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THE APENNINES, THE DINARIDES, AND THE ADRIATIC SEA: IS THE ADRIATIC MICROPLATE A REALITY?

ABSTRACT: OLLIER C.D. & PAIN C.F., *The Apennines, the Dinarides, and the Adriatic Sea: is the Adriatic Microplate a reality?*. (IT ISSN 0391-9838, 2009).

The Apennines and the Dinarides consist of nappes thrust towards the Adriatic Sea, which is underlain by largely undisturbed rocks. Plate tectonic reconstructions are very varied, with supposed subduction in many different directions. Besides this there is an over-ruling concept that a plate called the Adriatic (or Adria) Plate moved north from Africa to Europe where its collision helped to create the Alps. Some think the plate is still moving. The total tectonic setting, together with palaeontological and seismic data, suggests that the older model of two converging nappe belts meeting a common foreland best fits the observed facts.

KEY WORDS: Adriatic, Apennines, Dinarides, Plates, Arcs.

RIASSUNTO: OLLIER C.D. & PAIN C.F., *Gli Appennini, le Dinaridi e il mare Adriatico: la Microplacca Adriatica è una realtà?*. (IT ISSN 0391-9838, 2009).

Gli Appennini, le Dinaridi sono costituiti da thrusts vergenti verso il mare Adriatico che è costituito da vaste estensioni di rocce indisturbate. Le ricostruzioni secondo la tettonica a placche sono state molteplici con supposti piani di subduzione in diverse differenti direzioni. Tra esse quella più accettata è l'ipotesi di una placca chiamata Adriatica o semplicemente Adria che si sarebbe mossa dall'Africa verso l'Europa dove la sua collisione avrebbe permesso la creazione delle Alpi. Alcuni pensano che la placca si stia ancora muovendo. Il quadro tettonico globale, insieme con i dati paleontologici e sismici, suggerisce che il più vecchio modello di due corpi a falde convergenti verso un comune avanpaese meglio rispecchiano i dati osservati.

TERMINI CHIAVE: Adriatici, Appennini, Dinaridi, Placche, Archi.

INTRODUCTION

The long Adriatic Sea is bounded by the Italian Peninsula (with the Apennine Mountains) and a mountain range here called the Dinaride Mountains (which is sometimes split into different ranges in different countries, such as the Albanides in Albania) as shown in fig. 1. Structurally both the Apennines and the Dinarides are thrust towards the Adriatic. The tectonic position of this area is problematic.

In plate tectonic terms the Dinaride Mountains are usually explained as a result of subduction of a plate under the Dinarides. Similarly the Apennines are commonly ex-

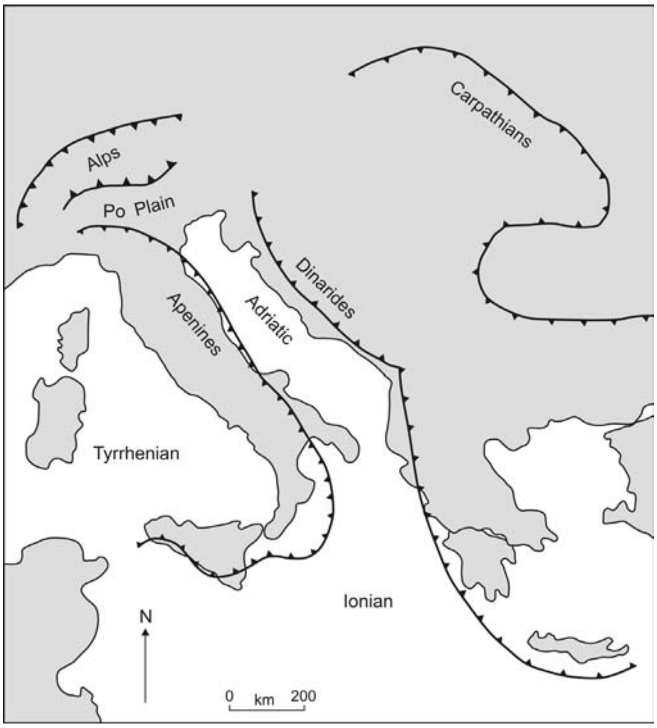

FIG. 1 - Geography of the Adriatic and its surroundings, showing postulated arcs.

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plained as a result of subduction of a plate under the Apennines. This means that an «Adriatic Plate» is being subducted both to east and west. On the other hand there are some plate tectonic reconstructions that have an Adriatic Microplate, complete with the Apennines and Dinarides, which impinges on Europe as part of a broad supposed collision between Africa and Europe.

In this paper we ask: where are the boundaries of the Adriatic Plate, when and how were the Dinarides and the Apennines formed, and is there really an Adriatic Plate?

THE SETTING

The Adriatic or Apulian Plate, sometimes called the Adria Plate, refers to a small tectonic plate carrying primarily continental crust that was supposed to have broken away from the African plate in the Cretaceous. Pinter & *alii* (2006) provide a series of papers giving modern ideas. The Adriatic Plate is surrounded by a number of features described here.

The Apennines

The Apennines make a broad arc in plan, convex to the east, and are built of a stack of nappes that moved for over 100 km. They consist dominantly of Mesozoic and Cenozoic sedimentary rocks.

A typical section of the Apennines shows nappes moving from west to east, abutting undisturbed strata in the Ligurian Foreland (fig. 2). Deformation of the nappes increases to the south west (front), and in the north east the strata are parallel and unfolded. The stack of nappes is over 10 km thick, much greater than the height of the Apennines, so much of the deformation occurred when the sediments were beneath the sea, and before the Apennine topography was formed (e.g. Calamita & *alii*, 1999).

Cowan & Brandon (2008) see the northern Apennines range as a wedge fashioned since the mid-Oligocene «as the dominantly continental Adria plate has been consumed beneath the Corsica-Sardinia block to the west».

At the simplest, Italian tectonics is seen to result from collision of Africa and Europe, but since the Italian mountains are not parallel to either Africa or Europe, and as there are spreading sites such as the Tyrrhenian Sea separating Europe from Africa, more elaborate scenarios must be invoked.

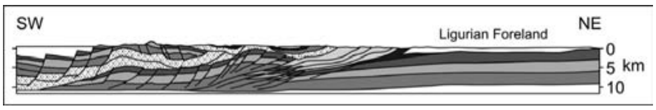

FIG. 2 - A SW to NE section of the Apennines, starting south of Naples. Several nappes are thrust against the foreland to the NE but the whole has been eroded and affected by normal faults that create much of the present topography. The three shaded layers on the foreland (right) are Cretaceous, Jurassic, Triassic, and the same sequence is repeated in the SW. (simplified after Cassano & *alii*, 1986).

The Dinarides

Geological sections across Albania (and other parts of the Dinarides) show thrusts, imbricate structures and overfolds verging towards the Adriatic. The Dinarides appear to be on a collision course with the Apennines. A section from the Geological Survey of Albania (1983) is shown in fig. 3. An interesting section and interpretation are provided by Picha (2002), which show the Paleogene-Quaternary sediments in the Albanian Foredeep, and the role of evaporites in the tectonics (fig. 4).

In the Dinarides an exceptionally large part of the literature is devoted to the ophiolites, which are usually interpreted as bits of ancient seafloor incorporated by subduction. To achieve this, a continental plate has to be subducted *under* an oceanic plate, a process called obduction. This is the reverse of "normal" subduction where the heavier oceanic plates are subducted under continental plates. Obduction seems to be just one of the *ad hoc* processes invoked to make plate tectonics work.

Be that as it may, the Dinaride ophiolites are of Triassic age (Gawlick & *alii*, 2008) and part of a melange of Jurassic age. «It formed as a synorogenic sediment during west-directed thrusting of ophiolite and sediment cover nappes representing ocean floor and underplated fragments of the western continental margin. «The tectonic structures are sealed by Late Jurassic platform carbonates (Calamita & *alii*, 1999; Coltorti & Pieruccini, 2002). The ophiolite ages show this as the oldest-known seafloor in the western part of the Neotethys Ocean. Ocean floor generation started in Middle Triassic times and not, as generally assumed, in the Jurassic. Gawlick & *alii* believe the ophiolites were obducted by a far-travelled part of the Neotethys Ocean, in the Jurassic, and as shown on their fig. 1D it is thrust over the Adria Plate. This is much older than the thrusting shown in fig. 4, though in the same direction. Their fig. 1D

FIG. 3 - Cross section of the Dinarides in Albania (simplified after Geological Map of Albania, 2002).

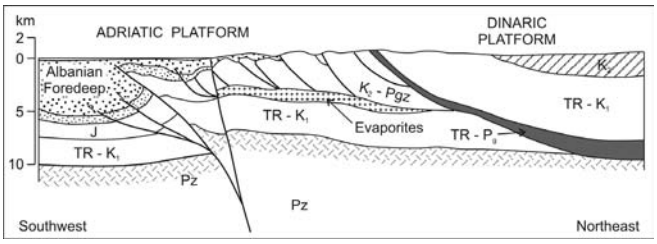

FIG. 4 - The junction of the Dinarides and the Adriatic (after Picha, 2002). The Albanian Foredeep contains over 5 km of Pliocene-Quaternary sediment. Note the role of evaporites in the tectonics.

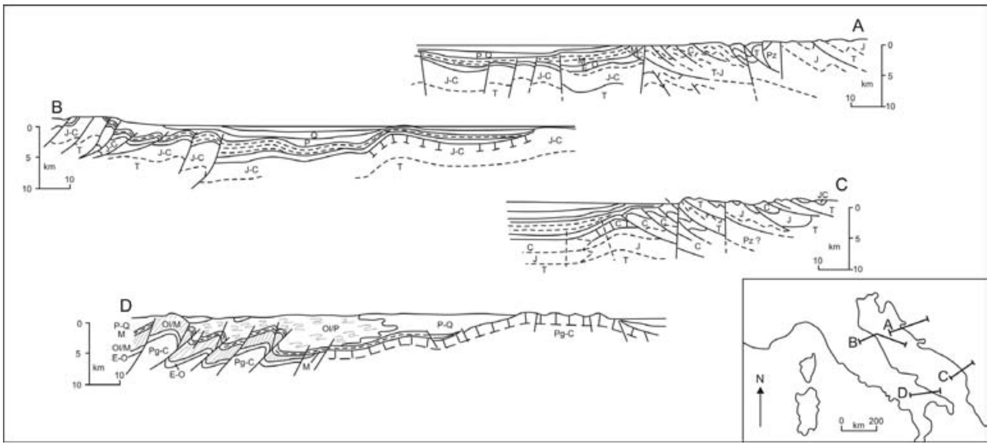

FIG. 5 - Sections from the Apennines to the Dinarides across the Adriatic (simplified after Celet, 1977). There are small gaps in the original.

also shows the Ligurian-Penninic Ocean on the other side of the Adria block, so they envisage it in position from the Triassic, with no drift to the north.

The Adriatic

The Adriatic Sea, between these two apparently converging ranges, is fairly simple in structure and does not appear to be strongly compressed, if compressed at all.

The geological map of Celet (1977) shows continuous continental crust right across the Adriatic. His sections (fig. 5) indicate a central zone of less-disturbed rocks forming the foreland to both the Apennines and Dinarides. Miljush (1973) has more and better sections. The Adriatic, an area of subsidence and below sea level at present, has deep basins of Pliocene and Quaternary age. Thrusting is confined to the margins, and any faults in the centre of the Adriatic are high angle, normal faults.

The map of Adriatic Pliocene and Quaternary basins (fig. 6) suggests fairly simple subsidence, making individual elongated basins parallel to the tectonic grain, uncomplicated by subduction. The many maps of basins of different age in Miljush (1973) indicate a united area with perhaps differential subsidence and uplift, but nothing as complicated as subduction.

The offshore Albanian Foredeep is a deep basin very close to the coast and contains up to 5 km of Pliocene-Quaternary sediments, in contrast to the thrust in the Triassic and Paleogene mainland (Picha, 2002). Although the eastern side of this basin has been slightly overthrust, it suggests an earlier vertical, tensional fault at the edge of the Dinarides with a throw of at least 5 km, and Picha describes it as due to «the opening of the post-Messinian pull-apart Albanian foredeep (South Adriatic Basin) in the Pliocene-Holocene».

There is no evidence at all for seafloor spreading, so it is improbable that any subduction is involved. If there is it has to be on both sides of the Adriatic, with continent-continent subduction.

The Adriatic extends to the north and becomes the Po Plain of Italy, an extension of the Adriatic that is filled by

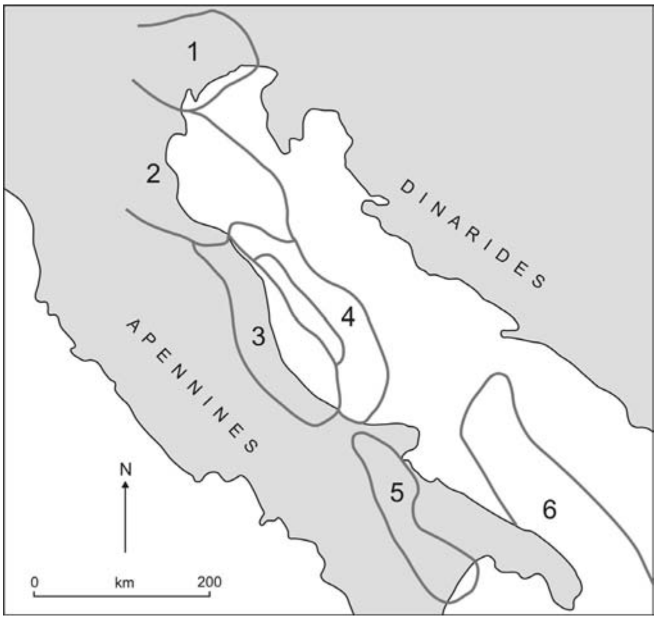

FIG. 6 - Adriatic Pliocene and Quaternary basins (after Miljush, 1973). 1. Venetian Basin (Pliocene), 2. Po Basin (Plio-Quaternary), 3. Marche Basin (Pliocene), 4. Central Adriatic Basin (Plio-Quaternary), 5. Bradanic Basin (Pliocene), 6. Adriatic-Ionian Basin (Pliocene).

sediments derived from the neighboring highlands, the North Apennines and the Southern Alps. Very detailed studies by oil searchers have shown the Po plain to be underlain by horizontal sediments (fig. 7), indicating stability and slow subsidence for the past 25 million years, a time span much longer than the Apennines have been in existence. The Po plain is clearly not a spreading site, so subduction appears to be impossible. It is much more likely that the Apennines are riding over the Po «plate» with its near horizontal sediments.

To the south the Adriatic gives way to the Ionian Sea, where sea-floor spreading is claimed by some authors. Rosenbaum & *alii* (2004) write: «The seismic structure of

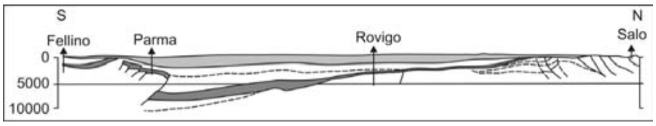

FIG. 7 - Cross section of the Po Valley from the Apennines to the Southern Alps. Apennine thrusts move in from the south and Alpine thrusts from the north, but instead of collisional compression there is subsidence and horizontal sedimentation. Upper shaded layer is Quaternary: lower shaded layer is Upper Miocene. Bedrock is Cretaceous. (Simplified after a section in Cassano & *alii*, 1986).

the floor of the Ionian Sea resembles the structure of the oceanic crust in marginal back-arc basins, suggesting that it formed as a small ocean basin».

Arcs

It is generally accepted that the direction of subduction is perpendicular to the edge of the plate it under-rides. The thrusts and nappes of the Apennines verge towards the Adriatic, and so do those of the Dinarides, but the situation is more complex as both are actually arcuate in plan. The Apennine arc is re-curved, and requires subduction from north through east and south to south-west (fig. 1), converging on the Tyrrhenian Sea which, far from being compressed from many directions, is a spreading site. Similarly the Dinaric Arc is continuous with the Hellenic Arc to the south and perhaps even with the Carpathian Arc, and also requires subduction from a great range of directions. The apparently continuous Adriatic-Po Plain region (or "plate") has to be "moving" in many different directions to be subducted under the Apennines, Dinarides and Alps, and the extension to the south - the Ionian and other parts of the Mediterranean is even more complicated and unlikely. The enormous range of directions required for movement of a rigid slab makes subduction look an improbable hypothesis.

OLD INTERPRETATIONS

Before the advent of plate tectonics the area was interpreted usually in geosynclinal theory, and the two fold belts were regarded as sedimentary piles thrust towards a common foreland. Fig. 8 shows the model of Aubouin (1972). Pieri (1966) had a very similar one. Both mark an axis along the centre of the Adriatic (Pieri calls it the Centripetal axis), which is the common foreland for thrusts converging from the Apennines and the Dinarides. In Pieri's version the centripetal axis swings east towards the Ionian zone of Albania. This is indeed the basic structure, but the nature of the foreland is variable. As described earlier, the Po Plain, if regarded as a foreland, consists of unfolded sediments deposited over at least the past 25 million years. Further south, the Italian foreland is unfolded (fig. 2), while further east the Adriatic has a succession of basins (fig. 6), indicating differential subsidence but not folding.

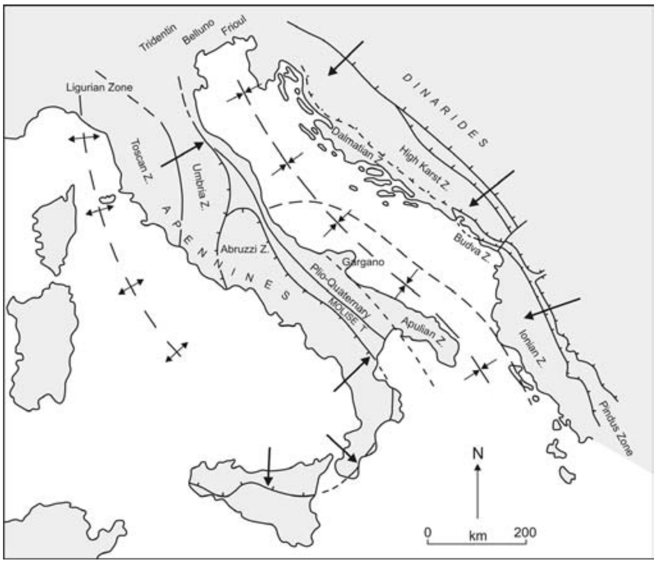

FIG. 8 - Tectonic model of the Apennine-Adriatic-Dinaric system (after Aubouin, 1972).

Van Bemmelen had similar ideas, but added a cause for the thrusting. He envisaged the intermittent growth of large domes (geotumors), from which the overlying strata slid radially to a lower position. To concentrate on the Apennine side, Van Bemmelen (1972a) described pulses of doming in the area of what is now the Tyrrhenian Sea, the most recent of which was in Mid-Pliocene, since when it collapsed to bathyal depths at a rate of 1mm/yr. An orogenic crustal wave migrated radially outwards from the Tyrrhenian centre accompanied by radially outward directed overthrusts, imbrications and other compressive tectonic features. «The driving forces of this orogeny are evidently active from the concave side of the orogenic arc».

In Van Bemmelen's day the geology of the Dinarides was not as well-known as it is today and he had less to say about it, but his figures show that he considered them similar in setting to the Apennines. He produced a map in 1933 (more accessible in Van Bemmelen, 1972b), reproduced here as fig. 9, which was very much ahead of his time. It shows a symmetrical plan of ranges and other features, and the geotumor that gave rise to the Dinarides is located near the site of the present Pannonian Basin. The directions of thrusting that he depicts are similar to those of Pieri (1966) and Aubouin (1972).

GRAVITY TECTONICS

Picha (2002) shows a section of the Dinarides, where many of the thrusts are based in a major evaporite stratum, suggesting gravity tectonics. The Dinaric Platform is thrust over these, in the same direction.

Gravity sliding has also been postulated for the Apennines, with different behaviour in different places depending on whether the basal glide planes were in gypsum,

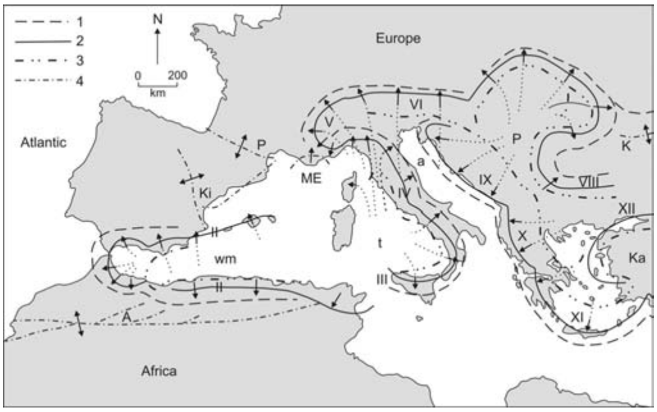

FIG. 9 - Tectonic features of the Mediterranean region (From Van Bemmelen, 1933). 1 = Foredeeps; 2 = Non-volcanic outer arcs with nappes; 3 = Volcanic inner arcs; 4 = Foreland ranges.

dolomite or salt. For example, de Feyter & *alii* (1986) wrote: «The structural features… are typical of thin-skinned fold-and-thrust belts. They resulted from gravitational spreading and detachment tectonics interacting at various levels throughout the Miocene».

Recent support for the gravity tectonics in the Apennines comes from Centamore & Rossi (2008), who wrote: «… the forming of the compressional structures are mainly referred to gravity-related forces driven by asthenospheric domings» and «… the flexuring of the Adria foreland seems due more to the effects of the load of the coupled lithosphere, detached from the outer megadome flank, than to a retreat of a subducted slab». With a boldness seldom seen since van Bemmelen's work, their fig. 2 suggests gravity detachment extending perhaps to the mantle.

PLATE TECTONIC EXPLANATIONS

Plate tectonic explanations of the region tend to come in two different kinds. There is a general story of the collision of African plate and the European plate, or in more detail the collision of a promontory of the African Plate, the Adriatic or Apulia plate, with the European plate (e.g. Mele 2001). For example, Robl & Stüwe (2005) write: «The eastern part of the European Alps has been described as a typical example of an orogen formed by indenting one continent into another. Within this model, the southern, Adriatic plate is assumed to be rigid and to have indented obliquely into a softer region along the southern margin of the European plate». Coward & Dietrich (1989) write of the «Adriatic promontory of Africa» thrusting in a variety of directions into the European plate. They also write that «The Adriatic promontory however was not rigid, but suffered a considerable amount of crustal extension throughout the Mesozoic», which is somewhat strange in a supposedly compressional environment.

At a different level there are interpretations of subduction (and other plate tectonic processes) at more specific sites. Different authors have used most of the plate tectonic supplements such as obduction, roll-back, indenters, back-arc spreading, and extrusion.

Early maps of the Adria plate (Dewey & *alii*, 1989) show Adria attached to Africa in the Late Jurassic, but it starts to drift away in the mid-Cretaceous, and collision between Adria and Europe starts in the Oligocene.

Ager (1980) is quite specific, and his fig. 17.2 (see fig. 10 in the present paper) shows both Italy and the lands east of the Adriatic as far as Greece as part of the Adriatic Microplate. Ager (1980) noted that the plate tectonic story of the Mediterranean is dominated by microplates. «No fewer than twenty-one such microplates have been postulated for the Mediterranean area, with one for every place where Palaeozoic rocks happen to reach the present surface. I find this excessive and at variance with all the borehole and geophysical evidence of geologically recent inversions». But although Ager was not happy with the large number of microplates postulated for the Mediterranean region, he was insistent about the unity of the Adriatic plate. «All round the Adriatic and particularly in carbonate facies there are shallow-water, benthonic faunas quite different from those of the rest of Europe. These are seen most clearly in the Apennines, the Southern Alps, the Dinarides and the Hellenides… I am more impressed by this stratigraphical and palaeontological evidence than by any amount of structural evidence».

If we accept Ager's view of the significance of the palaeontology, it is impossible to assemble a realistic Adriatic plate from far-flung regions that earlier had nothing in common.

But even if Ager's plate is accepted, there is still a strange coincidence. His figure shows the Adriatic Plate drifting into a space of just the right shape and size to accommodate it. This is similar to many figures showing In-

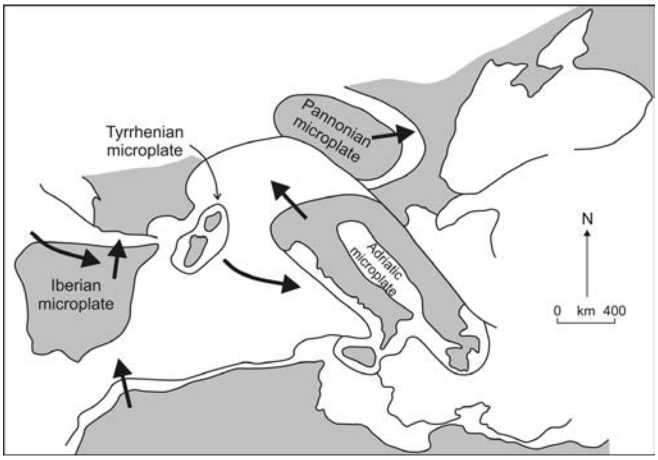

FIG. 10 - The Adriatic Microplate according to Ager (1980). Note that in this version the Plate includes not only the Adriatic Sea but all Italy and the Dinarides as well. It seems that the Pannonian Plate is moving aside to make room for the Adriatic Plate to drift the the north west.

dia drifting into an ideally-shaped gap to collide with Asia and make the Himalayas, but nevertheless the coincidence should provoke suspicion.

Rosenbaum & *alii* (2004) have a different view, and their fig. 1 shows Adria as covering only the Adriatic and the Po Plain, bounded by the Apennines, Dinarides-Albanides and the Alps. This seems a very small plate to be responsible for the formation of the Alps by its collision with Europe, which is a widely-assumed model. They claim that «Since the Jurassic, Adria and Africa have shared a relatively coherent motion path». Robl & Stüwe (2005) write: «Within this model, the southern, Adriatic plate is assumed to be rigid and to have indented obliquely into a softer region along the southern margin of the European plate…».

Chennell & Howath (1976) show the variations on the theme back to Argand in 1924 (their fig. 1). Motion of the Adria plate is supposed to cause compression. They wrote (p. 96) «The northward motion of Africa explains the Eocene-Oligocene compression of the Alps, Dinarides and Hellenides…» But of course it completely fails to explain the Apennines, which they never mention in this context.

Channell & *alii* (1979) clearly depict the Adria Plate (their figs 7, 8, 9) as including all Italy, the Adriatic Sea and the Dinarides. They write that «The Adriatic «subplate» consists of a stable foreland, most of which is now submerged beneath the Adriatic, and a surrounding orogenic belt made up of the Apennines, Southern Alps, Dinarides and Hellenides». But a foreland is merely a tectonic description of the stable block that thrust belts push against, so we have to imagine an Adria plate carrying a core that will become a foreland and a margin that will become thrust belts. However, they also depict nearby microplates (Moesian, Rhodope, Tisia) that are separated from Adria by marine environments, and say subsequent tectonics is caused by collision of the micro-plates. The description of the Adriatic Plate or subplate seems schizophrenic: does it or does it not include the Apennines and the Dinarides?

Ilic & *alii* (2005) show (their fig. 4) the Adriatic microplate being subducted under the Dinarides by the Late Cretaceous. Rosenbaum & *alii* (2004) claim «the Ionian lithosphere in the Calabrian arc has been subjected to rapid rollback, which commonly occurs only when the subducting slab is made of oceanic lithosphere».

Italian explanations usually invoke movement of Italy towards the Adriatic. This may result from the opening of the Tyrrhenian Sea (a known spreading site between the Sardinia block and Italy), or separation of Italy from France and rotation to its present position.

Locardi (1988) suggested a rotation of Italy around a fulcrum in the north, which created the Ligurian sphenochasm (fig. 11). Another version of rotation with a different fulcrum of rotation is provided by Castellarin & *alii* (1992) as shown in fig. 12. In either of these models it is odd that the Adriatic - Po Plain 'plate' is not compressed, and neither model explains the Tyrrhenian spreading site.

Contrasting dates and mechanisms come from Stein & Sella (2006). They think Adria became detached from

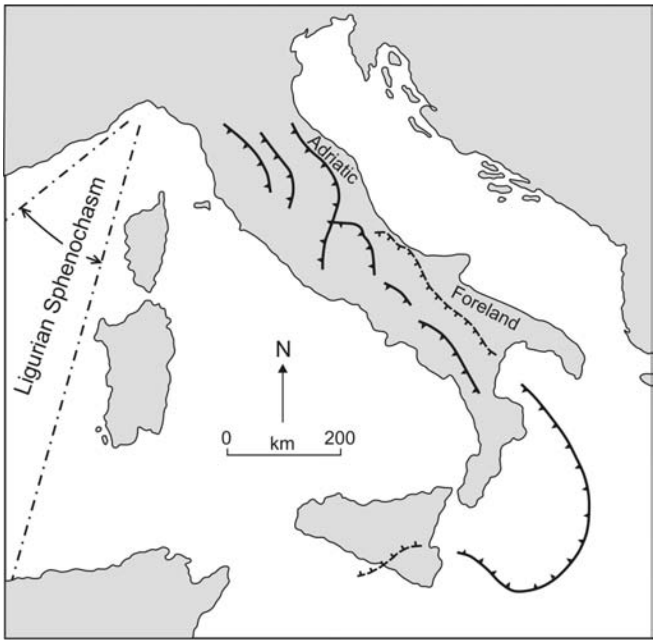

FIG. 11 - Formation of the Apennines by collision with the Adriatic Foreland caused by rotation of Italy as a result of opening of the Ligurian Sphenochasm (simplified after Locardi, 1988).

Africa in the Mio-Pliocene. Convergence occurred as Adria moved north-eastward with respect to Eurasia "because the faster back-arc spreading in the Tyrrhenian Sea caused Adria to move southwest with respect to Italy". Also, "The Transition from convergence to extension in the Apennines in the past 2 Ma resulted from the cessation of subduction in the Apennines accompanied by breakoff

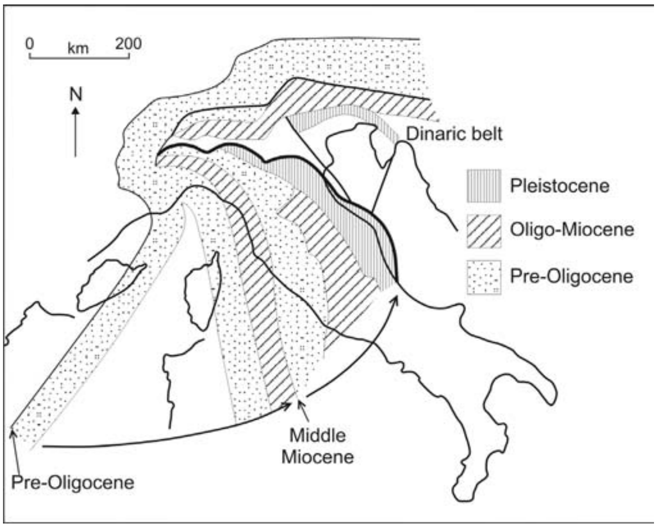

FIG. 12 - Evolution of the Apennines by rotation (simplified after Castellarin & *alii*, 1992). The rotation appears to affect the Alps and part of the Dinarides, though their sense of movement is opposed to that of the Apennines.

of the subducting Adria slab, and the associated cessation of back arc spreading in the Tyrrhenian Sea".

Beccaluva & *alii* 1997 describe "suprasubduction" in the Dinarides of Albania. Their fig. 6 shows subduction of a large amount of sea-floor between the Jurassic and Eocene, with only a bit remaining today as ophiolites. The diagram implies a large ocean offshore of Albania, but of course this history is earlier than the younger thrusting that made the nappes. Despite the large ocean, they still have an image of "plates" and write «Overthrusting of the Mirdita Zone [ophiolites and Triassic-Jurassic sedimentary rock] onto the Krasta-Cukali Maastrichian-Paleocene flysch may correspond to the collision between Pelagonian and Apulian continental plates, which may have occurred since Late Eocene».

Picha (2002) notes a contrast between the Apennines, where thin-skinned thrusting progressed normally to the foreland, and the Dinarides where the frontal zone is characterised by NW-SE faults, which he interprets as right-lateral strike slip faults. These are said to «indicate the existence of escape tectonics in the Dinaric-Hellenic region» by which he means tectonic transport from the collision zone of Apulia with Europe towards the subduction zone of the Hellenic Trench. Picha (2002) adds that to the north of the Adria plate lie the Southern Alps and the Insubric lines, and that the plate «represents a foreland for all three thrust belts».

Bortolotti & Principi (2005) believe the ophiolites were originally more or less in a straight line. «The present scattering of the ophiolites is a consequence of the Orogenesis…» Their fig. 11 shows the Italian Peninsula and the attached Adria Plate swinging counter-clockwise and moving north into their present position since the Jurassic.

SEISMICITY

The seismicity of this part of the world has been discussed in detail by Scalera (2008). He finds the seismicity does not reveal plate boundaries for the hypothetical Adriatic Microplate. Where Benioff zones should be present, with deep and intermediate hypocenters only shallow seismicity is detected. In the Apennines, for example, hypocenters are rarely below 50 km though a festoon can be recognized. His figures show deep earthquakes only in the Calabrian Arc (he terms it South Tyrrhenian) and Aegean, but no sign of earthquakes marking an Adriatic Plate. Furthermore, the hypocenters do not arrange themselves along inclined planes or spoon-like surfaces but display a series of elongated clusters or filaments that taper towards greater depth. They are present under the actively rising parts of orogens. Scalera believes these narrow isolated plumes of deep foci cannot be sites of subduction but are related to uplift of deep mantle material. «The evidence points to vertical displacements of materials as the main process responsible for deep earthquakes, volcanic phenomena and orogenesis».

He wrote «The geographical position of the four deep foci clusters, their narrowness and azimuth are not compatible with mechanical processes linked to a very long front of subduction between Africa and Eurasia». He further notes «Most geoscientists admit, without a valid explanation, that in this region subduction occurs largely aseismically». Such an attitude, not based on observation, would seem to us to be utterly unscientific: the idea that earthquakes mark a Wadati-Benioff zone is the prime support for the subduction hypothesis.

MORPHOTECTONICS

Another constraint on tectonic hypotheses comes from geomorphology and its relationship to tectonics-morphotectonics.

In the Apennines, after the folding and thrusting created the Apennine structures, there was a major erosion phase that created a planation surface that covered much of the country in the Pliocene. Neotectonic uplift created the present topography, on which the modern drainage evolved. The Italian peninsula as a whole is actually dominated by extension, which gives rise to the angulate drainage patterns of western Italy in contrast to the parallel drainage to the Adriatic (fig. 13). It is interesting to note that in plate tectonic terms the plates have been moving since the Jurassic, but thrusting of the nappes occurred in the Neogene, and uplift of the mountains is Plio-Pleistocene.

It has long been known that the Apennines were planated in the Pliocene (e.g. Demangeot, 1965), and most of the mountain building is due to Neotectonic vertical uplift in the Plio-Pleistocene. More recent work only reinforces this idea. Coltorti & *alii* (2008), for example, studied part of the northern Apennines and found that in the Early-Middle Pliocene rivers came from the Tyrrhen-

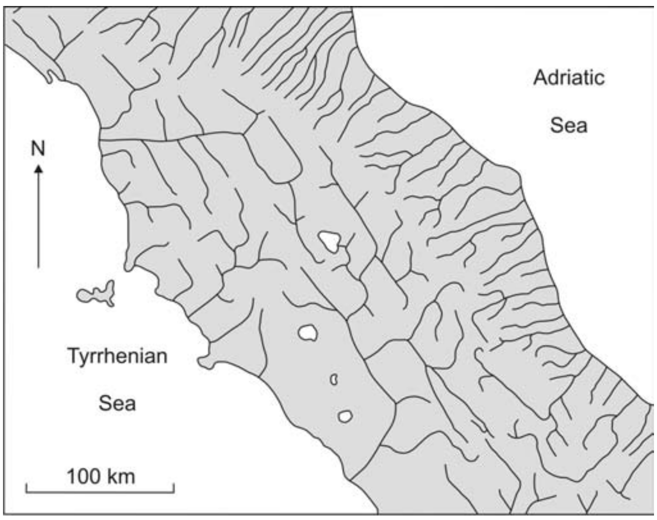

FIG. 13 - Drainage pattern of the central Apennines. Note the angular drainage on the western side associated with normal faulting, long after the thrusting that formed the nappes. (simplified after Mazzanti & Trevisan, 1978).

ian side across the Apuane Alps, carrying gravels of the Tuscan units, and at that time the Apennines did not exist. They were uplifted rapidly since the Early Pleistocene.

The Dinarides have not been studied to the same extent as the Apennines, but plenty erosion surfaces are obvious, though their age has not been determined so far as we know. The nappes and other major structures were formed in several compressive phases starting in the Cretaceous-Paleocene (Becculava & *alii* 1997), but these were planated before the uplift that created the present topography. Shehu (2004) suggests the last phase of uplift began about 2.5 million years ago.

The major "grain" of the country, that is the orientation of rocks, structures and topography is roughly NNW-SSE. Significantly there are rifts and rift valleys in the same direction, reflecting a late phase of extension, long after thrusts and overfolds were emplaced.

In Albania three major rivers, the Drin, the Devoll and the Vijose, start from relatively low land in the east and flow west to the Adriatic. The only way this could happen is by antecedence, which means that the major east west drainage was in position before the uplift of the Dinarides (which includes most of Albania). Thus major drainage was towards the Adriatic before the uplift of the present mountains and the break-up of topography by extensional faults. The major rivers maintained their antecedent courses by erosion during uplift, but tributary valleys are strongly influenced by structure.

The Plio-Quaternary tension and vertical uplift might suggest that there has been a change in tectonic style since earlier plate movement and subduction. But some think the plate movement is still on-going, and try to quantify it by GPS measurements (Battaglia & *alii*, 2004a, b).

CONCLUSIONS

The Apennine-Adriatic-Dinaride region appears to be a consistent block, with the Apennines and Dinarides being thrust towards a common foreland, though diverging to the south. A large number of interpretations have been presented, from simple geosyncline and thrusting, so some vastly different plate tectonic models, involving transport, subduction, in a very large range of directions and distances moved. The palaeontological evidence suggests a unity of the region since the Mesozoic, so long distance travel of different part of the region seems hard to sustain. Because the central (Adriatic) block is least disturbed, it seems more likely that the Apennines and Dinarides were thrust towards a common foreland, than that the Adriatic Plate was subducted under both. To the north the Po Plain replaces the Adriatic Sea, but is underlain by kilometres of horizontal sediments, so again the thrusts on both sides (in this case the Northern Apennines and the Southern Alps) have been thrust towards each other, but did not compress the central axis. It is hard to envisage the Po Plain being subducted both southwards under the Apennines, and northwards under the Southern Alps.

In parts of both the Apennines and Dinarides evaporites are involved in the slide planes, and suggest gravity tectonics. Elsewhere, and particularly in the Dinarides, ophiolites are associated with the thrusting. Although these have been the centre of much attention, they do not seem to relate to thrust mechanisms, and are just another old rock in the thrust belts. The thrusting did not make the present mountains. Certainly in the Apennines, and probably in the Dinarides, there was extensive planation in the Late Miocene to Pliocene. This was followed by vertical uplift, accompanied by extension and normal faulting, especially those parts of the Apennines and Dinarides that are further from the Adriatic foreland.

We may not know the full explanation of the present structure, but it shows a unity and symmetry that does not fit well with far travelled micro-plates. In fact the region as a whole does not support the concept of an Adriatic Plate drifting north, or the idea of collision between Africa and Europe.

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