X CONGRESS OF CARPATHIAN-BALKAN GEOLOGICAL ASSOCIATION

Outline of the Structure of the West Carpathians

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Introductory Excursion Guide-book

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Introduction

Forty-two years ago, the Third Congress of the Carpathian Geological Association was organized in Czechoslovakia.

On this occasion a comprehensive guide-book was published, being prepared by a number of geologists. It submitted a description of individual excursion routes, a survey of geology of the areas to be visited, and a general picture of the geological structure of the Carpathians in central Slovakia and neighbouring regions (cf. A. Matějka — D. Andrusov 1931).

We are glad that we have the honour of organizing this year (1973) another Congress, and the more so that it is the Tenth Jubilee Congress of the Association, which since 1965 has expanded and developed into the Carpathian-Balkan Association.

The introductory article of the Guide-book of 1931 was not centred by chance to the problems of the structure of the Carpathians in central Slovakia. It was because the systematic study of the Carpathians carried out since 1923 concerned in particular the area of Central Slovakia. The Flysh Belt and Neogene depressions received less attention. The investigations of the Vysoké Tatry (High Tatra) Mts. which were performed synchronously, mainly in Poland, made it possible to complement the study results from central Slovakia.

During the years 1920—1930 the investigations of the Flysch Belt were not much advanced in Czechoslovakia, although it was then in progress in Poland, and was the subject of discussion at the First Congress in Poland and the Second Congress in Rumania. The research in the Neogene basins, connected with extensive boring, which provided surprising results, was carried out mainly after the Second World War.

The difference between our present knowledge of the structure of the Carpathians and that of 1931 can be accounted for by the far larger volume of investigations made in the areas studied at that time, and by the extension of the investigations to the whole Carpathian region in our country and the neighbouring states. Consequently, the survey of the structure of the Czechoslovak Carpathians can be based on the data from the whole Carpathian mountain system.

Since the Congres of 1931, a number of papers dealing with the geology of the Czechoslovak Carpathians have been published (D. Andrusov 1938; D. Andrusov 1958—1965; V. Zoubek [ed.] et al., A. Matějka [ed.] et al., 1961; A. Matějka et al., 1968; D. Andrusov 1968; M. Mahel 1967; T. Bu-

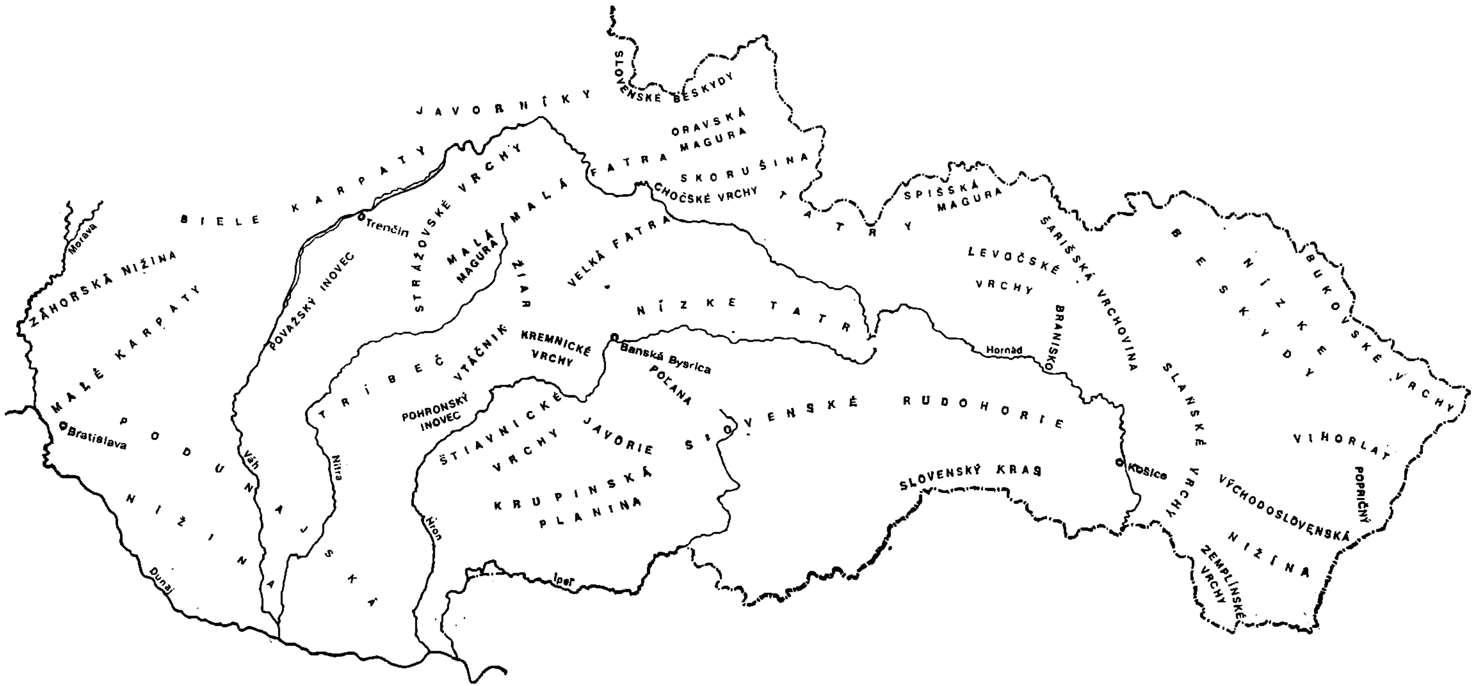

Fig. 1. Orographic division of Slovakia

d a y 1967, 1968). Many summarizing papers have also been published on the Polish Carpathians (M. K s i ą ż k i e w i c z [ed.] et al., 1951, 1953; M. K s i ą ż k i e w i c z 1972, S. S o k o ł o w s k i 1971; . C z e r o n i n s k i, S. S o k o ł o w s k i et al. 1970), on the Ukrainian Carpathians (N. Semenenko et al. 1966 [ed.]; V. G l u š k o — S. K r u g l o v 1972), and on the Carpathians of Rumania (Z. B ă n c i l a 1958, O n c e s c u 1960) and of Hungary (E. V a d á s z 1960; L. T r u n k ó 1964).

It should also be mentioned that on the occasion of the Association Congresses (in Poland, the U.S.S.R., Rumania, Bulgaria, Jugoslavia and Hungary) Reports and Guide-books concerning the geology of the Carpathian-Balkan-Dinaride system have been published.

Of much importance for the recognition of the structure of the West Carpathians was the extensive boring and geophysical-research programme, and the geological interpretation of these works (O. F u s á n et al. 1971). Since this subsurface exploration is still in progress moth in the Czechoslovak Carpathians and the neighbouring countries, we are justified in expecting further valuable information which would add to the present store of knowledge.

At the time of the Third Congress (in 1931) of the Carpathian Association our approach to the problem was correct in many respects. The stratigraphy of central Slovakia was relatively well known and should be modified in recent years mainly for the Triassic and Permian.

The opinions on the tectonics of the Klippen Belt in Central Slovakia and of the Inner West Carpathians are valid up to date in some respects, whereas in others they had to be changed. However, the views of the existence of nappes, chiefly in the Core mountáin area, have been reinforced by further investigations. The unusually complicated structure of the West Carpathians becomes more evident year by year, despite the objections to the nappe structures that were put forward, especially in the sixties (M. M a h e ľ 1955, 1960; A. M á š k a — V. Z o u b e k in A. M a t ě j k a 1961). Today the presence of nappes, as they were conceived originally, is accepted even by those who were adverse to this idea.

The hypotheses of the multiphasal development of the Carpathians and of the folding phases, as they were submitted at the Third Congress were also analogous to the opinions advocated at present. The compilation of the Banská Bystrica sheet of the Tectonic Map, published for this Congress, wass based on this principle, as well as the plotting af the extent of the individual tectonic units. The concept of several folding phases was likewise a subject of sharp controversy (N. Š a t s k i j 1950).

It should be emphasized, however, that at the time of the Third Congress of the Association, the folding of many zones was erroneously dated or little known.

The objective of this Outline of Tectonics of the Czechoslovak Carpathians is to acquaint the participants of the excursions of the Tenth Congress of the Carpathian—Balkan Association with the general problems that cannot be dealt with in sufficient detail in the Guides-books to individual excursions. On the other hand, we cannot call upon the excursionists to study some multi-volume work on the Carpathian mountain range in Czechoslovakia before the field trip; we have tried therefore to present a concise interpretation of its structure, as it is today universally accepted. In ambiguous cases, several interpretations are offered. The authors of the Excursion guides were granted a certain liberty in opinions, so that the readers can meet even divergent views — but

»Science and its teaching is free«.

GEOGRAPHICAL DIVISION OF THE CARPATHIANS

From the synoptic map of geographical units delimited in the Carpathian Mountains of Czechoslovakia, the topographical picture of the region can be visualized.

However, the division of the whole of the Carpathian mountain range into the principal units is not accepted unanimously. The preponderant part, if not the whole Carpathians of Czechoslovakia are ranged to the West Carpathians. Their western boundary is placed to the Danube, and the eastern is drawn along the Košice depression — Prešov — Ondava valley or along the Uh valley. The latter is well evidenced geologically, as several units both of the East and West Carpathians end at the Uh river. We are inclined therefore to this second view.

PRINCIPAL TECTONIC ZONES

In traversing the Carpathian Mts. of Czechoslovakia and their foreland from north to south, the following tectonic zones are encountered (see Figs, 2, 3).

I. *Carpathian foreland* — Bohemian Massif in Czechoslovakia.

II. *Carpathian foredeep* — filled mainly with Neogene and partly Oligocene sediments. The folding, where present, is of intra-Neogene date.

III. *Carpathian Flysch Belt* — made up dominantly of Cretaceous and Paleogene flysch deposits, folded towards the end of

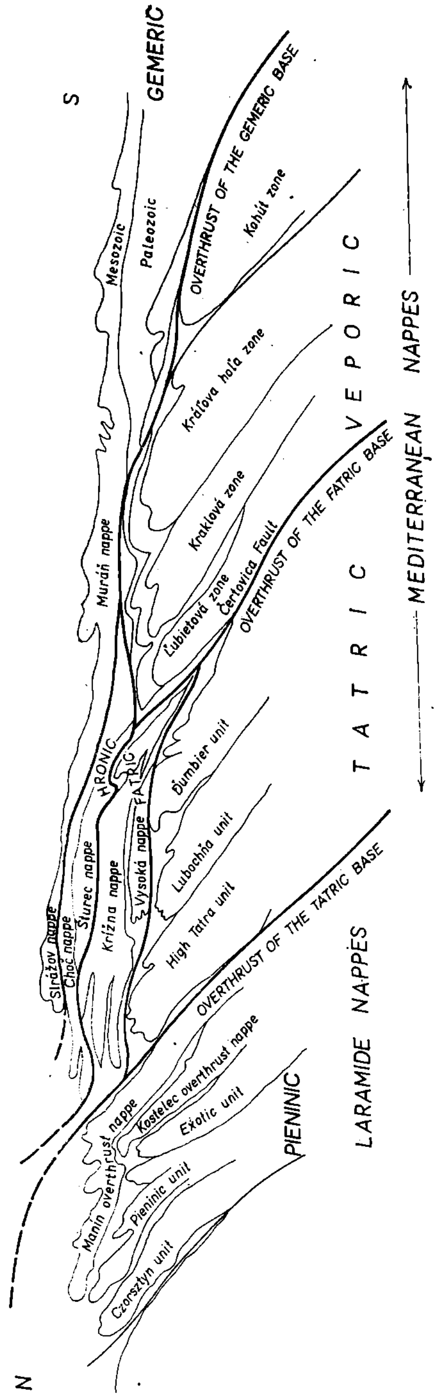

Fig. 2 Scheme of pre-Paleogene tectonic units of West Carpathians

the Paleogene or at the beginning of the Miocene, and deformed into north-vergent nappes.

IV. *Klippen Belt,* which is distinguished by numerous limestone klippen floating on the formations, topographically less marked. It underwent folding towards the end of the Cretaceous and again in the final phase of the Paleogene.

V. *Zone of Inner West Carpathians,* composed of ancient Paleozoic and? Precambrian formation (folded in the Paleozoic or probably in the Precambrian) and of the Mesozoic formations up to the Lower Turonian. They build up either separately or together with the basement extensive N-vergent tectonic nappes, which were formed during the Middle Cretaceous (chiefly Mediterranean) folding phases. The Upper Cretaceous and a thick Paleogene complex also take part in the structure of this zone; they are, however, post-tectonic and together with Neogene deposits they surround the elevated parts of the basement.

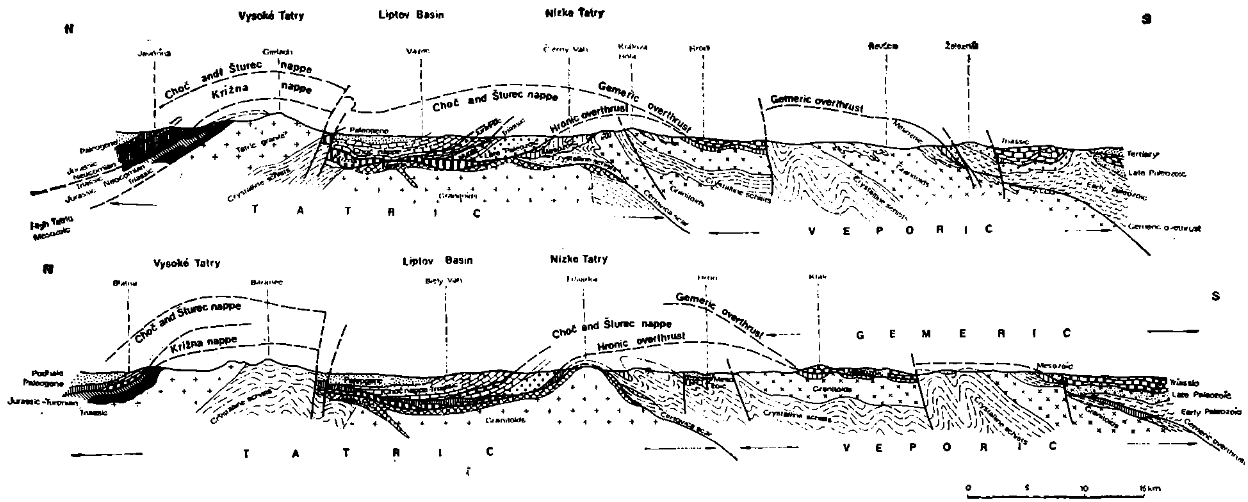

Fig. 3 Cross-Sections of the West Carpathians (after A. Biely and O. Fusán, 1967)

VI. *The Bükk zone,* which consists of marine Upper Paleozoic and Triassic deposits. It recalls the South Alpine development by its rich basic and in part acid volcanics.

VII. *The Hungarian median mass* spreads south of the Carpathian mountain system. It was not so intensely folded as the Carpathians either in the Middle Cretaceous or in post-Paleogene time. The older pre-Paleozoic, Paleozoic and Mesozoic formations, including the Lower Cretaceous, are covered by subhorizontal beds of Upper Cretaceous, Paleogene and occasionally by a very thick Neogene complex. The bulk of the mass occurs in Hungary, extending to south-western Slovakia.

VIII. In the southern part of the Carpathian mountain system there is a *volcanic arc built up of Neogene volcanic rocks,* which stretches to South Slovakia from Hungary. This unit also comprises Neogene sedimentary complexes. The dominant part of volcanic rocks builds up mountain groups, but a part of them composes together with Neogene and even Oligocene sedimentary sequences the fillings of depressions — basins. In the west, the northern Neogene basins are located on the flysch, the more southerly ones on the Klippen Belt and the Inner West Carpathians, and those in the extreme south on the older components of the Hungarian Central Highlands. Unit VIII is essentially a post-tectonic complex within the whole of the Czechoslovak Carpathians.

Although the individual zones and complexes differ substantially in composition and structure, they are linked up through some common elements and build up the uniform West Carpathian mountain range.

TECTONICAL AND STRATIGRAPHICAL ANALYSES OF THE DIFFERENTIATED UNITS

I. The Carpathian Foreland

is formed in the west of the units of the Bohemian Massif, which consist of numerous zones and components of different age. The following units contacting the Carpathians are differentiated in the basement affected by Precambrian, Caledonian and in particular Variscan (with several folding phases) orogenic movements: the Moldanubicum, presumably folded already in the Precambrian, the Moravo-Silesian zone folded intensively during one of the pre-Westphalian folding phases, the Brno massif subjected to Caledonian folding, and the outer Variscide zone (the area of Culm and productive Carboniferous of the Upper Silesian basin) folded in Asturian phase.

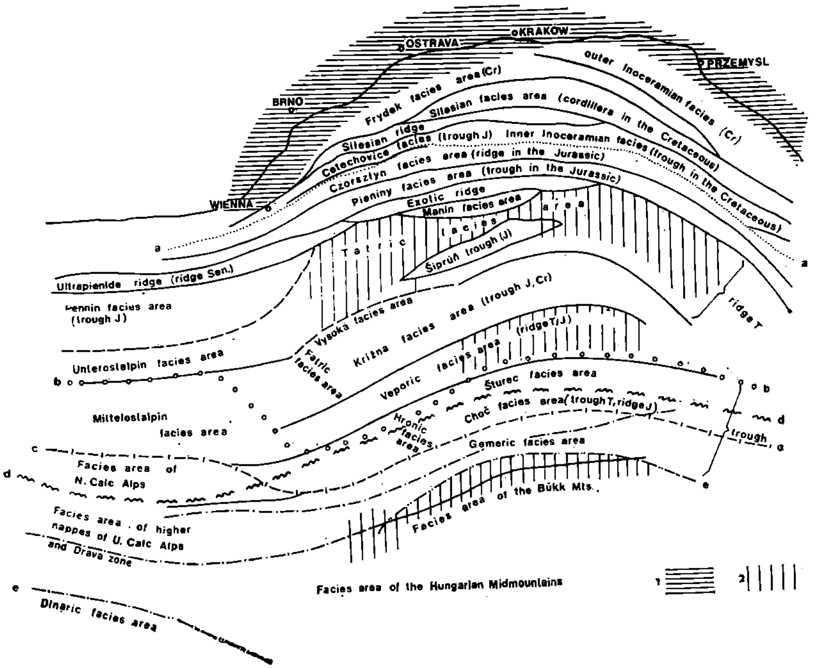

Fig. 4 Facial areas in the West Carpathians in the Mesozoic (after the unfolding of nappes). A scheme (by D. A n d r u s o v 1968)
a-a — northern limit of the area of the Alpine — Carpathian Triassic; b-b — southern limit of the area of the Keuper facies in Upper Triassic; c-c — southern limit of the area of Lower Triassic quartzites; d-d — northern limit of the area of the Alpine — Carpathian marine Carboniferous; e-e — northern limit of the area of the marine Permian; 1 — the area of Mesozoic in the Central-European facies; 2 — zones with breaks betveen the Triassic and Jurassic in the Carpathians

The rocks of these units occur mainly in the external zones of the Czechoslovak and Polish Carpathians as pebbles and olistoliths. This suggests that the older formations of the Bohemian Massif penetrated far eastwards beneath the Carpathians and made up the basement of the Carpathians north of the Klippen Belt. This does not imply that the Bohemian massif itself extends thus far but that some of its zones form or formed the basement of the Carpathian flysch. It is unknown to what extent were these formations involved in Alpine folding; they are mostly buried at depth, cropping out but exceptionally in the from of tectonic outliers. From the above said it is inferred that the Variscan units of the Bohemian Massif turned abruptly to the NE in Moravia and constituted thus the important Variscan Moravian sigmoid.

In the more interior zones of the Variscan fold system of the Bohemian Massif, the Upper Carboniferous and Permian are transgressive. In the area of Brno in Moravia, the Upper Jurassic and Upper Cretaceous of Central European type lie horizontally on the basement. In addition, the north-eastern margin of the Bohemian Massif is covered by Tertiary deposits which, however, belong for the greater part to the foredeep, but partially extend far north-westwards. In the external Variscan zones even the Westphalian sediments are folded, and the post-tectonic formations begin with the Stephanian.

II. The Carpathian Foredeep

The south-eastern margin of the Bohemian Massif is fringed by a mostly narrow belt of Neogene and locally also Oligocene sediments; it is a part of a very long trough, which stretches from Geneva along the whole Alp Mountains (where it is also called the »molasse zone«) and the Carpathian mountain range as far as the vicinity of Ploeşti in Rumania.

The thickness and completeness of development of the Neogene generally increases from the external to internal margin. The disturbance of Neogene beds also increases from north to south. The Neogene sequences rest either on the old complexes of the foreland or (in Moravia and in the adjecent part of the foredeep in Austria) on the marine Jurassic-Cretaceous sequence, or on various Cretaceous and Paleogene members, which are in normal position on the older formations of the foreland. The flysch Cretaceous and Paleogene beds underlie the Neogene in the interior (southern) part of the foredeep of the East Carpathians. The nappes of the Flysch Belt are overthrust from the south on the foredeep to various distances. Consequently, an exposed (not covered by nappes) part and a nappe-covered (southern part) can be distinguished in the foredeep. Since the migration of the nappes occurred during the whole Early Miocene, the age of the Neogene sediments in the two parts is not the same everywhere. In the Moravskoslezské Beskydy Mts. there is a trough filled with Karpatian sediments and another trough farther to the north is filled with Lower Badenian sediments, yet in the exposed part of the foredeep even the Upper Badenian sediments are developed. The division of the Carpathian foredeep into the outer nonfolded and the inner folded part can be applied to the East Carpathians. In the Czechoslovak Carpathians it is restricted to the occurrence of minor tectonic slices, of which the Pouzdřany slice is most important (Aquitanian and Oligocene in non-flysch development). In the foredeep, a fairly complete

Oligocene-Sarmatian stratal sequence can be developed; the complex is often sliced along the plane of flysch overthrust (Austria). The Neogene facies in the foredeep are of molasse type and may be salt-bearing (Poland). Thick masses of conglomeratic molasse occurring in the Alps and East Carpathians have not been established in the Czechoslovak Carpathians.

The age of movements in the faulted parts of the foredeep is intra-Miocene (Styrian); the overthrust of the flysch on the foredeep could be completed as late as during the intra- and post-Badenian phase.

III. Flysch Belt

This zone extending from the Alps can be followed along the whole West Carpathians and attains its maximum breadth in their eastern part. It is separated from the foredeep by a continuous overthrust, but is itself more or less heterogeneous even in the frontal part.

The Flysch Belt is built up of very thick Cretaceous and Paleogene complexes in flysch development. According to geophysical data, the thickness of the flysch sequence is estimated at 6000 m in the southern part of the Belt. We cannot, however, exclude a tectonic repetition. It has been established in the Moravskoslezské Beskydy Mts., but the boring near Staré Hamry, 2700 m deep, did not reach the base of the Cretaceous of the upper Godula partial nappe (part of the Silesian nappe).

On the basis of facies development and tectonic independence, two separate major units (three according to other classifications) can be distinguished in the Flysch Belt, i. e. the outer Krosno unit and the inner Magura unit.*

The outer unit is characterized by typical Menilitic Complex and a thick sequence of the Krosno Formation in the Oligocene.

a) The Krosno major unit

In the East Carpathians, the foredeep is overridden by a unit that is composed of tectonic slices (»skiby« in Polish), a part of which have the character of nappes (Skole nappe). This unit is called by some authors as the Skiby zone but we do not agree with this term for reasons mentioned in the note above. The unit passes without a tectonic boundary into the Central Carpathian depression, where the slice structure distinguished

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* In our opinion the tectonic units should be designated by geographical names, as are the stratigraphical units, and not according to their content; this principle will be therefore observed troughout the text.

by uplifted more resistant members of the Cretaceous and Lower Paleogene is not manifested.

1. The name *»Skole unit«* is faulty in that it was used first for one slice which is of marked nappe character. The outer unit of the Flysch Carpathians has been therefore termed as Dobšanka unit (O. Vjalov 1967). It will not be described here in detail, because it is not developed in Czechoslovakia.

2. The *Frýdek (Subsilesian) and Ždánice units* are the northernmost units of the Carpathian Flysch in Czechoslovakia.

In our country and in Poland, the Frýdek unit occurs north of the Silesian nappe and in tectonic windows at the southern margin of this nappe. It is composed of Upper Cretaceous and Paleogene beds in atypical flysch or non-flysch (couches rouges) developments. In Poland, the Lower Cretaceous complex is also represented. The unit consists of a number of slices and N-vergent recumbent folds, which were largely affected by the overthrust Silesian nappe. The northern belt of the Frýdek unit, which at the northern foot of the Moravsko-slezské Beskydy Mts. builds up the border of the Flysch Carpathians, trends southeastwards in Poland as a narrow strip between the Dobšanka and Silesian units; the latter ends in the Ukrainian region.

Towards the west, the Ždánice unit and the Waschberg Zone in Austria (traceable to the Danube) correspond to the Subsilesian (Frýdek) unit. The oldest member are the Jurassic Klippen (Mikulov—Waschberg) with transgressive Turonian and Senonian. The flysch-molasse Ždánice—Hustopeče Group (Oligocene—Aquitanian) of considerable thickness is the principal member. The boreholes have betrayed that the Frýdek unit was thrust as a nappe on the autochthonous Bohemian Massif and the overlying Neogene to a distance of at least 20 kilometres.

3. *The Silesian unit* is the principal tectonic unit in the Moravsko-slezské Beskydy area and is composed of the most typical flysch sequences of the Middle and Upper Cretaceous and Paleogene age. In the western part of the Beskydy Mts., it is divisible into the Těšín and Godula partial nappes. The bulk of the overthrust flysch mass belongs to the Godula nappe. The Lower Cretaceous flysch sequence is followed by Middle and Upper Cretaceous Godula and Istebna Formations and by the Paleogene in the Krosno facies. The complex beginning with the Middle Cretaceous is several thousand metres thick. The Godula partial nappe builds up the whole western ridge of the Beskydy Mts. and ends in the west abruptly near the river Bečva.

The Těšín partial nappe occurs north of the Godula partial nappe. We can distinguish there the Baška and the Godula facies. The former is characterized by the Štramberk Tithonian, transgressive Cretaceous, gaps in the Lower Cretaceous, and the transgressive Senonian. In the Godula facies, the flyschoid Tithonian grades into a continuous Lower and Middle Cretaceous sequence with the Variegated Godula Member in the Middle Cretaceous. The Těšín nappe occurs in the form of numerous nappe outliers on the Frýdek unit.

The Godula partial nappe is also overthrust on the Frýdek nappe but nowhere on the Těšín partial nappe. A sudden change of facies takes place on the overthrust plane. The Silesian unit loses the nappe character eastwards, and in Poland and Ukraine it passes into a system of N-vergent folds, thinning out allegedly in the Tereblja-river valley.

4. *The Dukla unit* designates a system of folds, which extends south of the Silesian unit, in eastern Slovakia and in the neighbouring part of Poland. It is overthrust to the north, but it does not show a nappe character. The unit is formed of very thick Upper Cretaceous — Oligocene flysch complexes. It differs from the Silesian unit in the development of the Upper Cretaceous, which is mainly of Istebna facies in the Silesian unit and of »Inoceramian« (older term) facies in the Dukla unit. This crops out in several tectonic windows from beneath the Magura Flysch in Poland, as far as the meridian of Cracow. The Dukla unit was mostly moved northwards together with the higher Magura nappe. It is of maximum extent and fold structure in eastern Slovakia and in Ukraine, where it makes up the highest ridge of the Východné Beskydy Mts. In places, a nappe structures is developed (nappe outlier of Polonina Rovna). In the river basin of Tisza the Čierna-hora flysch unit appears, continuing in Rumania as the Audia nappe.

In the West Carpathians, south of the Silesian unit, at the southern slope of the Západné Beskydy Mts., another flysch subunit of the Krosno unit appears discontinuously. It has so far been designated as the Fore-Magura unit. A particular development of the Upper Senonian with variegated and partly red marls and of the Paleocene with variegated claystones is distinctive of this unit.

In the Eeast Carpathians, south of the Dukla unit, there occurs the Porkulec unit with Lower and Middle Cretaceous in flysch development, which is similar to the flysch of the Polanca unit in Rumania (Curbicortical Flysch). It disappears westwards at the Latorica-river valley.

b) The Magura major unit

This unit is made up of Upper Cretaceous and Paleogene flysch. The latter sequence predominates. The Jurassic and Lower Cretaceous occur sporadically in the form of minor klippen, in the west mainly in the Chřiby Hills at the northern margin of the Magura unit, but many of these »klippen« are rather olistoliths. At the southern foot of the Moravsko-slezské Beskydy Mts., at the front of the Magura nappe, there are allegedly Cretaceous rocks, which resemble the Middle Cretaceous of the Godula nappe. However, the section through the Lower-Middle Cetaceous near Kurovce, which evolves gradually from the pelagic Upper Jurassic, is different. At the base of the Magura nappe in Poland and eastern Slovakia, the Upper Cretaceous of flysch development is designated as the »Inoceramian Beds« (or Ropa Beds); it does not extend westwards. In the west, the Senonian in the Variegated-marls facies is developed in places.

In the Paleogene of the Magura major unit, three facies zones have been differentiated from north to south, i. e. the Rača, Bystrica and Oravská Magura (Biele Karpaty) zones. The opinions on their character differ. A. Matějka and Z. Roth (1956) who were the first to establish their existence thought them to be facies-tectonic zones, whereas other writers regard them as more facies zones. In western Slovakia, the Oravská Magura zone proved to be thrust directly on the Rača zone to a considerable distance. It is not apparent there that the Magura unit would be translated as a uniform nappe on the elements of the Krosno unit. On the contrary, in Poland and eastern Slovakia the presence of tectonic windows (with flysch of in the Dukla unit) occurring within the Magura unit (Rača zone) indicates that this major unit was moved as a thrust nappe northwards to at least 35 km. The thrust plane coincides with the base of the Upper Cretaceous. Since the Paleogene facies of the Magura unit differ considerably, there are some discrepancies in stratigraphy. In the west, in the Rača and Bystrica tectonic units, the Paleocene at the base is developed as thick-bedded and coarse-grained sandstones with interlayers of variegated claystone (Soláň formation). Following is the fine-rhythmical flysch of the Beloveža Formation of Paleocene to Lower Eocene age, which is in turn overlain by the thick mediumrhythmical flysch of the Middle to Upper Eocene Zlín Formation. The Middle Eocene part of the Zlín Formation of the Bystrica zone bears layers of light-coloured calcareous marlstone (Łącko marls). In the southernmost part of the Magura unit in the west, the basal part of the Paleogene is formed of variegated and black claystones and of fine to medium-grained flysch of Paleocene-Lower Eocene age. Higher up there are thick-bedded sandstones of a special type, so-called Magura sandstones (Middle to Upper Eocene). In Poland, they make up the overlying flysch of the Rača zone and are termed as Babia-hora sandstones (up to Upper Eocene).

In eastern Slovakia, the Beloveža Formation (fine-grained variegated flysch) or dominant sandstone complexes forming the basal part of the Paleogene of the Magura unit overlie the Senonian. The Beloveža Formation is followed by the Zlín Formation. In the more southerly Bystrica and Oravská Magura zones of the Magura unit, the Zlín formation or variegated Middle Eocene marls are followed by the so-called Globigerina marls (upper Priabonian) and these in turn by the Oligocene Malcov Formation with lenses of Menilitic Beds in the lower part. Although the Malcov Formation is connected with the underlying complex (in sections) by transitions, it differs in distribution from the older Paleogene formations. This difference has been explained in terms of submarine discordance (Illyrian phase). In general, the facies changes in the Magura unit can not be regarded as elucidated, as in the Rača zone of eastern Slovakia there are no traces left of this folding, and the Zlín Formation is thought to end there in the Priabonian.

In eastern Slovakia, the Bystrica and Oravská-Magura (Čerhov) zones of the Magura unit are nowhere in normal contact with the Mesozoic of the Klippen Belt. The Paleogene of the Oravská Magura zone, however, lies normaly on the klippen Mesozoic in the Orava area, and that of the Bystrica zone in the middle course of the Váh. In the latter area, only the Mesozoic of the Klippen Belt can be presumed to form the substratum of the Paleogene of this type lies on the Mesozoic of the Klippen Belt

In eastern Slovakia, south of the units of the Magura major unit, the Paleogene sequence shows another development, in which the typical formations of the Magura unit are lacking (coarse-grained sandstones, Beloveža Formation, Zlín Formation). Paleogene of this type lies on the Mesozoic of the Klippen Belt with a normal contact on the northern side of the Belt or (Litmanova, Zlatne in Poland) in its central part. It has been denoted diferently (we will designet it as Inovce development). At its base is developped the Proč Formation- a flysh sequence with conglomerates bearing pebbles of Klippen Belt material, intercalated by variegated claystone beds (Paleocene to Lower Eocene); subsequent are the Middle Eocene variegated clay, Globigerina horizon of Upper Priabonian age, and the Malcov Formation.

The Magura Flysch constitutes a broad zone, which begins in W near the Wienerwald and extends together with the Inovce flysch zone to Ukraine. There, the flysch of the Magura unit thins out between the rivers Uh and Latorica, so that only the zone in Inovce facies continues farther to the east (Vulchovec Formation).

The southern boundary of the Magura unit may correspond to a local reverse or thrust fault. On the whole, the Magura unit together with the zone of Inovce facies lie normally on the pre-Paleogene units of the Klippen Belt.

The flysch complex was deposited in a trough, which was originally of arcuate form, concave to the south, and was by far broader than the present Flysch Belt. The formation of flysch nappes and folds occurred mainly during the Helvetian-Savian phases towards the end of the Paleogene. At the northern limit of the flysch, the movements continued even in the Styrian phases. The surface of detachment from the Precambrian to Mesozoic basement was essentially at the base of the flysch or, with regard to the plastic character of the flysch, at different levels in the flysch complex itself. The substratum of the flysch was built up north of the Klippen Belt by the complexes that also occur in the Bohemian Massif. During the folding and tectonic attenuation of the Flysch Belt, these older zones of the basement could have been strongly compressed and engulfed within a relatively narrow area, which is situated between the margin of the Bohemian Massif south of Ostrava (as evidenced by boring) and the northern margin of the Klippen Belt e. g. north of Žilina (20—25 km). The compression of the flysch sequences in the west provoked an extensive post-Paleogene overthrusting of, in particular outer, nappes of the Západní Beskydy Mts. In the central part of the flysch arc, the strong overthrusts affected chiefly the outer parts of the Magura unit. In the Carpathians, the narrowing of the flysch geosyncline was manifested dominantly by the formation of numerous tectonic slices (skiby) in the exterior part, or by the overthrust of the Krosno unit on the foredeep, which was intensively folded in the interior zone.

IV. The Klippen Belt

South of the Flysch Belt, there is another tectonic zone, relatively narrow (20 km at the most), which appreciably differs in character, the age of folding and the composition of its formations from the zones discussed above.

It differs even topographically from the monotonous configuration of the flysch area, in showing steep rock forms — klippen — protruding from the less resistant rocks of marly and flysch nature. This character of the Klippen Belt is caused by intricate history and complicate composition of its members. The klippen are composed of Triassic, Jurassic and Lower Cretaceous rocks, and are encompassed by complexes ranging in age from the Albian to Late Paleogene. Neogene beds are also present in the area of the Klippen Belt.

The Klippen Belt is often conceived as a tectonic unit sharply separated by faults from the flysch units in the north and the southern side. This idea is quite erroneous, as there are complicated relationships between the three zones in question. They differ in the age of the main phase of folding. a) The Flysch Belt was folded towards the end of the Paleogene and at the beginning of the Neogene. The Upper Badenian and in places even Eggenburgian are there post-tectonic formations. b) The Klippen Belt is a system of folds and nappes produced towards the end of the Cretaceous (Laramide phase). The Paleogene is post-tectonic, but was intensively refolded together with the Flysch Belt in the northern part of the Klippen Belt. c) In the more southerly zone of the Inner Carpathians, the alpine-type folding and the formation of nappes occurred in the Middle Cretaceous (mainly the Mediterranean phase). The Senonian and Paleogene are post-tectonic, but underwent partially germanotypical folding towards the end of the Paleogene. The Laramide folding was very weak in this area or altogether absent, but the system of pre-Senonian nappes produced by Mediterranean folding, was moved during the Laramide phase. The West Carpathians were thrust »en bloc« on the Klippen Belt, which may account for its intricate structure.

During the folding the Klippen Belt was greatly attenuated, and it can be justifiably presumed that within its range some important units disappeared in depth.

Under these conditions the following formations belong to the Klippen Belt:

1. *The Mesozoic building* up several Laramide nappes,

2. *Paleogene sequences* north of the Klippen Belt (south bordering Magura facies and zone of Inovce facies) which was folded during the Helvetian-Savian phase together with the Mesozoic of the Klippen Belt.

3. *Paleogene sequences* south of the Klippen Belt (in particular the special development of the Inner Carpathian Paleogene near Žilina), which were affected by germanotypical folding together with the Mesozoic of the Klippen Belt.

Orogenic phases in the Klippen Belt

In the Klippen Belt four to six orogenic phases may be postulated but only one or two were of alpine-type.

a) The oldest folding, which affected the basement of the Klippen Belt and the Inner West Carpathians was likely the *Variscan folding.* The Cretaceous conglomerates of the Klippen Belt contain pebbles of crystalline schists, granite and Lower Paleozoic rocks (besides Upper Paleozoic rocks) that do not crop out on the surface, but were certainly components of the basement of the Klippen Belt which underwent Variscan folding. It is not clear at all if several phases were active towards the end of the Carboniferous and in the Permian, but it is more than probable from the analogy with the Inner West Carpathians that this was the case.

b) The following orogenic movements affected some parts of the Klippen Belt between the Aptian and Albian (*Manín phase*). The presumption that nappes were formed at that time (D. Andrusov 1938) was derived from the intricate tectonics and the presence of the »couverture de remplacement«; at present it is accepted that the Manín movements were only of minor intensity.

c) Orogenic movements at the beginning of the Senonian, which are evidenced farther to the south in the Inner West Carpathians, manifested themselves also in the Klippen Belt. Some years ago, when the application of micropaleontological method was in initial stage, some authors (D. Andrusov et al. 1960, and many others) thought that Turonian and Coniacian are lacking in the Klippen Belt, and that the nappes of it were formed during the Senonian phase and not at the beginning of the Albian. The existence of major movements in the first half of the Senonian is evidenced by the thick masses of conglomerates with exotic blocks. Their presence also suggests that part of the Klippen Belt was uplifted at that time. On the other hand, recent investigations have revealed that the Albian—Cenomanian—Senonian stratal sequence in the Klippen Belt is continuous, and that no folding or unconformity took place at the beginning of the Senonian, the phase being probably germanotypical. The emergence is postulated only for one cordillera and not for the whole Klippen Belt.

d) The detailed investigation of the Upper Cretaceous and older formations with the Paleogene beds points to that at the beginning of (and possibly also during) the Paleocene intensive folding occurred and the Laramide north-vergent fold-nappe system originated. Mechanical properties of the component parts of the Laramide nappes were extremely different, which caused outstanding disharmonies provoked by the overthrusts of nappes. Many of the pre-Albian members are competent (limestones) and consequently their response to folding was different from that of incompetent members. The flysch or marly complexes which predominate among the younger formations are greatly plastic and only some of them constitute continuous solid mass (Senonian conglomerates). During the folding and the formation of nappes, large-scale detachment of competent members from the plastic ones, boudinage, and overriding of lower nappes (or autochthonous zones) by the higher nappes with occasional enrollment (so far not safely established) occurred. At that time, as mentioned above, the West Carpathians were thrust »en bloc« on the Klippen Belt. Synchronously, this was for the first time strongly compressed between the basement of the Outer West

Carpathians and the Inner West Carpathians. Thus, preconditions for the origin of tectonic forms were given, which in later development induced the klippen style of the Klippen Belt.

e) The *Savian* orogeny which led to the formation of vast N-vergent nappes in the Flysch Belt, also affected the northern margin of the Klippen Belt. Simultaneously S-vergent folds and tectonic slices originated either only in the northern zone or within the whole Klippen Belt. The competent members (mainly Dogger, Malm, and Neocomian limestones) were separated from their envelope to a greater extent than during the Laramide folding, and were subsequently modeled into morphologically conspicuous »klippen« (originally termed in Germany Klippen, »Klippenzone« »pieninische Klippenzone«). Later, tectonic implications have been attached to these terms, which are now used to designate rounded or lenticular (mostly older) competent forms encircled by younger, mostly plastic formation. The contact is either sharp and tectonic, or a strongly disrupted zone accompanies it. In some cases the (Albian) envelope lies transgressively on the klippe and the contact is normal. However, even in this case, a tectonic contact is more frequent, a lenticular strip being formed in the klippe envelope.

The southern limitation of the Klippen Belt is generally tectonic, and the zone deformed by Helvetian-Savian orogeny directly contacts the Inner Carpathian units (Podhale). In places, the southern part of the Klippen Belt did not undergo alpine-type folding. In that case, the transition between the Paleogene of the Klippen Belt and the Paleogene of the Inner Carpathians is gradual. However, a special type of Paleogene (of Žilina, or Hričovské Podhradie types), with Paleogene beds and bioherms is developed.

Laramide units of the Klippen Belt

The Laramide units are easy to distinguish from the Helvetian-Savian units, the more so that the Laramide folds and nappes were N-vergent and the Helvetian-Savian tectonic slices and folds vere S-vergent. The S-vergent Helvetian-Savian slices, which alternate mutually, are generally observable. The older Laramide structure should be deciphered on the basis of facies analogies.

Essentially, the following Laramide units have been differentiated in the Klippen Belt, especially in the middle sector of the Váh valley:

a) *The Czorsztyn unit* (with Czertezik and other subunits), was originally situated in the extreme north. It shows the most typical klippen style where the massive limestones are present. The stratigraphical sequence includes: Middle Triassic dolomite, Lower Liassic lumachelles, ?Liassic spotted limestones, Opalinum

Member, Murchisonia Member (Aalenian), light-coloured crinoidal limestones (Bajocian), red crinoidal limestone (Bathonian), Czorsztyn limestone (Callovian — Kimmeridgian), coarse-organogenic and Calpionella limestones of Tithonian to Valanginian age (Rogoźnik lumachelle of Tithonian age, among others). A hiatus. Albian marls and marly limestones, Cenomanian-Campanian ? to Maastrichtian variegated marls (Couches rouges, Púchov marls).

b) *Kysuca unit and Pieniny* s. s. unit (with Zázrivá, Pruské and Niedzica facies). Stratal sequence: Carpathian Keuper, Rhaetian, Gresten Formation, Liassic spotted marls (which are assigned to the Manín unit by M. M a h e ľ and A. B e g a n 1967, 1968) Aalenian flysch, Posidonia Member (Aalenian), supra-Posidonia Member (Bajocian-Bathonian), lower nodular limestone (Bathonian-Callovian, may be absent), radiolarites (Oxfordian), upper nodular limestones (may be lacking), Calpionella and radiolarian limestones (Tithonian — Lower Aptian), »radiolarian-globigerina (Tissalo-member) (Upper Aptian — Albian), variegated and red Globotruncana marls (Cenomanian — Lower Turonian), Snežnica Member — Sromowce Member (Coniac-Santonian flysch), occasionally with thick beds of conglomerates with exotic pebbles and boulders and with bioherms of Rudists limestones (flysch sequence: Sromowce Member; conglomerates: Upohlav or Upohlav-type conglomerates). The Campanian is represented by variegated Globotruncana (Gbelany) marls. In the Pieniny unit s. s. (Orava — Pieniny) the older members up to the Posidonia Member are lacking, and the whole Cenomanian- Turonian seems to be developed in the form of variegated marls.

The stratal sequence of the Czorsztyn unit differs from the Kysuca — Pieniny unit by the transgressive Albian. Many klippen show transitional development to the Czorsztyn unit. It is obvious that the sediments of the Czorsztyn unit were deposited on a ridge (cordillera) and those of the Kysuca and Pieniny s. s. units in a furrow situated to the south of it.

c) *The Manín unit* is widely distributed on the surface in the Váh valley.

Stratal sequence: Liassic, in general sandy-calcareous facies with modular crinoidal limestone, pink limestones (?Bathonian — Lower Malm), a thick series of massive or thick-bedded cherty or marly limestones (Tithonian — Lower Neocomian), very thick, massive, in part organogenic and Rudists limestone (Urgonian), and in places a thin bed of glauconitic limestone (upper part of Lower Albian) which is transgressive on the Urgonian. Following is the Albian-Cenomanian complex developed either as grey marls or flysch with pelosiderite concretions.

In the upper Cretaceous layers of the Manín nappe, two different facies — the northwestern and southeastern — are observable, mainly near Považká Bystrica. In the north-western facies, a thick complex of conglomerates with exotic material has been locally established in the (?) Albian. The Cenomanian is distinguished by the renomed Orlové sandstones with *Exogyra columba silicea* Lam. The Santonian is represented by thick masses of Upohlav conglomerates with exotic pobbles and blocks of reefal Hippurites limestones, or by coarse-detrital limestones with Hippurites-bearing interbeds. The Campanian-Lower Maastrichtian variegated marls (Couches rouges facies) are followed by Upper Maastrichtian flyschoid beds with orbitoids. There is no gradual transition between the Cretaceous and Paleogene. The pre-Albian complexes are missing. This part of the Manín nappe lies on tectonic windows and on the nappes of the Klippen Belt (e. g. the Upohlav window: red limestones — Malm, light-coloured limestones — Tithonian—Neocomian, spotted limestones — Albian (Tissalo-member), variegated marls — Cenomanian, sandstones and conglomerates — Santonian.

In the south-eastern facies, where there are large klippen (Manín, Butkov) built up of Lias-Urgonian rocks; the flysch-type of Albian and Cenomanian is overlain by Turonian-Santonian flysch (in places with Santonian conglomerates). Following are Campanian variegated marls, which are in turn covered by flyschoid orbitoidal Maastrichtian beds. The uppermost Maastrichtian occasionally bears bioherms.

In the area of Považská Bystrica, the Manín nappe overrides the Kysuca unit of the Klippen Belt, but westwards of it the nappe front recedes abruptly to the south, so that west of Púchov the nappe forms only a narrow border along the south-western margin of the Klippen Belt. It disappears east of Žilina and may re-appear in end around the Haligovce klippe in the Pieniny Mts.

From the above-said it follows that the principal elements of the Klippen Belt in the north are (I) the Pieninic, i. e. the Czorsztyn, Kysuca, and Pieniny s. s. units. They are interconnected by transitions and, in the middle reach of the Váh valley, covered by (IV) the Manín nappe.

We have intentionally omitted the units II. and III. as their position is very uncertain even if their existence is doubtless.

d) It should be mentioned that in the Klippen Belt near Púchov and Považská Bystrica, occur small klippen of rather aberrant type. Light-coloured coral and sponges limestones of Cordevol age (Trias) from the vicinity of Púchov are identical with the Wetterstein limestone of the higher nappes of the Inner West Carpathians. Variegated brachiopodal, mainly Spiriferina limestones of Liassic age near Považská Bystrica (Klape, Kostelec), are similar to the Hierlatz limestone of the higher nappes of the Eastern Alps. The following pale limestones extend to the Lower

Malm. These Mesozoic members have been separated as a particular tectonic unit III. with Kostelec development. Some authors tried to find whether a specific Cretaceous facies could be added to the Jurassic and Triassic just described. However, the Middle Cretaceous of the Klape klippe is definitely identical with the Manín Cretaceous, and the Lower Cretaceous clearly emerges in a tectonic window and belongs to the Kysuca unit. Only in a small klippe north of Púchov, the »hard ground« developed on the Triassic limestones of Kostelec facies is overlain by a thin bed of Coniacian marls. Undoubtedly, the Cretaceous in the Kostelec facies was only rudimentarily developed.

The Middle and Upper Triassic and (marine) Rhaetian limestones were found in large amount in the Senonian conglomerates (K. B o r z a non publ.). They could not be derived from the Inner West Carpathians. Moreover, the Triassic facies differs strikingly from the Triassic facies of the Kysuca unit in which, the Carpathian Keuper is developed in the Upper Triassic.

Consequently, it should be postulated that the Kostelec facies was deposited in a geosyncline with a typical marine Middle and Upper Triassic and with the Liassic in Hierlatz development. We have called this sedimentary zone as the Váh furrow, even if its extent and significance have so far not been elucidated.

e) The *exotic Pieniny ridge* is another unit II. that has been separated out in the Klippen Belt. This unit does not crop out on the surface at all. Its existence in the past and its uplift at the end of the Santonian and partially in the Albian-Cenomanian is inferred from the occurrence of large boulders and pebbles mainly in Santonian (but also in Cenomanian conglomerates and Albian olistoliths) in the Kysuca unit and the northern facies of the Manín nappe. Since they gradually wedge out south-eastwards in the Manín nappe and are developed in the Kysuca unit, being replaced by variegated marls in the Czorsztyn unit (Couches rouges), it is obvious that the exotic Pieniny ridge was located between the Manín nappe in the south and the Kysuca unit in the north. The exotic blocks are formed of crystalline schists, low-grade metamorphosed Lower Paleozoic rocks, Carboniferous rocks, presumably Variscan green granites known nowhere else in the Alpine-Carpathian system, Permian basic and ac'd magmatites, and Lower Triassic basal quartzites and conglomerates as well as calcareous rocks. Of importance are boulders of Urgonian rocks and pebbles of Jurassic rocks that are unknown in the adjacent zones and in the Carpathians altogether. It can thus be presumed that below the Klippen Belt exist rock complexes which today do not crop out on the surface. The transport of boulders to a greater distance along the Klippen Belt does not come into consideration (as evidenced by perfectly worn pebbles along the rocky cliffs of recent seas). Moreover, the exotic conglomerates of this type are restricted to a segment of the Klippen Belt extending from Tvrdošín in the Orava area to the middle reach of the Váh valley. The width of the conglomerate strip is also small (15—18 km).

Tectonic style

The klippen show a very varied tectonic character: some are normal folds, N-vergent folds, others complicated systems of normal or overturned folds, erected lenses, etc. They do not represent nappe outliers which are distributed in the Carpathians near the Core mountains. These have, however, never been called the »klippen«, although in central Switzerland the term »Klippe« is used just for the nappe outliers (Giesnilerstock, Stanzerhorn, Mythen). We will therefore distinguish klippen of the Carpathian type, which are tectonic lenses connected with the encircling rocks in different ways, and klippen of the Swiss type which are nappe outliers.

The southern boundary of the Klippen Belt in the Váh valley is not invariably tectonic. The Paleogene of the Žilina (Hričov—Podhradie) development lies the Mesozoic with a normal-transgressive unconformable contact, and begins with the Paleocene. In places, the Paleocene wedges out southwards and the Eocene (Súľov conglomerate) lies unconformably on the Manín and Krížna nappes.

The tectonics of the Klippen Belt is unusually intricate; its sedimentary area was a disturbed zone already in the Paleozoic, as the southernmost part of the Outer Carpathians, because its evidence available for the assumption that the Klippen Belt represents a lineament or a strike-slip fault. It cannot be regarded as the southernmost part of the Outer Carpanthians, because its interior part agrees in style with the Inner West Carpathians, Characteristic of the Klippen Belt is a system of Laramide nappes, which were generated near a zone of weakness between the ancient units underlying the flysch complex and the folded units of the Inner West Carpathians. The Paleogene is post-tectonic with respect to the Laramide folding, but in the northern strip it was subjected to alpine-type folding together with the underlying sequences and the adjacent flysch of the Magura unit. The formation of south-vergent structures in the Klippen Belt and of north-vergent structures in the Magura nappe gave rise to the asymmetric Magura fan.

The dominantly erected, often south-vergent tectonic slices formed during the post-Paleogene folding, combined with Laramide forms, cause the extremely intricate structure of the Klippen Belt. The effects of the Laramide and post-Paleogene folding episodes can be distinguished from each other in places. The combined activity of the two phases imprinted a diapiric character to many klippen.

V. The Zone of Inner West Carpathians

New investigations varried out in the Inner West Carpathians (concerning stratigraphy, facies, etc.) as well as mapping and deep boring led to some changes in the views of their structure. This resulted, understandably, in the revision of tectonic terminology and in the introduction of new tectonic terms. Proceeding from north to south, the following geological units are seen on the geological map. The zone of Core mountains in the north is distinguished by isolated granite massifs with crystalline mantle, which are encompassed by Upper Paleozoic, Mesozoic, Paleogene and, in places, Neogene sediments. The area situated south of it is called the Slovenské rudohorie zone. In the western part, a vast granitoid massif with crystalline schists is encircled by Upper Paleozoic deposits and metamorphosed Mesozoic sediments. In the eastern part, there are epi-metamorphosed Lower and Upper Paleozoic sediments, accompanied by volcanic rocks, and Mesozoic in particular Triassic sediments. These parts do not make up separate tectonic units, as some formations of this zone tak part in the structure of the adjacent Core mountain ranges.

The tectonic division of the Inner West Carpathians can be based only on the results of the Middle Cretaceous (Mediterranean) folding phase, because it obliterated for the most part the effects of the earlier pre-Mesozoic orogenies. The post-Mediterranean folding phases were not so intensive as to produce discriminable tectonic units. They only provoked the breaking of tectonic units formed during the Mediterranean phase.

According to the present state of knowledge, the following principal tectonic units of the Inner West Carpathians have been differentiated (they are arranged in the order of the presumed positions of their sedimentary areas, from N to S, in the Carpathian part of the Tethydian geosyncline):

1. Tatric with tectonic units of the second order:

   a) High Tatra unit
   b) Šipruň unit
   c) Ďumbier unit

The Malé Karpaty unit, also of the second order of magnitude, is also assigned to this principal unit, and possibly also others, the assignment of which is not safely known.

2. Fatric unit with tectonic units of the second order:
   a) Vysoká nappe
   b) Krížna nappe
3. Veporic unit with tectonic units of the second order:
   a) Ľubietová unit
   b) Kraklová unit
   c) Kráľova hola unit
   d) Kohút unit
4. Hronic unit with tectonic units of the second order:
   a) Šturec nappe
   b) Choč nappe
5. Gemeric unit with tectonic units of the second order:
   a) Strážov nappe
   b) Muráň nappe

In the sense of our concept, the southernmost principal unit of the Inner West Carpathians is the Bükk unit, which is located at the contact between the Inner West Carpathians and the Hungarian median mass.

1. The Tatric

includes the units of the Core mountains which build up the northernmost and thus also the lowest tectonic unit of the Inner West Carpathians. It is composed of crystalline schists and granitoids and of their Upper Paleozoic and Mesozoic sedimentary mantle.

Stratigraphically, the ancient crystalline basement is rather monotonous. The crystalline complex is formed of ectinites (biotite paragneiss, mica-schist) and migmatites of all grades, injection gneisses, and anatectites; the series ends by rocks designated as orthogneisses. The injections of gneisses on the southern slope of the Nízke Tatry Mts. are connected with the particular »high-tectonic« gneissic granite of Králička. Within the areas built up of crystalline schists, however, occur numerous major late-tectonic (serorogene) granite massifs (Ďumbier oligoclase granite in the Nízke Tatry Mts., Tatric granite, Prašivá orthoclase granite, etc.), which also induced the origin of later injection gneisses. In this meso- to katazonal crystalline complexes of unknown age, there are strips of amphibolites representing altered initial basic volcanics and their tuffs.

Radiometric age measurements have established Variscan age for the intrusions of Kralička granite and late-orogenic granitic rocks and for the metamorphism. This determination, naturally, does not concern the age of primary sediments from which the crystalline schists were derived.

In the Tatric area, the monotonous complex of crystalline schists has been found to occur in the Vysoké Tatry (High Tatra) Mts., in the Ďumbier and Lubochňa massifs, in the Suchý and Malá Magura massifs, and in the mountain ranges of Považský Inovec, Tribeč, Malá Fatra, Branisko, and Malé Karpaty. On boring evidence, it is also present in the western part of the Danube Lowland, but at a greater depth (to 5000 m).

Some complexes of the Malé Karpaty Mts. are of stratigraphic importance. It is, for example, the Harmónia formation, consisting of argillaceous bituminous shales, which are often contact-metamorphosed and bear layers of limestone with contact minerals. Basic volcanics and their tuffs also occur. The fossils suggest the Devonian (?Middle) age of the Group. Of interest is likewise the Lamač Formation composed of graphitic shales and gneisses with layers of basic magmatites. On microflora evidence the Formation would be Devonian — Carboniferous. Since the Middle Carboniferous is nowhere strongly metamorphosed or injected, the Lower Carboniferous should be considered. All these observations indicate that the older (pre-Middle Carboniferous) formations of the Tatric embrace members of different age, which underwent regional or contact metamorphism in the Carboniferous. The grade of metamorphism does not permit to distinguish the Proterozoic rocks from the Paleozoic ones. It was polymetamorphism connected with recurrent granite intrusions and injections, or with contact metamorphism at the boundary with granites.

The Middle and Upper Carboniferous is known but sporadically in the Tatric. Dark molasse sequence is developed in the Považský Inovec Mts., which is dated as Upper Carboniferous. The Carboniferous on the northern slope of the Branisko Mts. probably also belongs to the Tatricum. The Permian (probably only the Upper Permian) occurs but sporadically and is of Alpine Verrucano type. It is known from the Považský Inovec, Malá Fatra, Tatry and Branisko mountain ranges.

The Mesozoic does not attain a great thickness in the Tatricum. Some stratigraphical horizons are analogous in the individual tectonic units of the second order, whereas others widely differ.

In general, the Mesozoic begins with the transgressive Lower Triassic (Seisian), composed of quartzites and quartzose conglomerates, which are followed by »Werfen« shales. The basal part of the Middle Triassic is formed of dark Anisian (Gutenstein-Annaberg) limestones, and the upper part of the Ladinian dolomites. In the Tatry Mts., the Middle Triassic is represented by dolomites and limestones grading into each other. At the base of the Anisian there are breccias. Characteristic of the preponderant part of the Tatricum is the break in sedimentation during the Rhaetian, in places as early as at the end of the Middle Triassic. This is accounted for by the movements corresponding to the Early Cimmerian folding phase. Variegated shales and quartzites (Carpathian Keuper) occur in the Upper Triassic. The Rhaetian of the Vysoké Tatry Mts. bears continental flora. The transgressive Liassic invariably begins with coarse-detrital rocks (sandstones, conglomerates, crinoidal limestones), which occupy the whole Liassic sequence in the High Tatra unit. In some second-order units of the Tatric, Liassic dark crinoidal limestones are developed, whereas in others (Šipruň unit) dark spotted limestones and marls are present (Fleckenmergel facies). These differences are also observable in the Dogger. Shallow-marine variegated crinoidal limestones (in places transgressive on the Triassic) are developed in the High Tatra unit and in the Tribeč Mts. In the Šiprúň unit radiolarites and cherty limestones are present. In the High Tatra and the Ďumbier units, the Malm deposits have the character of thick-bedded or massive, pale to white limestones (the Alpine »Sulzfluhkalk facies«), and of deep-water cherty limestones in the Šiprúň unit. The Neocomian thick-bedded limestones locally pass upwards into dark cherty limestones, and these into Albian flysch beds. The Lower and Middle Cretaceous in the Tatry Mts. displays a quite different stratal succession: the complex of thick-bedded Neocomian limestones ends with the Urgonian organogenic limestones. Their sedimentation was followed by a hiatus, and the Middle Albian starts with glauconitic limestones. Higher up there is the Upper Albian to Lower Turonian marl complex with sandstone intercalations.

The Mesozoic complexes overlying the older complexes of the Tatric do not constitute separate tectonic units since they were translated together with them. In some cases, the Mesozoic sequences were given local names and designated as »series«, which term, however, denotes a stratigraphical unit of a given order of magnitude and cannot be conceived as a tectonic unit.

The second-order units of the Tatricum are allegedly separated from each other by steep, S-plunging tectonic planes, along which they were thrust one over another from the south northwards. Their overthrust to a greater distance cannot be evidenced, and their mutual relationship cannot be stated with certainty according to the Upper Paleozoic or Mesozoic facies.

In the High Tatra unit there are distinguishable recumbent folds and slices built up of crystalline but mostly of Mesozoic rocks (Červené vrchy fold, Giewont fold). Analogous lower-order units were previously also reported from the Nízke Tatry Mts., but recent investigations (A. Bujnovský). have not corroborated their existence.

2. The Fatric

is a major tectonic unit overthrust on the Tatric. It is characterized mainly by the Mesozoic, because the crystalline basement of the sedimentary mantle crops out on the surface only at one place north of Banská Bystrica.

The crystalline complex is analogous to that of the Tatric, but differs from it in having a dominant portion of migmatites. Granitoids are unknown there. The Upper Paleozoic is only represented by sediments of Permian age, which are developed in the Verrucano facies and rest on the crystalline north of Banská Bystrica.

The Permian is overlain unconformably by the Lower Triassic quartzite; then follow the Werfenian Formation, Middle Triassic dark limestones and dolomites, in places a thin interlayer of Lunz Beds, and on this the »Hauptdolomit«. The Upper Triassic molasse-lagoonal sequence (Carpathian Keuper) is deposited either on this dolomite or directly on the Middle Triassic. The Early Cimmerian hiatus is not marked, but the marine Rhaetian implies the re-ingression of the sea (without hiatus). Following is the detrital Lower Liassic — »Gresten Formation«, which is succeeded by three main Liassic facies: in the north — the facies of spotted limestones and marls, in the central part — nodular limestone facies (Adnet facies), and in the south — the facies of variegated crinoidal limestones. In some sections, the transitions between the facies are gradual, whereas in others the changes are connected with partial nappes and digitations. The Dogger-Oxfordian is invariably represented by deep-water radiolarian jaspers and cherty limestones, the Kimmeridgian by red, slightly nodular limestones, the Tithonian by thick-bedded Calpionella limestones, the Valanginian-Barremian by a thick complex of grey bedded limestones and marls, the Aptian by marls with intercalations of crinoidal limestones with orbitolins, and the Albian-Cenomanian by flysch or flyschoid beds.

The Fatric as a whole constitutes a very extensive nappe resting on the Tatric. Of the second-order tectonic units, the Krížna nappe is largest, being composed of several partial nappes and digitations. The Vysoká nappe is overrideen by the Krížna nappe, but occurs only in some Core mountain ranges (the Malé Karpaty Mts.). The Mesozoic of these partial nappes does not contain the Liassic Fleckenmergel facies in all of them.

3. The Veporic

which is another major tectonic unit, was thrust over the Tatric along the Čertovica thrust plane (projected on the surface as the »Čertovica line«). Characteristic membres of the Veporicum are the crystalline, and the overlying epi-metamorphosed Upper Paleozoic and Mesozoic.

In the northern part, the crystalline complex is of similar character as in the Tatric, but is more intensively diaphthorized, and contains more abundant amphibolites. Recently, the crystalline has been subdivided into several lithological units (A. Klinec), but their age is so far unknown. The radiometric measurements have determined the age of metamorphism, which is Paleozoic, corresponding to Variscan orogeny, and Cretaceous, connected with the Mediterranean folding. In the southern part of the Veporicum (the Kohút unit) there is the particular Kokava Group, formed of biotite-garnet mica-schists with intercalations of graphitic quartzite, carbonates, lydite, and with lenses of amphibolite and serpentinite.

The Hladomorná dolina Formation, another component of the southern part of the Veporicum consists of phyllites with interlayers of lydite and amphibolite beds, and of contact-metamorphosed schists.

The Upper Paleozoic sediments only occur on the southern and northern margins of the Veporicum. In the south (the partial Kohút unit), the Carboniferous is represented by dark phyllites, arkoses, sandstones, and in places conglomerates. The Permian is developed in an arkose facies with intercalations of sericite schists. In the western part, the development of Permian sediments recalls the Verrucano facies. In the northern part (the partial L'ubietová unit) the Permian Verrucano facies with quartz porphyries and their tuffs is the only representative of the Upper Paleozoic. In the Čierna hora Mts., where the L'ubietová and Krakľová partial units are probably present, the Carboniferous occurs in the dark-phyllite facies and the Permian in the Verrucano facies with quartz porphyries and their tuffs.

The Mesozoic of the Veporic begins with the epimetamorphosed Lower Triassic quartzites. Two facies have been distinguished, based on the development of the higher Mesozoic members. In the north, in the partial Krakľová unit, the Triassic of Veľký Bok is mainly composed of dolomites, with sporadic occurrences of the Lunz Member, Carpathian Keuper and in places of Rhaetian. The principal members of the Jurassic are crinoidal limestones, dark flaggy limestones, red cherty limestones, marly limestones and shales. The whole stratal succession was affected by epizonal metamorphism. An analogous succession has been established in the L'ubietová partial unit in the Hron valley and in the Čierna hora Mts.

In the south, in the Kohút and Kráľova hola partial tectonic units, the Mesozoic sequence is of a far smaller thickness; it comprises Triassic dolomites, epimetamorphosed grey and pale limestones, dark shales with interlayers of cherty limestone. The individual members cannot be stratigraphically assigned with certainty; they are dated as Triassic and/or Jurassic on the facies basis. This stratal succession has been designated as the »Foederata Formation«.

The so-called Zemplín »isle« may also be ranged to the Veporicum on the basis of its tectonic position, but its Upper Paleozoic and Triassic facies speak against it. The coalbearing Carboniferous (Stephanian) and light-coloured Triassic limestones are characteristic of this structure.

4. The Hronic

is the major tectonic unit overthrust on the Veporic and Fatric. In essentials, it is a large nappe, which was translated from the south over the Veporic and Fatric into the Tatric area.

The crystalline basement of this major unit is unknown on the surface. The composition of this crystalline mass may be inferred from the pebble material of the Carboniferous / Bindt-Rudňany / conglomerates, which is unknown on the present surface of the Gemeric. The transport of this material from the Veporic across the sedimentary area of the Hronic up to the Gemeric seems hardly possible. In our opinion, it was derived from this part of the Hronic that had been emerged in the Carboniferous and adjacent to the sedimentary area of the Gemeric.

The lowest member of the Hronic occurring on the surface are the Carboniferous dark shales with interbeds of sandstone and conglomerate. The complex encloses basites the age of which is unknown. It grades continuously into the Permian, which displays a particular development, unknown in other major tectonic units. This so-called Melaphyre Formation consists of variegated shales, sandstones and arkoses with layers of basic effusives (melaphyre). The Lower Triassic is transgressive, with quartzites at the base. The following variegated shales and the marly-calcareous sequence yield ammonite and other Campilian fossils. The Middle and Upper Triassic are the main representatives of the upper Mesozoic. Their different development in the partial tectonic units is a suitable criterion for their delimitation. the Nízke Tatry Mts. and minor recumbent folds. The higher nappe, the Middle and Upper Triassic occur dominantly in dolomitic facies. The Middle Triassic generally begins with the Gutenstein limestone; in the Upper Triassic there are local occurrences of the Lunz Member and/or Opponitz limestones. The Rhaetian in the facies of grey limestones is rarely developed.

The Jurassic and Lower Cretaceous of this nappe build up minor tectonic slices in the Strážovská hornatina Mts. The Liassic is represented by thick-bedded crinoidal limestones and variegated crinoidal limestones. The Dogger cherty limestones, which occur in places, resemble the Malm limestones. At the top there are flaggy limestones and marls of Tithonian-Neocomian age.

The Šturec nappe comprises partial units in places, such as the Boca and the Malužiná partial nappes on the northern slope of the Nízké Tatry Mts. and minor recumbent folds. The higher partial nappe, for which the name Choč nappe is retained, shows a far more varied succession. The Middle Triassic generally begins with the Gutenstein limestone. It is overlain by Pelsonian dolomites, which are followed by the Reifling limestones of Illyrian to Cordevolian age, and these in turn by so-called »Aon Beds« of the Lower Julian date or by the Lunz Member of Julian age. In places, the Reifling limestones pass into Raming reefal limestones. The Upper Carnian or Norian dolomites (Hauptdolomit) occasionally grade into the Dachstein limestones. The Triassic ends with the Kössen member which, however, has so far been found only at the southern foot of the Nízke Tatry Mts. The rudimentary Jurassic makes up lenses in dolomites, composed of bedded or nodular cherty limestones, red Liassic crinoidal limestones, green Dogger radiolarian shales, and light-coloured thick-bedded limestones of Malm to Tithonian age. The Šturec nappe and the Choč nappe were until recently regarded as two different developments of the Choč nappe (the Šturec nappe = Čierny Váh development, and the Choč nappe = Biely Váh development). In our interpretation, they are considered as partial units of the Hronic, which are in places superimposed, in places occurring side by side as nappe outliers on a common basement — the Neocomian complex of the Krížna nappe.

5. The major tectonic unit of Gemeric

was overthrust on the Veporicum along the Ľubeník-Margecany thrust plane (Ľubeník—Margecany line). It is built up of Lower and Upper Paleozoic and Mesozoic formations. The Triassic, which is the main representative of the Mesozoic, shows a development which is especially characteristic of the Gemeric. The preponderant part of the Gemeric occurs in the eastern part of the Inner Carpathians, where it was thrust over the Veporicum as a whole. In addition, the upper parts of the Gemeric form isolated nappe outliers resting not only on the Veporic but also on the Hronic in the Tatric area.

The stratal succession begins with the Lower Paleozoic series. The older of them, the Gelnica Group — is made up of slightly epimetamorphosed sericite or chlorite schists with intercalations of graphitic schists, lydite and ankeritized or sideritized limestones; the sequence is classed with the Cambrian to Silurian. Major bodies of acid volcanite and their tuffs, which are present in the Gelnica Group, were transformed to porphyroids. In this Group the Vlachov Formation (?Cambrian-Ordovician), the Pača Formation (?Ordovician), and the Betliare Formation with limestones and lydites (Silurian, evidenced palynologically) have been differentiated. The overlying Rakovec Group is composed of chlorite phyllites and encloses intrusive and extrusive basites and their tuffs, strongly epimetamorphosed. Some authors think the Rakovec Group to be of Devonian age and laid unconformably on the Gelnica Group after the Spiš folding, which would correspond to the principal phase of Caledonian folding. The unconformity, however, is not accepted unanimously.

The stratigraphy of the Lower Paleozoic cannot be stated precisely for the scarcity of organic remains.

The older member of the Upper Paleozoic (Moscovian, »Sudetic stage«, Westphalian) is represented by marine Middle Carboniferous, rich in brachiopod, trilobite and coral faunas. The sequence consists of dark shales, limestones (often transformed to magnesites) sandstones and limestones, in places with exotic material. The attempt to divided the Carboniferous into the Lower and the Upper has failed, because both the fauna and flora point to the Upper Moscovian, and the presumed Upper Namurian has not been evidenced. The Stephanian has not been paleontologically proved either. Remarkably, the Carboniferous bears basic volcanite and their tuffs. It was deposited after the Variscan orogeny, at the latest after the Sudetic phase, and is of a rather small thickness. The sedimentary complex is of molassic character but shows some features of eugeosynclinal development.

In the northerly part of the Gemeric, the Permian coarse-grained deposits occur in the Alpine Verrucano facies, with gypsum deposits and an abundance of acid volcanic rocks and their tuffs (porphyroids). The thick Lower Triassic complex has at the base (Seisian) marly shales with sandstone intercalations. Their upper part belongs to the Campilian, just as the overlying sequence of thin-bedded or slightly nodular limestones with ammonites.

In the Lower Triassic area of the Gemeric, there is a remarkable occurrence of intrusive, probably post-Triassic ultrabasites (dunites — lherzolites), which are for the most part converted into serpentinites. In the Middle Triassic, the base of the Anisian consists of dark (Gutenstein) limestones or dolomites, which are followed by light-coloured (Steinalm) limestones, and by pink ammonite-bearing (Schreieralm) limestones in the Upper Anisian.

The Ladinian is represented by dark, in places cherty limestones, which resemble the Reifling limestones and bear a tuff layer at the base (in the Slovakian Karst), but mainly by light-coloured massive (Wetterstein) limestones. The Upper Triassic comprises various facies similar to the reefal Dachstein limestone and the Hallstatt limestone, as well the Norian Zlambach Beds. In the Slovakian Karst, the Rhaetian seems to be lacking and the Liassic is transgressive (Early Cimmerian movements). In the northern part of the Gemeric, the Upper Triassic is developed in dolomitic facies, except for the reefal Dachstein limestones. They are underlain by light-coloured Steinalm and Wetterstein limestones and superjacent Werfenian beds with quartz porphyry. (Vernár Belt).

The Jurassic occurs spradically in the Gemeric, being represented by Lower Lias crinoidal limestones and breccias, by Middle and Upper Liassic nodular limestones (with ammonites), by spotted marls extending to the Dogger, and by radiolarites, presumably of Malm age.

The Paleozoic complex of the Gemericum encloses small bodies of Middle Cretaceous granitoids of particular types.

The Mesozoic sequences of the Gemericum in the eastern part of the Inner Carpathians originally lay normally on the Paleozoic, but during the Mediterranean folding they were sheared off from their basement. Since they lie on the Paleozoic, their nappe character is not too marked. In the Slovakian Karst, the Mesozoic is occasionally investively folded and sliced. On the other hand, the Gemeric Mesozoic was in the remaining part detached from its basement and translated nortwards as a conspicuous thrust nappe, which is known from nappe outliers of various size. In other tectonic units of the Gemeric, the Triassic development roughly coincides with that in the main

Gemeric area. The only difference concerns the Lower Triassic, which occurs (with the Upper Paleozoic slices at the base) only in the Muráň nappe and in the Drienok nappe outlier south of Banská Bystrica. In the northern part of the Gemericum, i. e. in the Strážov nappe and its partial units the sequence begins with the Middle Triassic ("troncature basale").

Numerous nappe outliers scattered over western Slovakia (Vetrník, Nedzov, the summit of Strážov and Kačka in the Strážovské pohorie Mts.) and in central Slovakia (Tlstá in the Veľká Fatra Mts.) belong to the Strážov nappe. All these outliers reposing on the Hronic are definitely tectonic outliers; they are built up especially of Triassic rocks. In the Malé Karpaty Mts. there are two nappes of Gemeric facies: the Vetrník nappe in the lower position and the Havran nappe in the upper position.

The Triassic facies differ somewhat in individual blocks; their common feature is the occurrence of Wetterstein limestones and a nearly complete lack of Reifling limestones which are typical of the Choč nappe. Stratigraphically, the outliers mentioned above are almost equal to the in situ Triassic of the Gemeric. It is therefore assumed that the Gemeric was originally a uniform whole, whose western part was moved to a more than 100 km distance. The amount of displacement decreases eastwards to 30 km or less.

Two alternative explanations were proposed for the location of the root area of the Fatric, in particular of the Krížna nappe. The first conception advocated at the Third Congress of the Carpathian Association in 1931, placed the root area in the northerly zones of the Veporic. As the Veľký Bok Formation wedges out on the northern slope of the Nízke Tatry Mts. and west of Boca is replaced by the incipient Krížna nappe, the area of Veľký Bok was first considered. In any case, the root area of the Krížna nappe occurs in the proximity of the southern margin of the Tatric. The length of the overthrust would be at least 80—90 km in the west, and 30—40 km in the east. According to the other alternative, the Krížna nappe was rooted along the Čertovica fault line, along which the Mesozoic zones are strongly crushed. This alternative is also possible.

The tectonic units occurring outside Slovakia will not be here treated in detail.

The Tatric, Veporic and Gemeric show the character of N-vergent tectonic units overthrust to various distances. In the E part of the Gemeric, with paleozoic basement the overthrust on the Veporic can be estimated at 20 km at least.

From this it follows that the total overthrust of all Inner Carpathian partial units on the Pieniny Belt was of a very large scale.

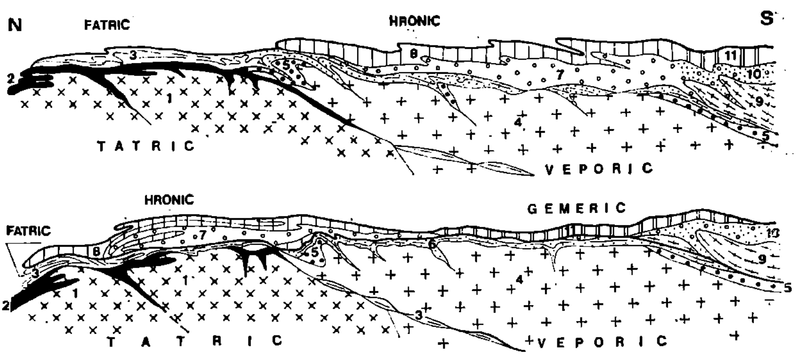

Fig. 5 Scheme of the genesis of Middle-Cretaceous nappes in the Inner West Carpathians. (According to A. B i e l y and O. F u s á n, 1967)
Tatricum: 1 — crystalline; 2 — Mesozoic; Fatric: 3 — Krížna nappe; nappe; Veporicum: 4 — crystalline; 5 — Later Paleozoic; 6 — Mesozoic; Hronicum: 7 — Younger Paleozoic; 8 — Mesozoic; Gemeric: 9 — Earlier Paleozoic; 10 — Later Paleozoic; 11 — Mesozoic

From the above-said it is evident that in the Inner West Carpathians numerous orogenic phases and episodes caused the origin of five main structural stages, which are separated by unconformities. They are as follows:

1. P r e c a m b r i a n stage that is not distinguishable from stage (2);

2. L o w e r P a l e o z o i c stage terminated by older (probably Sudetic) orogenic phase. In the Spišsko-gemerské rudohorie Mts. the existence of two substages is indicated: the older ended by (?) Caledonian folding and the younger closed probably by Sudetic folding;

3. U p p e r C a r b o n i f e r o u s to Lower Permian stage terminated by Saalian folding of slight intensity. The division of this stage into the lower substage closed by Asturian folding and upper substage closed by Saalian folding is not sufficiently substantiated;

4. U p p e r P e r m i a n stage closed by Pfalzian orogeny. It does not seem to be developed universally;

5. L o w e r T r i a s s i c to Middle Turonian stage ending with strong Mediterranean (pre-Coniacian) folding. The orogenic phases are termed according to A. T o l l m a n n (1966).

The Middle Variscan and Mediterranean orogenies were certainly of great intensity. The existence of folding in the latest Precambrian is not unquestionable, because no unconformities have been established in crystalline complexes which are partly of Paleozoic age (fig. 5).

Some phenomena in the area of pre-Middle Carboniferous formations are indicative (not quite decidedly) of pre-Middle Carboniferous overthrusts (Vepor). The relationship of the Gemericum (with low-metamorphosed Paleozoic) to the Veporicum, the older members of which are strongly metamorphosed crystalline schists, could also be more readily explained on the assumption of a pre-Mesozoic overthrust.

CHARACTERISTICS OF MEDITERRANEAN UNITS

The Mediterranean units are of two types:

a) Partial units of lower tectonic substratum, which submerge southwards and are separated by fault planes;

b) Nappe units, separated from their base and translated along subhorizontal surfaces from south to north to considerable distances.

The first group comprises the major part of the Tatricum, the Veporicum and a considerable part of the Gemericum (where the Paleozoic plays an important role).

Typical representatives of the second group are rootless, recurrently overthrust masses of the Tatric, Fatric, Hronic, and the north-western, exclusively Mesozoic part of the Gemeric. The first group of units is seemingly displaced to a small distance, being at least apparently »pseudo-autochthonous«. It is, however, evident that they form a body divided by a system of deep-seated reverse faults and that the Inner West Carpathians were subsequently overthrust as a whole on the Klippen Belt during the Laramide folding. The Middle Cretaceous units of the Inner West Carpathians are distinguished by markedly specific tectonic features such as:

1. The nappe units were presumably translated within a short interval in the Late Turonian as appreciably plastic plates, so that partial nappes and digitations originated. More competent complexes were moving separately and the intervening plastic complexes caused the formation of major disharmonies and shear planes (Werfenian, Keuper, Lunz Member).

2. Involutions due to the movement of a lower nappe being overridden by a higher one, or sinking of a higher nappe into the lower are not in the West Carpathians.

3. In the West Carpathians, in the Krížna and Choč nappes in particular, the basal truncation (troncature basale in the sense of Ellenberger) is a very prominent phenomenon.

4. In the West Carpathian units forming the upper tectonic substratum, younger stratigraphic units show the tendency of accumulating in the frontal parts of nappes.

5. In the West Carpathians, the upper members of a normal succession are often replaced by synchronous overthrust members, which results in the so-called »couverture de remplacement« (Ellenberger). This phenomenon is responsible for many an erroneous interpretation of Carpathian tectonics.

6. In the units forming the lower tectonic substratum, Mediterranean folding produced a number of virgations, of which the Spiš virgation is of primary importance.

7. In the Inner West Carpathians undoubtedly other units also existed besides those mentioned above, but they are known today only from exotic blocks in the Inner Carpathian Paleogene. One of them was, for instance the Orava cordillera, which extended south of the Klippen Belt, from Orava to Stará Lubovňa.

Post-nappe formations of the Inner West Carpathians and post-Paleogene tectonics.

The nappe system affected by Mediterranean folding is overlain in places by transgressive Senonian of Gosau type (Coniacian — Maastrichtian in the Brezovské pohorie Hills), which is of considerable thickness and in part of flysch type. In the upper Hron valley, only the Campanian or Santonian-Campanian (with Hippurites) are developed. The extent of the Senonian in this area is uncertain because the Paleogene is transgressive.

The Paleogene complex rests on the Senonian or, more frequently, on an older substratum. It begins with basal conglomerates and limestones, mostly of Late Lutetian age. In the Liptov basin this basal sequence is Priabonian, and Cuisian-Paleocene at the contact with the Klippen Belt. The bulk of the Paleogene is of flysch character (Zakopane Formation) and its top part of coarse-flysch type (Biely Potok Formation) with molasse elements. The uppermost members are of Early Oligocene age. In places, basal Paleogene beds bear traces of Illyrian movements. The Paleogene sequence similarly as the Senonian shows slight germano-type folding produced by Helveto-Savian orogeny and not by Pyrenean diastrophism, as is believed by some authors. The Paleogene of this character is typical of the northerly area. In southern Slovakia, the Gemeric is covered by transgressive Oligocene passing into the Miocene, which is linked with the Neogene of the Pannonian basin. During the Paleogene, after the overthrust of Cretaceous nappes, in the Inner West Carpathians originated a geosyncline with flysch deposits up to several thousand metres thick. It was a secondary geosyncline formed after the last alpine-type folding in Cretaceous time, without being itself deformed by folding of this type. It is imagined that during the Paleogene the subsidence of the Cretaceous-Paleogene geosyncline of the Flysch Belt probably involved the northern zone of the Inner West Carpathians, which had undergone Mediterranean folding before sinking.

In discussing the tectonic units of eastern Slovakia, we have not mentioned the East Carpathian (Marmaroš) massif; this matter will therefore be here outlined briefly). The Pieniny zone affected by Laramide folding stretches eastwards almost to the Tisza, re-appearing at the Rodno massif in Rumania (Poiana Boticei), where it trends east-west and ends with most probability. The more southerly crystalline-Mesozoic complexes of the East Carpathians (also the Apuseni Mts.) conjoin. They were folded in the Middle Cretaceous, i. e. earlier than the Pienides. The western continuation of the East Carpathian massif was not sought in the Inner West Carpathians but within a very wide strip of the Flysch Belt. However, the rule of the polarity of folding is valid for nearly all fold mountain ranges, and for the Carpathians as well. In the West Carpathians the sequence of Mediterranean — Laramide — Helveto-Savian — Styrian folding has been established from south to north. In the East Carpathian massif, the Cretaceous folding occurred either before the Albian (Manín phase), or before the Vraconian, or before the Cenomanian (Austrian folding). As the East Carpathian massif plunges beneath the Magura and Dukla flysch, some traces of these orogenies could be expected there, in particular dominant limestone material of the upper nappes. According to the assumption of M. Săndulescu (1971), parts of the East Carpathian massif were thrust on the innermost flysch unit (Ceahlău unit) before the Albian, and together with it they were translated over the Outer Flysch Belt during Laramide folding. The question remains whether they were not at that time also thrust over the Laramides of the Klippen Belt with, naturally, the Upper Cretaceous and the Marmaroš Klippen Belt.

In post-Paleogene time, the Inner West Carpathians suffered strong deformations, which produced major anticlines and major synclines but no nappes. This folding involved not only Paleogene (and/or Neogene) complexes but also their substratum. Some cores were uparched, and the nappes of Fatric and Hronic were uplifted in places or buried to depth (their position in depth is in no way original). The major folds can also be denoted as synclinoria or anticlinoria but they cannot be linked with the tectonic forms originated during Meditelrranean folding prior to the Senonian. Post-Paleogene movements affected the northern part of the Eastern Alps, which are the continuation of the Inner West Carpathians. The transition between these two major units occurs in the Záhorská Lowland, in the frontal part of the Inner West Carpathians. The Cretáceous and Paleogene in the development of the Brezovské-pohorie type intervene between the nappes composed mainly of Triassic sequences, which implies that some nappes south of the Pieniny zone are post-Paleogene. From this it follows that the age of nappe overthrusts varies not only transverse to the mountain range but also longitudinally.

In the West Carpathians and eastern Slovakia, Neogene sedimentation was accompanied by strong faulting and intensive volcanism, in particular by Miocene-Lower Pliocene subsidence volcanism and Upper Pliocene-Lower Pleistocene final volcanism. The deposition of Neogene sediments and partly of volcanogenic-sedimentary complexes was confined to peripheral and Intra-Carpathian subsiding basins. The origin of subsidence basins indicates that the Carpathian region suffered deformation still in the Miocene and possibly also in the Pliocene. Part of these basins originated at the site of Paleogene basins, but subsidence was not renewed in some of the latter during the Neogene. The Inner Carpathian crystalline complex underlies the Miocene and/or Pliocene of great thickness in some of the basins (e. g. Lesser Danube Plain). Extensive Neogene sedimentation also took place in the flysch area south of the front of flysch nappes (Vienna Basin). Subsidence-sedimentary processes were interrupted in the Miocene by folding phases of small intensity. As a result, lower parts of the Miocene are absent from many basins. The distribution of the Lower Miocene deposits differed from that of the Upper Miocene. The Eggenburg sedimentation probably extended from the Vienna Basin eastwards through central to eastern Slovakia.

Our knowledge of the Carpathian Neogene is so comprehensive thanks to extensive boring works that it surpasses the framework of this brief survey. For more details we refer to the Guidebook.

The Inner West Carpathians and, to a smaller extent also the external zones, are transsected by fault systems consisting of N-S, E-W, SW-NE, and NW-SE faults crossing each other. Many of them caused considerable changes in the height of tectonic nappes, and are of primary order. The origin of synsedimentary faults in the Neogene resulted in the unequal thickness of Neogene formations on the two sides of the respective faults. Analogous synsedimentary faults have so far not been established in the older formations, althought their existence cannot be excluded. The unequal thickness of stratal successions in the adjacent zones or units (e. g. in the Klippen Belt) may be explained more easily by the incompleteness of the geological section. In this sense the successions would correspond only to detached pieces of the sedimentary area, as is postulated for the Helvetic of Switzerland by R. Trümpy (1969).

Since the Hungarian median mass encroaches upon the Czechoslovak territory only to a small extent in south-western Slovakia and is covered by Tertiary sequences, it will not be dealt with in this outline.

Detailed geophysical measurements have shown that the thickness of the earth's crust under the Carpathians varies appreciably. Being about 60 km in the north of central Slovakia, i. e. in the vicinity of the Vysoké Tatry Mts. and below the Carpathian flysch, it is reduced to 30 km in southern Slovakia, in the Lesser Danube Plain and the East Slovakian Lowland. These results are consistent with those obtained for the East Carpathians (cf. V. Gluško — S. Kruglov 1972), where the Mohorovičić discontinuity is situated about 60 km below the flysch, 20—25 km below the Transcarpathian Neogene basin, and 45 km in the Podole massif.

In this brief survey we have tried to acquaint the participants of the Tenth Congress of the Carpatho-Balkanian Association with the present state of knowledge of the Czechoslovak part of the Carpathians. Many new data provided mainly by deep boring, geophysical measurements, radiometric dating and refined micropaleontological studies contributed to great advances that have been made since the last Congress of the Association held in Czechoslovakia 42 years ago. Many problems, however, have still remained unresolved.

Geophysical measurements performed in the West Carpathians made it possible to establish the configuration of the surface of older formations covered by the Neogene deposits and, in tracing the course of many major surface faults to depth, to decipher the connection between tectonic bodies.

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