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The Palinspastic Problem of the Hellenides

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ABSTRACT

The Hellenides are an Alpine nappe system with a southwesterly vergence. Before orogeny, most of the nappes formed part of the southern continental margin of the Mesozoic Tethys sea, with the ophiolite nappe originating in the adjacent deep ocean. The continental margin was of the stable carbonate type found now, e. g., in the Florida-Bahamas-Blake plateau region, and was characterized by rather irregularly distributed "carbonate platforms" where thousands of meters of shallow water carbonates were deposited, and which were separated by deep water passages and basins with pelagic sedimentation. The orogenic history of the internal Hellenides is essentially that of two major compressive phases (late Lower Cretaceous and Late Eocene), each followed by differential vertical block movements (in the late Lower to Upper Cretaceous and in the Oligocene to Plio-Pleistocene, resp.).

1. Introduction

This article was prepared as a formulated basis for discussion on the field trip to northern Greece organized for the "Commission on Structural Geology" of the "International Union of Geological Sciences". The main purpose of this trip was the study of the tectonic role of ophiolites in Alpine orogeny. The article was distributed to the participants and is here published with only a few additions which discussions have shown to be advisable. It is kept brief as detailed argumentation is planned for special publications.

The Hellenides are an Alpine-type mountain system composed of a pile of nappes. This view, already expressed by Renz (1940, 1955), has been confirmed by recent detailed mapping (Aubouin 1959; Brunn 1956, 1959; Celet 1962; Dercourt 1964; Godfriaux 1968; Mercier 1966; Geologic Map of Greece) though there are anti-nappists at work here as elsewhere in the world.

The kinematics and palinspastics of the nappes, including the preorogenic or «geosynclinal» history, however, are another matter again. The best publicized view is Aubouin's (1958, Pl. 1; 1965). Its rigid schematism, unfortunately, does not apply everywhere (criticism by Debelmas et al. 1966). Indeed, there is no actualistic counterpart for Aubouin's geosynclinal schemes anywhere in the world, and certainly there are other possible models, and to these authors more satisfactory ones, for the preorogenic arrangement of facies zones and for orogenic development in the Hellenides.

As an alternative, we should like to propose here an actualistic continental margin model. This, of course, is now rather commonplace. It has been suggested for the Alps by Laubscher (1967, 1969) and contemplated by us, though never published, for the Hellenides since 1968. Though the general features of the model are clear, the specific ones for the Hellenides are still somewhat ambiguous and call for reasoning on circumstantial evidence.

2. Premises for a working hypothesis

The varying facies of the Hellenide limestone nappes bear an obvious resemblance to present continental margins of the stable carbonate variety, of which the best-known is the Florida-Bahamas-Blake Plateau region. Indeed, this model has been used by the writers for some time now to illustrate the southern continental margin of the Tethys ocean from the Apennines through the Southern Alps and Austroalpine nappes into the Dinarides and Hellenides (Bernoulli 1969, 1972). The "Bahamas" model combines the following features which are most relevant for the external Hellenides (Fig. 1 and 2):

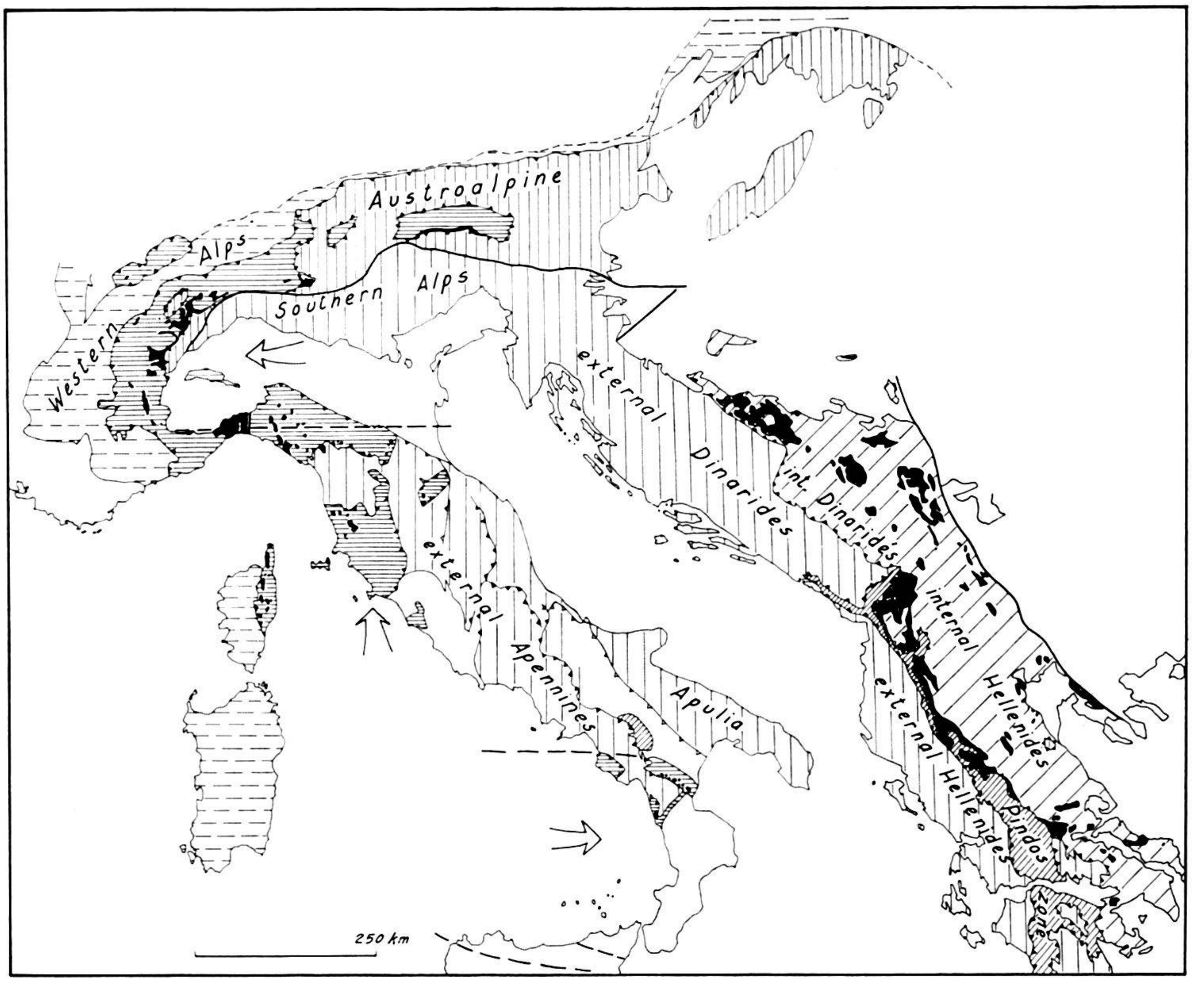
1. A carbonatic continental margin several hundred kilometers wide, differentiated into irregular belts of shallow and deep water.

2. Deposition of sediments several kilometers thick by subsidence through a time span on the order of at least 100 million years (perhaps 150 my for the Bahamas). For the Bahamas, Dietz et al. (1970) have pleaded in favor of an oceanic basement; however, the basement of the thick carbonate series of the southern Tethys is continental wherever exposed (Southern Alps, High Karst zone, Durmitor zone).

3. Ophiolites in the oceanic crust bordering the carbonate zone. This view implies allochthony for the ophiolites in contrast to the well-known interpretation by Brunn (1956) and Aubouin (1959, 1965) who postulate huge submarine flows within the stratigraphic sequence. The case against such flows has been argued in many articles and is not repeated here (e. g. Thayer 1967, p. 231).

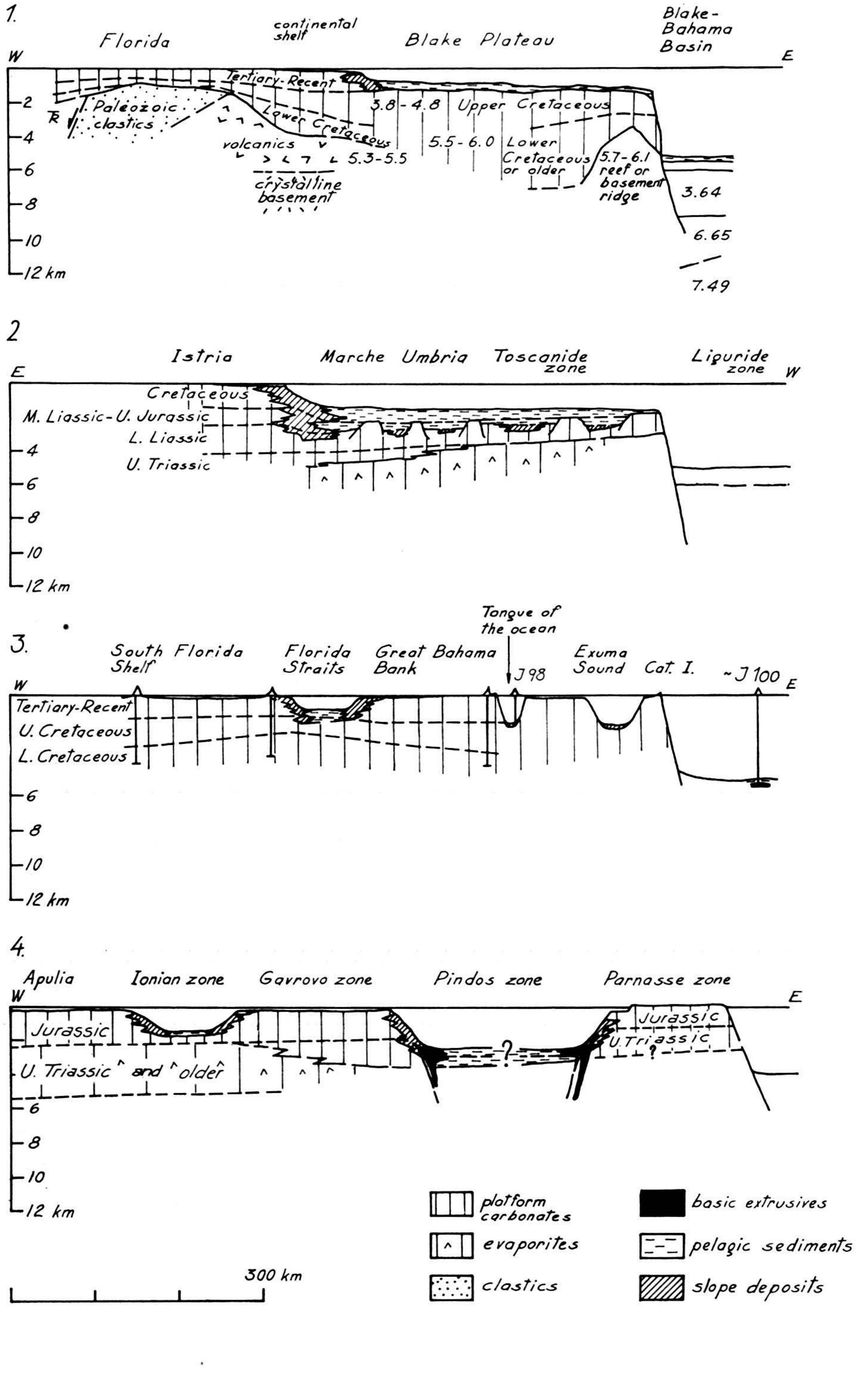
In Greece, the positions of these (orogenically external) carbonate platforms and deeper water areas are well known up to the Parnasse, but more internal elements are partly covered by the ophiolite suite and interpretation is controversial. Certainly, platform carbonates reappear in the Olympus window, they cover parts of the Pelagonian basement, and even more internally there are shallow-water carbonates in several of Mercier's (1966) subzones of the Vardar zone. All of these must have been components of continental margins, as viewed in our model, but it is uncertain in Greece whether the more internal ones had been continuous portions of the same continental margin as the external limestone nappes, or whether they had been micro-continents separated from the continent by oceanic crust.

This problem may be formulated more specifically: do the "subpelagonian" ophiolites root southwest of the Pelagonian realm, as assumed by Brunn (1956) and Aubouin (1959) (cf. also Moores 1969), or have they been transported across it from the northeast as a huge ophiolite nappe which was later partially eroded in some places and folded down in others (cf. Fig. 3 C; Laubscher 1971a; Zimmerman 1971)? On the face of it, the thickness and completeness of the "subpelagonian" ophiolite suite and the covering sedimentary sequence favors the first hypothesis (Moores 1969), but generally the polarity of facies development in Greece and in the surrounding regions – Turkey and Yugoslavia – favors the second. In Turkey, there is no evidence for a root of the Lycean ophiolites on the south side of the Menderes "massif" which is the eastern continuation of the Pelagonian nappe (de Graciansky in Brunn et al., in press, and oral communication, 1970). In Yugoslavia, north-west of the Skutari-Peć lineament, the High-Karst which corresponds to the Parnasse zone is followed more internally by a partly pelagic zone (Kuči zone, Ćirić 1963; Prekarst zone, Blanchet



- Alpine tectonic units of the northern continental margin of the Tethys: Helvetic, Ultrahelvetic zones, Chaînes subalpines, Jura Mountains, Sardinia, Corsica.
- Pennine and Ligurid nappes, including elements of the north Pennine basin and the Briançonnais ridge.
- Internal zones of the Dinarides and Hellenides.
- Pindos and Lagonegro zones: Upper Triassic-Cretaceous pelagic basins with unknown basement.
- Alpine tectonic units of the southern continental margin of the Tethys with a general "southern" vergence: external zones of Dinarides, Hellenides and Apennines; Southern Alps, Istria, Apulia.
- Alpine tectonic units of the southern continental margin of the Tethys with a northern vergence: Austro-Alpine nappes, Transdanubian Mountains, internal Carpathians.
- Ophiolites of the central Tethys.
- Overthrusts, mainly Paleogene-Neogene. The Cretaceous nappe structures are not indicated.
- Deep fracture zones, strike-slip faults.
- General direction of Neogene translations.

Fig. 1. Schematic tectonic map of the central Mediterranean area, mainly after LAUBSCHER (1971a, 1971b).


1.
Florida
continental shelf
Blake Plateau
Blake-Bahama Basin
W
E
Tertiary-Recent
Paleozoic clastics
Lower Cretaceous
volcanics
5.3-5.5
crystalline basement
3.8-4.8
Upper Cretaceous
5.5-6.0
Lower Cretaceous or older
5.7-6.1 reef or basement ridge
3.64
6.65
7.49
2
4
6
8
10
12 km
2
Istria
Marche Umbria
Toscanide zone
Liguride zone
E
W
Cretaceous
M. Liassic-U. Jurassic
L. Liassic
U. Triassic
3.
South Florida Shelf
Florida Straits
Great Bahama Bank
Tongue of the ocean
J 98
Exuma Sound
Cat. I.
~J 100
Tertiary-Recent
U. Cretaceous
L. Cretaceous
4.
Apulia
Ionian zone
Gavrovo zone
Pindos zone
Parnasse zone
Jurassic
U. Triassic and older
U. Triassic
platform carbonates
evaporites
clastics
basic extrusives
pelagic sediments
slope deposits
300 km

et al. 1970, cf. DIMITRIJEVIĆ et al. 1968) and then by the complex and still poorly understood Durmitor nappe system (BLANCHET et al. 1969; RAMPNOUX 1969). This constitutes the extension of a complex carbonate continental margin far beyond the Parnasse platform. Indeed, one would surmise that a part of the Durmitor zone somehow corresponds to the Pelagonian zone of Greece. The correlation, though, is not straightforward as the Skutari-Peć transverse structure intervenes.

All this local and regional evidence taken together, we believe, enhances the plausibility that in northern Greece the Mesozoic carbonate continental margin originally continued beyond the Parnasse into the Pelagonian zone and possibly even into the Vardar zone where the root of the ophiolite nappe has been largely demolished by later events. A schematic exposition of the kinematic consequences of this assumption for the development of the internal Hellenides is given in Figure 3.

3. A working hypothesis

Figures 4 to 6 illustrate a rough working hypothesis for which the premises have been set forth in the preceeding chapter.

Figure 4 corresponds approximately to the situation during the Late Jurassic. The Tethys ocean is bordered by a "Bahamas"-like carbonatic continental margin. It consists of irregular subsided plateaus with partly pelagic sedimentation (as on the Blake Plateau), partly, where carbonate sedimentation kept pace with subsidence, with shallow-water limestones (as on the various platforms of the Bahamas proper). They are separated by deep passages (Pindos trough) with pelagic and turbiditic sedimentation continuous since the Triassic. Though in roughly parallel belts, they are irregular and discontinuous in detail.

Some special features thought to be significant for the orogenic development of the Hellenides have been built into the model, to wit:

1. In the region of the Pelagonian plateau the continental seaward slope is shown to trend obliquely with respect to the external (continentward) slope of the plateau. This is of possible significance for the discordant external boundary of the "subpelagonian" ophiolites as observed today, for the pattern of partial coverage of the Pelagonian plateau by the ophiolite nappe of the Cretaceous orogeny, and for the appearance of ophiolite debris in the "premier flysch du Pinde" of Albian-Cenomanian age (see Fig. 5).

2. The abrupt swing to the northeast of the continental slope in the northern part of the figure is assumed because of the Skutari-Peć transverse structure (Fig. 1, see Fig. 5 and 6). The irregular northwestern termination of the Pindos zone is indicated by facies developments and is probably also significant for the orogenic development of the Skutari-Peć zone (RADOIČIĆ and SCANDONE, personal communication, 1969).

Figure 5 portrays the main features of the Cretaceous (?Albian) orogeny. If the continental slope and rise (ophiolite to subophiolite nappes) are translated to the southwest on and over the adjacent continental margin as indicated by the arrow, the

Fig. 2. Comparison of Recent continental margins of Atlantic (Bahamas) type with continental margins of the Mesozoic Tethys. North American continental margin (1 and 3) after SHERIDAN et al. (1966). Sections 2 and 4 give the preorogenic situation in the central Apennines during the Late Cretaceous, and in the Hellenides during the Late Jurassic, respectively.

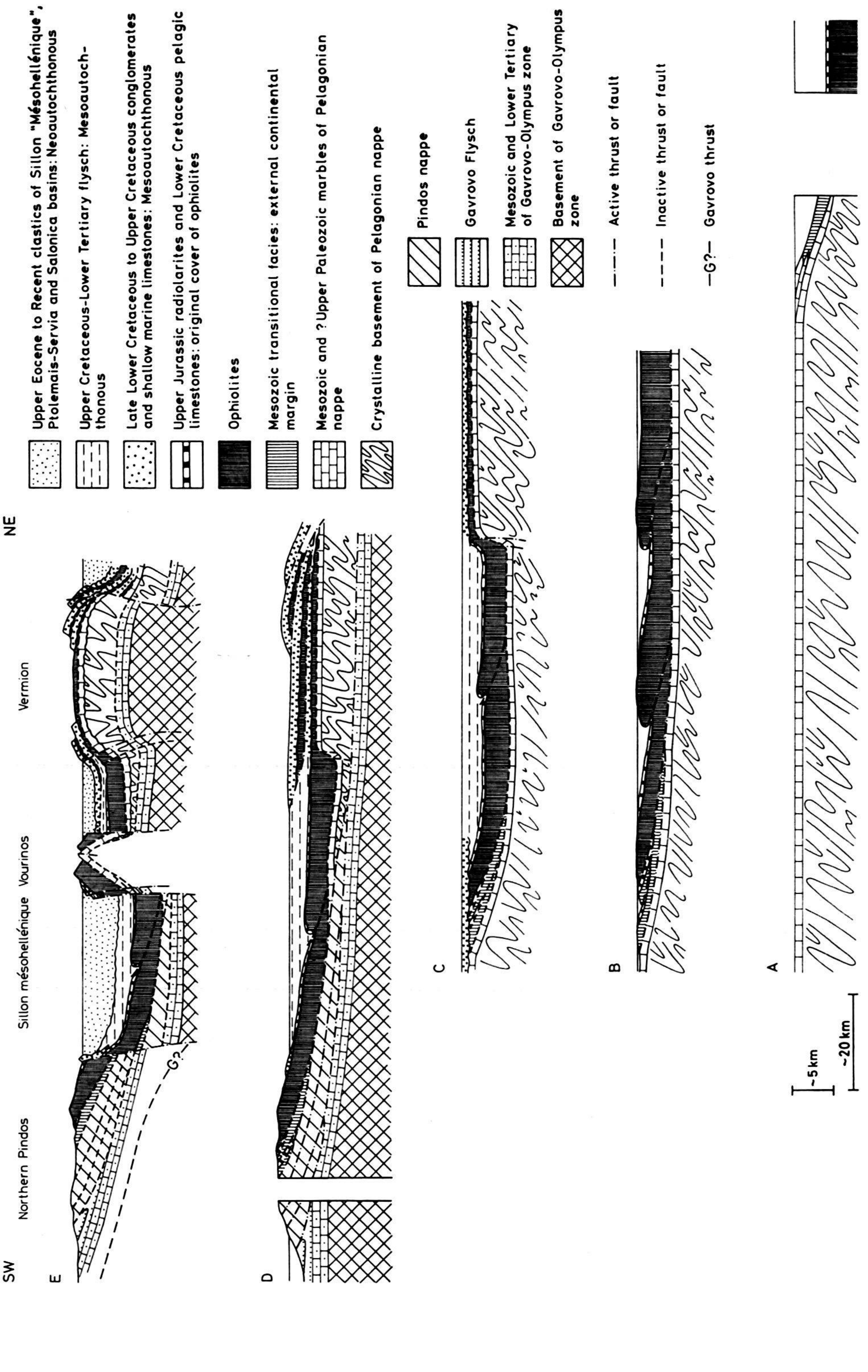


Fig. 3 The development of the internal Hellenides (schematic profiles).

A Pre-orogenic continental margin complex (cf. Fig. 2). Because of space requirements, a gap between the ocean and continental margin suites had to be inserted.

B Late Early Cretaceous orogeny. The oceanic ophiolite nappe – with a complex internal structure – is thrust southwest on the external continental margin sediments which are largely bulldozed out and frontally accumulated as a pile of imbrications or nappes (Kallidromon, Othrys).
The basal part of the continental margin sediments – neritic limestones of Triassic – Jurassic age – passing upward into siliceous limestones and cherts with volcanics, are left in a parautochthonous position. They were somewhat detached from basement and subjected to probably slight differential movements. At a late stage, centrifugal spreading of movement may have added internal thrusts cutting from the basement through the ophiolite nappe, thus adding limestone nappes as a source for the Upper Cretaceous conglomerates of the Pelagonian and Vermion units (not represented on Fig. 3). Possibly such structures have also contributed to the complexity of the Vardar zone. A part of the nappe may have remained below sea-level during transport and received synkinematic sedimentation similar to that postulated for parts of the Apennines by MERLA (1951) and others (cf. SESTINI et al., 1970).

C Postorogenic differential vertical movements. In the Pelagonian, the Vermion, and part of the Vardar units uplift and erosion eliminated all but inconspicuous remainders of the ophiolite nappe. In the Vourinos and some parts of northern Pindos and Othrys moderate uplift, or even subsidence, preserved the main part of the ophiolite nappe and its covering sediments, and there are places where the Middle Cretaceous unconformity is not readily recognized though as a rule it is very pronounced. In the Upper Cretaceous general subsidence follows the differential vertical movements.

D Paleogene (mostly Late Eocene) orogeny. Internally, a series of thrust slices and nappes, usually with decollement in the serpentinites of the Early Cretaceous ophiolite nappe, is thrust upon the Pelagonian zone (particularly Vermion nappe). Centrifugal mobilization of basement leads to the southwestward thrusting of a composite nappe: its rear part consists of a slab of Pelagonian basement with its cover of Mesozoic marbles, the remainder of the Cretaceous ophiolite nappe with its unconformable Upper Cretaceous to Eocene sediments and the internal thrust slices; the middle part is dominantly made up of the well preserved portions of the Cretaceous ophiolite nappe; and the frontal part is an imbricated pile of ophiolites and Pindos (or in some places Parnasse-) sediments. The existence of this composite nappe follows necessarily if the Olympos window in the Pelagonian nappe is taken at face value and associated either with the Parnassos or, as is preferred in this article, with the Gavrovo zone. If this latter view is accepted, it follows further that the Pindos sediments were detached from their basement (whatever its nature) and pushed frontally away by the composite Paleogene nappe instead of having been overridden by it: there is no Pindos nappe between the Pelagonian frame and the sediments of the Olympos window. The imbrications and thrusts of the ophiolites on the Pindos flysch in the Pindos mountains would be of a secondary and comparatively local nature, defining subunits of the composite Paleogene nappe system. How far back below the "Sillon Mésohellénique" this overriding of Pindos flysch by ophiolites continues is unknown; in Fig. 3 it has been assumed that it extends through the full width of the "Sillon" which would make it a very substantial thrust. Marine development in the later "Sillon Mésohellénique" has apparently begun before the final emplacement of the composite nappe during the Late Eocene (BIZON et al., 1968).

E Post-Eocene to Flio-Pleistocene differential vertical (and horizontal) movements. The dissection and deformation of the Paleogene nappe system by differential vertical movements is analogous to that of the Middle to Upper Cretaceous following the late Lower Cretaceous orogeny. In the central part a segment of the composite nappe subsides and is covered by several thousand meters of Tertiary sediments ("Sillon Mésohellénique"); other segments disappear below the Pliocene Kozani-Ptolemais system of basins; in between, the Vourinos and related mountains remain as a complex high where the ophiolite nappe and its substratum are exposed. As in the Middle Cretaceous, the Pelagonian zone is again uplifted, though not along the same faults and flexures; the frontal parts of the Cretaceous high lie below the Kozani basin, and its rear part below the Salonica basin depression. Zones of steepening that border the depressions should not be considered as root zones, e.g. the external flexures of the Salonica or the "Sillon Mésohellénique" depressions!

The authors realize that information at present is unsufficient to prove this solution to be unique or even ultimately adequate. However, they know of no contradictory data and of no model which would provide a similarly unified and simple sequence of events.

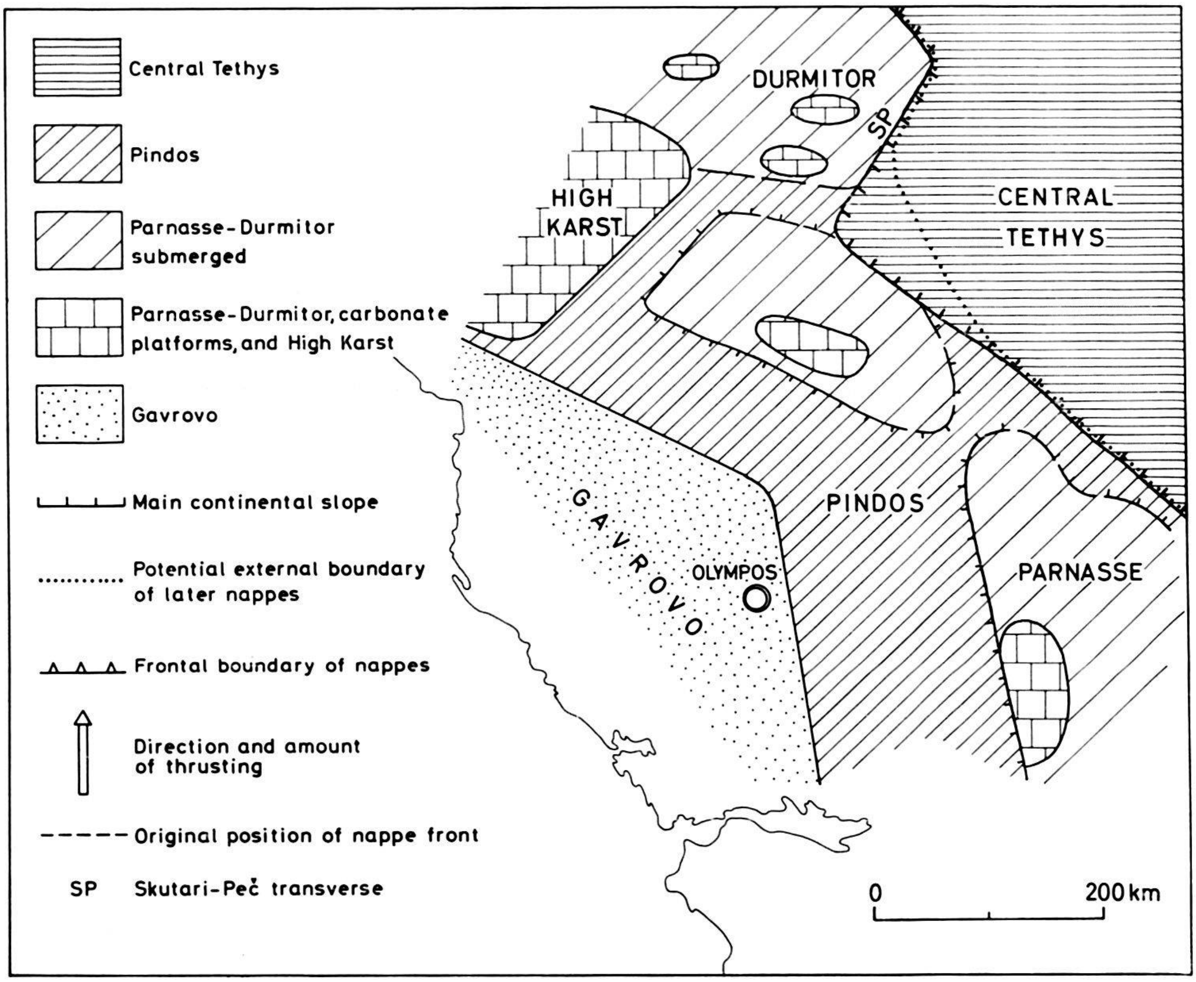


Fig. 4. The pre-orogenic (Upper Jurassic) configuration of the southern continental margin of the Tethys in the Hellenides. Detailed explanation in the text.

Cretaceous mountain front assumes the position as shown. A good part of the Pelagonian plateau is completely covered, but in the southwest the Parnassos remains outside the ophiolite nappe. The erosional products of the ophiolites are partly transported into the Pindos trough to be deposited as "premier flysch du Pinde" (AUBOUIN 1958, 1959). Subsidence of the continental margin continues, and the largely eroded ophiolite nappe is submerged again in the Cenomanian, and partly already in the late Albian. The northeast trending segment SP of the continental slope plays the role of a dextral sink–sink transcurrent fault („transform fault"), and begins to construct the Skutari-Peć line.

Figure 6 sketches some main features of the Paleogene orogeny, in particular the Pindos thrust. Not considered are the Paleogene thrusts that dissect the Cretaceous nappe system and its Late Cretaceous to Early Tertiary cover (e. g. Vermion nappe, BRUNN 1959; BRUNN et al. 1970) and the final emplacement of the ophiolites on the Pindos zone; for this see Figure 3. The Pindos thrust is discordant with respect to the thrust of the ophiolite nappe, and this in turn may have had important consequences: the thrust-sheet is widest in the south and disappears almost completely near the Albanian border (Fig. 1).

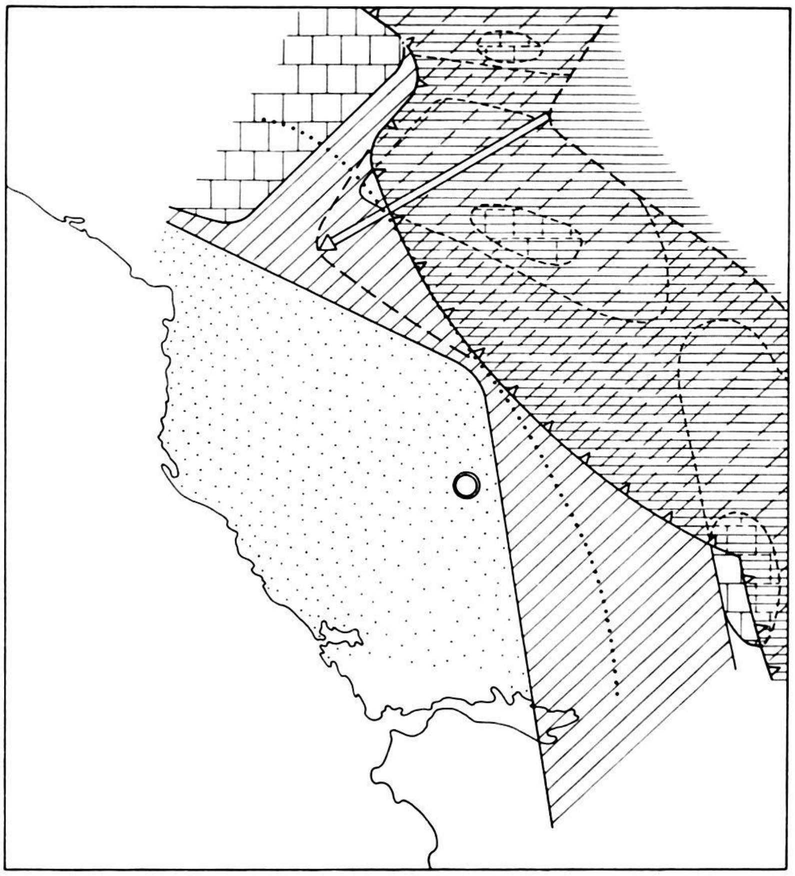


Fig. 5. The main features of the Cretaceous (Albian?) orogeny in the Hellenides. Detailed explanation in the text. Same symbols as in Fig. 4.

A further consequence is that the Olympus window in a northern cross-section is no farther behind the front of the Pindos thrust than the easternmost parts of the Gavrovo window in the Peloponnesos! Though the Olympus window is within the Pelagonian and ophiolite thrust masses, its tectonic position does not exclude it from being part of the Gavrovo depositional realm as the sedimentary sequence suggests (cf. AUBOUIN in GODFRIAUX 1964). The further continuation of the Pindos thrust across the Skutari-Peć zone is problematic, as the "Pindos thrust" of Figure 6 is a schematic simplification of a large number of individual thrusts, some of which probably parallel more or less the Cretaceous ophiolite thrust, whereas the most external ones continue a northwestern course and bound the Dalmatian (Gavrovo), Budva (Pindos) and High Karst units of Yugoslavia.

In the Paleogene and particularly in the Neogene, new discordant tectonic zones developed in the internal regions (Sillon Méso-Hellénique and Vardar zone in part), see Figure 3. Externally, the basins of the Mediterranean subsided during the Late Miocene and Pliocene. They are not a remnant of the Mesozoic Tethys whose central oceanic basin is preserved in the ophiolite nappe.

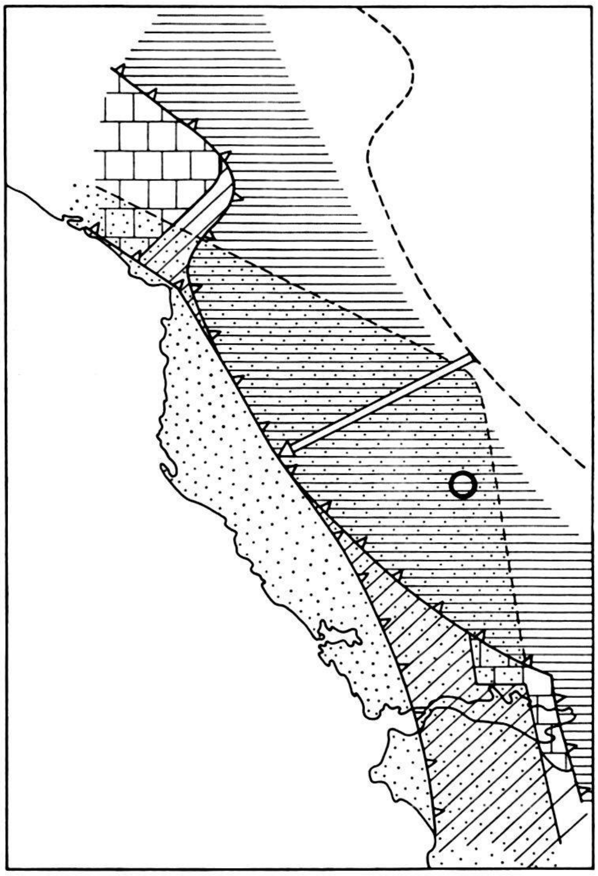


Fig. 6. The Paleogene orogeny: the Pindos thrust. Detailed explanation in the text. Same symbols as in Fig. 4.

Acknowledgments

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