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Geology of the Pieniny Klippen Belt of Poland

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(A review of latest researches)

(Plate I, fig. 1—5)

Contents

Zusammenfassung.

Die Klippenzone der Pieninen stellt ein zirka 550 *km* langes, aber auch ziemlich schmales (einige hundert Meter bis 20 Kilometer) Anticlinorium dar, das einen stellenweise horstähnlichen, stellenweise einen Diapir-ähnlichen Bau zeigt. Sie erstreckt sich vom Wiener Becken bis in die Pieninen und trennt zwei große Flyschbereiche: im Norden den Magura-Flysch von dem Innerkarpathischen Palaeogen oder anderen tektonischen Einheiten der Zentralen Karpathen im Süden (D. ANDRUSOV, 1938).

In der östlichen Slovakei und in der Transkarpathischen Ukraine sind die Pieninischen Klippen nur lückenhaft bekannt und moderne tektonische Untersuchungen fehlen teilweise.

Vor dem Palaeogen gehörten die Pieninen dem Sedimentationsbereich der Inneren Karpathen an. Im Palaeogen gehörte der Klippengürtel W von Ujak zum größten Teil dem Bereich der Äußeren Karpathen an.

S der Klippenzone spielen sich die hauptsächlichen orogenetischen Bewegungen im Zeitbereich der Laramischen und post-Palaeogenen Phasen ab. Die Deckenbildung ist vor dem Mittleren Eozän beendet.

N der Klippenzone liegen die hauptsächlichsten orogenetischen Bewegungen im post-Palaeogen.

Die Klippenzone selbst wurde gefaltet: nach dem Palaeogen (Savische Phase), im Grenzbereich Kreide-Palaeogen (Laramische Phase) und auch im tieferen Teil der Oberkreide (Subherzynische Phase).

Von diesem Gebiet wird auf Grund der jüngeren Untersuchungen des polnischen Sektors der Pieninen eine Übersicht vorgelegt, und zwar: die Geschichte der Klippenserien im Geosynklinalbereich von der Trias bis ins tiefere Coniac; die Geschichte der Klippenmantelserien im Geosynklinalbereich vom Obersanton bis ins Oligozän; die subherzynischen, laramischen und savischen Bewegungen und die von ihnen erzeugten tektonischen Strukturen in den Klippen; ferner der post-savische Vulkanismus, die Neogen- und Quartärgeschichte des Gebietes; und schließlich die Stratigraphie der Exotischen Massive, welche die Sedimentation der Klippengesteine und Klippenmantelgesteine beeinflußte.

Abstract

A review of recent geological investigations of the Polish sector of the Pieniny (Internal) Klippen Belt, Carpathians, is presented. Described are: history of the Klippen Series (Triassic to Lower Coniacian) geosyncline, history of the Klippen Mantle (Upper Santonian to Oligocene) geosyncline, sub-Hercynian, Laramide and Savian movements and their rôle in the formation of the tectonic structure of the Klippen Belt, post-Savian volcanic activity, Neogene and Quaternary history of the area and stratigraphy of exotic massifs which influenced the sedimentation of the Klippen Series and of the Klippen Mantle.

Introduction

The Pieniny Klippen Belt [1]) is an anticlinorium of a partly horst-like, partly diapiric structure, very long (c. 550 km), and very narrow (a few hundred metres to twenty kilometres) [2]). It runs from the Vienna Basin to the Pieniny Mts. separating two great flysch regions: the Magura Flysch to the north and the Inner Carpathian Palaeogene (or other tectonic units of the Central Carpathians) to the south (D. Andrusov 1938).

Further east in Eastern Slovakia and Transcarpathian Ukraine the relation of the Pieniny Klippen Belt to the External Carpathian Flysch is but partly known and modern tectonic investigations of many sectors are still lacking [3]).

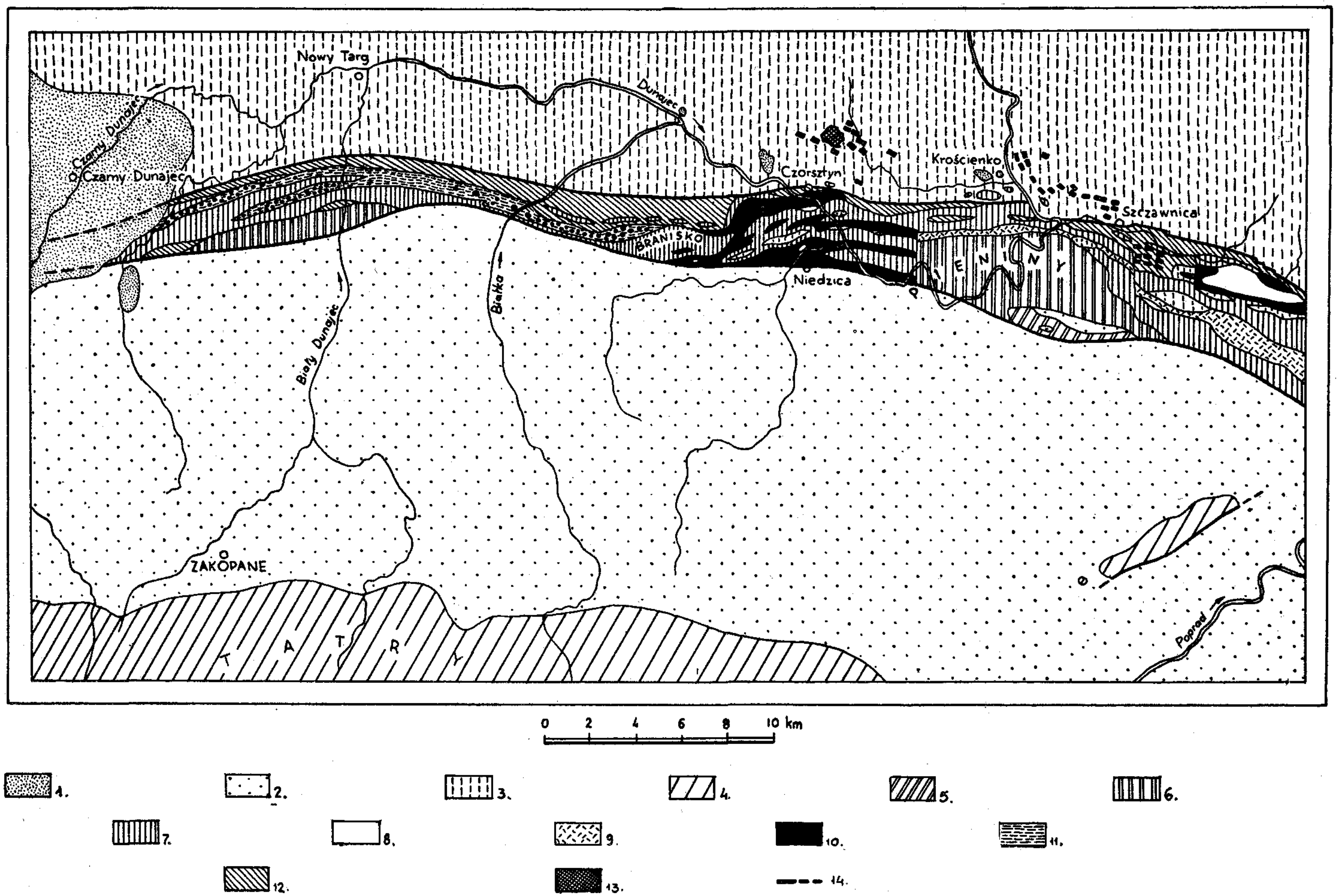
Before Palaeogene the Pieniny Klippen Belt belonged to the sedimentary region of the Inner Carpathians. In the Palaeogene the Klippen

[1]) Known also under the name of the Internal Klippen Zone.

[2]) cf. K. Birkenmajer (1958 d, 1959 d).

[3]) The results of the geological investigations of the Ujak (Údol) region in Eastern Slovakia recently made by Prof. Dr. H. Świdziński in order to elucidate the relation of the Inner Carpathian Palaeogene and of the Magura Flysch to the Klippen Belt, have not been published so far.

Fig. 1: Schematic tectonic map of the Pieniny Klippen Belt in Poland (after K. Birkenmajer, 1959 c): 1 = Fresh-water Neogene, 2 = Podhale Palaeogene, 3 = Magura Palaeogene, 4 = Tectonic units of the Tatra Mts., 5 = Haligowce Series, 6 = Pieniny Series, 7 = Branisko Series, 8 = Niedzica Series, 9 = Czertezik Series, 10 = Czorsztyn Series, 11 = Pre-Laramide Mantle: Púchov Marls and Variegated Beds, 12 = Pre-Laramide Mantle: Úpohlav Beds, Jarmuta Beds, Variegated Beds, 13 = Andesitic intrusions, 14 = Main Tertiary dislocations.



Nowy Targ
Dunajec
Czarny Dunajec
Czarny Dunajec
Czorsztyn
Krościenko
Szczawnica
BRANISKO
Niedzica
Białka
Biały Dunajec
ZAKOPANE
T A T R Y
Poprad
0 2 4 6 8 10 km
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
13.
14.

Belt west of Ujak belonged in its main part to the sedimentary region of the External Carpathians.

To the south of the Klippen Belt main orogenic movements belonged to the Laramide and post-Palaeogene phases. The nappe folding occurred there before the Middle Eocene.

To the north of the Klippen Belt main orogenic movements were post-Palaeogene. The Klippen Belt itself was folded after the Palaeogene (Savian phase), at the boundary of the Cretaceous and Palaeogene (Laramide phase) and in the lowermost part of the Upper Cretaceous (sub-Hercynian phase) [1]).

I. Klippen Series and Klippen Mantle

The sequence of beds in the Pieniny Klippen Belt may be subdivided into the Klippen Series and the Klippen Mantle. These terms have been introduced more than fifty years ago. Since this time their meaning has changed several times [2]).

V. Uhlig (1890, 1903) distinguished the "Klippengesteine" formed by the Triassic, Jurassic and Neocomian, and the "Klippenhülle" formed by the Upper Cretaceous and the Eocene.

Within the "Klippengesteine" the Haligowce Facies (Triassic and Liassic), the "Hornsteinkalkfacies" (Dogger, Malm and Neocomian) and the "Versteinerungsreiche Facies" (Aalenian to Tithonian) have been distinguished by Uhlig.

After the discovery of nappes in the Carpathians by M. Lugeon (1902, 1903) [3]) the "Hornsteinkalkfacies" was renamed (V. Uhlig 1907) "Pieninische Decke" and the "Versteinerungsreiche Facies" — "Subpieninische Decke" ("Czorsztynische Decke" of the Polish authors).

After the first World War geologists investigating the Pieniny Klippen Belt modified Uhlig's views on the tectonic rôle and stratigraphical composition of the "Klippengesteine" and of the "Klippenhülle". L. Horwitz and F. Rabowski (1929) considered that the Klippen Series consisted of members from the Triassic to the Lower Palaeogene inclusively (Haligowce Nappe), from the Liassic to the Lower Palaeogene (Pieniny Nappe) or from the Aalenian to the Lower Palaeogene (Czorsztyn Nappe). Thus the "Klippenhülle" has been included in the Klippen Series.

Later on L. Horwitz (1933, 1935, 1938) modified once more his views and restituted the Klippen Mantle. According to his latest opinion there existed in the Pieniny Klippen Belt the Klippen Series formed by members from the Liassic to the Neocomian (Pieniny Nappe) and by members from the Aalenian to the Tithonian (Czorsztyn Nappe). The Haligowce Series has been included, after J. Nowak (1916, 1927), in the "Hochtatrische Decke". The Klippen Mantle consisted, according to L. Horwitz (*o. c.*) of the Cenomanian and of the higher Senonian.

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[1]) Therefore, as it was pointed out by H. Stille (1953, p. 136) the determination of the age of the orogenic movements in the Pieniny Klippen Belt is extremely important for the understanding of the tectogenesis of both the Internal and External Carpathians.

[2]) The history of investigation of the Klippen Series and of the Klippen Mantle has been discussed in papers by D. Andrusov (1938) and by the present author (1953 a, 1957 a, 1958 d, 1959 c).

[3]) cf. S. Sokołowski (1954 a).

An unusual view on the development of the Klippen Series has been expressed by J. OPPENHEIMER (1926, 1927), who believed that the members of the "Subpieninische Decke" and of the "Pieninische Decke" (*sensu* UHLIG) belonged to one stratigraphical series divided tectonically into klippes. Furthermore, Oppenheimer considered the Albian as the possible uppermost member of the Klippen Series, and not as an element of the Klippen Mantle.

The views of J. OPPENHEIMER have not been accepted by D. ANDRUSOV (1927), who, at the same time, subdivided the Klippen into the Pieniny Series, the Pieniny Transitional Series and the Sub-Pieniny Series. Three types of facial development i. e. the Kýsuca facial type, the Podbiel facial type and the Pruské facial type have been distinguished within the Pieniny Transitional Series.

According to D. ANDRUSOV (1927, 1938), the Sub-Pieniny Series consisted of the members from the Aalenian to the Tithonian [1]), the Keuper, Jurassic and Neocomian have been distinguished in the Pieniny Transitional Series. Finally, the Pieniny Series consisted of the members from the Liassic to the Lower Neocomian.

These series, according to D. ANDRUSOV have been folded during the uppermost Neocomian and lowermost Middle Cretaceous (the limit of the Aptian and Albian) in an orogenetic phase called by him "the Pieniny Phase". The Pieniny Nappe (with two digitations formed by the Pieniny Series and by the Pieniny Transitional Series) has been thrust over the Sub-Pieniny Nappe. These nappes formed a tectonic group called by A. MATĚJKA and D. ANDRUSOV (1931) the Pienids.

In his last synthetic papers D. ANDRUSOV (1945, 1953) reduced, however, the Pieniny Transitional Series to the facial types of the Pieniny Series. Thus he returned in some respects to the old views of V. UHLIG.

The Manín Series (Liassic to Neocomian) distinguished by D. ANDRUSOV *(o. c.)* has been considered as connected with the high-Tatra Series. He thought that it was thrust over the Pieniny Nappe during the "Pieniny Phase" (upper Aptian-lowermost Albian), and was subsequently covered by the Klippen Mantle common with the mantle which covered the Pieniny Nappe and the Sub-Pieniny Nappe. The Kostelec Series (Triassic and Liassic) distinguished by D. ANDRUSOV in the Klippen Belt of Western Slovakia has been considered by him as connected with the uppermost unit (Stražov Nappe) of the Sub-Tatra nappes, thrust over the Klippen Mantle during the Laramide folding of the Internal Carpathians.

The Klippen Mantle has been subdivided by D. ANDRUSOV *(o. c.)* into the Older Mantle and the Younger Mantle. The Older Mantle consisted of the Albian Spherosideritic Marls and of the Cenomanian Orlové Sandstones rich in *Exogyra columba silicea* (LAM.).

The Younger Mantle consisted of the Úpohlav Beds (Upper Santonian) with *Hippurites* and of the Púchov Marls (Campanian ? and Maestrichtian), separated from the Palaeogene by a marl-breccia of a supposedly Danian age. The Palaeogene of the Magura type has been considered to be the youngest mantle of the Klippen Belt in its central and northern parts, and the Palaeogene of the Sulov-Podhale type to be the mantle of the southernmost part of the Klippen Belt.

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[1]) The Neocomian members lacking due to regression.

New views on the relation of the Klippen Mantle to the Klippen Series have been presented after the World War II. It was S. Sokołowski (1954 b) who observed transitions between the Neocomian of the "Pieniny Series" and the "Lower and Middle Cenomanian" of the "Klippen Mantle" distinguished by L. Horwitz in his unpublished map in 1 : 10,000 scale. The present author (K. Birkenmajer 1953 b, 1954 a) found the Neocomian members in the Czorsztyn (Sub-Pieniny) Series and transitions between the Neocomian and the Middle Cretaceous in all the Klippen Series. This implied the absence of the "Pieniny Phase" (Upper Aptian-lowermost Albian) distinguished by D. Andrusov. Therefore the "Older Mantle" of D. Andrusov has been included into the Klippen Series.

The Spherosideritic Marls (Albian) and the Orlové Sandstones (Cenomanian) of the Middle Váh valley considered by D. Andrusov (1938, 1945, 1953) as a typical member of the "Older Mantle" of the Pieniny Klippen Belt, were included by the present author (K. Birkenmajer 1953 a, 1957 a, 1958 d) into the Manín (high-Tatra) Series.

The following Klippen Series have been distinguished by the present author: the Czorsztyn Series, the Niedzica Series, the Branisko Series and the Pieniny Series (K. Birkenmajer 1953 b, 1957 a, 1958 d). The Czorsztyn Series is identical with the Sub-Pieniny Series of D. Andrusov [1]). The Niedzica Series of the present author comprises, among others, some klippes of the Pruské type (klippe in Podhradský Stream, Western Slovakia) and of the Kýsuca type (klippe of Oravský Zamok, Western Slovakia) described by D. Andrusov (1931, 1938, 1945, 1953; A. Matějka, D. Andrusov 1931) [2]). The Branisko Series of the present author is an equivalent to the major part of the "Kýsuca Series" of D. Andrusov, taking in mind the reservations presented above.

Finally, the Pieniny Series of the present author is identical with the typical Pieniny Series of D. Andrusov *(o. c.)*.

Further field investigations of the present author allowed him to state that the Haligowce Series belonged not to a high-Tatra unit but was a Klippen Series (K. Birkenmajer 1959 a). Later on a new (sixth) Klippen Series named the Czertezik Series has been distinguished (K. Birkenmajer 1959 b) [3]).

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[1]) "Versteinerungsreiche Facies" of V. Uhlig consists of elements both of the Czorsztyn Series and of the Niedzica Series in the present author's meaning. The "Czorsztyn Series" of L. Horwitz consists of the members belonging to the Czorsztyn Series, to the Niedzica Series and to the Branisko Series of the present author.

[2]) Therefore the "Kýsuca Series" and the "Pruské Series" distinguished by D. Andrusov in his earlier papers (before 1945) are not independent stratigraphical, facial, and tectonic units. Some klippes ascribed by D. Andrusov to one of these series should be considered on his own definitions as belonging to the other one. Thus the "Kýsuca Series" and the "Pruské Series" are heterogeneous, and cannot be traced over longer distance, for example within the Polish sector of the Klippen Belt. The "Podbiel Series" distinguished before 1945 by D. Andrusov, and considered at first by the present author (1953 b, 1957 a) as connected with the Niedzica Series is, according to field observations of the present author in Slovakia in 1956 related to, but not identical with, the Niedzica Series.

[3]) Particular stratigraphical members of this series have been referred by V. Uhlig either to the "Versteinerungsreiche Facies" or to the "Hornsteinkalkfacies", and by L. Horwitz to the Czorsztyn Series and to the Pieniny Series.

New investigations on the stratigraphy of the Klippen Series (K. Birkenmajer 1952, 1953 b, 1954 a, 1957 a, d, 1958 b, d, 1959 a; B. Kokoszyńska and K. Birkenmajer 1956; K. Birkenmajer and B. Kokoszyńska 1958; K. Birkenmajer and J. Znosko 1955; S. M. Gąsiorowski 1956; M. Książkiewicz 1958) indicate that the Klippen Series consist of the Triassic, Jurassic, Neocomian, Middle Cretaceous (Albian to Turonian) and probably Lower Coniacian members. These members have been deposited in the Pieniny Klippen geosynclinal trough before the first folding of the Belt, which occurred between the Lower Coniacian and Upper Santonian. The sequence of the beds and differences of facies, especially in the late Dogger and in the Malm, when the Klippen geosyncline reached its maximum depth, are the criteria of particular Klippen Series.

A number of papers published after the II-nd World War in Poland pertained to the stratigraphy of the Klippen Mantle (K. Birkenmajer 1954 b, 1956 a, b, 1957 a, d, e, 1958 c, d, 1959 d, e; K. Birkenmajer, T. Wieser 1956) and its fauna (S. Geroch 1957; K. Birkenmajer, S. M. Gąsiorowski 1959). The beds of the Klippen Mantle have been divided by the present author into two groups. The older group named the "Pre-Laramide Mantle" consisted of the Upper Santonian, Campanian, Maestrichtian and probably Danian. This group is separated from the Klippen Series by an orogenic phase, equivalent to the sub-Hercynian folding sensu H. Stille (1924) which took place in Upper Coniacian and Lower Santonian. The younger group, named the "Post-Laramide Mantle", consisted of the Upper Paleocene, Eocene and ? Oligocene of the Magura Flysch type (in the northern and central part of the Klippen Belt) and of the Middle Eocene, Upper Eocene and ? Oligocene of the Internal Carpathians type (Sulov Palaeogene and Podhale Flysch) in the southernmost part of the Klippen Belt in the Pieniny sector. The "Post-Laramide Mantle" was separated from the older members by the Laramide folding probably in connection with a sedimentary gap in the Lower Paleocene.

In the northern part of the Belt the Post-Laramide Mantle deposits covered the Laramide tectonic structure and commenced with the Upper Paleocene. On the other hand, in the southern part of the Belt the Post-Laramide Mantle deposits covered the Sub-Hercynian tectonic structure not submerged during the Upper Cretaceous and commenced with the Lower Eocene or, still more southward, with the Middle Eocene.

II. History of the Klippen Series geosyncline *)

II a. Primary substratum

Members older than the Triassic have not been found within the Klippen Belt. According to D. Andrusov (1938) the Klippen nappes have been torn off their basement during the first folding of the Belt. Nevertheless, the character of the primary substratum can be determined indirectly on clastics (and heavy minerals) [1]) in the Jurassic and Cretaceous members

*) See Plate 1: Stratigraphy of the Klippen Series in Poland.

[1]) Heavy minerals from the Jurassic and Cretaceous clastic deposits in the Klippen Belt have been investigated by J. Łoziński (1956, 1957, 1959).

of the Klippen Series. Some clastics have been supplied to the geosynclinal trough from the north (K. Birkenmajer 1958 d; K. Birkenmajer, S. M. Gąsiorowski and T. Wieser 1960), other from the south (K. Birkenmajer 1958 d) and, finally, a part of the clastics is of an intra-geosynclinal origin (K. Birkenmajer 1957 b, c).

These clastics imply that the primary substratum of the Klippen Belt consisted of a cristalline (probably Hercynian) basement covered by chiefly marine deposits of the Werfenian and of the Middle Triassic and of lagoonal (or lacustrine) deposits of the Keuper. The last two members have been found in some parts of the Klippen Belt in the Klippen Series (V. Uhlig 1890; L. Horwitz, F. Rabowski 1929; D. Andrusov 1931, 1938, 1950).

It was D. Andrusov who considered that the exotic fragments investigated by himself (A. Matějka, D. Andrusov 1931; D. Andrusov 1938, 1945, 1953) and by V. Zoubek (1931) abundant in the Klippen Mantle, derived from the primary substratum (exotic massif) of the Pieniny Nappe subjected to the erosion in the Upper Cretaceous. This massif, according to D. Andrusov, was situated to the south of the Klippen Belt.

Andrusov's supposition that the exotic fragments in question derived from the older members of the Pieniny Nappe (Series) has been refuted by the present author (K. Birkenmajer 1958 d), who found similar exotic fragments in the Turonian clastic deposits of the Klippen Series indicating that the erosion of the exotic massif in question commenced before the first folding and overthrusting in the Klippen Belt. The exotic massif in question supplied clastics both to the north, i. e. to the Turonian deposits of the Klippen Belt geosyncline, and to the south, where the Cenomanian Orlové Beds of the Manín Series have been deposited, as it was proved by sedimentological studies (K. Birkenmajer 1958 a). Thus the exotic massif in question is considered by the present author to be situated between the Pieniny Klippen Belt geosyncline and the sedimentary basin of the High-Tatra Series, the Manín Series included.

The petrographic character, direction of transport, and probable age of the magmatic and metamorphic exotic fragments in question described by T. Wieser (1958) and of the sedimentary exotic fragments described preliminarily by the present author *(o. c.)* from the Polish sector of the Klippen Belt, allowed him to presume that they derived neither from Pienids, nor from Tatrids (*sensu* A. Matějka and D. Andrusov 1931), but from an independent series called the Exotic Series (see below).

II b. Triassic shelf deposits and early-Cimmerian synorogenic movements

The Triassic deposits are extremely rare within the Pieniny Klippen Belt. They have been found only in the Haligowce Series (Pieniny Mts.), where Middle and Upper Triassic members probably occur, in the Sub-Pieniny (Czorsztyn) Series of the Váh River valley, where D. Andrusov (1950) has found Middle Triassic dolomites, and in the "Kýsuca Series" (in this case equivalent to the Branisko Series of the present author) in the western part of the Klippen Belt of Slovakia (Drietoma and Zablatie) where sandstones, quartzites and variegated shales with gypsum and dolomite intercalations of the Upper Triassic (Keuper) age occurred (D. Andrusov 1931, 1938).

The Werfenian deposits have not been found within the Klippen Belt. Nevertheless, it is probable that some clastic Werfenian deposits existed. This supposition is based on the investigation of clastics in the Liassic and Dogger deposits of the Klippen Belt, supplied to the geosynclinal basin from the north and from the inner part of the trough, and on the investigation of exotic fragments found in the Middle and Upper Cretaceous deposits supplied from the south.

The Middle Triassic sea deposited dolomites and dolomitic limestones of a type similar to that common in the Internal Carpathians and in the Eastern Alps.

At the close of the Triassic a regression occurred and gypsiferous variegated deposits of the Keuper, as well as cavernous limestones (Rauhwacken) have been formed. The presence of the Keuper facies depended on the early-Cimmerian synorogenic movements, which are distinguishable in the Inner Carpathians, especially within the High-Tatra Series sedimentary basin.

II c. Early stages of the Jurassic transgression

The Lower Jurassic [1]) deposits have been found only in the Haligowce Series, in the Pieniny Series and in the Branisko Series of the Pieniny sector of the Klippen Belt, and in the Pieniny Series, in the "Kýsuca Series" and "Podbiel Series" in Western Slovakia. In many localities particular members of the Lias (especially of its lowest part) are lacking due to the tectonic causes. There are, however, data indicating that only the southern and deeper part of the Klippen Series geosyncline was submerged by the Lower Jurassic sea. The northern part of the basin, the Niedzica Series, the Czertezik Series and the Czorsztyn Series included, was emerged till the Aalenian.

The Jurassic transgression in the Klippen Series trough advanced eastward. Therefore the Rhaetian dark shales and limestones with pelecypods and brachiopods of the Swabian type have been deposited only in the western part of the Belt near Trenčín, Slovakia (D. Andrusov 1931, 1938). The Hettangian marine deposits are to be found also in more eastern regions, especially in the Orava River valley and in the Pieniny Mts.

The Lower Liassic sea (Hettangian, Lower Sinemurian) deposited mainly clastic sediments (Gresten Facies) of a shallow neritic type, composed of sandstones, conglomerates and shales with ammonites and brachiopods.

During the higher part of the Lias (Upper Sinemurian, Pliensbachian and Toarcian) the sea deepened and dark spotted limestones and marls with thin-shelled pelecypods and cephalopods, as well as green limestones and marls with belemnites and, locally, red crinoidal limestones [2]) have been deposited.

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[1]) The stratigraphic subdivision of the Jurassic used in the present paper is based on Arkell's (1956) scheme, which differs from that used by D. Andrusov (1945, 1953) and by the present author in his previous papers (1953 b, 1957 a, 1958 d). However in the present paper the Aalenian (= Lower Bajocian of W. J. Arkell) is treated as a separate period.

[2]) In the western part of the geosynclinal trough (cf. D. Andrusov, 1931, 1938).

The development of the Lias in the Haligowce Series is different from that in the remaining Klippen Series. The lower part of this period is, according to L. HORWITZ and F. RABOWSKI (1929), represented by crinoidal limestones and oolitic limestones, while the upper part is represented by quartzitic sandstones, red shales and arenaceous limestones. This development resembles that in some varieties of the Manín (High-Tatra) Series in the Váh River valley, especially near Trenčianské Teplíce (see M. MAHEL 1950 a, b; K. BIRKENMAJER 1959 a), visited by the present author in 1956. These resemblances indicate the possibility of transitions between the Haligowce Series on one side and the Exotic Series and the Manín (High-Tatra) Series on the other.

II d. Aalenian transformations of the geosynclinal trough and the evidence of the Central Cordillera

In the Aalenian nearly the whole geosynclinal trough of the Klippen Series has been covered by the sea. The lowermost Aalenian deposits known consist of dark shales with concretions of siderites, pyrites and dolomites and with traces of copper (K. BIRKENMAJER, W. ŻABIŃSKI 1957, K. BIRKENMAJER, W. NARĘBSKI 1958) with rare *Posidonomya alpina* (GRAS.). They have been called the Sub-Flysch Beds as they underlie a complex of clastic deposits called the Flysch Aalenian.

The flysch complex belongs to the Lower Aalenian. It consists of light and dark sandstones alternating with shales abundant in mica, with rare intercalations of redeposited (graded) crinoidal limestones in its lower part, and with thin allochthonous coal seams in its upper part. The sedimentological investigations carried out by the present author (K. BIRKENMAJER 1957 b, c) indicated that the clastic components of the flysch beds in question came from the inner part of the geosynclinal trough, where an intrageosynclinal cordillera emerged. This cordillera, called the Central Cordillera, separated the geosynclinal trough into two basins: the northern one with the Czorsztyn Series, the Czertezik Series and the Niedzica Series included, and the southern basin with the Branisko Series, the Pieniny Series and the Haligowce Series.

The flysch beds of the Lower Aalenian (pre-*opalinum*) age are developed best in the Branisko Series, to the south of the Central Cordillera, where they are nearly 200 m. thick. More southward they disappear and are replaced by dark *Posidonomya* Shales in the Pieniny Series and by dark crinoidal limestones with cherts in the Haligowce Series.

To the north of the Central Cordillera the flysch member of the Lower Aalenian occurs in the Niedzica Series where it is 20—30 m. thick (tectonic reduction ?), in the Czertezik Series, where it is only 5 m. (?) thick (tectonically reduced ?), and, finally, in the Czorsztyn Series has been found in one profile (near the Czorsztyn Castle) a thin layer 0.5 m. thick of similar deposits in a rather ambiguous tectonic position [1]).

During the Middle Aalenian the Central Cordillera was submerged in its greater part, and grey spotted *Opalinus* Marls have been deposited to

[1]) It is possible that the Flysch Aalenian found in contact with the Czorsztyn Series near the Czorsztyn Castle belongs to the Branisko Series, and that no flysch deposits of the Lower Aalenian age occurred in the Czorsztyn Series.

the north, and dark *Posidonomya* Shales — to the south of the Cordillera. The spotted *Opalinus* Marls are to be found south of Cordillera, only in a northern variety of the Branisko Series. In the southernmost part of the geosynclinal basin the crinoidal dark cherty limestones continued in the Haligowce Series till the Callovian.

The only clear evidence of the Central Cordillera as the source of clastic sediments during this time is the presence of sideritic sandstones intercalated with shales and limestone-siderite lumachelles with *Liogryphaea*, deposited in the northernmost part of the Branisko Series. The silt components of the *Posidonomya* Shales and of the *Opalinus* Marls are, with a high probability, of the same provenance.

A slight positive movement of the sea bottom occurred in the Upper Aalenian. Two geosynclinal basins separated by the almost entirely submerged Cordillera have been but poorly aerated and black *Murchisonae* Clays and Shales with carbonate concretions have been formed. The petrochemical investigations of these so-called "Shales with Spherosiderites" carried out by W. NARĘBSKI (*cf.* K. BIRKENMAJER, W. NARĘBSKI 1958) indicated that in the northernmost part of the geosyncline where the Czorsztyn Series has been formed, the carbonate concretions are of a sideroplesitic character, those from the Niedzica Series are calcite-pistomesitic, and those from the Branisko Series are sideroplesite-calcite-colophanitic.

The fauna of the Upper Aalenian is commonly pyritized and consists of ammonites, belemnites and pelecypods, as well as of scarce foraminifers and ostracods.

II e. The influence of the northern coast of the geosynclinal trough on the sedimentation in the Bajocian and Bathonian

The last evidence of the Central Cordillera active in the Jurassic is the presence of a small amount of quartz grains found in the Bajocian spotted limestones of the northernmost variety of the Branisko Series. Nevertheless the sedimentation in the Bajocian and the Bathonian is chiefly controlled by other factors. In the southern regions of the geosyncline poorly aerated sediments i. e. dark spotted limestones and marls (Supra-*Posidonomya* Beds) with ammonites, belemnites and pelecypods are found in the Branisko and in the Pieniny Series, and dark crinoidal limestones with cherts in the Haligowce Series.

The facies in the northern parts of the geosynclinal trough indicated fairly good aeration. White crinoidal limestones developed in the Bajocian of the Czorsztyn Series (150 to 100 m. thick), of the Czertezik Series (c. 50 m. thick) and of the Niedzica Series (3 to 5 m. thick). They are followed by red crinoidal limestone in the Czorsztyn Series representing the Bathonian, by grey or red crinoidal limestone of a similar age in the Czertezik Series, and by red crinoidal limestone (Bajocian) and red nodular limestone (Bathonian-Callovian) in the Niedzica Series. The last development indicates bathyal conditions of sedimentation; the fauna of the Lower Nodular Limestone of the Niedzica Series consists of ammonites, belemnites, pelecypods, brachiopods etc. (K. BIRKENMAJER, J. ZNOSKO 1955) and of various *Aptychi* and *Rhyncholithes* (personal communication of S. M. GĄSIOROWSKI).

The influence of the northern coast of the geosynclinal trough on the sedimentation of the Bajocian and Bathonian is visible especially in crinoidal limestones where an admixture of quartz grains and fragments of the Middle Triassic limestones and dolomites and of red shales (Keuper ?) occur. The diameter of the clastic components in these limestones increases northwards thus indicating the source.

Furthermore, exotic fragments of muscovite gneisses, biotite augengneisses, biotite gneissoid-granites, biotite-muscovite gneissoid granites, aplites, felsophyres, porphyric tuffs, microgranitic and micropegmatitic quartz porphyries, granophyres and limestone with algues have been found in pelagic deposits (Lower Nodular Limestone) of the Bathonian of the Niedzica Series (K. Birkenmajer, S. M. Gąsiorowski and T. Wieser 1960). These fragments have been transported to the geosyncline probably by a floating island of tangled growth or by driftwood. The composition of these exotic fragments indicated that they derived from an area north of the Klippen Series geosyncline. From the exotic fragments in question and from the clastic fragments in the crinoidal limestones the geology of the land of their provenance may be tentatively reconstructed. In this land could have been present pre-Upper Carboniferous (gneisses, gneissoid granites etc.) basement rocks intruded with Upper Carboniferous aplites and with Lower Permian microgranitic and micropegmatitic quartz porphyries and granophyres. To the Lower Permian most probably belonged the extrusions of felsophyres and porphyric tuffs, to the Werfenian — the quartzitic deposits, to the Middle Triassic — limestones with calcareous algues and dolomites, and to the Keuper (?) — red shales.

The land these exotic fragments came from, separated the Pieniny Klippen Series geosynclinal trough from the troughs developed in the External Carpathians, for example from the Bachowice trough submerged by the Aalenian and Bathonian sea (*cf.* M. Książkiewicz 1954, 1956). This land, in its greater part has not been submerged after the early-Cimmerian synorogenic movements, probably till the Tithonian or Neocomian.

II f. Bathyal and abyssal deposits in the Dogger and in the Malm

In the uppermost Dogger (Callovian) and in the Lower Malm (Oxfordian and Kimeridgian) the Klippen Series geosyncline reached its maximal depth. Bathyal red nodular limestones with fairly well preserved ammonites, belemnites, gastropods, pelecypods, brachiopods etc. described by many older authors, among others by V. Uhlig, are most conspicuous in the northern part of the geosynclinal trough (*cf.* Pl. I). It is only in the Czorsztyn Series that the nodular limestone (Callovian to Kimeridgian in this series) is not associated with the radiolarites, the deepest facies within the Klippen Series sequence. In other series nodular (or pseudo-nodular) limestones occur immediately above the radiolarites and are of the Kimeridgian age (Czertezik Series, Branisko Series, Haligowce Series and some varieties of the Niedzica Series and of the Pieniny Series) or of the Kimeridgian-Valanginian age (a variety of the Niedzica Series).

There are also nodular (or pseudo-nodular) limestones underlying the radiolarites in the Niedzica Series (Bathonian-Callovian) and in the Haligowce Series (Callovian or Lower Oxfordian).

The presence of radiolarites is the most characteristic feature of the Oxfordian and partly also of the Callovian and Kimeridgian in the Klippen Series other than the Czorsztyn Series. No Jurassic series in the Carpathians, the Sub-Tatra Series excepted, contains a radiolarite complex developed in such thickness and variability as that of the Klippen Belt. Stages of deepening of the geosyncline are especially well observable in the Niedzica Series, where above the lower nodular limestone (Bathonian-Callovian) lie (from bottom to top): lower red radiolarites (Lower Oxfordian), green radiolarites *(transversarium* zone *s. l.)*, upper red radiolarites *(bimammatum* zone *s. l.)* and upper nodular limestone (Kimeridgian or Kimeridgian to Valanginian).

This sequence implies that the green radiolarites have been formed when the geosyncline reached its maximum depth.

The conditions of the oxydation of the geosynclinal sediments, which led to the formation of the red crinoidal limestones, of the red nodular limestones and of the red radiolarites rich in $Fe^{\cdot\cdot\cdot}$, were worse when the green radiolarites with $Fe^{\cdot\cdot}$ have been deposited. This suggests that the southern part of the Klippen Series geosyncline where the dark manganese radiolarites (Callovian ? — Lower Oxfordian) of the Branisko Series and of the Pieniny Series, and the green radiolarites of the Branisko Series *(transversarium* zone *s. l.)*, of the Pieniny Series (Upper Oxfordian and Lower Kimeridgian) and of the Haligowce Series (? Oxfordian) have been deposited, was aerated worse than the northern part of the geosyncline. Furthermore it could indicate that the southern part of the geosyncline in the Lower Malm was deeper than the northern part.

The macrofauna of the radiolarites and some nodular limestones consists mainly of numerous *Aptychi* and *Rhyncholithes* (S. M. Gąsiorowski 1958, 1960). The former, according to S. M. Gąsiorowski (personal communication) allow a fairly exact determination of the age of particular members of radiolarites and nodular limestones.

II g. Upper Malm-Lower Neocomian sedimentation and the neo-Cimmerian synorogenic movements

The positive movement of the sea bottom commenced in the upper part of the Lower Malm (nodular or pseudo-nodular limestones of the Kimeridgian) and reached its maximum in the Tithonian. It is in the Czorsztyn Series that the influence on sedimentation of the neo-Cimmerian synorogenetic movements (equivalent to the Osterwald phase *sensu* Stille 1924) is most clearly visible. In this series breaks in sedimentation occurred, caused by submarine erosion of the deposits uplifted to the wave-base (K. Birkenmajer 1958 b) [1]).

[1]) Late Jurassic synorogenetic movements extended over a wide area of the Tethys between the Western Alps and Central Carpathians. A discontinuity (gap) of faunal sequence between the Lower Tithonian *Subplanites* fauna and the Upper Tithonian *Berriasella* assemblage of Chomérac and Neuburg (Bayern) was reported by G. Mazenot (1939). Evidences of the Tithonian synorogenesis in form of false-breccias are widely distributed in the Western Alps and in the adjacent areas, as for example near Sisteron and Col de Lauzon between Briançon and Château Queyras. The turbidity currents action is clearly visible in the Morcles Nappe (A. Carrozzi, 1955, 1957). According to W. J. Arkell (1956, p. 155) "the most remarkable of all the evidences for geanticlines active during the Jurassic are contained in the Breccia Nappe of the Prealps. The breccias are built up of a series of superimposed submarine slides, which travelled a maximum distance of 5 km. and seem to have slid off the rear of a rising geanticline" (cf. Ph. H. Kuenen, A. Carrozzi, 1953). A part of these breccias (Upper Breccia) represent the Upper Jurassic and Lower Cretaceous.

It is also to be noted that the Tithonian-Berriasian organogenic deposits of the Czorsztyn Series are more variable than anywhere in this time in the Internal Carpathians.

The Lower Tithonian members of the Czorsztyn Series consist of red (lower) and white (upper) subpelitic *Calpionella* limestones with abundant tintinnids and calcareous pelagic algues (*Globochaete alpina* LOMB.). In some types of the Czorsztyn Series red *Calpionella* limestones are replaced by pink and white *Globochaete* limestones.

The general positive movement transforming the Czorsztyn Series into a geanticlinal zone became differential during the Middle Tithonian.

In some parts of the Czorsztyn Series sedimentary area no beds of presumably Middle Tithonian age are visible. It is quite probable that the sea bottom reached the wave-base, and the bottom currents swept off the organic remains (shells of brachiopods, segments of crinoids, shells of ammonites etc.) to the adjacent deeper zones. There have been formed brachiopodal limestones, crinoidal limestones, limestones with crinoids and brachiopods, and white *Calpionella* limestones. The lumachelle of Rogoźnik with a well known Middle Tithonian fauna with *Semiformiceras semiforme* described by K. ZITTEL, M. NEUMAYR, V. UHLIG, and by others, is partly contemporaneous with the brachiopodal limestones. The great number of ammonites, brachiopods, gastropods, belemnites, crinoids etc., gathered in the lumachelle, commonly not filled with sediment, and feebly joined together with secondary calcite, can be explained by the action of the submarine bottom currents.

At the beginning of the Upper Tithonian, the positive movement of the sea bottom reached its maximum. There is, however, no evidence of emergence. In one profile of the Czorsztyn Series a small-scale fissure formed probably by an earthquake, transversing both the Lower Tithonian and Kimeridgian limestones and filled with the Upper Tithonian or Berriasian sediments is visible. The Lower Tithonian white *Calpionella* limestones from some parts of the sea bottom fragmentated by wave action and probably by shaking up by earthquakes, have been transported by bottom currents to the deeper parts of the basin and formed thin intercalations of detrital limestones within the Upper Tithonian deposits [1]). These limestones show no graded bedding and cannot be explained by turbidity currents [2]).

The higher part of the Upper Tithonian and probably a part of the Berriasian is represented by limestones with crinoids and brachiopods and with *Aptychi*.

A new tendency to the negative bottom movement occurred in the Upper Tithonian-Berriasian. It is marked by the appearance of a red crinoidal limestone with rare tintinnids and calcareous algues, with *Lamellaptychus angulocostatus* (PET.) var. div. and with other *Aptychi* (S. M. GĄSIOROWSKI 1956; K. BIRKENMAJER *o. c.*). In some profiles in the lower part of the limestone in question a hard-ground surface has been observed.

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[1]) Similar detrital limestones have been found by D. ANDRUSOV (1953, p. 361, 388) in a Pieniny Transitional Series in Western Slovakia.

[2]) In some instances the Upper Tithonian limestones show false-brecciation. It can be explained by the action of earthquakes on partly diagenezed bottom lime deposits (K. BIRKENMAJER, 1958 b).

Sedimentary gaps in some northern varieties of the Czorsztyn Series correspond to the Middle Tithonian. In the central part of the area of the Czorsztyn Series between the Czorsztyn Castle and the Białka River sedimentary gaps correspond to the upper part of the Lower Tithonian, to the Middle and Upper Tithonian and to the Berriasian. Finally, in some southern varieties of the Czorsztyn Series, the sedimentary gaps were found in the Upper Tithonian, Berriasian and Valanginian.

During the Valanginian the greater part of the sedimentary region of the Czorsztyn Series was covered with thin variegated limestones and marls rich in globigerinids. They pass upwards into marly limestones with cherts overlain by marly limestones and marls, with globigerinids and radiolarians considered to represent the horizons from the Valanginian to the Albian inclusively.

A sedimentary gap corresponding to the Middle (?) and Upper Tithonian, as well as the Berriasian and Valanginian probably exists in the Czertezik Series (K. Birkenmajer 1959 b) and in a variety of the Niedzica Series, where the Lower (and Middle ?) Tithonian *Calpionella* limestones are surmounted immediately with the supposedly Hauterivian-Barremian cherty or pseudo-cherty limestones.

Cherty limestones (Hornsteinkalk) of a biancone type are developed well in the southern part of the Klippen Series geosyncline where they are up to 150 m. thick (in the Pieniny Series). The cherty limestones within the Klippen Series appeared first in the Pieniny Series where they commenced in the Kimeridgian. The Tithonian-Berriasian and Valanginian cherty limestones of the Branisko Series, of the Pieniny Series and of the Haligowce Series contain tintinnids and pelagic calcareous algues (*Globochaete alpina* Lomb.). These fossils are absent in the Hauterivian and Barremian part of these limestones. Calcified radiolarians and *Nannoconus* (found by M. Mišík 1958) are abundant in the whole profile of the cherty limestone complex.

II h. Influence of the Upper Neocomian synorogenic movements on the sedimentation of the Klippen Series

At the end of the Neocomian the sedimentation became uniform (K. Birkenmajer 1957 c) in the Klippen Series, the Haligowce Series excepted. Black, green and spotted thin-bedded limestones, marly shales and marls, usually without cherts, with a high amount of globigerinids and radiolarians are deposited. Intercalations of siltstones have been found within these deposits in the Branisko Series and in the Niedzica Series. As these siltstones probably do not occur in more northern Klippen Series (i. e. the Czertezik Series and the Czorsztyn Series) and in more southern series (i. e. the Pieniny Series and the Haligowce Series) it can be assumed that the clastic components of the siltstones came from the inner part of the geosyncline, i. e. from the Central Cordillera activitated by an "austrische Synorogenese" [1] *sensu* H. Stille (K. Birkenmajer 1958 d). However, no clastic fragments beside the quartz grains occur in the siltstones. If these grains really

[1]) The "austrische Synorogenese" is visible also in the High-Tatra Series (E. Passendorfer, 1930, 1951) in the Tatra Mts. and in the Manín Series of the Váh River valley (cf. D. Andrusov, 1938, 1945, 1953; V. Kantorová, D. Andrusov, 1958) where the Albian rests in penaccordance on the Urgonian limestones.

derived from the Central Cordillera, it might be supposed that a part of the Cordillera though submerged between the Bajocian and the Lower Neocomian inclusively, was not covered by sediments and formed a submarine ridge elevated above the wave-base [1]).

The development of the Upper Neocomian (Barremian and Aptian) in the Haligowce Series differs from that in the remaining Klippen Series, and resembles some members of this age in the High-Tatra Series. The present author (1959 a) has found in the Haligowce Series some organogenic somewhat bituminous dark (in the lower part) and light (in the higher part), often detrital limestones rich in organic fragments. They resemble the Urgonian facies, especially of the Manín Series near Trenčianské Teplíce in Western Slovakia.

II i. Pelagic facies of the Middle Cretaceous and pre-orogenic flysch facies

During the Middle Cretaceous similar deposits have been formed within all the Klippen Series. There are slow transitions between the Upper Neocomian beds with globigerinids and radiolarians and the Middle Cretaceous beds. The Albian deposits similar to those of the uppermost Neocomian, i. e. black, green and spotted marls and shales, and marly limestones, contain in the western part of the Pieniny Mts. a poor fauna of *Hamites* aff. *attenuatus* (Sow.), *H.* aff. *flexuosus* (d'Orb.), *Neohibolites minimus* (List.), *Aucella* aff. *gryphaeoides* Sow. and *Thalmanninella ticinensis* (Gand.) (K. Birkenmajer 1957 a; B. Kokoszyńska, K. Birkenmajer 1956) [2]).

The Albian deposits are followed by green, spotted black marls of the Cenomanian age with *Neohibolites ultimus* (d'Orb.) and *Aucellina gryphaeoides* Sow. (L. Horwitz 1938) and with an abundant microfauna consisting of: *Rotalipora apenninica* (Renz) [3]), *R. apenninica reicheli* Książk., *R. reicheli* Mornod, *R. globotruncanoides* Sigal, *R. turonica* Brotz., *R. montsalvensis* Mornod, *R. cushmani* (Morrow), *R. evoluta* Carbonnier, *Globotruncana stephani* Gand., *G. stephani turbinata* Reichel, *G. helvetica* Bolli, recently described by M. Książkiewicz (1958).

The upper part of the Cenomanian consists of variegated marls with *Neohibolites ultimus* (d'Orb.) [4]) and with abundant microfauna consisting

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[1]) Microscopic quartz grains found by D. Andrusov (1953, p. 335) in light *Calpionella* limestones of the Sub-Pieniny (Czorsztyn) Series of the Western Slovakia might have derived from this Cordillera activitated during the neo-Cimmerian synorogenic movements.

[2]) Similar beds have been found recently in the "Kýsuca type" of the Pieniny Series (s. l.) of the Klippen Belt of the Western Slovakia by E. Scheibner (1958), where they yielded a fauna consisting of: *Globigerina infracretacea* Glaessn., *G. cretacea* d'Orb., *Ticinella roberti* (Gand.), *Thalmanninella ticinensis* (Gand.), *Nannoconus* sp. V. Kantorová and D. Andrusov (1958) found recently in the Klippen Belt in Western Slovakia an Albian microfauna within the Sub-Pieniny (Czorsztyn) Series: *Thalmanninella ticinensis* (Gand.), *Ticinella roberti* (Gand.), within the "Podbieł Series": *Rotalipora reicheli* Mornod, *Ticinella* sp., *Glomospira gordialis* (J. et P.), within the Pieniny Series: *Clavulina gaultina* Moros., *Marssonella trochus* (d'Orb.), *Lenticulina dunkeri* (Reuss.), *L. rotulata* Lam., *Globigerina infracretacea* Glaessn., *Ticinella roberti* (Gand.), *T. gaultina* Moros.

[3]) Reported first by M. Książkiewicz (1950, p. 351, footnote) from the Czorsztyn Series and, subsequently found by the present author (1953 b, 1954 a, 1957 a, 1958 d, 1959 a, b) in the remaining Klippen Series.

[4]) Determined by B. Kokoszyńska (in preparation for printing).

of: *Rotalipora apenninica reicheli* KSIĄŻK., *R. reicheli* MORNOD, *R. globotruncanoides* SIGAL, *R. turonica* BROTZ., *R. turonica expansa* CARBONNIER, *Globotruncana stephani* GAND., *G. helvetica* BOLLI, *G. sigali* REICHEL, *G. imbricata* MORNOD, *G. lapparenti lapparenti* BROTZ., *G. lapparenti coronata* BOLLI, *G. lapparenti tricarinata* (QUER.), *G. lapparenti angusticarinata* GAND., determined by M. KSIĄŻKIEWICZ *(o. c.)*.

The variegated marls transist upwards to the red *Globotruncana* marls with numerous foraminifers from the *Globotruncana lapparenti* group. These marls have been included in the Cenomanian by L. HORWITZ (1938) [1]) and in 1954 [2]) in the Turonian by the present author (B. KOKOSZYŃSKA, K. BIRKENMAJER 1956; K. BIRKENMAJER, B. KOKOSZYŃSKA 1958; K. BIRKENMAJER 1957 a, 1958 d). The Turonian age of the red *Globotruncana* marls in the Pieniny Klippen Belt of Poland has also been accepted by M. KSIĄŻKIEWICZ (1956 a). The microfauna of the red marls in question described by M. KSIĄŻKIEWICZ (1958) consists of: *Rotalipora apenninica reicheli* KSIĄŻK., *Globotruncana stephani* GAND., *G. helvetica* BOLLI, *G. sigali* REICHEL, *G. renzi* GAND., *G. lapparenti lapparenti* BROTZ., *G. lapparenti coronata* BOLLI, *G. lapparenti tricarinata* (QUER.), *G. lapparenti angusticarinata* GAND., *G. concavata* (BROTZ.), *G. fornicata* PLUMMER.

Gradual transition can be observed between the red *Globotruncana* marls and the flysch member of the Sromowce Beds [3]) which form the youngest member of the Klippen Series. The Sromowce Beds consist of calcareous sandstones rich in organogenic hieroglyphs *(Palaeodictyon, Palaeobullia)* alternating with arenaceous marls (in the lower part) and with marly shales and shales (in the upper part). The flysch member in question, a typical sediment formed by turbidity currents, is c. 100 m. thick, graded, with flute casts (Strömungs-Marken) indicating the supply of the clastics from the south. This direction of transportation may be verified by the investigation of conglomerate intercalations in the Sromowce Beds, which contain exotic fragments closely similar to those in the Upper Cretaceous Mantle, and which originated due to submarine slumping of the coarser loose material from the coastal fringe.

The macrofauna of the Sromowce Beds is very poor, redeposited (occurs at the bottom of graded sandstone layers) and consists of fossils of a Middle and Upper Cretaceous character (K. BIRKENMAJER, B. KOKOSZYŃSKA 1958):

Exogyra columba (LAM.): Cenomanian-Turonian
Alectryonia diluviana (L): Aptian-Senonian
Alectryonia semiplana (SOW.): Senonian
Neithea aff. *quadricostata* (d'ORB.): Senonian
Crania ignabergensis RETZ.: Senonian

A poor assemblage of foraminifers described by M. KSIĄŻKIEWICZ (1958) consisting of: *Globotruncana lapparenti coronata* BOLLI, *G. lapparenti tricarinata* (QUER.), *G. lapparenti angusticarinata* GAND., *G. fornicata* PLUMMER,

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[1]) And also in an unpublished map in 1 : 10,000 scale of the Pieniny Mts. by L. HORWITZ.

[2]) Published in 1958 (K. BIRKENMAJER, 1958 d).

[3]) Name introduced by the present author (1959 b).

G. ventricosa (WHITE), *G.* cf. *spinea* KIKOINE and *Stensiöina prae-exculpta* (KELLER) is suggestive of the Upper Turonian or Coniacian [1]).

On both the micro- and macrofauna the present author is inclined to attribute the Sromowce Beds to the Upper Turonian and Lower Coniacian.

The flysch facies (Sromowce Beds) preceded the first orogenic movements in the Klippen Belt (pre-orogenic flysch facies). The development of the flysch facies was controlled by tectonic instability of the southern border area of the Klippen geosyncline, where the Exotic Massif emerged and supplied clastics to the south, to the so-called "Orlové Beds" (Albian and Cenomanian) [2]) of the Manín Series, and subsequently, became the source of clastics for the Upper Turonian-Lower Coniacian Sromowce Beds of the Klippen Series geosyncline.

II j. Orogenic movements of the sub-Hercynian phase and the nappe formation of the Pienids

The first orogenic movements in the Pieniny Klippen Belt occurred after the deposition of the flysch (Sromowce Beds — Upper Turonian to Lower Coniacian) and before the deposition of the Úpohlav Beds (Upper Santonian). This indicates that these orogenic movements correspond to the sub-Hercynian phase *sensu* H. STILLE (1924).

The direction of the orogenic stress was from the south to the north. The Klippen Series geosyncline was compressed between two mobile border areas i. e. between the more active southern border area formed by the Exotic Massif (which emerged in the Albian) and the more passive northern border area formed by a prolongation of the crystalline-sedimentary substratum of the Czorsztyn Series [3]).

During the sub-Hercynian orogenic movements the Czorsztyn Series and (probably) a northern part of the Czertezik Series were autochthonous. They were tectonically overlain by the Branisko Nappe overthrust from the south. A tectonic megabreccia was formed at the contact of the Branisko Nappe with the Autochthone which consisted of scales of the Niedzica Series and of a part of the Czertezik Series.

The Branisko Nappe, the greatest nappe within the Klippen Belt, was only in part covered tectonically by the Pieniny Nappe (present only in the Pieniny Mts., in an area west of Nowy Targ and in the Orava River valley), which in its turn was overthrust by the Haligowce Nappe (present only in the Pieniny Mts.). A part of the Autochthone formed by the northern

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[1]) Cenomanian and Turonian microfaunas from the *Globotruncana* marls of the Klippen Belt in Western Slovakia have been recently described by V. KANTOROVÁ and D. ANDRUSOV (1958), by E. SCHEIBNER and V. SCHEIBNEROVÁ (1958) and V. SCHEIBNEROVÁ (1958).

[2]) The "Orlové Sandstones" yielded a fauna of *Exogyra columba silicea* (LAM.), and orbitolines which according to D. ANDRUSOV (1945, 1953) indicated their Cenomanian age. New investigations of V. KANTOROVÁ and D. ANDRUSOV (1958) and V. SCHEIBNEROVÁ (fide V. KANTOROVÁ and D. ANDRUSOV, 1958) indicated that a part of these sandstones belonged to the Albian, and that the main part of the so-called "Orlové Beds" belonged to the Úpohlav Beds (Upper Cretaceous Mantle) of the Santonian age and to the Turonian of the Klippen Series.

[3]) The northern border area was the source of the clastics for the Bajocian and the Bathonian of the Klippen Series geosyncline (see above), and possibly formed the substratum of the main part of the Magura Palaeogene flysch unit.

varieties of the Czorsztyn Series remained uncovered tectonically until the Senonian.

The tectonic units mentioned above formed probably the oldest alpine tectonic units within the Carpathians. The name "Pienids" as used to denote these units by the present author (1957 a, f, 1958 d) is the same as that used by A. MATĚJKA and D. ANDRUSOV (1931) and by D. ANDRUSOV (1938), but the meaning is different. According to these authors the first nappe folding of the Klippen Belt occurred in the "Pieniny phase" (uppermost Aptian-lowermost Albian), which, according to the present author (see above) did not exist in the Pieniny Klippen Belt.

South of the tectonic belt of the Pienids units of the High-Tatra Series and the Sub-Tatra Series emerged after the Cenomanian or Turonian [1]). According to the present author (1958 d) the Manín Series was autochthonous during the sub-Hercynian movements in the Carpathians, a view different from that of D. ANDRUSOV (1938), who considered that this Series was thrust over the Pieniny Nappe during the "Pieniny phase". The first orogenic movements which affected the Sub-Tatra Series and the High-Tatra Series, and which led to the formation of the nappes in the Internal Carpathians were post-Senonian (Laramide phase) [2]).

III. Stratigraphy of the Exotic Massif situated between the Pienids and the Tatrids

The exotic massif situated to the south of the Klippen Series sedimentary region influenced the sedimentation of the Sromowce Beds (Upper Turonian-Lower Coniacian) of the Úpohlav Beds (Upper Santonian), of the Jarmuta Beds (Campanian-Maestrichtian), of the Szczawnica Beds (Upper Paleocene — Middle Eocene) and, partly, of the Variegated Beds (Danian ?).

The first data on the position of this Exotic Massif (crête exotique) south of Pienids have been established by A. MATĚJKA and D. ANDRUSOV (1931) and D. ANDRUSOV (1938, 1945, 1953). The sedimentological investigations of the present author (1956) confirmed the opinion of these authors, as they showed that the trend of transportation within the Jarmuta Beds and within the Szczawnica Beds was from the south to the north.

The stratigraphy of the Exotic Massif in question based on the investigations of exotic pebbles by V. ZOUBEK (1931) and D. ANDRUSOV (1938, 1945, 1953) was reconstructed by D. ANDRUSOV *(o. c.)*. According to D. ANDRUSOV this massif formed the primary substratum of the Pieniny Nappe. This view was not, however, accepted by the present author (1958 d) who found that some Jurassic and Neocomian exotic rocks were completely different from those of the Pienids and of the Tatrids.

Basing on the investigations of the metamorphic and magmatic rocks by T. WIESER (1958) and on the investigations of the sedimentary exotic

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[1]) The lack of the Cenomanian deposits within the High-Tatra and the Sub-Tatra units of the Tatra Mts. is, according to the present author, due to the erosion which acted in the Senonian. The presence of the Cenomanian and Lower Turonian deposits in the Manín Series and of the Cenomanian deposits in the Sub-Tatra Series in Western Slovakia (D. ANDRUSOV, 1938, 1945, 1953; M. MAHEL, 1950 a, b; V. KANTOROVÁ, D. ANDRUSOV, 1958) agrees with this supposition.

[2]) The Laramide age of the Sub-Tatra nappes was accepted already by A. MATĚJKA and D. ANDRUSOV (1931) and D. ANDRUSOV (1938).

rocks by the present author (1958 d) the following stratigraphy of the Exotic Massif is proposed:

Middle Cretaceous:	probably lacking due to regression.
Barremian-Aptian:	typical Urgonian limestones rich in orbitolines and miliolids.
Lower Neocomian:	unknown ?
Malm:	pink oolitic limestones with *Globochaete alpina* LOMB.
Dogger:	unknown ?
Upper Liassic (?):	brown cristalline limestones with spicules of sponges, with bluish cherts.
Middle Liassic (?):	light-grey limestones with black spots.
Lower Liassic (?):	fine-grained conglomerates composed of fragments of the Triassic dolomites cemented with calcareous-arenaceous matrix.
Rhaetian (?):	black coral limestones.
Upper Triassic:	red argillaceous shales without mica.
Middle Triassic:	to the Anisian may belong dark-grey limestones with calcareous algues. To the Ladinian may belong grey, fine-cristalline limestones and grey dolomites.
Werfenian:	pink, grey and white quartzites, quartz-feldspar sandstones and conglomerates, and micaceous-argillaceous green and red shales. To the Werfenian with a high probability also belong extrusive rocks of melaphyric porphyrites, green spilites, propilites etc., and intrusive keratophyres (albitophyres).
Younger Palaeozoic:	there is a probability that to the Permian may belong some intrusive and extrusive porphyries described by V. ZOUBEK (1931). To the Carboniferous may belong some dark feldspar-bearing coarse-grained sandstones and grey and pink limestones (?) mentioned by D. ANDRUSOV (o. c.), and black graphitoid quartzites.
Pre-Upper Carboniferous intrusive rocks:	microgranites, aplogranites, bi-mica granites etc. mainly greenish.
Pre-Carboniferous rocks:	orthogneisses rich in Na, and K, and phyllites.

IV. History of the Klippen Mantle geosyncline

IV a. Pre-Laramide Mantle

The tectonic units formed during the sub-Hercynian phase in the Klippen Belt, emerged from the sea and were subjected to the erosion before the transgression of the Pre-Laramide Mantle. The products of weathering and erosion have been carried by rivers probably to the north.

The transgression of the Mantle sea commenced in the Upper Santonian in the western part of the Klippen Belt and afterwards advanced eastward. The Úpohlav Beds, the oldest member of the Pre-Laramide Mantle, are developed best in the areas of the rivers Váh and Orava in Western Slovakia (D. ANDRUSOV 1938, 1945, 1953) [1]). In Poland, the Úpohlav Beds occur only at Stare Bystre west of Nowy Targ, where they consist of conglomerates with *Hippurites* and with calcareous algues known already to V. UHLIG (1890), but considered by him to be the Eocene. The pebbles of the conglomerates consist mainly of exotic material like granites, aplogranites, spilites, propilites, albitophyres, keratophyres, Werfenian

[1]) According to the previous papers by D. ANDRUSOV (1938, 1945, 1953) the Úpohlav Beds are Upper Santonian. New micropalaeontological investigations of V. KANTOROVÁ and D. ANDRUSOV (1958) indicate, however, the Upper Santonian-Campanian age of these beds.

quartzites, dolomitic limestones of the Middle Triassic etc. (K. BIRKENMAJER 1958 d, T. WIESER 1958). The frequency of the pebbles of the Klippen Belt provenance averages only a few per-cent of the total number of the pebbles. These are fragments of the Neocomian and of the Middle Cretaceous rocks of the Branisko Series.

The transgression of the Pre-Laramide Mantle expanded eastward in the Campanian and in the Maestrichtian, and the whole northern and central parts of the Pienids were covered by the sea. It was only the southernmost part of the Pienids range which remained not submerged till the Eocene and formed the southern coast of the Mantle sea.

Age		S		N
Danian		Variegated Beds 30m. – 180m.		c.10m.
Senonian	Maestrichtian	Jarmuta Beds 50m. – 450m.		Púchov Marls c.50m.
	Campanian			
	Upper Santonian	—	Úpohlav Beds c.50m	?

Fig. 2: Stratigraphy of the Pre-Laramide Mantle in Poland.

During the Campanian and Maestrichtian clastic deposits called the Jarmuta Beds have been formed in the southern part of the submerged area. It was mainly on the Branisko Nappe [1]) that supra-littoral gravels and cliff breccias have been formed. Towards the north cliff deposits transisted into conglomerates and sandstones, which transisted northward into flysch deposits composed of sandstones alternating with shales and with subordinate conglomerate intercalations.

The fauna of the Jarmuta Beds consists of *Lepidorbitoides socialis* LEYM., *Siderolites vidali* DOUV. and *Orbitoides* cf. *media* d'ARCH. F. BIEDA (1935, 1946) who determined this fauna considered it to be Maestrichtian. Nevertheless, the first two foraminifers mentioned above were found by A. PAPP (1954) also in the Campanian. Fragments of *Inoceramus* and *Ostreidae* are common organic remains within the Jarmuta Beds (K. BIRKENMAJER 1954 b, 1958 d).

The sedimentological investigations carried out by the present author (1956, b, 1957 c) indicated that the clastic material was supplied to the Jarmuta Beds from the south [2]), from the same exotic massif, which yielded the clastics to the Sromowce Beds (Upper Turonian-Lower Coniacian) of the Klippen Series.

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[1]) A part of the Pieniny Nappe and of the Niedzica and the Czertezik units as well as a part of the Czorsztyn Autochthone have also been covered by the Jarmuta Beds.

[2]) It coincided with the direction of the transportation accepted by D. ANDRUSOV (1938) for the Úpohlav Beds.

The pebbles of the conglomerates within the Jarmuta Beds consist in a great part of the exotic material similar to that found in the Sromowce Beds and in the Úpohlav Beds. The local material, however, occurs in abundance and fragments of nearly all members of the Branisko Series and of the Czorsztyn Series have been found in the conglomerates of the Jarmuta Beds (K. BIRKENMAJER 1958 d) as well as secondarily deposited Jurassic, Neocomian and Middle Cretaceous macrofossils (K. BIRKENMAJER, S. M. GĄSIOROWSKI 1959) and microfossils.

To the north of the area covered by the Jarmuta Beds, pelagic Globotruncana marls (Púchov Marls) have been deposited on a substratum formed by the Czorsztyn Autochthone. The Púchov Marls *s. s.* in Poland are mainly red and contain *Globotruncana lapparenti tricarinata* (QUER.), *G. stuarti* (LAPP.) etc., and thin-shelled *Inoceramus* fragments. The Púchov Marls in question contain no clastic intercalations. Transitions between the Jarmuta Beds and the Púchov Marls are not visible in Poland probably because of a great overthrust during the Laramide orogeny. However, the Púchov Marls complex with intercalations of sandstones in the Orava and Váh river valleys, described by D. ANDRUSOV (1938, 1945, 1953) and by V. KANTOROVÁ and D. ANDRUSOV (1958) with a Campanian-Maestrichtian microfauna could be considered as the transitional zone [1]).

Both on the Púchov Marls in the north and on the Jarmuta Beds in the south the so-called Variegated Beds have been deposited. The Variegated Beds [2]) surmounting the Púchov Marls consist of red shales with a poor agglutinated microfauna (without *Globotruncanae*) determined by S. GEROCH (see K. BIRKENMAJER 1958 d): *Uvigerinammina jankói* Majzon, *Glomospira charoides* (J. et P.), *Ammodiscus* ex gr. *incertus* REUSS etc.

The member of the Variegated Beds which covers the Jarmuta Beds consists of red, green and variegated shales intercalated with thin hieroglyphic sandstones with problematic organogenic casts *Fucusopsis angulatus* PALIB. (K. BIRKENMAJER 1954 b, 1958 d, 1959 e) and with biotite-feldspar tuffites (K. BIRKENMAJER, T. WIESER 1956). The microfauna determined by S. GEROCH (see K. BIRKENMAJER 1954 b) consists of: *Uvigerinammina jankói* MAJZON, *Thalmannammina subturbinata* (GRZYB.), *Glomospira charoides* (J. et P.), *Haplophragmoides walteri* (GRZYB.), *Ammodiscus incertus* (REUSS) etc. This fauna consists almost entirely of agglutinated foraminifers of little stratigraphical value. It is probable that the Variegated Beds in question belong to the Danian as they are older than the pre-Upper Palaeocene folding of the Laramide phase.

IV b. Orogenic movements of the Laramide phase

After the deposition of the Variegated Beds overthrusting occurred (Laramide phase). The Branisko Nappe with its pre-Laramide Mantle was thrust over the Czorsztyn Autochthone and its shaly and marly mantle, in the form of probably horizontal nappe (K. BIRKENMAJER 1958 d, 1959 d). Several tectonic sheets built up of the Branisko Series and its Pre-Laramide Mantle (i. e. Jarmuta Beds and Variegated Beds) thrust one over another

[1]) According to the investigations of V. KANTOROVÁ and D. ANDRUSOV (1958) the name "Púchov Marls" is not correct, because in the vicinity of Púchov on Váh the Senonian *Globotruncana* marls do not occur.

[2]) These beds have been described by L. HORWITZ (1938) as Púchov Marls.

were formed. This overthrusting took place below the sea level, and was caused probably by submarine large-scale gliding. The tectonic units thus formed were covered with the Palaeogene marine deposits.

The youngest members of the Pre-Laramide Mantle are probably of Danian age. The oldest members of the Post-Laramide Mantle contain a fauna of the Upper Paleocene. Thus the Laramide orogenic movements in the Polish sector of the Klippen Belt took place in the Lower Paleocene or in the Upper Danian-Lower Paleocene.

During the Laramide folding of the Klippen Belt the Exotic Massif (situated between the Pienids and the Tatrids) was probably covered in its greater part by tectonic units of a High-Tatra Series (Tatrids). The Inner Carpathian Laramide nappes, especially the Sub-Tatra Nappes were, with a high probability, thrust over the tectonic structure of the Klippen Belt, as it was assumed by D. Andrusov (1938) in the western sector of the Belt.

IV c. Post-Laramide Mantle

After the Laramide structure of the Klippen Belt was formed, the sea transgressed southwards. The southern part of the Klippen Belt in Poland built up of the Branisko Nappe and of the Pieniny Nappe was submerged in the Lower Eocene and the southernmost area built up of the Haligowce Nappe was covered by the sea in the Middle Eocene. The tectonic units of the Inner Carpathians, as the Sub-Tatra Nappes (Granids) and the High-Tatra Nappes (Tatrids) formed during the Laramide orogeny were submerged in the Middle and Upper Eocene.

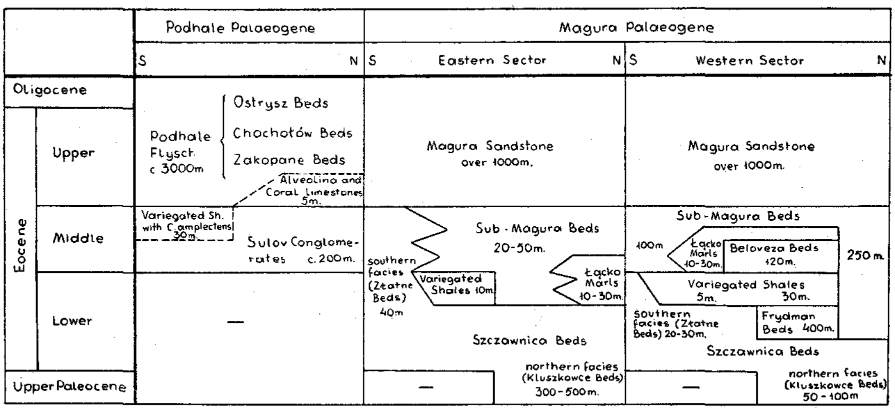

Fig. 3: Stratigraphy of the Post-Laramide Mantle in Poland.

During the Upper Eocene and Oligocene the tectonic structure of the Klippen Belt was entirely covered by the sea. Only in the Lower Eocene a poor association of exotic fragments resembling those present in the Middle and Upper Cretaceous of the Klippen Belt, has been found. It must have derived from the Exotic Massif south of Pienids.

The fragments of the Klippen Belt rocks may be found only in the Middle Eocene of the Inner Carpathians close to the Klippen Belt. They completely disappear in the Upper Eocene-Oligocene flysch members of the Inner Carpathians. Fragments of the pre-Palaeogene rocks found in the flysch complexes of the Upper Eocene-Oligocene resemble the rocks common in the Sub-Tatra units.

In the western part of the Klippen Belt from the Vienna Basin to the Pieniny Mts., the Post-Laramide Mantle belongs to the Magura Group Flysch (D. ANDRUSOV 1938, K. BIRKENMAJER 1954 b, 1958 d). The sub-Hercynian and Laramide structures of the Klippen Belt are (probably) here the root-zone of a part of the Magura Nappe formed during the Savian phase.

East of the Pieniny Mts. in the southern part of the Klippen Belt the Post-Laramide Mantle seems to belong to the Inner Carpathian Palaeogene. This may be seen in Haligovce (Pieniny Mts.) where the Middle Eocene of an Inner Carpathian type (Sulov Conglomerates, coral limestones, *Alveolina* limestones) rests immediately on the Haligowce Nappe (cf. V. UHLIG 1890, L. HORWITZ, F. RABOWSKI 1929, F. BIEDA 1929, 1946, K. BIRKENMAJER 1959 a) and in the vicinity of Údol (Ujak), where Prof. Dr. H. ŚWIDZIŃSKI [1]) found the Inner Carpathian Palaeogene forming the mantle of the Klippen Belt.

Transitions between the Magura Flysch and the Inner Carpathian Palaeogene have not yet been found. It seems very probable that these transitions could be found in the eastern part of the Klippen Belt of Slovakia.

In the Magura Flysch in the Klippen Belt of Poland several stratigraphic members can be distinguished. The oldest member is called the Szczawnica Beds (K. BIRKENMAJER 1956 c, 1957 e). The Szczawnica Beds are developed in two facies. The northern facies (called the Kluszkowce Beds — K. BIRKENMAJER 1958 d) consists of calcareous dark sandstones intercalated with dark shales, a few hundred metres thick. Coarse-grained intercalations within these sandstones yielded a fauna of the Upper Palaeocene-Lower Eocene age determined by F. BIEDA: *Nummulites* cf. *fraasi* de LA HARPE, *Operculina* ex gr. *granulosa* LEYM. (cf. *O. couizaensis* DONC.), *O.* ex gr. *ammonea* LEYM. (cf. *O. libyca* SCHW.) (F. BIEDA 1929, 1935), *N. exilis* DOUV., *N. subplanulatus* HANTK. & MADAR, *N. praelucasi* DOUV., *N. solitarius* DE LA HARPE, *N. pernotus* SCHAUB, *Operculina couizaensis* DONC., etc. (see K. BIRKENMAJER 1958 d, p. 93).

The southern facies of the Szczawnica Beds (called the Złatne Beds — K. BIRKENMAJER 1954 b, 1958 d, K. BIRKENMAJER, T. WIESER 1956) consists of medium-grained and coarse-grained calcareous sandstones and fine-grained conglomerates only 20—30 m. thick. They yielded a Lower Eocene fauna determined by F. BIEDA (1929, 1935, 1946): *Operculina ammonea* LEYM., *Nummulites planulatus* LAMK., *N. irregularis* de LA HARPE, *N. nitida* DE LA HARPE, *Assilina granulosa* d'ARCH. These beds are often surmounted by a thin horizon of variegated shales.

The sedimentological investigations of the present author indicated that the clastic material of the Szczawnica Beds came from the south, and, therefore, probably from the same Exotic Massif which supplied the clastics for the Sromowce Beds, for the Úpohlav Beds and for the Jarmuta Beds. Rare exotic fragments found within the Szczawnica Beds consist of the Middle Triassic dolomites, oolitic limestones (Malm ?), rhyolite

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[1]) Lecture delivered to the Geological Society of Poland, Cracow, 1957.

porphyries, spilites and crystalline schists (K. BIRKENMAJER 1958 d, T. WIESER 1958). Besides in the southern facies of the Szczawnica Beds (i. e. in the Złatne Beds) which rests immediately upon the Branisko Series, fragments of radiolarites and of biancone limestones of the Klippen Series occur.

A somewhat different development of the Lower Eocene called the Frydman Beds [1]) is visible between Czorsztyn and Frydman, west of the Pieniny Mts. The Frydman Beds consist of feebly calcareous sandstones alternating with shales (K. BIRKENMAJER 1954 b, 1958 d) which yielded a fauna determined by F. BIEDA (see K. BIRKENMAJER 1954 b): *Nummulites pernotus paraburdigalensis* SCHAUB, *Operculina couizaensis* DONC., *Discocyclina* sp. ind. etc. In this region thin variegated shales overlying the Frydman Beds and underlying thin Beloveza Beds (Middle Eocene ?) which are surmounted by the Łącko Marls (Middle Eocene ?) occur.

Transitions of the Szczawnica Beds to the Sub-Magura Beds (Middle Eocene) are visible in most profiles, especially to the north of the Klippen Belt. The Łącko Marls (Lower and Middle Eocene) are present as intercalations in this transitional zone.

The Sub-Magura Beds [2]) (Middle Eocene) with *Nummulites laevigatus* BRUG. determined by F. BIEDA (1946) which overlie the Szczawnica Beds consist of greenish sandstones alternating with shales. They are developed best to the west of Szczawnica and disappear to the east of Szczawnica, where the Szczawnica Beds transist immediately to the Magura Sandstone [3]). The Magura Sandstone consists of a very thick (probably over 1000 m.) complex of non-calcareous thick-bedded sandstones, devoid of shale intercalations or intercalated with thin shales only in its lowermost part. No fossils have been found in the Magura Sandstone. Its age can be tentatively determined as the Upper Eocene-Oligocene.

The sedimentological investigations of the present author indicated that the direction of the supply of clastics to the Sub-Magura Beds and to the Magura Sandstone in the vicinity of the Klippen Belt was from the N. or NE., i. e. it was opposite to that found in the Szczawnica Beds.

The contact of the Inner Carpathian Palaeogene with the Klippen Belt is, over a great distance exclusively tectonic. In no place within the Polish sector of the Klippen Belt [4]) the flysch members of the Podhale Palaeogene rest stratigraphically on the Klippen Series or on the Pre-Laramide Mantle. The stratigraphic contact of the Inner Carpathian Palaeogene with the Klippen Belt is visible in Haligovce, in the southern part of the Pieniny Mts., Czechoslovakia. The lowermost member of this Palaeogene — the Sulov Conglomerates — rests here immediately upon the Haligovce Nappe.

The Sulov Conglomerates in Haligovce consist of fragments of the Middle Triassic dolomites supplied from the south, from the Sub-Tatra Nappes eroded in the Middle Eocene, and of fragments of the Haligowce Series.

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[1]) These beds have been called also "Hieroglyphic Beds" (K. BIRKENMAJER, 1958 d).

[2]) Called also the "Hieroglyphic Beds" (K. BIRKENMAJER, 1954 b, 1958 d, K. BIRKENMAJER, T. WIESER, 1956).

[3]) In the zone of transition intercalations of the Łącko Marls occur.

[4]) The supposition of J. GOŁĄB (1954) that the Podhale Flysch is folded with the Klippen Series and the Klippen Mantle is based on not sufficiently exact observations, because a part of the so-called "Maruszyna Beds" (= a facies of the Zakopane Beds sensu Gołąb) distinguished by him west of Nowy Targ belongs not to the Podhale Flysch but to the Sromowce Beds (Upper Turonian-Lower Coniacian) of the Pieniny Series.

The fauna of the Sulov Conglomerates in Haligovce determined by F. BIEDA (F. BIEDA, L. HORWITZ 1931) consists of *Nummulites perforatus* DEN. DE MONTF. and *N. millecaput* BOUB. and is of the Middle Eocene age.

The conglomerates are surmounted with thin coral limestones and *Alveolina* limestones which yielded a fauna with *Nummulites ramondiformis* DE LA HARPE (= *N. incrassatus* DE LA HARPE) indicating their Upper Eocene age (F. BIEDA 1929).

Variegated shales with *Cyclammina amplectens* (GRZYB.), indicating their Middle Eocene age have been found at the contact of the Podhale Flysch with the Haligowce Series in the vicinity of Haligovce (K. BIRKENMAJER 1959 a). It is possible that these shales represent a member transitional to the Podhale Flysch.

The Podhale Flysch in Poland is developed to the south of the Klippen Belt. It is subdivided by J. GOŁĄB (1947, 1952, 1954) into three members. The lower member called the Zakopane Beds consists of a thick series of dark shales alternating with sandstones and intercalated with conglomerates and ferrugineous dolomites. The fauna determined by F. BIEDA (1946, 1949) consisting of *Nummulites variolarius* LAMK., *N. semicostatus* KAUFM. sp., *N. incrassatus* DE LA HARPE, *N. chavannesi* DE LA HARPE, *N. bouillei* DE LA HARPE, *N. striatus* BRUG., *N. discorbinus* SCHLOTH., *N. latispira* MENEGH., *N. millecaput* BOUB., *N. perforatus* DEN. DE MONTF., *N. puschi* d'ARCH., *N.* from the group *gallensis* HEIM, *N. fabianii* PREV., *Assilina exponens* SOW., *Discocyclina aspera* GUEMB., *D. nummulitica* GUEMB., *D. pratti* MICH., *Asterocyclina stella* GUEMB., *Grzybowskia multifida* BIEDA, indicates the Upper Eocene (Lower Bartonian) age [1]).

The middle member of the Podhale Flysch called the Chochołów Beds consists of thick-bedded sandstones intercalated subordinately with shales and with exotic-bearing clays. It is possible that this member, which yielded no determinable fauna, belongs to the uppermost Eocene.

Finally the upper member of the Podhale Flysch called the Ostrysz Beds (Oligocene ?) consists of shales alternated with subordinate sandstones.

The sedimentological investigations of the Podhale Flysch carried out by S. DŻUŁYŃSKI and A. RADOMSKI (1955, 1957) and A. RADOMSKI (1957, 1958) indicate the transportation of the clastics mainly from the west and subordinately from the south. Nevertheless the investigations of K. GRZYBEK and B. HALICKI (1958) suggest also the transportation from the east in the oldest member (Zakopane Beds) of the Podhale Flysch.

Fragments of exotic rocks found within the Podhale Flysch (J. GOŁĄB 1954, A. RADOMSKI 1958, K. GRZYBEK, B. HALICKI 1958) have not been petrographically described. Nevertheless lithological descriptions of the granites, amphibolites, gneisses, chlorite schists, phyllites, quartzites, dolomites, limestones etc. given by the authors mentioned allow to state that the exotic fragments in the Podhale Flysch are different from those characteristic for the Sromowce Beds, for the Úpohlav Beds, for the Jarmuta Beds and for the Szczawnica Beds. It is, therefore, possible, that the exotic fragments of the Podhale Flysch have been supplied by a massif different from the Exotic Massif which influenced the sedimentation of the

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1) The fauna mentioned was collected in Szaflary near the contact of the Podhale Flysch with the Klippen Belt.

Pre-Laramide Mantle, of the lowermost members of the Post-Laramide Mantle, and of the youngest member of the Klippen Series of the Klippen Belt.

IV d. Orogenic movements of the Savian phase

After the deposition of the Post-Laramide Mantle, at the beginning of the Neogene (? Oligocene-Aquitanian), a new orogenic movement, the Savian phase (D. ANDRUSOV 1938), occurred. The Klippen Belt was compressed between the northern and southern crystalline and sedimentary basements of the Palaeogene Flysch series. In this way the horst structure of the Belt was formed.

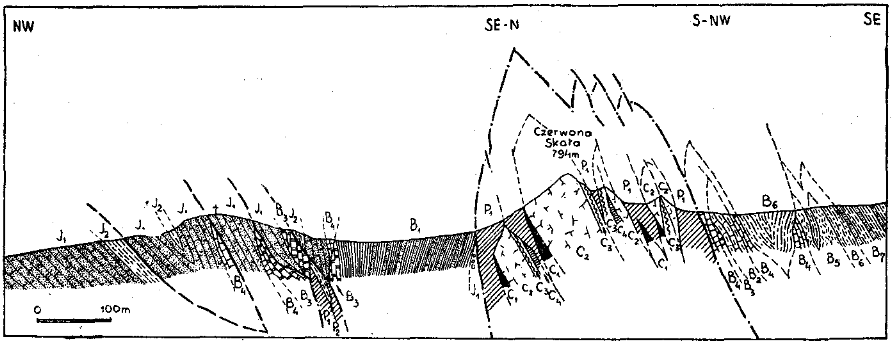

Fig. 4: Cross section through the diapiric chain in the vicinity of Dursztyn, west of the Branisko Mountain (after K. BIRKENMAJER, 1959 d, modified). The Czorsztyn Series: C_1 = marls and shales of the Middle and Upper Aalenian, C_2 = white and red crinoidal limestone (Bajocian-Bathonian), C_3 = nodular limestone (Callovian-Kimeridgian), C_4 = light Tithonian limestones. The Pre-Laramide Mantle of the Czorsztyn Series: P_1 = Púchov Marls (Campanian-Maestrichtian), P_2 = Variegated Beds (? Danian). The Branisko Series: B_1 = Flysch Aalenian (Lower Aalenian), B_2 = Supraposidonomya Beds (Bajocian-Bathonian, partly Callovian), B_3 = Green and Red Radiolarites (Oxfordian), B_4 = Cherty limestone (Tithonian-Barremian), B_5 = Beds with globigerinids and radiolarians (Barremian-Albian), B_6 = Green, variegated and red Globotruncana Marls (Cenomanian-Lower Turonian), B_7 = Sromowce Beds (Upper Turonian-Lower Coniacian ?). The Pre-Laramide Mantle of the Branisko Series: J_1 = Jarmuta Beds (Campanian-Maestrichtian), J_2 = Variegated Beds (Danian ?).
Thick lines denote main tectonic contacts. Diapire bordered with thick dashes and points.

The Czorsztyn Series (till then autochthonous) was torn off from its basement, cracked and faulted, its competent rocks being squeezed up into Upper Cretaceous marls, forming a mega-breccia diapiric chain zone (K. BIRKENMAJER 1958 d, 1959 d).

A great compressional fault developed between the Klippen Belt and the Podhale Flysch. This dislocation can be traced over a great distance: from the Western Slovakia to the Pieniny Mts. (D. ANDRUSOV 1938, K. BIRKENMAJER 1958 d).

As an effect of the Savian orogenic movements the Klippen Belt was elevated in the form of a horst above the adjacent synclinories of the Palaeogene Flysch series, i. e. above the Magura Nappe and above the Podhale Flysch. This horst reveals a very complicated structure, the result of the three orogenic phases which acted during the history of the Belt.

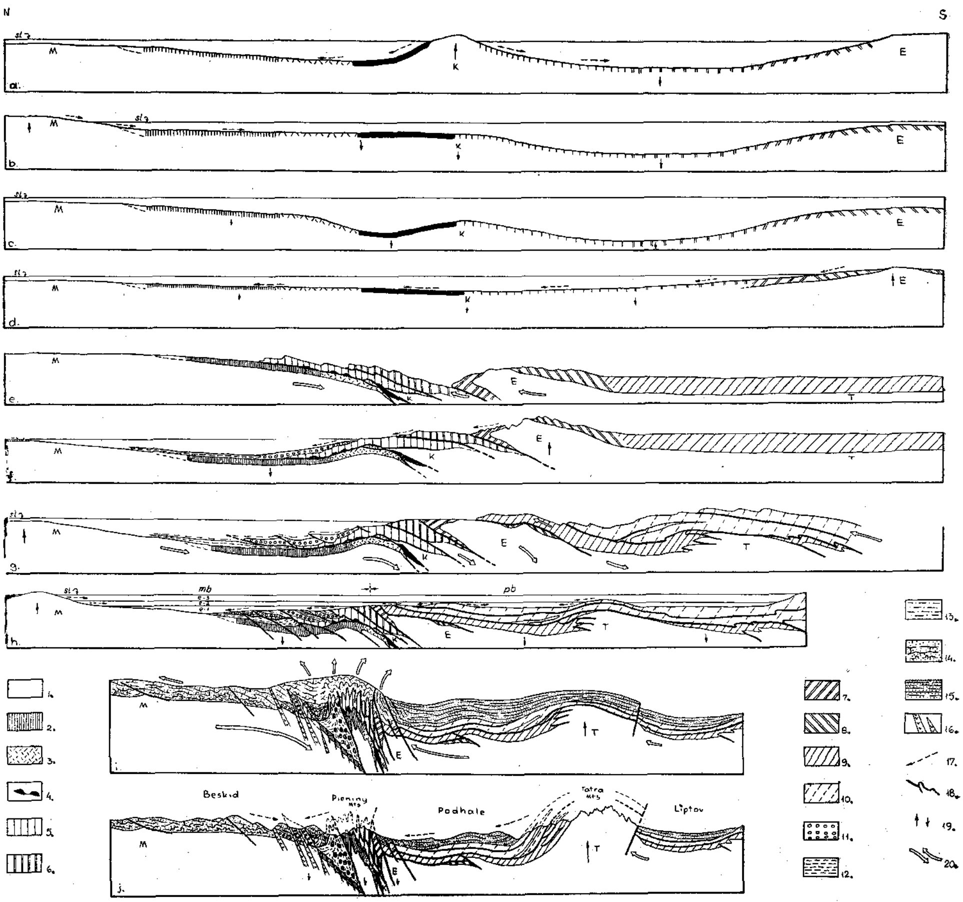

Fig. 5: Origin of the Pieniny Klippen Belt (after K. BIRKENMAJER, 1958 d, modified). Schematic presentation for the Pieniny Mts. sector. Vertical scale exaggerated. 1 = Pre-Jurassic basement rocks (in the region of the High-Tatra Series — Pre-Triassic basement rocks), 2 = Czorsztyn Series, 3 = Czertezik Series, 4 = Niedzica Series, 5 = Branisko Series, 6 = Pieniny Series, 7 = Haligowce Series, 8 = Exotic Series, 9 = High-Tatra Series *(sensu lato)*, 10 = Sub-Tatra tectonic units, 11 = Jarmuta Beds (Campanian-Maestrichtian) of the Pre-Laramide Mantle, 12 = Púchov Marls (Campanian-Maestrichtian) of the Pre-Laramide Mantle, 13 = Variegated Beds (? Danian) of the Pre-Laramide Mantle, 14 = Magura Palaeogene (Post-Laramide Mantle), 15 = Podhale Palaeogene (Post-Laramide Mantle), 16 = Andesitic intrusions, 17 = direction of supply of clastics to sedimentary basins, 18 = Main tectonic contacts (overthrusts, faults), 19 = direction of the vertical movements, 20 = direction of the orogenic movements. M = Cristalline and sedimentary (Pre-Cretaceous) basement complex of the Magura Series, K = Central Cordillera in the Klippen Series basin, E = Exotic Massif (Cristalline basement and Triassic covering), T = Cristalline basement complex of the High-Tatra Series *(sensu lato)*, mb = sedimentary basin of the Magura Palaeogene (e-1 = Upper Paleocene and Lower Eocene, e-2 = Middle Eocene, e-3 = Upper Eocene and Oligocene), pb = sedimentary basin of the Podhale Palaeogene, sl = sea level, a = Lower Aalenian stage, b = Bajocian stage, c = Oxfordian stage, d = Upper Turonian stage, e = Sub-Hercynian phase (Upper Coniacian-Lower Santonian) stage, f = Campanian-Maestrichtian stage, g = Early stage of the Laramide phase (Lower Paleocene), h = Upper Paleocene-Oligocene stage, i = Savian phase (Oligocene-Aquitanian) stage, j = Upper Miocene-Pliocene stage.

V. Volcanic activity in the Lower Miocene

The volcanic rocks exposed in the Pieniny Klippen Belt of Poland occur near the northern border of the Belt, between Czorsztyn and Biała Woda. They form small dikes or sills (in some cases resembling harpoliths) intruded in the Jurassic, Cretaceous and Palaeogene rocks. Most of them are andesites, two types of which have been distinguished by S. Małkowski (1922, 1924, 1928, 1958), i. e. the amphibole andesites and amphibole-augite andesites. The only non-andesitic intrusion in the Klippen Belt of Poland (in Biała Woda) consists of olivine basalt (M. Kamieński 1931) [1]).

It was S. Małkowski *(o. c.)* who discovered that the amphibole andesites are older than the amphibole-augite andesites. According to the present author (1958 c) the amphibole andesites could be regarded as contemporaneous with the tension existing at the close of the Savian phase (i. e. the lowermost Miocene or uppermost Oligocene). The age of the amphibole-augite andesites and of the basalt cannot be exactly determined. It can be assumed that they also belong to the Lower Miocene.

The source of the andesite and basalt magmas was, probably the northern exotic massif now underlying the Magura Flysch.

VI. Post-Savian denudation, sedimentation and tectonic movements

The Savian Klippen Belt orogene emerged from the sea and was subjected to erosion in the Lower Miocene. The erosion advanced so far that the transgression of the Burdigalian and Helvetian sea in the Klippen Belt of the Váh river valley in Western Slovakia (D. Andrusov 1938) covered the Jurassic and Cretaceous cores of the Belt exposed from under the denuded Palaeogene (Post-Laramide) Mantle.

The deposits of the Burdigalian and Helvetian in the western part of the Klippen Belt of Slovakia have been subjected to feeble tectonic movements, equivalent to the "altsteirische Phase" of H. Stille (1924, 1952), as it was found by D. Andrusov *(o. c.)*. The existence of these movements has not been ascertained in the Klippen Belt of Poland. It is possible, however, that slide-mirrors covering some joint planes within some Pieniny andesites have been formed in the "steirische Phase" (K. Birkenmajer 1958 c, d).

The marine Miocene deposits do not occur within the Polish sector of the Klippen Belt [2]). There are, however, lacustrine and fluviatile deposits of the Miocene developed in the western part of Podhale, and, especially in the Orawa basin. The Miocene deposits rest there in a distinct angular discordance on the Podhale Flysch, on the Jurassic and Cretaceous

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[1]) New data on the petrology and mineralogy of the Pieniny andesites and associated rocks are contributed by J. Wojciechowski (1950, 1955), I. Kardymowicz (1952), S. Małkowski (1958), A. Michalik (see K. Birkenmajer, 1958 d, Pt. III, pp. 14—20), E. Gajda (1958 a, b), and Z. Skrzatówna (1959). Geological investigations of the andesites have been carried out by the present author (1956 a, 1957 e, 1958 c), magnetic investigations—by S. Małoszewski (1956, 1957, 1958) and, finally, the technical properties of the andesites have been studied by S. Kozłowski (1958).

[2]) The marine deposits in Szaflary near Nowy Targ attributed by W. Friedberg (1906) to the Miocene, have been investigated by the present author (1952) who found that they belong not to the Miocene, but to the Aalenian.

members of the Klippen Belt and on the Palaeogene of the Magura Nappe, indicating thus an advanced erosion in the Lower Miocene.

The Miocene deposits consist of gravel and conglomerates alternating with sand, clay, clay-shale and lignite seams. The coarse material prevails in the SE. part of the Podhale-Orawa Neogene basin, while in the NW. and W. parts of this basin lignite clays are the characteristic sediment (K. BIRKENMAJER 1954 c, 1958 d).

The thickness of the Miocene in question reaches over 200 m. The Miocene represents an intra-mountaineous fresh-water molasse deposited in an erosional trough. The sedimentation of this molasse was controlled by the negative movements of the basin bottom and by the positive movements of the basin borders [1]).

The fauna of the Orawa Miocene consists of fresh-water snails and pelecypods (K. BIRKENMAJER 1954 c). The flora of these deposits determined by M. RACIBORSKI (1892) and W. SZAFER (1950) consists of *Sequoia*, *Taxodium*, *Magnolia*, *Ilex*, *Carpinus*, *Tetrastigma*, *Vitis teutonica*, *Diclidocarya menzeli*, *Decodon globosus*. It indicates with a high probability the Tortonian age (Middle and Upper Tortonian ?) of the Orawa Neogene. Nevertheless, the youngest members of these deposits with a flora not yet described could belong to the Sarmatian [2]).

In the Lower Pliocene (Meotian and Pontian) the general land uplift and bottom and lateral erosion of the rivers valleys occurred. Thus the Pliocene fresh-water sediments found in the vicinities of Czorsztyn and Krościenko to the north of the Pieniny Mts. (M. KLIMASZEWSKI 1946, K. BIRKENMAJER 1951, 1954 c) belong to another, and younger, cycle of the intra-Carpathian non-marine Neogene. They rest immediately upon the Palaeogene members of the Magura Nappe.

The flora of these sediments described by W. SZAFER (1946, 1947, 1950, 1954) is extremely rich and consists among others of: *Podostemonites corollatus* SZAFER, *Ranunculus reidi* SZAFER, *Staphylea pliocaenica* KINK., *Proserpinaca reticulata* REID, *Picea omoricoides* WEB., *Corylopsis urselensis* MÄDLER, *Carex flagellata* REID, *Magnolia cor* LUDWIG, *Fagus decurrens* REID, *Sinomoenium dielsi* SZAFER, *Vitis ludwigi* A. BRAUN, *Liquidambar europaea* A. BRAUN, *Tsuga europaea* (MENZEL), *Scirpus pliocaenicus* SZAFER etc.

The fresh-water deposits of the Pliocene represent, with a high probability, its middle (Piacentian) and upper (Astian) divisions.

According to W. SZAFER (1954) the Pliocene deposits transist to the Pleistocene fresh-water, non-glacial sediments with flora (equivalents to the Günz glacial and to the Tegelen interstadial).

During the Pleistocene the Klippen Belt in Poland has not been covered by glaciers. Three glaciations of the Tatra Mts. (B. HALICKI 1930, M.

[1]) The evidence of the positive movements of the basin border areas is especially well seen in the southern part of the basin, where the fresh-water deposits are dipping NE., N., NW. at angles up to 25—30 degrees. These positive movements were probably connected with the raising of the Tatra Mts. and of the adjoining Podhale Flysch.

[2]) W. SZAFER (1950) supposed that the youngest members of the Neogene sequence in the vicinity of Czarny Dunajec (DOMAŃSKI WIERCH) belonged to the Pliocene, and that there was a transition between the Miocene and Pliocene deposits in this area. These views, however, are not supported by an index flora (K. BIRKENMAJER, 1958 d).

KLIMASZEWSKI 1948) corresponding to the Mindel, Riss and Würm glaciations, and two interstadial periods corresponding to the Mindel/Riss and to the Riss/Würm (Eemian) are traceable in the Pleistocene deposits of the Klippen Belt. Intense erosion in the interglacial periods and accumulation of thick fluvio-glacial gravels washed out from the moraines of the Tatra glaciers, and also solifluction (congelifluction) and accumulation of intra-mountaineous loesses in cold periods have influenced the landscape forming of the Klippen Belt.

The Holocene period in the Klippen Belt of Poland began with the sweeping off a great part of the fluvio-glacial gravels of the last glacial period, and with the erosion of their basement. A new gravel terrace has been formed in the river valleys during the climatic optimum in the Middle Holocene. This terrace is now being eroded by rivers, and the erosion is now the main factor of the landscape forming (K. BIRKENMAJER 1958 d).

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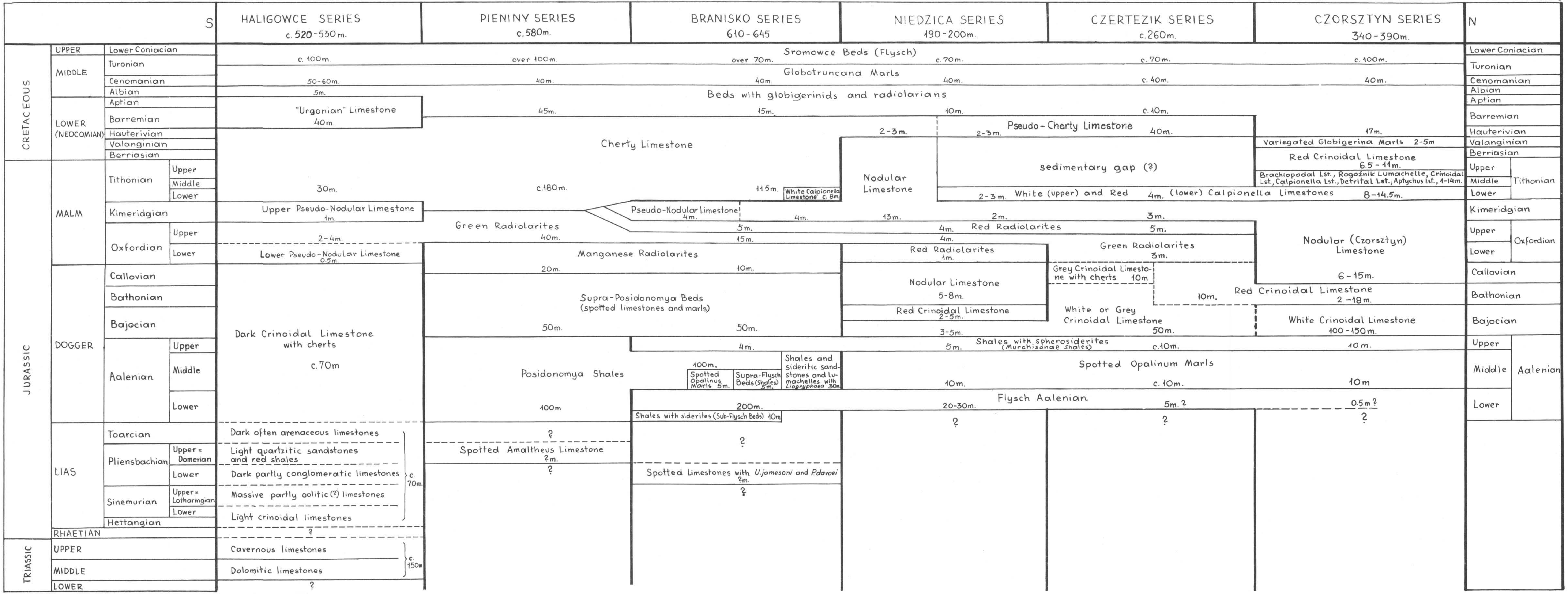
S
HALIGOWCE SERIES c. 520-530 m.
PIENINY SERIES c. 580m.
BRANISKO SERIES 610-645
NIEDZICA SERIES 190-200m.
CZERTEZIK SERIES c. 260m.
CZORSZTYN SERIES 340-390m.
N
CRETACEOUS
UPPER
Lower Coniacian
MIDDLE
Turonian
Cenomanian
Albian
LOWER (NEOCOMIAN)
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
JURASSIC
MALM
Tithonian
Upper
Middle
Lower
Kimeridgian
Oxfordian
DOGGER
Callovian
Bathonian
Bajocian
Aalenian
LIAS
Toarcian
Pliensbachian
Upper = Domerian
Sinemurian
Upper = Lotharingian
Hettangian
RHAETIAN
TRIASSIC
UPPER
MIDDLE
LOWER
Sromowce Beds (Flysch)
c. 100m.
over 100m.
over 70m.
c. 70m.
c. 70m.
c. 100m.
Globotruncana Marls
50-60m.
40m.
40m.
40m.
c. 40m.
40m.
Beds with globigerinids and radiolarians
5m.
"Urgonian" Limestone 40m.
45m.
15m.
10m.
c. 10m.
Cherty Limestone
2-3m.
2-3m.
Pseudo-Cherty Limestone
40m.
17m.
Variegated Globigerina Marls 2-5m
Red Crinoidal Limestone 6.5-11m.
Brachiopodal Lst., Rogoźnik Lumachelle, Crinoidal Lst., Calpionella Lst., Detrital Lst., Aptychus Lst., 1-14m.
sedimentary gap (?)
Nodular Limestone
30m.
c. 180m.
11.5m.
White Calpionella Limestone c. 8m.
2-3m.
White (upper) and Red
4m.
(lower) Calpionella Limestones
8-14.5m.
Upper Pseudo-Nodular Limestone 1m.
Pseudo-Nodular Limestone 4m.
4m.
13m.
2m.
3m.
Green Radiolarites 40m.
5m.
4m.
Red Radiolarites
5m.
2-4m.
15m.
4m.
Lower Pseudo-Nodular Limestone 0.5m.
Manganese Radiolarites
Red Radiolarites 1m.
Green Radiolarites 3m.
Nodular (Czorsztyn) Limestone 6-15m.
20m.
10m.
Grey Crinoidal Limestone with cherts 10m
Nodular Limestone 5-8m.
Supra-Posidonomya Beds (spotted limestones and marls)
10m.
Red Crinoidal Limestone 2-18m.
Red Crinoidal Limestone 2-5m.
White or Grey Crinoidal Limestone 50m.
White Crinoidal Limestone 100-150m.
Dark Crinoidal Limestone with cherts c. 70m
50m.
50m.
3-5m.
Shales with spherosiderites (Murchisonae shales)
4m.
5m.
c. 10m.
10m.
100m.
Spotted Opalinus Marls 5m.
Supra-Flysch Beds (shales) 5m.
Shales and sideritic sandstones and lumachelles with Liogryphaea 30m.
Spotted Opalinum Marls
Posidonomya Shales
10m.
c. 10m.
10m
Flysch Aalenian
100m
200m.
20-30m.
5m.?
0.5m?
Shales with siderites (Sub-Flysch Beds) 10m.
?
Dark often arenaceous limestones
Light quartzitic sandstones and red shales
Dark partly conglomeratic limestones
Massive partly oolitic (?) limestones
Light crinoidal limestones
c. 70m.
Spotted Amaltheus Limestone ?m.
Spotted Limestones with U. jamesoni and P. davoei ?m.
Cavernous limestones
Dolomitic limestones
c. 150m