MICHAL MAHEĽ*

SOME CHARACTERISTICS OF THE DEVELOPMENT AND STRUCTURE OF THE INDIVIDUAL ALPIDE SEGMENTS

Abstract: As fundamental principles of the structure of the European Alpides we consider: a) The age of formation of tectonic units, i. e. the age of folding processes as time dimension; b) The paleotectonic type of fundamental rock complexes, so called tectonogroups as content dimension; c) Structural features and particularities of the tectonic units.

From the aspect of the fundamental principles mentioned above, on the basis of the named common features and common tendencies of development, the particularities of the structure of the Eastern Alps, West Carpathians, Hungarian Median Mass, Apusins, East Carpathians, South Carpathians, Balkan and Dinarides including the Albano-Hellenides are discussed in the paper.

Резюме: Основными принципами строения европейских альпид считаем: а) возраст возникновления тектонических единиц, т. е. возраст складкообразовательных процессов как размеры времени, б) палеотектонический тип основного состава пород, так называемых тектоногрупп как размеры содержания, в) структурные знаки и особенности тектонических единиц.

Исходя из аспектов вышеприведенных основных принципов, на основании перечисленных общих признаков и общих тенденций развития в статье обсуждаются особенности строения Восточных Альп, Западных Карпат, Венгерского междугорья, Апусин, Восточных Карпат, Южных Карпат и Динарид, включая Альбаногелениды.

One of the features of European Alpides ist their great diversity, not only as to their longitudinal zones-units but also as to their transversal segmentation. There are considerable differences in the structure of individual segments. The subject of our contribution is to point out some particularities issuing from the application of principles used in compilation of the tectonic map of the Eastern Alps, Carpathians (with segments — West Carpathians, East Carpathians, South Carpathians and Apusins), Balkan, Dinarides and Hungarian Central Mountains.

The applied principles — a) age of origin of tectonic units and structures; b) paleotectonic type of supporting construction of the units; c) their structural character — we consider as fundamental principles of structure; we suppose that consideration of the particularities in their reach will show the fundamental differences in development and structure of the individual segments. However, we are also aware of the intricacy of their structure and thus also of the number of particularities given by us by far not to be complete.

Whatever particularity may be considered only on a uniform basis and this way the fundamental features of development and structure are characteristic of the Alpides of Europe. The extent of this article does not permit us to treat them more in detail and so we refer to the article of M. Maheľ (l. c.) — we do it at least in a survey.

To the fundamental particularities of the structure of the European Alpides are to reckon — 1. polycyclic development with a complicated and long-dated course of Alpine foldings, 2. less paleotectonic and thus also facies diversity of the Pre-Alpine complexes, a great diversity of Alpine complexes with a whole series of types different in paleogeography at all stages of development, 3. intricacy of structure with extensive ma-

* Prof. RNDr. M. Maheľ, Dr.Sc., Dionýz Štúr Institute of Geology, Bratislava, Mlynská dolina 1.

nifestation of nappes in the majority of segments, not only of complexes of the Alpine cycle, however, also of older ones; a considerable part in formation of structures was also taken by fault tectonics.

1. The Pre-Alpine basement of the European Alpides was affected by Hercynian folding, also by distinct earlier folding, Assyntian and possibly even earlier folding, mainly in the southwestern segments. However, the Alpine folding was so strong that it has to a considerable degree veiled older structural plans and has incorporated the older complexes into the Alpine plan essentially as the crystalline basement of the Alpine units or their hinterland. The Alpine folding was taking part in three periods: Cretaceous, mainly Middle Cretaceous (starting so early as the end of the Jurassic in southern zones), Paleogene (Laramide-Pyreneic) and Neogene (Savian-Styrian). Areal extension and intensity of manifestation of the individual periods and orogenetic polarity are different at each segment.

2. Lithological diversity of Pre-Alpine complexes is rather a consequence of intricacy of metamorphic and magmatic processes than a paleotectonic diversity. Aspidic and flyschlike facies are predominating. Only in the Hercynian cycle some segments (Balkan, South Carpathians), in some segments only some zones have the tendency to accomplish cycles of sedimentary evolution with molasses (West Carpathians and East Carpathians, Apusins).

The Alpine cycle, however, is heterogeneous with fundamental tendencies of development as well as analogous groups of facies preserved.

For the Triassis everywhere limestones and dolomites are charakteristic paleotectonically: Dinaride, South Alpine — South Gemeride, Oberostalpin, Unterostalpin — Bucovinian, Balkanian type.

The Alpine geosyncline was of greatest paleotectonic variety during the Jurassic to Early Cretaceous. On the basis of the paleotectonic character several paleotectonic groups can be discriminated: stable zones — ridges: dissected geanticlines or block-structures, broad troughs — bathyal zones, narrow, often dissected troughs.

The onset of the orogenic movements at the beginning of the Cretaceous (in places already in the Malm) increases the share of flysch facies. The following flysch types have been differentiated: flysch sensu stricto or thin rhythmic flysch, sandy or coarse flysch, aleuritic flysch to cryptoflysch, wildflysch, heterogeneous flysch and flysch of Dalmatian type. As to their relationship to folding we have separated: pre-folding flysch terminating carbonate sedimentation, intra-orogenic flysch, flysch originated in separate troughs, flysch formed in flysch geosyncline, late tectonic flysch, and flysch facies sandwiched between limestone complexes.

In late and/or intra-orogenic stages, superimposed structures originated in the internal zone. Their pre-molasse filling is of the following type: flyschoids — molassoids, heterogeneous sedimentary-volcanogenic formations, carbonate molassoids, and early molasses.

Representing the last geosynclinical stages of the Alpides are molasse complexes, which are markedly differentiated owing to their geotectonic position, in structural character and partly in facies.

a) Structural features: The Alpides are distinguished by intensive tangential compression, which was active during the Hercynian cycle (Bretonian-Asturian period) and principally during the Alpine orogeny. In result of it, the old basement complexes were reworked at Alpine times, and mass movements at lower structural levels gave rise to the basement nappes composed mainly of crystalline complexes. Near the surface, cover nappes of sedimentary complexes of Alpine cycle were produced; these show a dominant outward vergency. These processes invariably lose their intensity towards the exterior.

b) The Alpine geosynclinal system is genetically connected with the deep-seated faults, as is evident from its foundation and typical differentiation into structural-facies zones. The faults were the sites where magmatic activity was concentrated and where the old carbonate but especially flysch troughs originated. The longitudinal and cross faults controlled the formation of superimposed structures, chiefly depressions, and of the morpho-structural plan in general. They constitute the fundamentals of the structural plan itself .

Special characteristics of the individual segments

The Eastern Alps

1a) Despite the large extent of pre-Hercynian crystalline complexes, the character of the Baikalian and older folding processes is difficult to determine precisely. The two different metamorphic types, i. e. the Koralm and Kleinalm crystallines suggest the poly-cyclicity of pre-Hercynian metamorphism. The former is distinguished by eclogite-amphibolite facies with staurolite and disthene the latter by the amphibolite facies.

b) Hercynian folding processes (Bretonian-Sudetic) were of great intensity and produced nappe structures established, for example, in the Graz Paleozoic. The Hercynian cycle was not closed: the structures formed by Hercynian folding persist in the basement of the Alpine geosyncline.

c) In the Alpine development cycle, all three folding periods left their traces. The Cretaceous period gave rise to the structural plan of the southern zones, of the Drau zone, of the central zone built up mainly of the crystalline, and of the Northern Limestone Alps with extensive Oberostalpin und Unterostalpin nappes.

The Paleogene orogeny also played an important role, and during the Illyrian-Pyrenean subperiods the Northern Limestone Alps were again folded. The tectonic deformation resulted in slicing and thrusting of Cretaceous nappes over the inner parts of the Flysch Zone. The intensity and effects of Paleogene folding increases westwards, proportionately to the decreasing influence of Cretaceous folding. The Paleogene folding is the main structural agent not only in the Penninicum but also in the Austroalpinicum right in the Grisonides (R. Trümpy 1970). Neogene folding affected the outermost zones, the Flysch Zone, Helveticum (Gresten zone) and the foredeep. This folding occurred towards the end of the Oligocene and at the beginning of Neogene; it can be denoted as Early Neogene. In addition to the Externide zones, it also affected the frontal parts of the Northern Limestone Alps, contributing to their final translation over the Flysch Belt (S. Prey 1971). Remarkably, the Neogene folding period is younging westwards: the outermost zones of the Helvetides and of the Subalpine area in the Western Alps were folded as late as at the close of the Miocene and in the Pliocene (J. Debelmas — A. Lemoine 1970).

In general, the Alpine folding of the Eastern Alps is distinguished by the following features: a high intensity and nappe style in all three periods; metamorphic effects which in the Cretaceous and Paleogene periods were partly limiter to the central zone of the Unterostalpin and Penninicum: spectacular orogenic polarity in the effects of folding periods and subperiods.

2a) Of the *lithological peculiarities* of the basement (pre-Paleozoic and Paleozoic) complexes, we should mention the limestone layers in the crystalline and a large extent of carbonate complexes, chiefly in the Graz Paleozoic (mainly the Devonian).

b) The Triassic is the dominant representative of the Mesozoic complexes; the Jurassic and Lower Cretaceous are subordinate but their role increase to the west. The Triassic builds up the essential part of the near-surface units (the Drau zone) and of the North Limestone Alps units. It is strongly differentiated in facies but is mostly of the Oberostalpin type, which was derived from the heavily dissected geosyncline (aristogeosyncline in the sense of A. Tollman). The uppermost parts of the „Hochalpinicum" show facies relations to the South Alpine development. The Drau zone with abundant volcanics in the Middle Triassic can be regarded as a transitional type with some South Alpine characteristics. The Unterostalpin, more northerly type exhibits periplatform features, whereas the Penninicum is a pronouncedly trough type connected with a deep fault along which basic magmas ascended.

c) The proportion of flysch complexes is not large in the Eastern Alps, the lack of flysch facies being distinctive of the Northern Limestone Alps. The only exception is the Frankenfels nappe with pre-orogenic flysch of Albian-Cenomanian age. This unit shows paleotectonic sedimentary complexes of special character, which resemble the type of a dissected trough in thickness and variety of the Jurassic and Lower Cretaceous. The proportion of flysch and flyschoid complexes increases in the Grisonides in the west, not only in the Oberostalpin (Albian-Cenomanian) but also in the Unterostalpin (A. Trümpy 1970). The principal representative of diastrophic facies in the Eastern Alps is the relatively narrow Flysch Zone. It represents a flysch trough which started at the beginning of the Early Cretaceous and died out in the Paleocene in the west and during the Late Eocene in the east (S. Prey 1968). It is relatively monotonous, being represented by flysch s. s. with coarser-grained sandstones, reflecting the folding processes, in the Cenomanian, Maastrichtian and Upper Paleocene. The cryptoflysch, so-called „Buntmergelserie" is characteristic of the Gresten zone. In the west, the Flysch Zone embraces several strips of flysch, which was folded together with the Penninicum during Pyrenean folding.

d) The large extent of intraorogenic formations in the Northern Limestone Alps is genetically connected with the spatial overlapping of the Cretaceous and Paleogene folding. The formations are of Gosau type comprising a variety of facies, among which detrital facies dominate over organogenic limestones, as well as the flysch and cryptoflysch complexes at the end of the complicated sedimentary cycle (Paleocene). They represent the fillings of early depresions which incorporated as the upper stage of Cretaceous units in the Alpine structural plan by Paleogene folding.

e) A relatively small extent of late tectonic and post-tectonic structures — the molasse-filled depressions is another distinctive feature of the Eastern Alps. The eastern marginal depression zone with the Vienna basin and Steyer depression at the boundary with the West Carpathians and the Hungarian massif is the only exception.

3. *Structurally*, the Eastern Alps are a classical area of huge nappes both in the Northern Limestone Alps and the Flysch Zone. The Drau zone in the south is of para-autochthonous character.

In the Pennicicum and partly also in the Unterostalpin, the basement nappes were formed simultaneously with regional metamorphism and retrograde metamorphism of the older crystalline.

The West Carpathians

1a) In the West Carpathians, two metamorphic complexes of different age can be distinguished: the meso-katametamorphosed Jarabá Group and the epimetamorphosed

Kokava and Pezinok-Pernek Groups. Their existence suggests also two folding periods, i. e. the Paleobaikalian and Baikalian. Because of the polymetamorphism of the crystalline it is difficult to decide whether the younger rocks of lower-grade metamorphism are not of Paleozoic age.

In contrast to the Eastern Alps, the Carpathian crystalline displays a strong Alpine reworking in the southern (Veporide) zone and not in the northern sectors. Hercynian folding was of great importance. The overthrusts established particularly in the Veporide Crystalline, however, seem to be rather the result of Alpine processes that occurred at lower, deeper structural levels.

b) For the large amount of granitoid bodies and their location in anticlinal structures the Hercynian orogenic processes are responsible; the distribution of granitoids laid the foundation to the Core mountains, which are a peculiarity of the West Carpathians.

c) Alpine folding occurred in two periods, the effects of which were separated in space: the Cretaceous structural units are located in the Inner Carpathians and the main Neogene units in the Outer Flysch Carpathians. The zone where these two foldings overlap is narrow and is represented by the Klippen Belt showing manifestations of strong Paleogene folding. This Belt welds both systems into one whole. Each of these systems is distinguished by prominent orogenic polarity of folding phases, which is congruent with the polarity of the geosynclinal evolution, i. e. with the successive migration of the geosyncline axis (M. M a h e ľ 1971).

2a) The pre- and Early Paleozoic complexes are characterizes by a very small amount of carbonate facies. Major carbonate bodies appeared first in the Carboniferous. On the other hand, beginning with the Permian, the products of the Alpine cycle are so varied in composition as in no other segment. As many as five types can be differentiated in the Permian of the Carpathians: South Alpine, dominantly marine; North Gemeride, molassoid with marine deposits and intensive quartz-porphyry volcanism: molassoid Permian of Melaphyre Formation with intensive basic volcanism; Veporide Permian with quartz-porphyry volcanism, and Tatride peri-platform Permian representing the molasse filling of Neohercynian depressions. This variety of Permian facies indicates that in the boundary interval between the Hercynian and Alpine cycles the Inner Carparthians were strongly dissected.

Paleotectonic variety is also distinctive of the Triassic. It occurs in three types: South Gemeride, similar to the South Alpine type; Oberostalpin, and peri-platform type with special facies of Carpathian Keuper and Carpathian Rhaetic (M. M a h e ľ 1967).

b) The areas of peri-platform Triassic were markedly distinguished only during the Jurassic and Lower Cretaceous, which comprise the trough type with local cordilleras (in the Krížna unit), the geanticlinal type with cordillera (Tatra) subtype, and the Fatra subtype with euxinic facies. An undisputably specific feature of the West Carpathians is the Klippen Belt, which comprisses opposing structural-facies zones (trough-cordillera). It is genetically connected with a deep fault.

c) The increased dynamics of the West Carpathian evolution is mirrored in the large extent and mainly the geotectonic diversity of flysch. In the external units of the Inner Carpathians, the pre-orogenic flysch, structurally connected with the older carbonate complexes is richly developed. The post-tectonic flysch in longitudinal downwarps predetermining the present depressions is typical of the northerly parts of the Inner Carpathians. The main representative of the flysch period in the West Carpathians is the Flysch Belt, which is strongly differentiated both in facies and structure. Specific of the Flysch Belt are the Internal group of nappes — the Magura unit, connected with the Klippen Belt in development and partly also structurally, and the External group of nappes with cryptoflysch complexes grading into molassoid to molasse beds (the Ždánice-Subsilesian unit). The Silesian unit is distinguished in the West Carpathian sector by a large proportion of carbonate flysch (Těšín partial nappe) and of coarse flysch (Godula partial nappe).

d) The horizontal disposition of the two foldings and slight intensity of Paleogene orogeny account for a small amount of intra-orogenic formations, which are restricted to the Klippen Belt and the peri-Klippen area. They are more numerous in the neighbourhood of the Eastern Alps, in the reach of Paleogene folding (Brezová Cretaceous).

e) One of the characteristics of the West, mainly Inner Carpathians is the large number of superimposed post-tectonic basins and their diversity. There are as many as five stage types: Upper Cretaceous early depressions with coarse-molasse filling; Early Paleogene longitudinal superimposed depressions and grabens filled with late-tectonic flysch; Late Oligocene to Early Miocene basins with marine-molasse filling and Schlier facies; Miocene transversal basins with variegated molasse; and Pliocene basins filled with lacustrine molasse.

3. *The specific structural features* of the West Carpathians are as follows:

a) In very few segments are the structures of the crystalline so closely connected with the near-surface Mesozoic structural-tectonic units as in this mountain range. The near-surface style of Mesozoic complexes is joined to the deep-seated style, which is distinctive for the preponderant part of the Gemeride Early Paleozoic, the older crystalline strongly reworked by Alpine deformation (i. e. the Veporide crystalline) and for the Tatride crystalline, which was affected by Alpine folding only slightly in near-surface layers.

The nappes are cumulated in the synclines which are mostly covered with the fillings of younger superimposed depressions. Some of these synclinoria of Cretaceous age, such as the Hron, North Gemeride, South Gemeride (linked up with the North Hungarian) synclinoria are structures of great importance (M. M a h e ľ 1967). Granitoid bodies are very frequent in major anticlines, being diapirically squeezed into their cores.

b) No other segment of the Alpides shows such a morphotectonic diversity expressed by anticlinal horsts and depressions. The former are built up of older formations and the latter are filled with younger deposits of great variety. The depressions are situated not only at the western, eastern and southern margins of the Inner Carpathian, but also at the Outer/Inner Carpathian boundary and inside the Inner Carpathians. This morpho-structural differentiations of the Inner Carpathians is the result of strong faulting and, consequently, the dissection into a system of minor blocks, and of the variety in fault trends. The basic pair systems strike NE-SW, NW-SE, NNE-SSW, NNW-SSE, N-S and E-W, depending on the position and development stage of the given section; one of these systems had the leading position (M. M a h e ľ 1969). As a result, the basin axes frequently diverge in consecutive stages. The semiarcuate course of the West Carpathians can probably be also explained in these terms. Many of the major young faults are continuous with the deep-seated older faults, which played an important role in the Cretaceous structural plan; many longitudinal faults are of fundamental importance for the Early Alpine structures. The boundary depressions of the Eastern Alps and of the East Carpathians as well as the depressions inside the Inner Carpathians are on transversal fault zones. The deep reach of the East and Central Slovakian transverse fault zones provoked at their crossing with deep longitudinal faults the origin of extensive late-geosynclinal Prešov-Tokaj and Central Slovakian volcanism. The is of intra-block type, differing in its structural position form the longitudinal volcanic zones following the boundaries of blocks.

The Hungarian median mass

1a) The pre-Mesozoic complexes of the Central Hungarian Highlands and its projections exhibit broadly the characteristics of the Eastern Alps and/or the West Carpathians. They are assigned to the Assyntian units and partly to the Paleo- and Neohercynian units. The development of Alpine structural-facies zones began in the Permian.

b) The effects of the Alpine movements differ markedly from those in the Alpides proper in being of uncomparably smaller intensity, which is smallest in the Transdanubian Mesozoic. Not even the units that were more strongly folded during the Cretaceous such as the Bükk, Mecsek, Vilany, bear signs of Alpine regional metamorphism or local schistosity and mylonitization. which are common in the neighbouring Alpine systems. This implies that the Cretaceous orogeny and the younger folding did not rework the basement (Gy. Wein 1969). The assignment of the Hungarian Central Highlands to the median mass is based on this very characteristics. The decreasing dynamics of this region manifested itself already during the evolution af the Alpine geosyncline but not in the smaller thickness of sediments, which is in places even greater than in the West Carpathians, up to 3000—4000 m. mainly in the Triassic. It was expressed by a slighter paleotectonic differentiation than is characteristic of other parts the Alpine geosyncline.

Manifestations of post-Cretaceous orogenic processes are known from the buried Solnok flysch trough, being ascertained by boring. From the presence of Oligocene beds in this trough some authors connect them with the Savian folding (K. Balogh — L. Körössy 1968), whereas others with the Pyrenean movements (personal communication by Gy. Wein).

Intensive Pliocene compression produced two-sided overthrusts of older Mecsek complexes into the Pliocene basin filling to a distance of more than one kilometer.

2a) *As to the lithology,* the Hungarian median mass is characterized mainly by the type of the Bükk and Mecsek (in part) Paleozoic and Mesozoic. The Igal-Bükk syncline with abundant limestones in the Devonian and especially in the Permian, and with the Middle Triassic volcanics (South Alpine type) indicates that the South Alpine branch of the geosyncline protruded far northwards into the vicinity of the Carpathians. This NE-tranding structural-facies zone passes through the transitional South Gemeride development into the West Carpathian geosynclinal system; in the genetic and structural sense it constitutes the hinterland of the West Carpathians.

The Mecsek Mts. show special characteristics, such as the Lower Cretaceous dolerite volcanism and detrital development of the Upper Triassic, but their Lias Gresten Formation and the Middle Triassic suggest an affinity with the interior areas of the South Carpathians.

b) The Solnok flysch basin (Senonian-Paleogene) being the only flysch type of the Hungarian Central Highlands is of special interest.

c) During the Paleogene and Neogene, the Hungarian Central Highlands underwent an appreciably more complicated evolution than other segments. This period is represented by the formation of depressions of Late Cretaceous containing structural layers. Paleogene, post-Savian, post-Styrian and post-Attican stages. Still in post-Styrian time. there were seven minor basins in existence. which were separated by elevated blocks and subsided independently of one another. Oscillations of sea level caused the interruption of sedimentation on the blocks between Burdigalian and Helvetian. Helvetian and Karpatian. Early and Late Tortonian, and Tortonian and Sarmatian (K. Balogh — L. Körössy 1968). As a result, the continuous Neogene sequences were deposited only in the basins. Only the intensive Pliocene subsidence had joined these basins into one extensive superimposed Alföld basin. The thickness of Pliocene in the Alföld basin attains up to 4000 m.

3. *In the structural aspect*, the divergency of units deserves to be mentioned in addition to the special features ensuing from the slighter intensity of folding, as e. g. the lack of nappes.

The Apuseni Mts.

The western part of the Apuseni Mts. is in many respects analogous to the Inner West Carpathians.

1. The analogy mainly concerns the age *of Alpine folding*, which ended after the Cenomanian. It was preceded by the deposition of a thick flysch and flyschoid complex during the Early Cretaceous in the individual autochthonous and nappe units. The Upper Cretaceous (Turon-Maastrichtian) complexes are of late to post-tectonic character.

A marked component of the Apuseni Mts. is the range of Muntii Metaliferi, which forms an Externide zone modelled by Middle and post-Upper Cretaceous folding.

2a) *One of the lithological characteristics* is the large amount of limestones of the Štramberk (swell) type in the Bihor autochthon, which is analogous to the Tatride units in many aspects and shows East and South Carpathians elements.

b) The zone of Muntii Metaliferi has also a special lithological character, being composed of a heterogeneous flysch complexes with plenty of wildflysch and various volcanics, e. g. basalts, dolerites accompanied by gabbro and peridotite bodies, the basalt-andesite-dacite-rhyolite association, and basalt-limburgite-trachy-andesite-orthophyte association.

3. *Of structural interest* is the ENE-WSW trend of the axis of the northern part of the northern part of the Metaliferi Mts. zone, compared with its gradual change to NE-SW, NNE-SSW in the south, i. e. diagonally to the axis of the Cretaceous units of the western part of the Apuseni Mts. This changing trend of the Metaliferi Mts. zone follows the bend of the Carpathian arc. In this sense it constitutes a fore deep in the back of the South Carpathians. The vergency of individual slices of the Mts. Metaliferi to the NW or NWN, towards the interior of the Apuseni Mts., indicates that the Metaliferi Mts. represent an interior depression and not an exterior. The opinion on the connection of the Apuseni Mts. with the Vardar zone is warranted by the paleotectonic type of the Lower-Upper Cretaceous flysch trough (with abundant volcanics) and the structural position (M. Andelkovič — M. Lupu 1967).

The East Carpathians

1. *The characteristics related to the age of the tectonic units* are as follows:

a) The Late Proterozoic and Early Paleozoic complexes were epi-metamorphised during Baikalian and Early Hercynian folding.

b) The East Carpathians are distinguished by two belts of Internide units, which differ both in genesis and lithological composition — the Inner and Outer Dacides (J. Dumitrescu et all. 1963). The Inner Dacides (the sub-Bucovinian, Bucovinian, and Transylvania groups of nappes — Haghimaş and Perşani) are in essentials Cretaceous units. Their folding was accompanied by the deposition of Barremian-Albian and Vraconian-Cenomanian wildflysch and of paramolasse of the Bucecei type. During Paleogene orogenic movements, these units were thrust on the Externide units; their incorporation into the structural plan of the Externides is particularly evident in the western corner of the Marmaroš massif. The Outer Dacides, a particular component of the East Carpathians, are represented by the Ceahlău unit and the local Baraolt unit. Their composition (mainly carbonate flysch), their disposition and morphostructural character place them in the Flysch Belt. Their present form is the result of Cretaceous folding with esential reworking by Paleogene orogenic activity (M. Sandulescu 1971).

The final movements of the external nappes of the Flysch Belt, mostly of Styrian age, persisted untill the Sarmatian. The Late Neogene folding affected the external foredeep.

2. *The lithologico-paleotectonic characteristics of the East Carpathians* are the following:

a) Large extent of carbonates in pre-Paleozoic and Early Paleozoic complexes (Upper Cambrian Rebro-Barna Foramtion; Paleozoic Rusaia and Tibau Formations).

b) The mixed character of Transylvanian nappes with southern facies of Hochalpin type (Werfen Member, Hallstatt limestones in the Triassic, Liassic Adneth limestones) and even peri-platform facies, as are the Štramberk limestones. The development of the Triassic in the Bucovinian and mainly the Sub-Bucovinian nappes is near to the Unterostalpin; it is, however, distinguished by a relatively thick Neocomian complex, the so-called Lunca-Member, formed of marls with detrital material, and flyschoid rocks with conglomerates in the upper part.

c) Remarkable is the large proportion of basites in the Barremian-Aptian conglomerates of the Bucovina nappe and in the Sinaia Formation (Neocomian) of the Ceahlău unit.

d) None of the Alpide regions has such a proportion of synorogenic and inter-orogenic (between Cretaceous and Paleogene orogenes) wildflysch and conglomerate paramolasse. The Bucegi paramolasse is up to 2000 m thick. The distribution of conglomerates and accompanying olistoliths and basites suggests the presence of a deep-fault zone at the boundary between the Inner and Outer Dacides. It seems to be analogous to the deep-fault zone of the Klippen Belt of the West Carpathians.

e) The spatial distribution of individual flysch types is also specific for the East Carpathians. Whereas the Ceahlău unit is characterized mainly by a thick carbonate (marlstone-carbonate) flysch of Neocomian age, the more exterior units Magla, Zagon and Audia are composed of richly developed black aleuritic flysch (Lower Cretaceous); the structural core of the Curbicortale unit is built up chiefly of the flysch s. s. and in the more exterior Tarcău unit predominates a sandy flysch (mostly Paleogene sandstones, up to 2000 m in thickness); the outermost marginal unit contains besides non-flysch facies of cryptoflysch type also limestones and conglomerates of Eocene-Oligocene age (J. Dumitrescu et all. 1962).

The passage from the flysch to the molasse is clear-cut both vertically and horizontally, obviously due the accomplished orogenic polarity.

f) The Transylvanian basin is distinguished by its position on several Alpide segments, i. e. at the boundary between the East and South-Carpathians and the Apuseni Mts.

3. *Structurally*, the East Carpathians show the following features of interest:

a) The importance of diapiric tectonics caused by the abundance of salt bodies in the foredeep and the Transylvanian basin.

b) The nappes of the Inner Dacides differ in genesis: whereas the nappes of the Transylvanian internal zones are cover nappes fully detached, the Bucovinian nappes are the basement nappes with a large amount of crystalline masses involved.

c) A small number of interior basins, which is striking especially relative to the West Carpathians. The faults, in particular the cross faults were evidently of minor concern. Most basins are localed, being connected with longitudinal zones of weakness. Transversal basins are more frequent in the Pliocene.

The sublinear distribution of the Vihorlat-Gutin-Calimati-Hărghita young (Pliocene to Quaternary, but beginning already in the Tortonian) late-geosynclinal volcanism at the interior margin of the East Carpathians, at the contact with the Hungarian median mass and the Transylvanian massif, suggests that the longitudinal faults were important controlling factors even in the latest evolution stages.

d) The gradual dying out of some tectonic units and the appearance of others in the west of the East Carpathians demonstrate lateral changes in the structural plan of the mountain ranges. Whereas the Klippen Belt and the Magura and Subsilesian units disappear gradually, the Silesian unit passes from the West to the East Carpathians and joins laterally the Tarcău major unit of the Outer East Carpathians.

e) The termination of the Klippen Belt and the merging of the Silesian and Skiba units in the east, as well as the gradual disappearance of the Transcarpathian late tectonic flysch in the west heralded the progressive change of the structural plan.

The South Carpathian

1. *Age characteristics of the tectonic units* are as follows:

a) The pre-Hercynian complexes vary greatly in age, ranging from Early Baikalian and Late Baikalian to Baikalian-Hercynian.

b) The Alpine structural plan of the South Carpathians is mainly the product of Paleogene folding, which affected the whole segment. The external Cenozoic folded during the Neogene fade out inwards. Cretaceous folding was intensive only in the interior zones; it account for the origin of the Getic nappe and of the Golubac-Penkovo and Morava nappes in the south. The first movement of the Getic nappe occurred before the Cenomanian. The most intensive overthrust was completed by post-Upper Cretaceous folding (A. Codarcea — Gr. Pap 1969). In the Severin unit, which derived from the trough localed between these inner units and the outer Danubicum-Poreč-Miroč units, Cretaceous folding was of small intensity. The nappe form of the Severin unit is the result of Paleogene folding, which occurred during the Laramide episode in the north and after the Lutetian in the south (Kraina, Bulgaria).

c) Remarkable is the overthrust of the older South Carpatian complexes on the Miocene to more than 10 km distance in the innermost zone of the South Carpathians, at the contact with the Serbo-Macedonian massif.

2. *Lithological characteristics of the South Carpathians:*

a) The amount of Triassic complexes in the South Carpathians is remarkably small. With the exception of the innermost (Golubac-Penkovo) zones, the Triassic is of a particular South Carpathians type with Alpine elements, mainly the Middle Triassic. The Upper Triassic lacks detrital components. The structural core of the units consists of the (frequently transgressive) Jurassic and Lower Cretaceous with a predominance of shallow-water facies of the Štramberk limestone type. They also bear local zones of bathyal, chiefly marly facies of the broad-trough type (in the Danubicum — e. g. Svinica — Greben — Poreč and in part Preascina — Miroč) and of synclinal type (in the Getic area — e. g. Resița — Moldava Nuova).

The carbonaceous flysch fills the Severin-Kraina trough (in the south of the Kraina unit also flysch s. s.) and takes part in the structure of the upper structural layers of the

Danubicum. The latter flysch complex is intra-orogenic, coarse-detrital (Turon-Senonian Mehedinti flysch) and contains a large proportion of conglomerates (Arjana flysch).

The characteristic Timok trough, localed in the central zone of the South Carpathians is filled with a sedimentary-volcanogenic complex, up to 3000 m thick (Cenomanian-Danian) and unusually varied in facies. It consists of brackish-lagoonal, shallow-water detrital and orogenic-carbonate facies with cryptoflysch and a smaller amount of flysch bearing abundant extrusives (andesites, dacites and their tuffs with numerous porphyrite dykes). Since the volcanics of the Timok zone resemble the Tertiary late-tectonic volcanics with liparite-andesite-trachyte, andesite-latite, and alkaline basalt formations. They are often designated as subsequent. However, they are structurally connected with the longitudinal grabens and not with depressions of normal type. Their intraorogenic character is evidenced additionally by other volcano-tectonic forms and by the accompanying subvolcanic bodies (gabbro, diorite, monzonite, grandiorite and granosyenite).

3a) The lack of Externide tectonic flysch units in the foredeep is compensated for by the Severin and Timok troughs. The filling of the former was deformated into a nappe and the latter, which was intensely folded during the Paleogene, masks the extent of Cretaceous folding in the pre-Upper Cretaceous complexes.

The nappe structure is most spectacular in the innermost units. Towards the south, the Balkan influence is perceptible not only in composition but also in structure. The system of longitudinal and cross faults caused a block structure, which is typical of the southernmost sector, i. e. the Kraistides.

b) The Severin unit represents a paleotectonic and structural link between the South and East Carpathians, and the Poreč—Stara Planina and Timok units between the South Carpathians and the Balkan.

The Balkan Mountains

1. *Age characteristics of the structural plan:*

a) The vast Rhodopian Massif exhibits two prominent mesokatametamorphosed complexes, which correspond to two pre-Baikalian cycles. The Baikalian and/or Baikalian-Hercynian complexes are disposed along the margins.

b) The Hercynian evolutionary cycle was completed. It contains not only Carboniferous (Namurian-Westphalian) depressions with lower marine detrital molasse but also Upper Carboniferous-Permian (Stephanian-Permian) depressions with upper lagoonal-detrital molasse.

c) Except for the western block adjacet to the South Carpathians the Balkan was subject to relatively intensive Cretaceous folding. The main folding in the western block is Paleogene, and some authors (E. Bončev 1956) believe it to be the only folding in this part of the Fore-Balkan and Stara Planina.

The more southerly Sakar—Stranža area and the southern and western parts of the Rhodope Mts. underwent Early Cretaceous, possibly Cimmerian folding, which also produced intensive metamorphism.

Paleogene folding affected the whole of the Balkan Mts. area, including its western block. Surprisingly enough, its intensity was appreciably smaller in the northerly zones (in the Fore-Balkan) than in other parts and than of Cretaceous folding. In the Stredohorje, Luda Kamčija and Kotel units of the central zone and in the western block, the movements were of greater intensity. Radiometric age values of about 40 m. y. indicate a wide time range of Paleogene folding in the Rhodope massif. Paleogene folding occurres mainly during the Late Illyrian to Pyrenean subperiods. The Neogene orogenic period did not manifest itself pronouncedly in the Balkan. The Alpine folding shows there a particular development and distribution. The orogenic polarity of this folding is expressed only within the scope of individual periods, mainly within the Cretaceous. As a result, the Externides are missing in the Balkan, as well as the foredeep. The Flysch Belt of the Carpathians is substituted by a large Luda Kamčija trough extending between the outer and inner zones.

d) The major Balkan depressions were formed in the Priabonian, and in the extreme south as early as the Lutetian. Late geosynclinal (subsequent) volcanism, mostly of intra-block character and developed on transverse fault zones, is genetically connected with the origin of these depressions. Pliocene basins are of different type. The extent of the Miocene is small.

2. *Lithologico-paleotectonic characteristics of the Balkan:*

a) A large extent of marbles in the pre-Paleozoic complexes of the Rhodope Mts., chiefly in the Late Baikalian gneiss complex (the marbles contain diopside and phlogopite); their proportion increasses upwards. Marble intercalations are also found in the higher layers of Early Proterozoic meso-katametamorphosed gneiss series, which, according to some authors (B o j a n o v — K o ž u c h o r o v 1968) may be partly of Archean age. The data from the Greece region suggest that part of this series is likely to be younger, probably Permian, and that it was intensively metamorphosed by Alpine folding processes (Cimmerian and Early Cretaceous and Paleogene).

b) The Balkanian type of the Triassic is characteristic not only of the Balkanian units but also of the neighbouring Kraistides, i. e. the southernmost corner of the South Carpathians. It is distinguished by peri-platform elements. The Lower Triassic is of Buntsandstein type, the Middle and Upper Triassic is rather monotonous with limestone-dolomite sequences. Rhaetic complex is detrital. A marked paleotectonic differentiation started in the Late Jurassic (I. K. N a č e v 1969); it includes the periplatform type with limestones and marlstones as well as the filling of a broad flysch trough.

c) A special phenomenon of the Balkan is the narrow Kotel zone, which is exceptional both in composition and the intricacy of structure. It is located south of the Fore-Balkan and connected genetically with a deep fault. Its facies heterogeneity is unusual: flysch and flyschoid facies, wildflysch, radiolarites, olistostromes, olistoliths, and shallow-water limestones and sandstones.

d) The extent of the flysch complexes in the Balkan is considerable, particularly relative to the South Carpathians. The greater part of the upper stage of the Cretaceous units consists of the Tithonian—Lower Neocomian flysch, thin-rhythmical with sub-flysch, coarse- and wildflysch facies. It attains a thickness up to 3000 m and was deposited in a trough about 500 km long. It is of interest that it was not deposited immediately before the folding, but grades into terrigenous carbonate sediments of Barremian—Aptian age (molassoid ? — I. K. N a č e v 1969).

The Luda Kamčija unit represents another flysch trough filling. This Turon-Paleocene carbonate flysch is thousands of metres thick. The upper complex has a predominance of sandstones with wildflysch conglomerates. The flysch complex is pre-Pyrenean.

The Stredohorje zone north of the Rhodope massif, representing a system of synclinoria filled with a volcanogenic-sedimentary complex (analogous to that of the Timok graben in the South Carpathians) has also a large portion of flysch beds. These are abundant mainly in the Burgas and Surna Gora synclinoria. The flysch is of interorogenic type.

3. *Structural characteristics of the Balkan:*

a) The pre-Hercynian crystalline mass of the eastern part of the Rhodope massif, with a nappe of late pre-Baikalian (?) mesometamorphosed complexes is overthrust on the Upper Proterozoic to Lower Paleozoic phyllite-diabase series (B o j a n o v 1969). The nappe has been described as the (Hercynian or Alpine?) Kulidžak nappe.

b) The Cretaceous structural plan is obliterated by a younger plan, especially in the Stredohorje zone. This younger plan affects several pre-Upper Creaceous units and suppresses the Cretaceous nappe structure.

c) The large extent of Alpine metamorphism in the southern areas is remarkable mainly in the Rhodope crystalline and in the east of the Stredohorje (Sakar—Strandža).

d) The great importance of block tectonics is given by the deep faults, which also controlled the Alpine evolution of the structural plan. Longitudinal fault-lines are very marked, such as the deep Marica fault which is accompanied by structural anomalies, volcanism and metamorphism. The transversal Tvardice and Etropole cryptofractures separate blocks differing in structure (E. B o n č e v 1966). The intra-block late geosynclinal volcanism is located on cross-faults, mainly in the Rhodope massif, and genetically connected with the foundation of post-Pyrenean (Priabonian) basins. It attests to the important role of several, even transversal fault systems. The development of Pliocene basins was not accompanied by volcanism to a great extent.

T h e D i n a r i d e s

Although the Dinarides in the broader sence are a separate part of the Alpine system occupying an independent position in Alpine Europe and showing a western, south/western or southern vergency differing from that of the northern Alps-Carpathians-Balkan branch, their evolution trend and basic structure are congruous. They do have some features in common with the members of the northern Alpide branch, even if the particularities are more numerous. The individual Dinaride segments — the Southern Alps, the Dinarides s. s. and the Albano-Hellenides — in having many units in common that join them into one system, do not differ substantially from one another. The following features are specific for the Dinarides s. l. as a whole:

1. *Age characteristics of structural plan:*

a) The pre-Alpine complexes have a smaller share in the superstructure than in other segments: they are present in the interior units. The basement and the core are made up of late pre-Baikalian and/or paleo-Baikalian complexes of the Pelagonian massif and the paleo-Hercynicum. At the western margins of the Vardar zone, the border of the Serbo-Macedonia massif with late pre-Baikalian and Baikalian complexes are incoporated in the Alpine structure and markedly diaphtorized.

b) Upper Paleozoic complexes build up the lower structural stage of the Alpine units. The early Hercynian complexes are also components of the Alpine structure. Some authors (G a e r t n e r — B. Č i r i ć 1950) even anticipate a slight effect of Hercynian folding.

The Hercynian evolutionary cycle is incomplete and the intensity of Hercynian folding is smaller than in other segments. The same holds for the proportion of Hercynian granitoids.

c) Alpine folding processes of Creataceous period were of smaller areal extent and, in the north, also of slighter intensity. In the south, early-Cretaceous and even Cimmerian folding was active. Other distinctive features of Alpine folding are a large extent and intensity of Paleogene folding, uneven extent of Neogene folding in individual segments, and the evident polarity of the distribution of folding periods during Paleogene orogeny.

The early-Cretaceous folding extends the Late Cimmerian movements in the Vardar and Pelagonian zones; it was intensive as early as at the Dogger-Malm boundary. The folding was accompanied by metamorphism of younger complexes (anchito higher-temperature grade of greenschist facies), schistosity, diapthoresis and anatexis of crystalline rocks (F. Kockel — H. Mollat — J. W. Walther 1971). The metamorphic grade increases to the SE. The age of these processes has been determined more precisely at 180 m. y. by K/Ar method. It is also suggested the molasse character of the Upper Jurassic bearing not only coral limestones and sandstones but also conglomerates and coarse breccias. The folding from the final period of the Early Cretaceous (dated 113 m. y. by K/Ar method) is also accompanied by metamorphism, schistosity and diaphthoresis.

Paleogene folding is generally preceded by flysch sedimentation. In the interior zone the flysch is of Maastrichtian-Danian age (affected also by Cretaceous folding — B. Ćirić 1963, T. Bisocu — A. Papa 1970, J. Aubouin — J. Ndojaj 1964): of Maastrichtian to Lower Eocene age in the Albanian Alps; of Latest Early to Late Eocene age in the frontal part of the Visoki Krš unit; of Maastrichtian to Late Eocene age of the frontal part of the Visoki Krš unit; of Maastrichtian to Late Eocene age of the Budva-Zukali zone and Early Oligocene in the Pindos unit.

The units produced by Neogene folding are the following: the zone of Dalmation folds in the Dinarides s. s., which was folded towards the end of the Oligocene, the Kruja-Gavrovo units of Hellenides (Upper Priabonian to Oligocene Flysch) and the Ionian zone folded after the Early Helvetian. The flysch begins in the last-named zone with the Upper Eocene and extends to the lowest Miocene, granding into the Lower Helvetian Schlier. The orogenic polarity vanished at the beginning of the Neogene; the foredeep starting with the Upper Helvetian is superimposed on the syncline of the Ionian unit and not on the exterior Sazan zone, in which the flysch is absent.

The late tectonic depressions were formed in the interior zones during the Lutetian to Priabonian. Towards the north they originated at progressively later periods: in the Southern Alps the molasse filling of, e. g. the Ljubljana zone begins with the Lower Oligocene. Cretaceous folding of the Southern Alps was of small intensity; even in the interior units the Neogene folding was more pronounced.

2. *The lithologico-paleotectonic characteristics of the Dinarides:*

a) The Lower and Upper Paleozoic, including the Permian contains abundant carbonates; molasse facies only occur as interlayers.

b) The Dinarides differ markedly from other segments by a stronger dissection and deep-seated troughs, the marginal faults of which reach down to the magma chambers; on account of basic volcanics the troughs are grouped with eugeosynclines. In the Jurassic and Early Cretaceous, broad ridges subsiding intensively were significant tectonic elements beside the deep narrow troughs. They constitute the so-called West Dinaric type with the Jurassic up to Lower Eocene limestones and dolomites attaining a thickness up to 7000 m. Thick dolomite layers, extending up to the Cretaceous, which are common in other segments only in the Triassic are a special feature of this segment. This subsiding swell type is accompanied and disrupted by troughs filled with bathyal carbonate facies. The Ionian zone was of this type during the Dogger until Middle Senonian. Characteristic of the Helenides is another narrow trough located on a deep fault, which is represented by the Zukali-Pindos unit. It displays a rapid alternation of facies, both in vertical and horizontal directions, an abundance of volcanics (mainly) in the Triassic and radiolarites in the Jurassic of Hellenide facies. The trough stretches as far as the southern part of the Dinarides, being represented by thick Anisian flysch in the Budva unit.

c) Flysch troughs are also distinctive of the strong dissection of the Dinarides s. s. and Hellenides. The Bosna and Vardar troughs are marked Cretaceous structures. The former is situated at the boundary between the interior (affected by Cretaceous folding) and central zones, which only suffered Paleogene folding. The filling of the begins with the Tithonian, which is locally transgressive on the Rožňačka diabase series (D o d o m a — M e l l o 1967) and persists to the Aptian. This complex is thrust over the Upper Cretaceous Durmitor flysch (R. B l a n c h e t et all. 1969).

In the Vardar zone, the flysch consists of the Tithonian-Lower Cretaceous cycle with volcanics and of the Upper Cretaceous (Cenoman-Senonian) cycle. They are separated by an uncoformity, which is in places accompanied by molassoid coarse-detrital and limestone facies.

The wide stratigraphic range and large thickness of the pre-orogenic flysch in the Zukali and Ionian zones suggest that the flysch troughs are superimposed on the older ones. In the Zukali zone, the Krasta variegated flysch covers the interval from the Maastrichtian to the Early Oligocene, and in the Ionian zone from the Priabonian to the earliest Miocene.

The abundance of flysch zones is reflected in the variety of types. The common Alpide types, such as flysch s. s., sandy flysch, calcareous flysch, crypto- and wildflysch, are complemented by special, so-called Adriatic flysch type with thick layers of organogenic limestones. It is connected genetically and structurally with the underlying and adjacent limestone masses (M. M a h e ľ 1972). In the Zukali zone, the heterogeneous Krasta flysch (T. B i c o c u — A. P a p a 1968) is distinguished by the variability of facies: in the lower part it is mostly of carbonate type, higher up it contains the wildflysch with limestone olistoliths and flysch s. s., and in the toppart there is a predominance of sandy flysch.

d) In the interior zones of the Dinarides and Albano-Helenides the Upper Cretaceous neritic, partly rudisti limestones of Gosau type are widely distributed. They are underlain by detrital limestones and conglomerates and overlain by pre-orogenic flysch. Geotectonically this limestone mass represents the intra-orogenic pseudomolasse.

Specific of the Visoki Krš zone is the late tectonic transgresive Promina Formation (Upper Eocene-Lower Oligocene) bearing abundant limestone conglomerates and breccias, in addition to limestones, calcarenites, sandstones and claystones with coal seams. This sequence represents the filling of early depressions.

The stronger dissection of the Dinarides and Albano-Hellenides in their interior zones, due to deep-seated faults, is reflected in the large extent of magmatites, which are early geosynclinical as in the interior zones of the Albano-Hellenides also in the Centralide Zukali-Pindos zone. The proportion of Alpine granitoids, which are distributed mainly in the marginal (western) part of the Serbo-Macedonian massif, is relatively large. The amount of late geosynclinal subsequent volcanics and basalts located at the margins of the Serbo-Macedonian massif is smaller.

3. *Structural characteristics of the Dinarides:*

a) The Vardar zone shows the most spectacular character owing to several features. It is connected with deep faults, which were the sites of basic volcanism in Early Paleozoic and the Mesozoic (towards the end of the Jurassic and of Cretaceous). In the

Late Jurassic, Late Cretaceous and Neogene subvolcanic granitoid bodies were emplaced on them. The zone is tectonically exceptional in that it is a hinterland depression (B. Ćirič 1962). The intensive tectonic reworking of the Vardar-zone crystalline connected with Mesozoic metamorphism is also remarkable. The intensive folding and structural connection with the Serbo-Macedonian crystalline massif and its intensive diaphthoresis in the contact area points to a strong compression reaching to a great depth, and very likely to extensive engulfment.

b) The Zukali zone of the Hellenides is a prominent genetic and structural phenomenon. The Budva zone in its northern projection links it with the Dinarides. The slicing of the Zukali zone results from its lithological variety as well as from strong compression. It represents a deep-seated suture of structural importance.

c) The intricate structure of the Dinarides and Albano-Hellenides is due greatly to diapir tectonics, which is expressed on the one hand by diapirs of evaporites (chiefly in the Permian), which are manifested on the thrust lines, and by diapiric structure of magmatites, mainly serpentinites, on the other.

d) The Dinarides do not possess a true foredeep. It is substituted by the molasse-filled depressions superimposed on the synclines of the Ionian zone. The contact of the Dinarides with the platform is mediated by Cretaceous-Eocene carbonate complexes showing the gradual reduction of folding intensity.

e) Although the longitudinal SE-NW and (in the north) WNW-ESE trends are structurally dominant, the transversal fault lines also influenced the structural plan, particularly three of them that separate the individual segments.

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