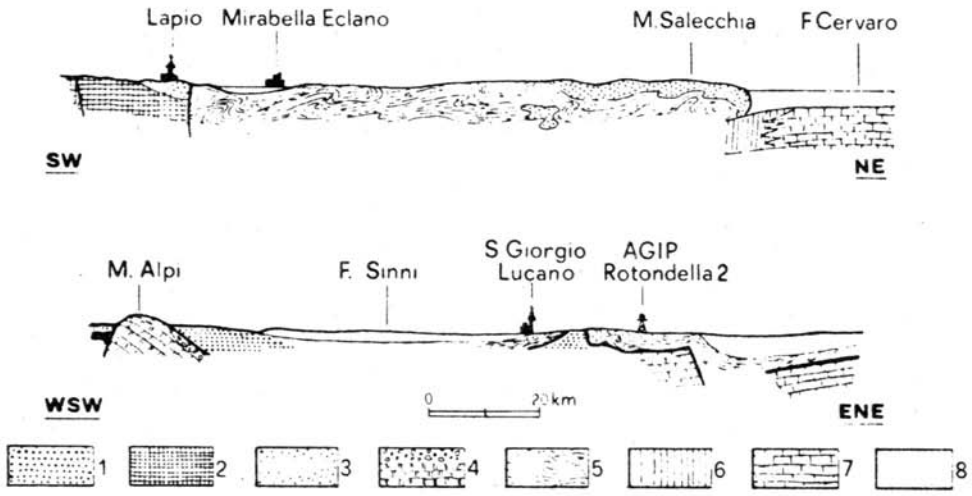

Fig. 3 - Stratigraphic and tectonic relationships among structural-stratigraphic units (see also Tab. III).
1. Sicilidi Units ("argille varicolori"); 2. Foraporta-Monti della Maddalena Unit; 3. Irpinian Units; 4. Matese-Monte Maggiore Unit; 5. Frido Flysch, Cilento Units; 6-7 Murge-Gargano Unit. 6. internal margin of the original Apulia Carbonate Platform (interpolated), 7. back reef lagoon facies; 8. Bradano Unit and sediments of intra-apenninic troughs. (Da D'Argenio et al. 1973).

The sequence consists of:

— Dolomites of upper Triassic, weackly metamorphic in the Coastal Chain (about 1.500 meters);

— Mainly calcareous sediments (Triassic to Paleogene) reaching a thickness of over 2.500 meters;

— Calcarenites of Aquitanian age rapidly passing to clastic sediments with flysch facies (maximum thickness of 20 meters).

— Mesozoic facies are neritic and reefoidal from upper Triassic on. In the coastal Chain of Calabria. north of Sangineto Line, this sequence is underlain by schists several hundred meters thick, with interbeds of fossiliferous - sometimes metamorphosed - limestones and of prasinites.

i) - Mt. Bulgheria-Verbicaro Unit. - This unit outcrops in Campania at Mt. Bulgheria and at the Island of Capri) and in Calabria (Coastal Chain north of the Sangineto Line).

Lithologically the lower part of the unit (upper Triassic to lower Liassic) is mainly dolomitic, while the upper part (Liassic to Aquitanian) is mainly calcareous. Locally we find some intercalations of lava. Generally facies are neritic and show to belong to the margin of a carbonate platform; sometimes we can have intercalations of pelagic facies. In the Aquitanian-Langhian age facies become terrigenous (flysch). The whole thickness ranges from a few hundred meters to over 2.000 meters. The sediments of this unit belong to the inner margin of the Campano-Lucania carbonate platform.

The top is an arenaceous-marly flysch with some conglomeratic levels of Eocene-upper Oligocene age and has a thickness of over 2.000 meters (S. Mauro and Albidona formation).

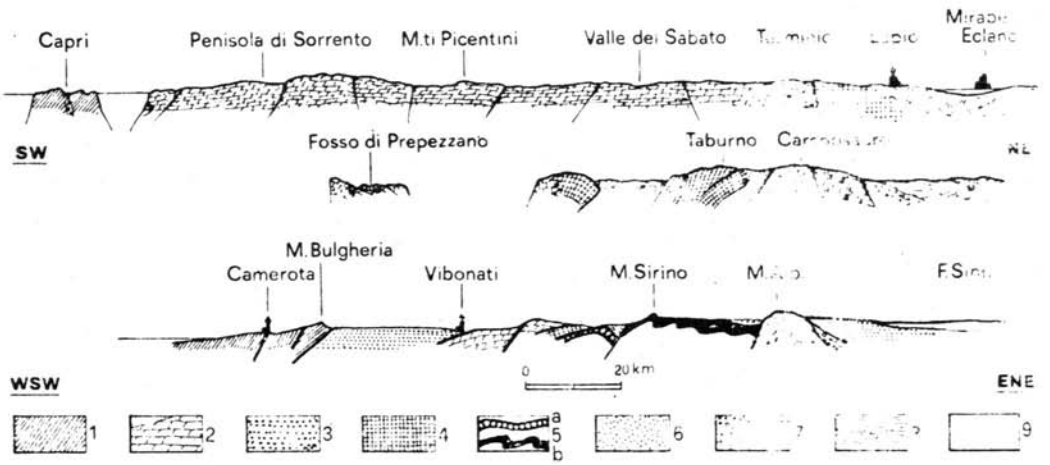

Fig. 4 - Stratigraphic and tectonic relationships among structural-stratigraphic units (see also Tab. III).
1. Bulgheria-Verbicaro Unit; 2. Alburno-Cervati Unit; 3. Sicilidi Units ("argille varicolori"); 4. Foraporta Monti della Maddalena Unit; 5. Lagonegro Units, a. upper unit, b. lower unit; 6. Irpinian Unit; 7. Matese-Monte Maggiore Unit; 8. Frido Flysch, Cilento Units; 9. Bradano Unit and sediments of intra-apenninic troughs. (Da D'Argenio et al., 1973).

Internal Units of the Chain.

Some of the internal stratigraphic-structural units are involved in the Southern Apennines orogenesis north of calabrian crystalline body. When we use the term "internal", we want to say that these units are derived from paleogeographic areas originally oceanic or in any case located between ocean floors and the areas of neritic carbonate sedimentation of the apenninic continental margin.

The sequence, from up down, is as follows:

a) - Silicidi Units. Sediments of these units widely outcrop in Campania and in northern and eastern Lucania, The sequence (Ogniben, 1969) from down up shows:

- about 500 meters of sandstones and conglomerates (Aptian to Cenomanian);
- 500 to 1.000 meters of "argille varicolori" (varicoloured shales) (upper Cretaceous);
- 500 to 1.500 meters of calcareous-arenaceous flysch (upper Cretaceous to Paleocene);
- 400 to 600 meters of "argille varicolori" (Eocene);
- 250 to 300 meters of andesitic tuffs (Tusa tuffs) (upper Eocene to Oligocene).

b) - Cilento Unit. This unit outcrops widely in western Cilento, in southern Lucania and in northern Calabria east of the Mt. Pollino. The sequence, which has a flysch facies, consists of deposits mainly pelitic at the base (Crete Nere formation) of Aptian-Albian age, 350 to 400 meters thick, arenaceous (Pollica formation) or calcareous-arenaceous (Saraceno formation) of the Albian to Paleocene age, with a variable thickness of 500 to 1.000 meters.

c) - Frido Unit. It outcrops in the Cilento area, in southern Lucania and in northern Calabria, east of Mt. Pollino. This unit underlies tectonically the Cilento unit

in the Cilento area, whereas in Calabria is overlain by the ophiolitic units and the crystalline dioritic-kinzigitic formation.

Sequence, slightly metamorphosed, is made of shales, limestones and quartz-arenites. Ophiolitic olistostromes of different size, more or less metamorphosed, are found within this unit in the Frido Valley. east of the Mt. Pollino.

2.3 Pre-Pliocenic Paleogeography

It is of a great interst to give a palinspastic picture of the whole, by taking again towards the inner areas (i. e. towards the ancient oceanic areas) the structural-stratigraphic units, after the interpretation of their original sedimentary environment.

The original paleogeography may be represented as paleogeography a belt several hundred Km. wide within which carbonate platforms (shallow sea sedimentation) alternate with basins (carbonate-marly-siliceous sedimentation of open and deep sea).

These areas were connected by more or less steep talus. where a synsedimentary tectonics was active. During the Mesozoic great sedimentary bodies, elongated (even several hundred Km.) and with single volume of some hundred thousand of cubic Km (paleogeographic units). were formed. From the Triassic to Paleogene this picture does not change characters. From Triassic, until Pliocene, we can find two periods of palogeographic evolution:

- a paleotectonic period during which we assist to an active sedimentation and to a series of moviments of distention, so that an oceanic area develops as the result of processes of continental drift. The paleogeographic areas therefore become sedimentary sheets of continental margin.

- a shorter tectogenetic period still corresponding to sedimentation, accompanied by deformation of the continental margin and their sedimentary sheets. Indeed, the oceanic area was already contracting at the end of the former period, so that continental margins begin to close again (collisio orogenesis).

Paleotectonics: this interval essentially cover those stages allowed the evolution both of the southern continental margin of Thethys and of the facing oceanic area. The lenght of the priod covers about 200 m.y., from Triassic lower Tertiary. Major tectonic episodes nappened during middle Triassic, Norian-lower Liassic. upper Malm, middle Cretaceous and finally upper Cretaceous and Paleocene.

a) - Ancient physiographic features. The picture is that of an alternation of sedimentary belts with basins and shallow water characters with a carbonate sedimentation, gradually prograding towards the foreland and developing parallely to the above continental margin. The wideness of single belt may range from some dozens to few hundred Km. A number of synsedimentary faults and a prononced subsidence characterize the sedimentary belts. The subsidence is gradually decreasing from about 150 to about 10 m/MY.

b) - Features of the emerged areas. During the emersion phases which affected only the carbonate platforms, the relief never was over a few meters above the sea level; the emerged areas where widely affected by karst with inter and intrastratal and/or superficial cavities with bauxitic (middle Cretaceous) or clayey (Paleocene) deposits.

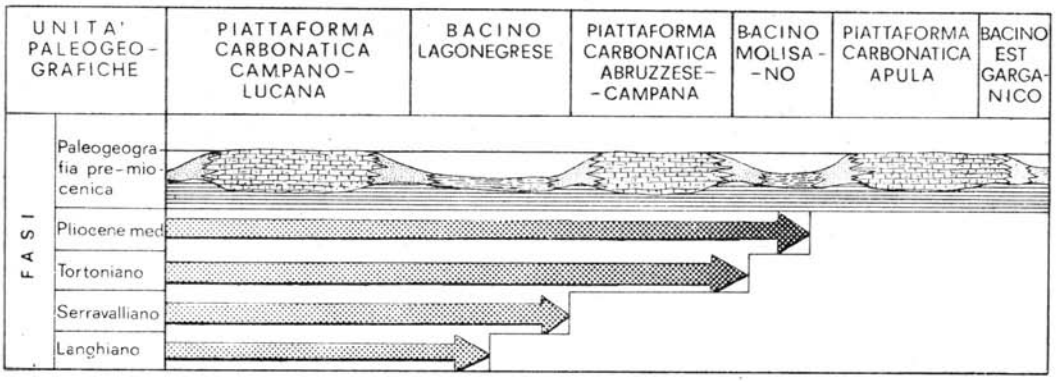

Fig. 5 - Tectogenetic phases and paleogeographic units in the Campania-Lucania Apennines. (Da D'Argenio et al., 1973).

Petrological, geochemical and paleontological evidences show warm-dry paleoclimates (from Triassic to Liassic) gradually evolving to warm-wet paleoclimates (from Jurassic to Paleocene).

c) - Influence on the present morphology. Relationships among different original facies belts often correspond to ancient synsedimentary fault lines.

These faults during tectogenetic and neotectonic periods, were rejuvenated. By this rejuvenation the location of the structural-stratigraphic unit, margins often depend on these ancient fault lines, which had afterawrds a morphological importance during the neotectonic uplift.

Tectogenesis: this interval includes compression stages during which the structural-stratigraphic units were detached from their basement and thrusted. The continental margin above mentioned, and the facing oceanic area were therefore deformed. The process covered a priod of less than 100 m.y. (from middle-upper Cretaceous to lower-middle Pliocene), of which 30 m.y. (from Miocene to lower-middle Pliocene) needed for the tectonization of the Apennic continental margin ("external zones").

a) - Ancient physiographic features. These are similar to those above delineated for the paleotectonic interval except for the more internal areas gradually deforming and tectonically migrating towards the foreland (paleochain).

b) - Features of emerged areas. We have no fossil evidences of such features. Sedimentological study of deposits (for instance, the Cretaceous-Tertiary flysch) shows in any case a more marked morphology, with an evident hydrographic pattern. From the Tertiary on the paleoclimates are gradually wetter.

c) - Influences on present day morphology. All we said about paleotectonic interval is valid here. Present day

morphology inherited features from this period. These features are related either to the regional arrangement of different rocks forming the structural-stratigraphic units or to their superposition.

2.4 Neotectonics.

Geomorphological features of the Southern Apennines, as already mentioned, have been and still are controlled by lithology, tectonics and climate.

Especially to the small scale is evident the influence of different morphoclimatic systems occurred during the Pleistocene. Nevertheless, when we cosider great morphological units (or groups of units) we find that tectonics is a controlling factor.

Indeed, actual geometric relationship between lithologically distinct geological bodies (i.e. mainly arenaceous or, mainly argillous-calcareous bodies as well as mainly carbonate bodies) were produced by the overthrusting of the structural-stratigraphic units during the tectogenesis.

By this way the main groups of morpho-structural units (i.e. carbonate massifs, arenaceous-flysch reliefs) took place.

Uplift of the following neotectonic period gave to the single sectors a different role, in connection either with direction (tectonic valleys and surrected blocks) or with intensity of the movement.

We have often, for instance, that a fast uplift favoured a likewise fast denudation of the terrigenous cover revealing underlying carbonate rocks. In both cases morphoclimatic systems only shaped substratum already differentiated as regards height and/or lithology.

The main movement is therefore uplift, to which followed gravitational glidings towards the foredeep (glidings of the Bradano Foretrough in Plio-Quaternary age), as well

as towards the Tyrrenian Sea (gliding of the Paola Basin). Both these depressions were gradually thorowing of even 1 mm p.y.

The uplift begins in the Pliocene, after the last great tectonic translation, and two periods can be recognized corresponding to as many morphological cycles:

- a period covering upper Pliocene to lower Pleistocene;
- a period covering middle to upper Pleistocene.

Uplift is gradually more marked during these periods and so wideness of the morphological units decreases. This is confirmed by the records of these processes in the calcareous blocks (i.e. tectonically truncated valleys).

Present geomorphological cycle is still young and affected by the uplift, as the seismic activity proves.

This activity is evident along the great cross lines (i.e. Naples-Bari) and longitudinal lines of the chain. and goes together with geochemical and/or thermal anomaly of many springs whose circulation is, almost partly, very deep, even far away from the volcanic areas.

2.5 Plio-Pleistocene Geomorphological Cycles.

a) - Villafranchian morphogenetic cycle.

The uplift in this period is not well recognized, and we can only say that present boundaries with the facing seas are determined as well as the main morphological structural units are definite.

From a more strictly morphological point of view, at the end of the period the mature topographic surface (after the erosion of the upper terrigenous sheets) has reached the carbonate sediments and there geomorphic cycle is often superimposed.

b) - Late Villafranchian morphogenetic cycle.

During this period ($\simeq$ 0,8 m. y.) the former topographic surface (of which in present times only some residu-

al strips remain) was broken out by a stronger uplift of varying intensity along the chain. This led to the formation of internal grabens often occupied by lakes and now filled (Diano Valley, Latina Valley).

In the same time calcareous areas were affected rapidly by the karstic processes, whose activity is favoured by the Pleistocene cold climate. By this way a complex system of cavities at various levels took place.

Records of ancient erosional surfaces in non-calcareous areas are indeed very rare.

At this time the discordance between orography and hydrography in Southern Apennines occurs. It consists of a displacement to the east of the watershed, leaving to the west the main reliefs and producing the actual pattern of the hydrographic network, chiefly subsequent and rarely obsequent (f.i.: Bianco river, Mingardo river etc.).

At the end of the Riss age ($\simeq$ 0,2 m.y.) probably the chain is completely uplifted.

2.6 Coast Morphology.

Features of the coasts of the inner part of the chain are chiefly controlled by the great perithyrrenian faults, whereas a longitudinal subsidence and some less important faults are the controlling factors respectively of the ionian and adriatic coasts.

Eustatic movements of the Pleistocene are also important in featuring coasts, and their records widely occur in Southern Italy. Consequently a number of marine-cut terraces were formed, which can be divided as follows:

- eustatic terraces, ranging between 2 and 10 meters a.s.l. (normally they correspond to 2,4 and 8-10 meters a.s.l.), whose age belongs to the last 1,5 m.y. (f.i.: the Salento Peninsula).
- tectonically dislocated terraces, corresponding to sec-

tions of the coast prior to or rarely contemporary with eustatic terraces (f.i.: the shores with Strombus of southern Calabria uplifted to over 100 meters, while normally they are at about 8 meters a.s.l.).

The greatest uplift of the coast is found in Calabria (terraces of the Calabrian age of Mt. Aspromonte, 1.400 meters high); generally, on the thyrrenian side the uplift decreases northward; in the ionian and adriatic side it is of a few meters.

High Coasts.

In calcareous dolomitic sediments high coasts are evidently controlled by the structure. The cliffs move back slowly, as shown by the well preserved pleistocenic waterline marks.

These parts of the coast are therefore controlled by fault systems striking NW (apenninic direction) and NE, sometimes EW. Naturally the cliffs move back more rapidly when formed of softer rocks as sandstones, marlstones and volcanic tuffs.

Coastal Plains.

On the thyrrenian side there are some plains corresponding to transverse tectonic troughs in which to a marked subsidence counterparts a great sedimentation at the mouth of main rivers (Garigliano, Volturno, Sele, Lao rivers). Thickness of the sediments may be over 3.000 meters (Volturno and Sele River Plains), displaying a rate of sedimentation of even 1 meter p.y.

On the contrary, the coastal plains of the ionian side are the result of coalescing deltas.

All things considered, the present time shoreline tend to move back thanks either to eustatism or to anthropic activity along the rivers, whose solid charge notably decreased in the last years.