AUSTRIAN EASTERN ALPS

INTRODUCTION

P. BECK-MANNAGETTA

The Eastern Alps form a natural connecting link between the Carpathians in the north-east, the Dinarides in the southeast and the other mountain ranges of the Alpine orogen in the west of Europe. This extensive structure, differentiated both spatially and chronologically cannot be divided satisfactorily in terms of structural layers (Stockwerke). A reconstruction as true as possible can be arrived at with the use of a division into individual structural elements (P. Beck-Mannagetta 1965).

Penninicum. The starting point of the dynamic modelling of the Eastern Alps was centred in the Central Alps to the Penninic zones, mainly to the Hohe Tauern region.

A Triassic sequence of small thickness, developed in a foreland facies, was deposited on the pre-Alpine crystalline basement with Variscan granites. In the Jurassic an intensive eugeosynclinal sedimentation took place, being accompanied by the formation of basic and ultrabasic magmatites (ophiolites), which presumably persisted until the Early to Middle Cretaceous. In the result of extremely strong tectonic stresses, the Penninic trough and its filling were transformed into nappes with cores of Central gneisses. These nappes show a northern vergency. The tectonic development of the Penninicum was accompanied by the metamorphism mostly in the greenschist facies („Tauernkristallisation"), which overlasted the main tectonic activity. It is thought that the rise in temperature resulting from the presence of the superimposed Ostalpin nappes caused this metamorphism, but a supply of juvenile heat within the area of strong metamorphism must also have played an important role.

The classification of metamorphic effects has been made with the use of mineral zones (as in Switzerland), and the individual characteristic rocks make local zoning possible (Ch. Exner 1954).

The conditions at the boundary between the Eastern and Western Alps suggest that the uppermost sedimentary parts of the Penninicum had been tectonically separated from their basement before they were affected by metamorphism and are today situated as the Flysch nappe ("Flyschzone") in the north of the Limestone Alps. The assignment of the Rechnitz "Schieferinsel" in the east to the Penninicum as a tectonic window is not yet fully substantiated.

The Ostalpin. At present, the Ostalpin occurs above the Penninic unit. It is divisible into several subunits, which are either correlated as a Central Alpine unit with the Upper Ostalpin, or are separated as the Lower Ostalpin and Middle Ostalpin from the Upper Ostalpin.

While the Lower Ostalpin nappe unit is separable tectonically from both the Penninicum and the Upper Ostalpin, no clear boundaries exist between the Middle and the Upper Ostalpin, because of the tectonically discontinuous distribution of the Mesozoic that separates the nappes in the central zone of the Eastern Alps.

The extensive participation of the central crystalline cores in the nappe structure is of decisive importance for the mechanism of movements. In addition to the granite masses and old crystalline complexes (Altkristallin) building up the cores of nappes, quartz-phyllites representing the Lower Paleozoic, and diaphthorized Altkristallin played an important role in the nappe structure. The Altkristallin itself consists of the rocks of the amphibolite facies, pre-Alpine in age. The intensity of diaphthoresis was rising towards the Penninic Zone, or the crystallization (Tauernkristallisation) of the Penninicum transgressed its boundary producing neomineralization even in the Altkristallin of the Lower Ostalpin (Ch. Exner 1954). The Altkristallin mineral assemblage has been therefore best preserved (Grobgneisserie) in the east and north-east of the Eastern Alps.

The assignment of the nappes to the Lower Ostalpin, however, has not been inferred from their crystalline cores but from the character of the Mesozoic members. The Middle and Upper Triassic dolomites and limestones of the Lower Ostalpin are of greater thickness than are those of the Penninicum; beginning with the Jurassic the breccia beds appear recurrently. The rapid facies alternations of Jurassic beds of a small thickness indicate a substantial unrest in the sedimentary area. In the east of the Lower Ostalpin no Jurassic deposits have so far been evidenced. In the west and south, serpentinites (ophiolites) occur together with radiolarites in the Upper Jurassic (?), but the "Bündner Schiefer" facies is not developed in any substantial thickness. Distinctive of the Lower Triassic Central Alpine facies is the Lantschfeld-Semmering Quartzite and occasional replacement of the Triassic dolomites by pyrite shales that persists up to the Lower Jurassic (Radstädter Tauern).

The Permo-Mesozoic of the Central Alpine zones shows only sparse local deviations. K. Metz (1962, 1969) places the Rannach Conglomerate at the base of the Triassic, but without any stratigraphic evidence; however, the tectonic consequences of this arrangement are of importance.

Remarkably, the Early Paleozoic complexes between the Altkristallin and Triassic are lacking, except for the quartz-phyllite which, however, also occurs in the higher structural layers (E. g. Ennstal Phyllite). Recently, an Early Paleozoic metadiabase complex has been established in the upper Wechsel sequence between the Semmering Triassic and the Wechsel Crystalline (P. Faupl 1970).

The Mesozoic of the Central Alps continues east of the Hohe Tauern Mts., and east of Innerkrems it turns in sharp jumps northeastwards, and after a break disappears beneath the Greywacke Zone (profile I).

A. Tollmann (1959) grouped it together with the basal crystalline and granite-gneiss with the Middle Ostalpin. Despite all tectonic deformations (many of them of Late Tertiary age) the merging of the Lower Paleozoic with the phyllite roof of the Altkristallin of Saualpe is observable in the south. A transgressive contact of the Upper Carboniferous and Permian substratum of the Triassic with the Greywacke Zone has been established with certainty. This Triassic sequence is of North-Alpine facies and thus shows relations to the Northern Limestone Alps. Consequently, it may be presumed that the crystalline basement of the Upper-Ostalpin nappe can be seen in the Koralm Crystalline of the Central Alps (P. Beck-Mannagetta 1969). Accordingly, the "Middle Ostalpin" partial nappes cannot be expected in the southern part of the Eastern Alps, where the overthrust structure of the Hohe Tauern dies out to the east.

In the Greywacke Zone, the so-called Veitsch nappe (H. P. Cornelius 1952) occupies a transitional position; there is no equivalent of this nappe in the southern Greywacke Zone (profile III). Its composition of Lower and Upper Carboniferous (without paleontologically evidenced Lower Paleozoic), which can also be taken for the basement of the Triassic (Rannach sequence), and of the crystalline (e. g. Seckauer Tauern Mts.), resembles more a Central Alpine nappe (Middle Ostalpin in the sense of A. Tollmann). In the north, the nappe is sharply delimited by the "Norian line" which can be conceived as a Variscan overthrust plane revived by alpine tectonics. The Norian nappe (H. P. Cornelius 1952) together with the Limestone Alps were thrust northwards along it. The southern boundary of the Veitsch nappe cannot be stated precisely, because this unit is connected with the Seckau and Gleinalm Crystallines, whose tectonic boundary with the overlying Koralm Crystalline is not marked by any inserted thrust slices of Mesozoic sediments.

Upper Ostalpin. The bulk of the Eastern Alps consists of the Upper Ostalpin nappe. The Koralm Crystalline is regarded essentially as its crystalline basement, mainly in the east of the Hohe Tauern (P. Beck-Mannagetta 1969). The Lower Paleozoic of the Eastern Alps with its Mesozoic cover (Limestone Alps, Drauzug, etc.) is to be generally considered as the Upper Ostalpin. Proceeding to the east, the crystalline complex of the Central Alps develops an autochthonous character and can be connected with the crystalline basement of the Little Hungarian Plain. South of Stubalpe the gradual transitions of the mantle of the Gleinalm Crystalline (garnetiferous mica-schists) to the Koralm Crystalline (gneissic mica-schists) can be followed (profile III). No tectonic boundary is therefore observable between these two crystalline units.

The Crystalline of the Central Alps. The Altkristallin east of the Hohe Tauern Mts. is divisible into a number of units on the basis of differences that are of pre-Alpine derivation. The individual units, however, are not everywhere sharply limited (K. Metz 1965, P. Beck-Mannagetta 1968—1970). In addition to the division into the Koralm and Gleinalm Crystallines (F. Heritsch 1932, W. Fritsch 1962), the Gleinalm Crystalline (amphibolite facies) was subdivided into the Schladming Crystalline, the Bundschuh massif, Gailtal Crystalline, Seen Crystalline, Wölz Mica-schists, Gleinalm Crystalline and Seckau Crystalline. The crystalline complex of the coarse-gneiss sequence (Grobgneisserie) adjacent in the north-east is tectonically assigned to the Lower Ostalpin (profiles II, III).

Some of these crystalline subunits display particular properties, such as: The Seen Crystalline (and the Gailtal Crystalline), was partly affected by the Variscan Villach Granite (gneiss). According to K. Metz et al. (1964), the Seckau and Bösenstein Granite-gneisses represent the Gleinalm Granite-gneiss mobilized in Alpine time. The Wölz Mica-schist builds up the envelope of the Schladming Granite-gneiss and because of abundant pegmatites (E. Jäger — K. Metz 1971) it is thought to be connected with the Koralm crystalline in the south.

The Koralm and the Saualm crystalline complexes should not be separated, the term "Koralmkristallin" having the priority in time (F. Angel 1925, "Koriden" L. Kober 1938).

In addition to tectonic and petrological differences, the Koralm crystalline can be distinguished from that of Gleinalm mainly on the basis of the presence of eclogite-amphibolites and disthene pseudomorphs after andalusite. The rich penetration of mica-schists (P. Beck-Mannagetta 1967, 1970) by pegmatoid dykes and rootless bodies is another distinctive feature of the Koralm Crystalline. The distinguishing of the units according to their tectonic position can rarely be admitted; in the Bundschuh Crystalline the granites occur too high above the fine-grained gneisses and mica-schists.

Of special interest are the isolated occurrences of the Gleinalm Crystalline, some of which are thought to be connected with the boundaries of nappes (A. Tollmann 1959, A. Pilger — N. Weissenbach 1965), whereas others are looked upon as local squeeze-ups of special type (P. Beck-Mannagetta 1968, 1970), such as the "tectonic windows" of Oberhof and Wimitz in the Gurktal Alps or Kliening, Wolfsberg, Auerling and Trahütten in the Koralm crystalline. The Gleinalm Crystalline invariably occurs below the Koralm Crystalline. In the Wolfsberg window the contact between the granite-gneiss and its envelope is shown by the biotitization of amphibolites (Schloßbach). Migmatites are known from the Gleinalm-Schladming Tauern and other localities (F. Angel 1925).

Isolated blocks of the Koralm crystalline occur near Schäffern (eastern Styria), and in Burgenland a nappe block is known at Sieggraben.

Among the tectonic features of the crystalline massifs, the so-called "Schlingentektonik" is remarkable (O. Schmiedegg 1936); it is developed in the area of Villgraten, south of the Hohe Tauern Mts. In the east, the "Plattengneis" of the Koralm Crystalline showing roughly a N-S lineation is of particular importance, as the N-S lineation is also developed in the Graz Paleozoic and in the isolate relics of the Sieggraben nappe block.

The Koralm crystalline series is characterized by eclogite — amphibolites, paramorphs of disthene after andalusite, and frequent "roofless" venoid veins in mica-gneisses (P. Beck-Mannagetta 1949, 1967).

Recent investigations of the southern Saualpe have brought evidence that the Lower Paleozoic (Silurian-Devonian) sequences plunge into the epizonal cover of the Saualm (= Koralm) Crystalline. Besides, this finding suggests a Variscan nappe structure in the southern Greywacke Zone (J. Neugebauer 1970, A. Pilger — N. Weissenbach 1970). As the Metadiabase (= Magdalensberg) sequence is thought to be older than the Wandelitzen sequence (Silurian-Devonian), a regional overthrust of the calcareous — phyllite series apparently was effected so that the underlying sequences occur as repeating slices beneath the Metadiabase sequence. A fault zone also separates the deeper crystalline, and it may be inferred that the long-known succession — eclogite complex overlying the marble complex in the Koralpe and Saualpe Crystalline — represents but a Variscan nappe structure that was later involved in the posttectonic metamorphism of the Koralm Crystalline.

The radiometric data of the Ostalpin crystalline complex are thus far too contradictory to provide a uniform picture that would agree with the established geological facts. Consequently, there exist diverse interpretations of the age data. Some authors presume Alpine crystallization of the Altkristallin (A. Pilger — N. Weissenbach 1970), whereas others, in contrast, postulate an autochthonous character of the western termination of the Pannonian Massif (P. Beck-Mannagetta 1967).

Paleozoic. The Paleozoic of Graz, as well as the Northern and Southern Greywacke Zones belong decidedly to the Upper Ostalpin.

In the Paleozoic of Graz, a nappe structure allegedly of Variscan age has been established; it is thought to consist of three partial nappes thrust over one another. They are as follows: the Schöckel nappe, parts of which at the margin of the Graz Paleozoic might be of Triassic age (H. Flügel 1961), the Rannach nappe and the Hochlantsch nappe. The carbonate deposits of a great thickness are dominantly of Middle Devonian age, but the whole sequence ranges from the (Ordovician?) Lower Silurian to the Lower Carboniferous (in the Rannach nappe); at a few places it is overlain unconformably by the Upper Carboniferous. The nappes must have been overthrust to the west and north-west.

In the eastern Central Alps the Norian nappe of the Northern Greywacke Zone is limited by the Norian line against the Veitsch nappe; this boundary fades towards the west, and at various places (northern sector of the Enns valley, north-west of Bischofshofen) the Upper Carboniferous overlies the Lower Paleozoic complex. A particularly distinctive member is the porphyroid of the eastern Greywacke Zone, which was dated as Early Silurian by W. Flajs (1967).

Northern Limestone Alps (A. Tollmann 1967, 1969, 1970). The Northern Limestone Alps are the most spectacular and significant tectonic member of the Eastern Alps. Their Triassic deposits, up to 3,000—4,000 m thick, built up broad, light coloured flat-topped mountain ranges in the north and south of the Central Zone (profiles II, III, IV).

The unit of the Northern Limestone Alps together with its basal part, i. e. the Northern Greywacke Zone, were torn off from the crystalline basement in the south and thrust at least several tens of kilometres northwards over the foreland units. Whereas the older Triassic rock complexes are of greater thickness in the south, the Jurassic and Cretaceous increase in thickness towards the north. The tectonic history of the Northern Limestone Alps was polyphasal; it is distinguished in the south by the overthrust of the Juvavian group of nappes over the Tyrolian or Reichraming-Lunz one. The Gosau sequence (Coniacian-Lower Eocene) overlaps both these groups of nappes unconformably, being incorporated in the nappe structure farther in the north. The latter event occurred after the Early Eocene. The northernmost continuous nappe of the Limestone Alps (Frankenfels nappe) does not involve any Gosau sequence; geosynclinal sedimentation persisted uninterrupted until the Cenomanian. This polygenous nappe pile of the Northern Limestone Alps began to being moved over the Penninic Flysch trough and the Helveticum ahead (Gresten Klippen Zone and the Buntmergel Zone) in the Late Eocene. During the molasse sedimentation there appear indications of progressive overthrusting of the Helveticum, Flysch and Subalpine molasse on the autochthonous molasse. This recurrent travelling from south to north was so strongly revived during the Late Tertiary that the Limestone Alps themselves also travelled northwards over the foreland molasse. Simultaneously, a gradual shift in intensity of the overthrust movements from west to the east took place, covering the time interval from the Aquitanian (surroundings of Salzburg) until the Burdigalian (Eggenburgian in the east).

The Flysch Zone. The intricate mutual interference of overthrust tectonics overlapping in time and space developed from the most diverse structural units a fold-nappe belt, dragged steadily farther and farther to the north. This structure is called the Flysch Zone and extends along the northern margin of the Northern Limestone Alps over hundreds of kilometres and can be followed along the whole arc of the Carpathians. The composition of the Flysch Zone changes from west to east. Whereas west of Salzburg the Helveticum plays a more important role than the Flysch (profile II—V), the two large units combine into one uniform belt east of Salzburg; farther to the east, east of Gresten, the elements of the Subalpine molasse are also incorporated in it. In the Waschberg Zone, north of the Danube, the anterior Subalpine molasse increases in breadth and particularly in the stratigraphic range (Ottnangian-Upper Jurassic), and in the West Carpathians it becomes a tectonic and morphological component of the Flysch Zone. At the bend of the Eastern Alps, on the western margin of the Vienna Basin, are also exposed the Flysch and Klippen Zones of the Carpathians that disappear at a sharp angle beneath the Limestone Alps.

The flysch tectonic windows at Wolfgangsee (B. Plöchinger 1964) and in Windischgarsten (B. Plöchinger — S. Prey 1970) emerging on the north-western faults, similarly as the Brettl (A. Ruttner 1960) and Mayerling (B. Plöchinger 1970) windows, show the appreciable overthrust amplitude of the Northern Limestone Alps over the Flysch, Klippen and Molasse Zones.

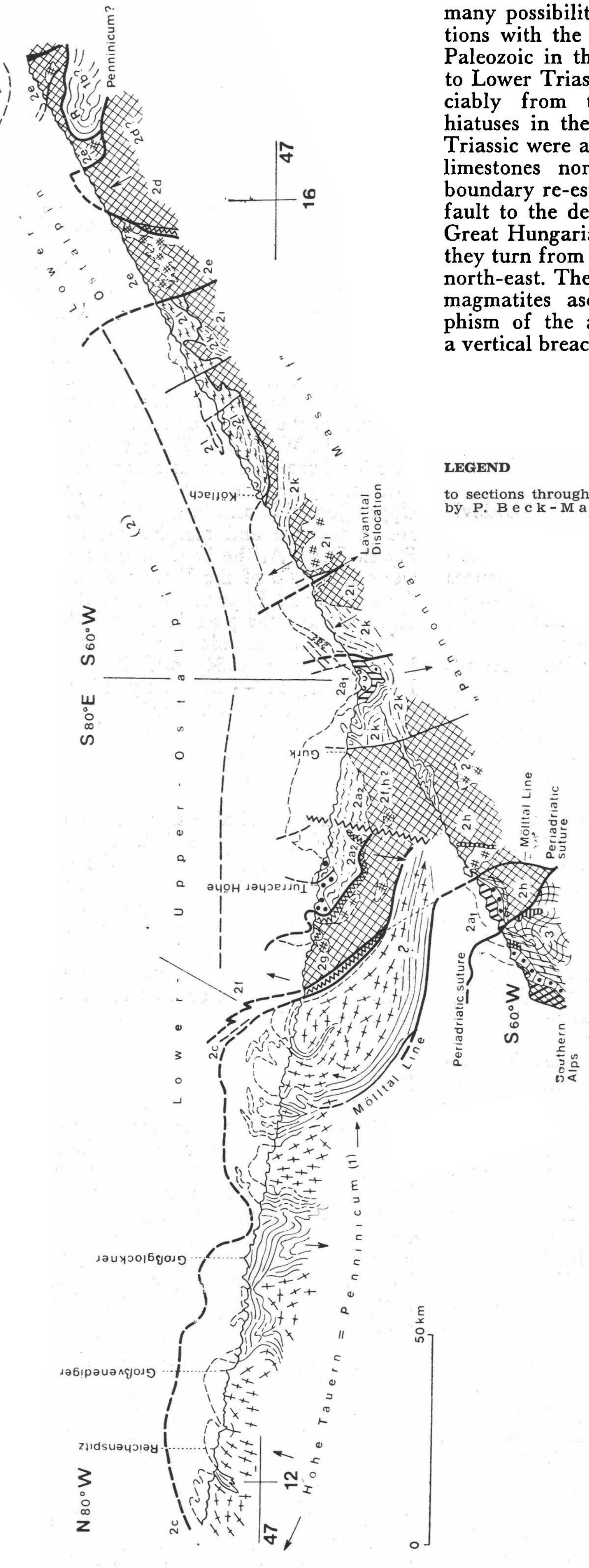
Gravitational gliding alone can hardly be applied to disentangling the confused structure of the Flysch Zone (S. Prey 1972), because of the large amplitude of the movement. Yet, the window outcrops of the Flysch Zone, which occur evidently at the boundaries of the Limestone-Alps nappes can hardly be explained satisfactorily by other processes. Downfaulting and sliding along the surfaces of sedimentary inhomogeneity are a frequent phenomenon also in the area of the Limestone Alps itself.

Summary

The conditions at the eastern end of the Eastern Alps show how, since early (Variscan ?) times, the new structures had to adapt themselves to the older fabric, by overcoming the older prominent fabric elements. The shape of the old infrastructure is repeatedly expressed in the more recent suprastructure; it is thus not a mere chance that the apex of the triangle formed by the intersecting major faults of the Bohemian Massif points southwards to the Weyr arc and farther southwards to the Lavanttal Fault. Analogously, the general lineation of the "Plattengneis" (platy gneiss) projected to the north coincides with the lineation of the Bíteš Gneiss of the Moravicum. On the other hand, the torsion of the "Plattengneis" linear elements is an image of the large-scale turning-aside of the eastern part of the Alps with respect to the Carpathians and Dinarides.

At the Alpine-Dinaric boundary line, outstanding facies differences are demonstrable chiefly in the Upper Paleozoic. Whereas the Lower Paleozoic of the Seeberg elevation (R. Schönenberg 1970) offers

many possibilities of stratigraphic and facies correlations with the Carnic Alps in the west and the Graz Paleozoic in the north-east, the Upper Carboniferous to Lower Triassic sequences in the south differ appreciably from the terrigenous deposits with many hiatuses in the north. Only as late as in the Middle Triassic were analogous developments of the dolomitic limestones north and south of the Alpine-Dinaric boundary re-established. The linkage of this boundary fault to the deep-reaching NE- to ENE faults of the Great Hungarian Plain is effected in such a way that they turn from the SE- continuation of this fault to the north-east. The fact that on such a deep fault plutonic magmatites ascended and caused contact metamorphism of the adjacent schists is a natural result of a vertical breach in this part of the range (figs. 1, 2).



LONGITUDINAL PROFILE THROUGH THE CENTRAL ZONE OF THE EASTERN ALPS BY P. BECK-MANNAGETTA 1970, ACCORDING TO W. FRANK and G. FRASL 1968, CH. EXNER 1957, H. STOWASSER 1956, N. ANDERLE 1951, F. KAHLER 1962, W. MEDWENITSCH 1964, A. PILGER and N. WEISSENBACH 1965, H. FLÜGEL 1960, A. PAHR 1960, A. TOLLMANN 1967

LEGEND

to sections through the Eastern Alps Nos I, II, III, IV, V
by P. Beck-Mannagetta (1973)

Bohemian Massif

- B Kr Crystaline rocks, profiles III, IV, V
- Pearl gneiss, profile V
- Granite, profile V
- gr Granulite, profile II
- gf Gföhl gneiss; profile II

Moldanubicum

Moravicum, profile II

- Crystalline schists i. g.
- BL Biteš gneiss; P Pleißling gneiss; G Granite (gneiss)
- P Permian, profile II
- G Foreland Mesozoic; profiles III, IV

Eastern Alps

- M Molasse, Neogen; profiles III, IV, V; SM Subalpine Molasse; profiles II, III, IV
- E Helveticum (Ultrahelveticum); profiles II, IV, V
- Fl + BK Flysch + Buntmergel series; profiles II, III, IV, V

enninicum

- Schieferhülle, profiles I, IV, V; R Rechnitz series, profiles I, II
- Central gneiss; profiles I, IV, V

Lower (Central) Ostalpin

- ZA Central Alpine Mesozoic; profile I, II, III, IV, V
- V Veitsch nappe; profiles III, IV
- Quartz phyllite; profile IV
- Seckau granite gneiss; profile III
- gn Grobgneis series; profile II
- Altkristallin; profiles I, II, IV
- Granite gneiss of Altkristallin; profile IV

Continuation p. 61

BECK-MANNAGETTA, P. u. M. 1952: Zur Geologie und Paläontologie des unteren Lavanttales. — Jb. d. G. B. A. Bd. 95, S. 1—102.
BECK-MANNAGETTA, P. 1960: Die Stellung der Gurktaler Alpen im Kärntner Kristallin. — Int. Geol. Congr. XXI. Sess. Norden, Copenhagen, Part. XIII., S. 418—430.
BECK-MANNAGETTA, P. 1968: Über das Kristallin der Koralpe (Ostalpen), (Vortragsbericht). — Časopis nun. geol. Bd. 13 Ac. Praha, S. 251—254.
CLAR, E. 1965: Zum Bewegungsbild des Gebirgsbaues der Ostalpen. Verh. GBA. Wien Sdh. G, S. 11—35
CORNELIUS, H. P. u. CLAR, E. 1939: Geologie des Großglocknergebietes, Teil I. — Abh. d. Reichst. f. Boden. Zw. Wien Bd. 25, S. 1—305.
EXNER, Ch. 1957: Erläuterungen zur geologischen Karte der Umgebung von Gastein 1 : 50 000. — GBA. 168 S. Wien.
EXNER, Ch. 1964: Sonnblickgruppe (östl. Hohe Tauern). Petrographie und Tektonik im Tauernfenster. — Mitt. Geol. Ges. in Wien Bd. 57, S. 33—38.
FLÜGEL, H. — HERITSCH, H. 1968: Das Steirische Tertiär-Becken, 2. Auflage. — Sammlung. Geol. Führer Bd. 47, Gebr. Borntraeger, S. 1—196.
FRASL, G. 1968: Zur Seriengliederung der Schieferhüllen in den mittleren Hohen Tauern. — Jb. G. B. A. Wien, Bd. 101, S. 323—472.
HEISSEL, W. 1958: Zur Tektonik der Nordtiroler Kalkalpen. — Mitt. Geol. Ges. Wien, Bd. 50., 1957, S. 95—132.
HOMANN, O. 1962: Die geologisch-petrographischen Verhältnisse im Raume Ossiachersee-Wörthersee (südlich Feldkirchen zwischen Klagenfurt und Villach). — Jb. GBA. Wien, Bd. 105, S. 243—272.
HORNINGER, G. 1956/1957: Geologische Ergebnisse bei einigen Kraftwerkbauten. — Vh. GBA. Wien 1956, Vh. GBA. Wien 1957, S. 114—118, S. 99—102.
JANOSCHEK, R. 1969: Erdöl und Erdgas im Oberösterreich. — Geologie u. Paläont. d. Linzer Raumes, Stadtmus. Linz, S. 91—108.
JANOSCHEK, R. — GÖTZINGER, K. 1969: Exploration for Oil and Gas in Austria. (The Exploration for Petroleum in Europe and North Africa). — The Inst. of Petroleum S. 161—180.
KAHLER, F. u. M. 1962: Geologische Karte der Umgebung von Klagenfurt, Geol. Karte d. Rep. Österreich, Blatt Klagenfurt, 1 : 50 000. — Verl. d. G. B. A. Wien.
BECK, H. — KIESLINGER, A. — TELLA, F. — WINKLER, A. 1929: Blatt Unterdrauburg (5354) 1 : 75 000. — Verl. d. G. B. A. Wien.
MEDWENITSCH, W. — SCHLAGER, W. — EXNER, CH. 1964: Exkursion I/5: Ostalpenübersichtsexkursion. — Mitt. Geol. Ges. in Wien Bd. 57, S. 57—106.
OXBOURGH, E. R. 1968: 1) An Outline of the Geology of the Central Eastern Alps; 2) The Eastern Alps — A Geological Excursion Guide. — Proc. Geol. Ass. Bd. 79, S. 1—127.
PAHR, A. 1960: Ein Beitrag zur Geologie des nordöstlichen Sporns der Zentralalpen. — Verh. d. G. B. A. Wien, S. 274—283.
PLÖCHINGER, B. 1962: Geologischer Führer für Strobl am Wolfgangsee, Salzburg. — Strobl, Gmd. Amt., 6 Bl.
PLÖCHINGER, B. 1964: Die tektonischen Fenster von St. Gilgen und Strobl am Wolfgangsee (Salzburg, Österreich). — Jb. GBA. Wien Bd. 107, S. 11—69.
PREY, S. 1957: Ergebnisse der bisherigen Forschungen über das Molassefenster von Rogatsboden (N. Ö.). — Jb. G. B. A. Wien 100, S. 299—358.
PREY, S. 1969: Geologische Karte der Umgebung der Stadt Salzburg 1 : 50 000. — Verl. GBA. Wien.
SCHÖNLAUB, H. P. 1974: Schwamm-Spiculae aus dem Rechnitzer Schiefergebirge und ihr stratigraphischer Wert. — Jb. GBA. Wien Bd. 116; 1973, S. 35—49.
STOWASSER, H. 1956: Zur Schichtfolge, Verbreitung und Tektonik des Stangalm-Mesozoikums (Gurktaler Alpen). — Jb. G. B. A. Wien, Bd. 99 S. 75—199.
TOLLMANN, A. 1963: Ostalpen-Synthese. — F. Deuticke, Wien, 256 S.
TOLLMANN, A. 1967: Tektonische Karte der Nördlichen Kalkalpen 1. Teil: Der Ostabschnitt. — Mitt. Geol. Ges. Bd. 59, 1966, S. 231—253, Wien.
TOLLMANN, A. 1967: Ein Querprofil durch den Ostrand der Alpen. — Ec. Geol. Helv. Bd. 60, S. 109—135, Birkhäuser Basel.
TROLL, G. 1964/1967: Geologische Übersichtskarte des Bayerischen Waldes 1 : 100 000. — Geol. Bavar. Teil I, München.

INTERNAL ZONES

P. BECK-MANNAGETTA

Penninicum

The Penninic formations of the Western Alps reappear in the Central Zone of the Eastern Alps. The flysch nappes in the northern part of the Eastern Alps were correlated with the uppermost members of the Penninic schists series. W. Schmidt (1956) and A. Pahr (1960) assume a Pennine window in the Rechnitz "Schieferinsel", at the eastern margin of the Alps, whereas A. Erich (1961) and G. Wein (1969) think the rock series to be Early Paleozoic (similar to the Greywacke Zone).

The Penninicum unit encompasses the central granite-gneiss with the lower and upper schist envelopes. The contact of the granite-gneiss with its crystalline cover (lower schist envelope) is mostly migmatic (F. Angel and W. Staber 1937). With the increase in potassium the granite-gneisses grade into syenitic rocks and with the supply of hornblende into tonalitic and banded gneisses as they become more schistose and richer in mica.

The lower schist envelope of old crystalline and metamorphosed Early Paleozoic rocks ("Habach Serie", G. Frasl 1958), which consists of mica-schists to phyllites, amphibolites, metadiabases, greenschists, albite-gneiss, porphyroids and other acid volcanics, could have been locally removed by erosion as early as before the Triassic (Ch. Exner 1957, 1962). The upper schist envelope has in addition to arkosic gneisses, phyllites and other rocks (Wustkogel Formation, Permian) an impersistent Triassic sequence of quartzites, rauhwacken, dolomites, banded limestones, gypsum and shales of a small thickness. It is overlain by a voluminous mass of calcareous mica-schists, calcareous phyllites and black phyllites with ophiolite (Bündner Schiefer) of the Jurassic (Cretaceous?) age (H. P. Cornelius — E. Clar 1939; G. Frasl 1958). The members of the Penninic trough had been metamorphosed by the alpine Tauern crystallization, which had reached the grade of the epidote-amphibolite facies. A nappe structure is presumed for the internal structure of the Penninicum, deep tectonics round the gneiss cores is distinguishable from the penetrative, "Stockwerktektonik' in the upper schist envelope. In the eastern Hohe Tauern a north-south lineation of the deeper central part (Glockner depression, gneiss cores, etc.) has been differentiated from the east-west plications and schistosity inside the schist envelope in the north. The central granite-gneiss makes up cupoles of various forms. The overlying schist envelope contains several gneiss layers of a small thickness but large areal extent, which are a characteristic tectonic feature of the eastern Tauern following from the nappe structure and plasticity of the schists (A. Tollmann 1963). The frontal part of the Sonnblick core is represented by the enrolled Mallnitz fold (Ch. Exner 1948). The elements of the Sonnblick massif extend to the east, where they appear in the Mölltal, roughly along the southern margin of the Ankogel-Hochalm cupole. The calcareous mica-schists are there frequently deformed into elongated bodies with flat W-dipping fold axes within the black phyllites (E. Braumüller 1939).

Of interest for the tectonics of the area under study are the flyschoid formations fringing the eastern Hohe Tauern in the north. They are composed of sandstones, fine breccias and grey phyllites. As no diagnostic fossils have so far been found, the age remains uncertain. It cannot either be decided whether they really represent

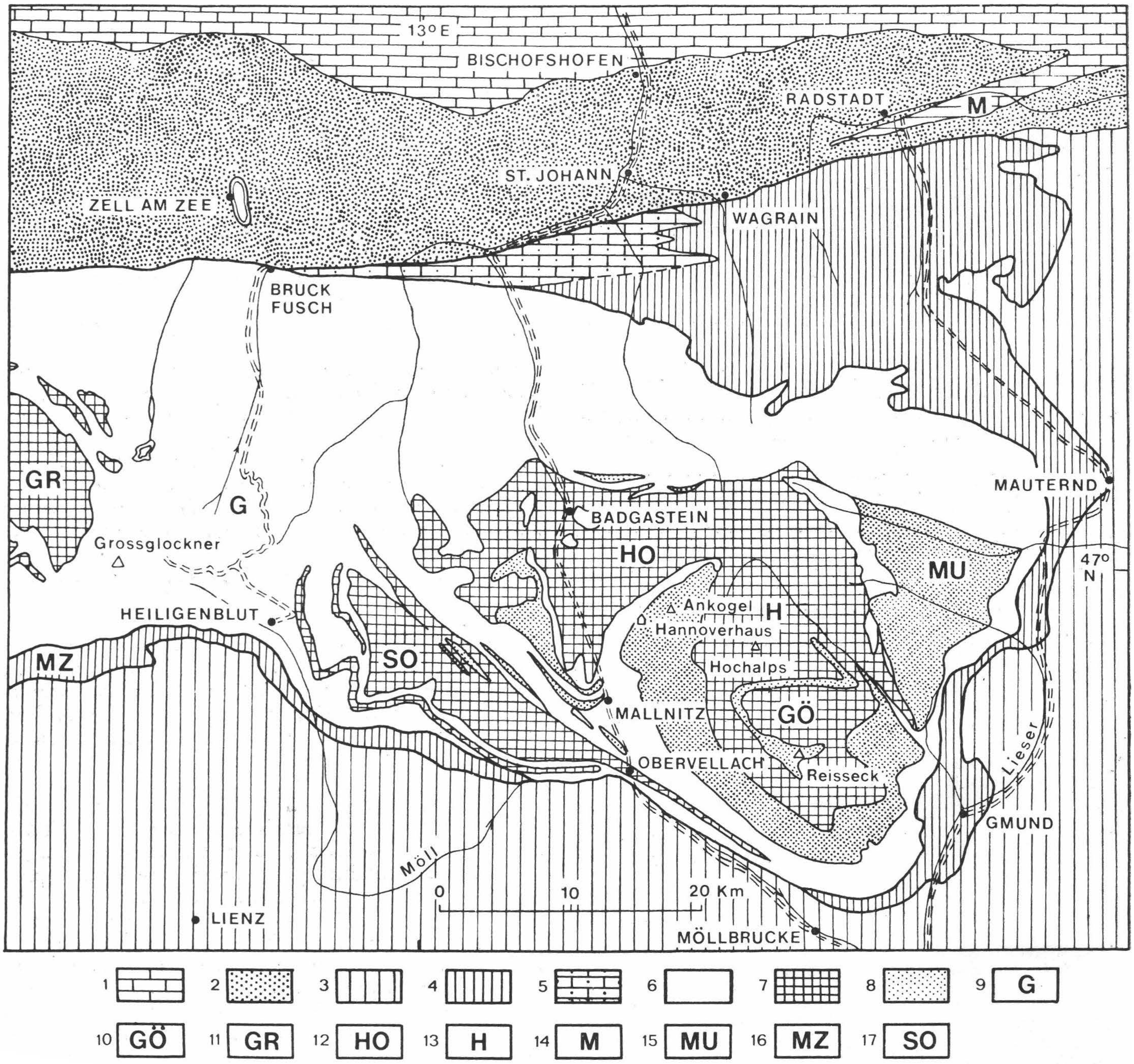


Fig. 1
The Eastern part of the Tauern window (after Exner in Medwenitsch and Schlager 1964
1 — Northern Limestone; 2 — Greywacke Zone; 3 — Altkristallin; 4 — Lower East Alpine Sheet Complex; 5 — Klamm Limestone Zone; 6 — Schieferhülle; 7 — Central Gneiss after Exner; 8 — Marginal Gneiss after Exner; 9 — Glockner Depression; 10 — Göss Valley Dome; 11 — Granatspitze Dome; 12 — Hölltor Dome; 13 — Hochalm Dome; 14 — Mandlingzug; 15 — Mureck nappe; 16 — Matrei Zone; 17 — Sonnblick Dome

the Penninic Flysch comparable to that of Oberhalbstein (Graubünden).

In the Mölltal the tectonics of the southern margin of the Tauern is buried by a younger fault (Mölltal line) stretching far south-east wards (Ch. Exner 1962).

A Late Tertiary fault also accompanies the Tauern window in the north (W. Heissel 1951; G. Horninger 1956/1957). As a morphologic deep line it limits the Tertiary of Wagrain north of the Radstädter Tauern and extends from the North Alpine Triassic along the steeply squeezed-in Mandling segment to the southern border of the Northern Limestone Alps.

The eastern boundary of the Tauern window is distinguished by E-dipping axes of E-W trend, the origin of which was connected with the translation of the East Alpine pile of nappes northwards (Ch. Exner 1954). The domal structure of the Hohe Tauern presumably extends beneath the East Alpine nappes as far eastwards as the cross zone of Stadl a. d. Mur-Ossiacher See (P. Beck-Mannagetta 1960; K. Metz 1965) (profile I, Puffle Zone).

The rocks occurring within the Rechnitz Crystalline inlier resemble the calc-phyllites and serpentinites (ophiolites) of the younger "schist envelope" and have therefore been classified as "Penninic." This complex showing metamorphism of phyllite grade lacks the "older schist envelope" and central granite-gneiss.

The absence of fossiliferous beds does not permit the age of the Tauern tectonics to be stated with certainty. The conditions at the boundary between the Western and Eastern Alps suggest a Tertiary age. The absolute age of the central granite-gneiss of the Tauern window is 20—25 m. y. (E. R. Oxbourgh et al. 1966).

THE EAST ALPINE UNITS

The former geographical division into the Northern and Southern Limestone Alps and the intervening East Alpine Central Zone had to be abandoned on tectonic grounds. It has been recognized that the Northern Limestone Alps may be joined with the Greywacke Zone of the Central Alps into one nappe unit, and that the Greywacke Zone is connected with a part of the crystallinen complex in the south (P. B e c k - M a n n a g e t t a 1969).

The Penninicum is encircled by the Lower Ostalpin nappe units of the Central Zone. The Radstadt nappes north and east of the Tauern window partly correspond to the Matrei zone in the south. The bed complexes of the latter are divided into a number of slices and their separation from the upper schist envelope is not everywhere quite unequivocal, as the richly developed Middle Triassic is followed by calc-phyllites with serptentinite which are likewise contained in the upper schist envelope.

The crystalline slices inside the schist envelope are often difficult to recognize.

In the sequence of the Central Alpine nappe units the Mesozoic bed complexes are intricately connected with the crystalline cores of nappes (quartz-phyllite and medium-metamorphosed complexes showing great facies differences).

The old crystalline cores of the nappes had undergone selective retrograde metamorphism (diaphthoresis) of various intensity. The diaphthoresis is connected with the selective alpine penetrative movements, decreasing in the eastward direction. Finally, it is restricted to local strips the breadth of which changes substantially. The recrystallization in the greenschist facies is mostly preceded by cataclastic mylonitization whose axial position with the restriction or shearing of the complexes is affected by alpine deformation. The differential stresses continue into the Upper Ostalpin Crystalline complex, but the Mesozoic members do not display there the dissection into nappes. No pre-alpine faults have been recognized with certainty in the deep crystalline cores of nappes (Lower Ostalpin). From the knowledge of the structural forms the following layered structure can be inferred for the Central Zone of the Eastern Alps:

1. Crystalline tectonic slices, predominantly affected by strong alpine retrograde metamorphism; Mesozoic showing indications of Penninic sedimentation: deep Radstadt nappes and the Matrei zone.
2. Crystalline cores of nappes of alpine derivation,

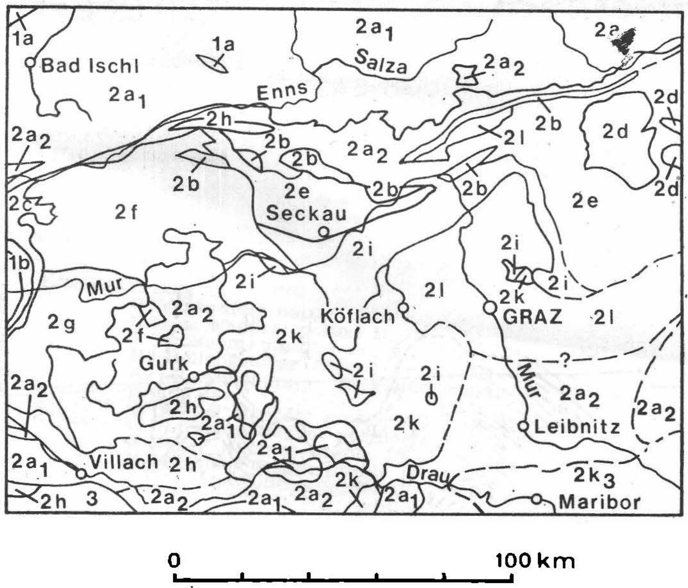


Fig. 2
Sketch map showing the distribution structrural units of Styria, by B e c k - M a n n a g e t t a (1968/70)

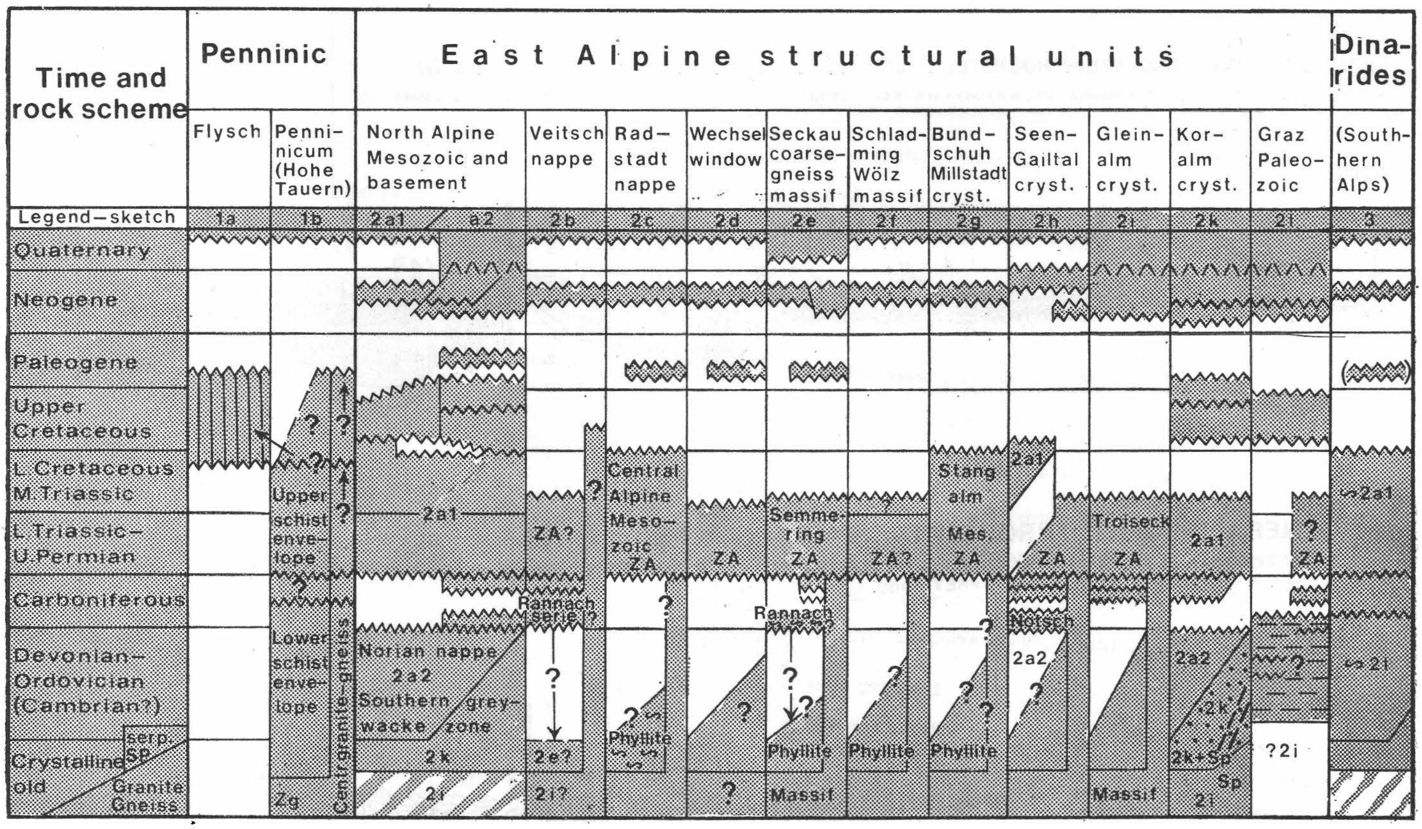


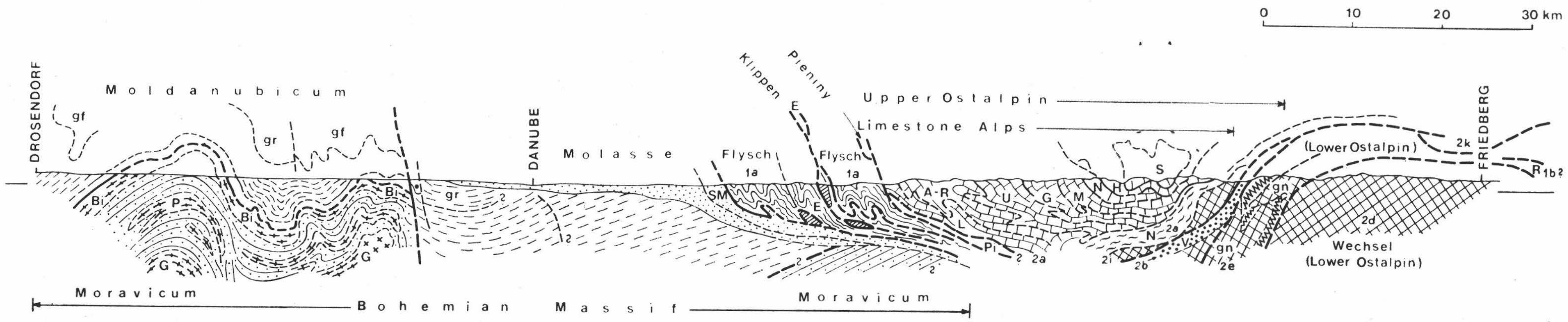
Fig. 3. Diagram legend showing the distribution structural units of Styria, by B e c k - M a n n a g e t t a (1968/70)

NAPPE BOUNDARIES AND DISTURBANCES OF TECTONIC UNITS. PROFILES II—V

PROFILE THROUGH EASTERN AUSTRIA BETWEEN DROSENDORF AND FRIEDBERG

ACCORDING TO P. BECK-MANNAGETTA 1955 and A.TOLLMANN 1967, MODIFIED BY P. BECK-MANNAGETTA 1970

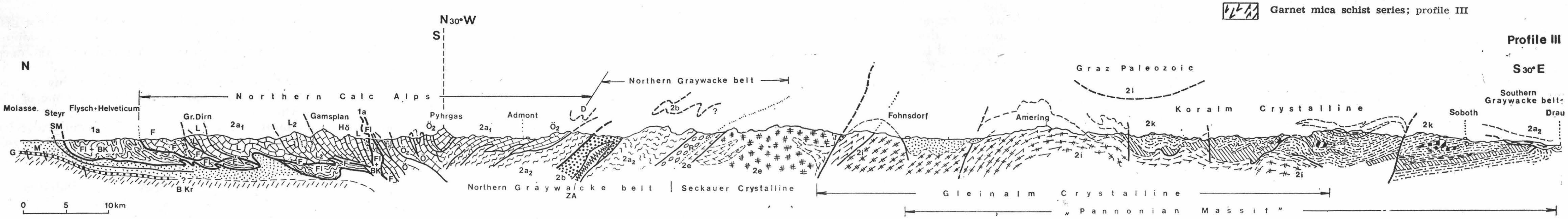
Profile II



PROFILE THROUGH THE EASTERN ALPS, STEYR-ADMONT-FOHNSDORF-SOBOTH

BY P. BECK-MANNAGETTA 1970, ACCORDING TO R.JANOSCHEK 1969, S.PREY and B.PLÖCHINGER 1968, K.METZ 1969, A.KIESLINGER 1929

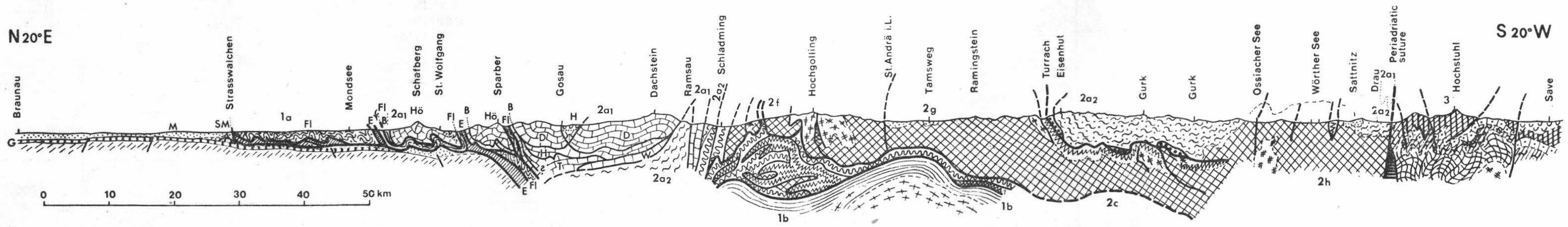
Profile III



PROFILE BRAUNAU-DACHSTEIN-HOCHSTUHL (SOUTHERN KARAVANKS) BY P. BECK-MANNAGETTA 1970

ACCORDING TO E.CLAR 1965, B.PLÖCHINGER 1963, H.P.FORMANEK 1964, H.STOWASSER 1956/64, F.KAHLER 1962, O.HOMANN 1962, S.PREY 1957

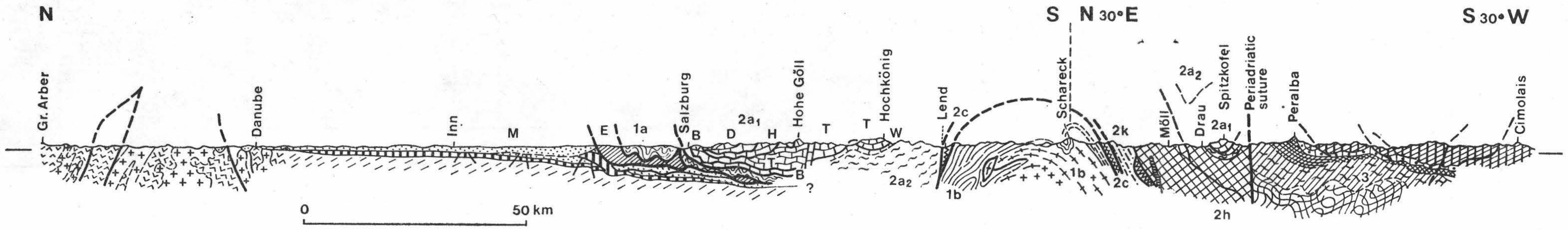
Profile IV



GENERAL PROFILE THROUGH THE EASTERN ALPS

BY P. BECK-MANNAGETTA 1970, ACCORDING TO G.TROLL 1964/67, R.JANOSCHEK 1961, B.PLÖCHINGER 1967, W.HEISSEL and CH.EXNER 1957, 1964, P. BECK-MANNAGETTA 1960, 1964, S.PREY 1969.

Profile V



- Gleinalm granodiorite gneiss; profile III
- Granite gneiss of Altkristallin; pro-file I
  Villach granite gneiss, Upper Ostal-pin; profile IV
  Cima d'Asta granite gneiss, Dinari-des; profile IV
- Pi Pieniny Klippen zone; profile II

Upper Ostalpin

- Northern Limestone Alps
  - B Bajuvaricum; profiles IV, V
  - F Frankenfels nappe; pofile III
  - L Lunz Nappes; pofiles II, III
  - T Tirolicum; profiles IV, V
  - Hö Höllengebirge nappe; profile III
  - A—R Annaberg — Reisalpe Nappe; profile II
  - Ö Ötscher Nappes; profile III
  - U Unterberg Nappe; profile II
  - G Göller Nappes; profile II
  - M Mandling Slice; profile II
  - N Nußberg Slice; profile II
  - H Hohe Wand Nappe; profile II
  - S Schneeberg Nappe; profile II
  - D Dachstein Nappe; profiles III, IV, V
  - W Werfen scale zone; profiles IV, V
- Mesozoic of Upper Ostalpin: profile I
- Upper Cretaceous + Eocen; profile I
- N Norian Nappe, Northern Greywac-ke zone; profiles II, III, IV, V
- Gurktal Nappe, Southern Greywacke zone; profiles I, IV
- Graz Paleozoic; profile I
- Garnet mica schist series; profile III

Koralm crystalline rocks, profiles I, (III), V

- Gneiss — mica schists series; profile I, V
- Eclogite amphibolite; profile III
- Plattengneis; profile III
- Marble series; profile III
- Granite gneiss of Altkristallin; pro-file IV
- R Altkristallin; profiles I, IV

Dinarides

- Tertiary profile IV
- Mesozoic; profiles I, IV, V
- Upper Paleozoic; profiles I, IV, V
- Lower Paleozoic, calcareous; profile V
- Lower Paleozoic i. g.; profiles I, IV, V
- Crystalline rocks; profiles I, IV, V
- Periadritic intrusive rocks; profiles I, IV, V
- Basalt; profile I
- Nappe boundaries and faults of tec-tonic units; profiles I, II, III
- Faults i. g.; profiles I, II, III, IV, V
- Ruffle zone; profile I

strongly diaphthorized, with more or less thick quartz-phyllite mantle; partly carbonate, partly schistose Mesozoic; strikingly impersistent Jurassic — Lower Cretaceous: Radstadt nappes.

3. Crystalline cores weakly diaphthorized with a thick quartz-phyllite mantle;

(a) Triassic recalling the Carpathian facies (e. g. variegated Keuper): Semmering nappes.

(b) Triassic preserved as slices and klippen associated with faults: Central Alpine Mesozoic.

(c) Basal crystalline complex slightly diaphthorized; Central Alpine Triassic to Lower Cretaceous (Jurassic and Neocomian in a reduced development): Stangalm Mesozoic overridden by Paleozoic (± crystalline) complexes.

(d) Crystalline complex almost free of alpine deformation ("Muriden" of L. K o b e r 1938); Rannach Formation (Early Paleozoic to Lower Carboniferous?, regarded as Permo-Triassic by many geologists — K. M e t z, from 1947); extensive Upper Paleozoic with sparse relics of Central Alpine Mesozoic: Veitsch nappe of the northern Greywacke Zone (K. M e t z 1965).

4. Crystalline complex diaphthorized in certain belts, without squeezed-in relics of Triassic; pre-alpine structures predominantly well preserved ("Koriden" — L. K o b e r 1938); Early Paleozoic in demonstrably conformable contact with the crystalline complex (with pre-alpine nappe structure Southern Greywacke Zone); no alpine overthrusts over alpine calcareous Triassic of Northern Alpine facies: Upper Ostalpin (Oberostalpin) of the Central Alps.

(a) Early Paleozoic in metamorphic contact with the old crystalline mass; in places sedimentary unconformity between it and the Triassic or Lower Eocene; autochthonous Southern Greywacke Zone; no alpine overthrusts except for the pre-alpine mountain structure.

(b) Paleozoic with faulted base and alpine nappe structure (with Central Alpine Triassic? — H. F l ü g e l 1961): Paleozoic of Graz.

(c) Paleozoic of the southern Greywacke Zone with crystalline in places thrust over the Mesozoic of the Central Alps (Gurktal nappe).

(d) Lower Paleozoic sheared off from the crystalline basement during alpine orogeny (with crystalline slices); originally connected with the Northern Limestone Alps through a Triassic transgression, but frequently sheared off along thrust lines, which run at the base of the Triassic at a varying depth: Norian nappe of the Northern Greywacke Zone (E. C l a r 1965; A. T o l l m a n n 1959/63; H. P. C o r n e l i u s 1950).

5. According to this division the Drauzug can be regarded as a stratal sequence with autochthonous Mesozoic lying on the Paleozoic and crystalline complexes; the Southern Karawanken as the allochthonous (para-autochthonous) Mesozoic and the Southern Alps possibly as the Mesozoic in the South Alpine facies resting on the Upper and Lower Paleozoic with nappe structure and/or phyllites (N. A n d e r l e et al. 1964).

This division of the eastern Central Alps, which is based chiefly on the alpine deformation of its crystalline mass, makes it possible to express in which way the individual structural elements were incorporated in the alpine structure of the Eastern Alps. Whereas this division implies a certain vertical zoning, the division based on the Mesozoic facies and deformation of the nappe cores, approaches that of H. F l ü g e l (1960/64) or A. T o l l m a n n (1959), who do favour the concept of an extremely long tectonic transport of the units, and the opinion of E. C l a r (1965) and K. M e t z (1965) on the overthrusts moved to only small distances. The above mentioned division should be preferred to a strict segmentation of the nappes into the Lower, Middle and Upper Ostalpin, as it gives a better picture of the pecularities of the individual tectonic and stratigraphic units of the Central Zone (K. M e t z 1965; P. B e c k - M a n n a g e t t a 1967/70, figs. 2, 3).

The attached sections reveal that a similar division to that of A. T o l l m a n n (1959) can be arrived at, when the Alpine Mesozoic is considered jointly with the crystalline and Paleozoic cores: the Central Alpine Mesozoic with the crystalline, which is tectonically limited on all sides, can be regarded as the "Unter-Ostalpin"; the Mesozoic of the Limestone Alps with Greywacke and Crystalline Zones (P. B e c k - M a n n a g e t t a 1969) can be designated as the "Oberostalpin"; the medium zone with the Central Alpine Mesozoic (without Greywacke Zone) and crystalline complexes would be "Mittelostalpin" in the sense of A. T o l l m a n n (1959, 1963), although there is no well-defined tectonic boundary in the crystalline complex. The diagramatic sketch (fig. 2, P. B e c k - M a n n a g e t t a 1970) presents an arrangement of the structural units irrespective of the order of rank (Lower, Middle, Upper), which is based on the division of the crystalline basement and the sedimentary mantle. K. M e t z (1965) assented to this conception.

The actual conditions, however, cannot be expressed without excluding the vertical zoning altogether. Therefore, the differentiation that was used for the Tectonic map of Styria (P. B e c k - M a n n a g e t t a 1970) is regarded as a "neutral experiment" — figs. 2, 3).

The regional division shown in the attached sections (I—V, one longitudinal and four transverse), refers to the division (1a—3) given in sketch (fig. 2) and legend (fig. 3). After this representation the structural units 2b, 2g and partly also 2e and 2i can be designated as "Mittelostalpin", on account of their position between the "Unterostalpin" (2 c, 2 d and partly 2 e) and the "Oberostalpin" (2i + 2k with 2a 1/2 and 2 l). However, the positions of 2e, 2f, 2i and 2h point to the questionability of such a general vertical division.

The forezone of the Central Zone, which is not shown in the sketch (flysch, molasse) displays in this sector of the Eastern Alps a well-defined nappe structure, which clearly differs from the autochthon of the foreland (profiles II—V).

Whereas the simple alignment of the structural units in the sections recedes northwards to the alpine nappe structure, the Upper Ostalpin of the Central Zone in the south becomes progressively more autochthonous and passes into the "Pannonian mass". The latter is overlain by the Mesozoic in the Northern Limestone Alps, which rests on the Southern Greywacke Zone, without having been incorporated into the alpine nappe structure (profile I; P. B e c k - M a n n a g e t t a 1967, 1969).

Northern Limestone Alps

In the Northern Limestone Alps the stratal sequences of the Eastern Alpine Mesozoic geosyncline are of a very marked development (region of North Alpine facies). The Triassic of a great thickness and homogeneous development is replaced by the heteropic Jurassic to Neocomian sequence, which is succeeded by Upper Cretaceous in the Gosau facies; this persists into the Lower Eocene in some basins. From the tectonic point of view, this complex unit is unquestionably allochthonous in the north, whereas southwards its transgressive contact with the Lower Paleozoic of the

Greywacke Zone (Norian nappe) has been partly preserved and partly can be restored. Farther to the south, autochthonous to para-autochthonous conditions Drauzug, Gailtal Alps, Karawanken, etc.) can be evidenced, which seem to reach as deep as the crystalline basement showing Variscan deformation. While the northern boundaries of the Northern Limestone Alps are the overthrust lines of the first order, the extent of the shear-off becomes reduced southwards to a partial thrust line at the southern margin of the Northern Limestone Alps. Farther in the south, at the northern border of the Gailtal Alps, the undisturbed transgressive contact is demonstrable at many places on the base of the Lienz Dolomite and around the Eberstein-St. Paul Triassic. The alpine overthrust lines that would extend into the underlying complexes are absent or are sure to die out in the last-named areas (fig. 4).

The surface on which the main movements occurred must therefore have lain at the base of the Norian nappe, where it was also placed by A. Tollmann (1959), P. Beck-Mannagetta (1970); profile IV.

In the stratal complex of the Limestone Alps there are facies differences that under certain conditions led to the formation of surfaces on which the movements took place. In this way "the facies and multifacies nappes" (A. Tollmann 1963) could have originated. At the same time a general change from north to south can be proved. The Northern Limestone Alps are, moreover, divisible into the western, central and eastern sectors, based on geological predispositions. In the west, from the Rhine to the gap of the Inn river near Kufstein, there are stratigraphic transitions between the two large nappe groups — the Bajuvaricum and Tirolicum. Owing to these transgressions, the tectonic separation is not everywhere definable as the nappe boundary. For this reason the nappe character of the Limestone Alps has been doubted altogether.

The central sector from Kufstein to the Weyerer Bögen is distinguished by the Juvavian and Dachstein Limestone nappes, by the thrust of the "Tirolischer Bogen" northwards (F. Hahn 1913), and by the Bajuvaricum cropping out in the flysch windows disposed on the NW faults.

In the eastern sector, east of the Weyerer Bögen to the eastern termination of the Northern Limestone Alps in the Vienna Basin, a similar arrangement of the nappes essentially remains. Farther away, the strikes of the nappes repeatedly turn from east-west direction to the north-east trend, which progressively dominates towards the east. Since L. Kober's time (1912) the Frankenfels, Lunz, Ötscher, Hallstatt and Schneeberg nappes are differentiated from north to south.

Whereas in the northern units the stratigraphic range and content vary (Jurassic dominates the Triassic, Cenomanian in the Frankenfels nappe and its western equivalents in the deep Bajuvaricum, Algäu nappe), the facies in the east approach the corresponding nappes of the Carpathians (Cenomanian in the Frankenfels nappe, Gosau in the Lunz and Ötscher nappes, Kalksburg Formation in the Lower Lias, and red marls in the "Hauptdolomit" as indication of the Keuper facies).

The differences within the individual nappes should thus be defined not only by the differentiation of single beds but also by the characteristic combinations of the stratal successions. The kind of rock material understandably controls to a certain extent the tectonic structure of the individual sectors. In the Allgäu and Frankenfels nappes the Carnian stage with gypsum and the Opponitz Rauhwacke at the base of the Hauptdolomit served mostly as a shearing surface. The stratal sequence of the Lunz nappe also reaches only in its southern sector down to the clay-rich, partly gypsum-bearing Werfen Formation. The "Haselgebirge" (tectonic salt breccia) of the Juvavian nappes led to the separation of the Hallstatt nappe (with shreds of the Greywacke zone). At the southern border, the Limestone Alps are transgressively connected with the underlying Lower Paleozoic through the Permian Prebichl- and the Lower Triassic Werfen Formations (E. Spengler 1951; K. Metz 1953; G. Flajs 1967). The increase in the thickness of sediments southwards is well apparent, for example, in the difference between the thickness of the Hauptdolomit of the Frankenfels and the Lunz nappes. The southern Tirolicum shows narrow relations in space and facies to the Triassic of the Dachstein nappe ("Dachsteinkalk-Decken"). In the Tirolicum of the western sectors and of the Ötscher nappe in the east, the Wetterstein Dolomite and Limestone are of more importance than in the Lunz nappe. The Dachstein Limestone with the Ramsau Dolomite becomes so thick southwards in the central and eastern sectors of the Tirolicum that the Tirolicum facies is not distinguishable from the upper Juvavian Dachstein nappe; in many places the Dachstein nappe seems to have evolved from the southern Tirolicum. These transition zones, subsequently disturbed tectonically, such as that transitional to the Haltstatt nappe that was called by A. Tollmann (1967, 1969) the Lammer nappe, or Mürzalpen nappe (1964; A. Thurner 1963), were interpreted as multifacies nappes. The extensive multifacies developments occurred at the level of the Carnic sequence, which is the product of the Triassic shallowing sea silted from time to time. In the east, in the Lunz nappe there is the coal-bearing Lunz facies, and in the west and south the Cardita- or Raibler Formations were laid down. Within the Dachstein nappe the Carnic beds of the dolomite facies occasionally disappear completely. W. Medwenitsch (1958) distinguished as true facies nappes the lower and upper Hallstatt nappes, and regarded only the lower tectonic salt breccia as representing the salt-forming basin of a Permo-Scythian horizon. In the upper one, the Carnic-Norian Hallstatt Limestone predominates and the Dachstein Limestone is virtually lacking. This differentiation, however, is not accepted universally.

The succession of the nappe units one above the other has been evidenced in the windows, such as the windows of Annaberg, Urmannsau, (A. Kröll — G. Wessely 1967) etc. Two units frequently appear within one window (Ödenhof window, Schwechat window — B. Plöchinger 1967, 1970). The windows of the Bajuvaricum and flysch within the Limestone Alps provide a substantial evidence of the nappe structure of the Northern Limestone Alps.

Northern Limestone Alps (particularities)

According to the tectonic division of the Central Zone, as given above, the whole Northern Limestone Alps would be only a pile of nappes forming part of the whole group, i. e. only the roof of the Norian nappe. Their nappes, however had not been translated as a whole from the northern Greywacke Zone; the northern nappe units, such as the Frankenfels, Lunz and the northern Ötscher nappe, must have been derived from an unknown (presumably crystalline) socle (E. Clar 1965). Therefore, they may be considered as one major tectonic unit, as it was thought hitherto.

In spite of the partial facies analogies, the following large nappe groups are distinguishable in the Limestone

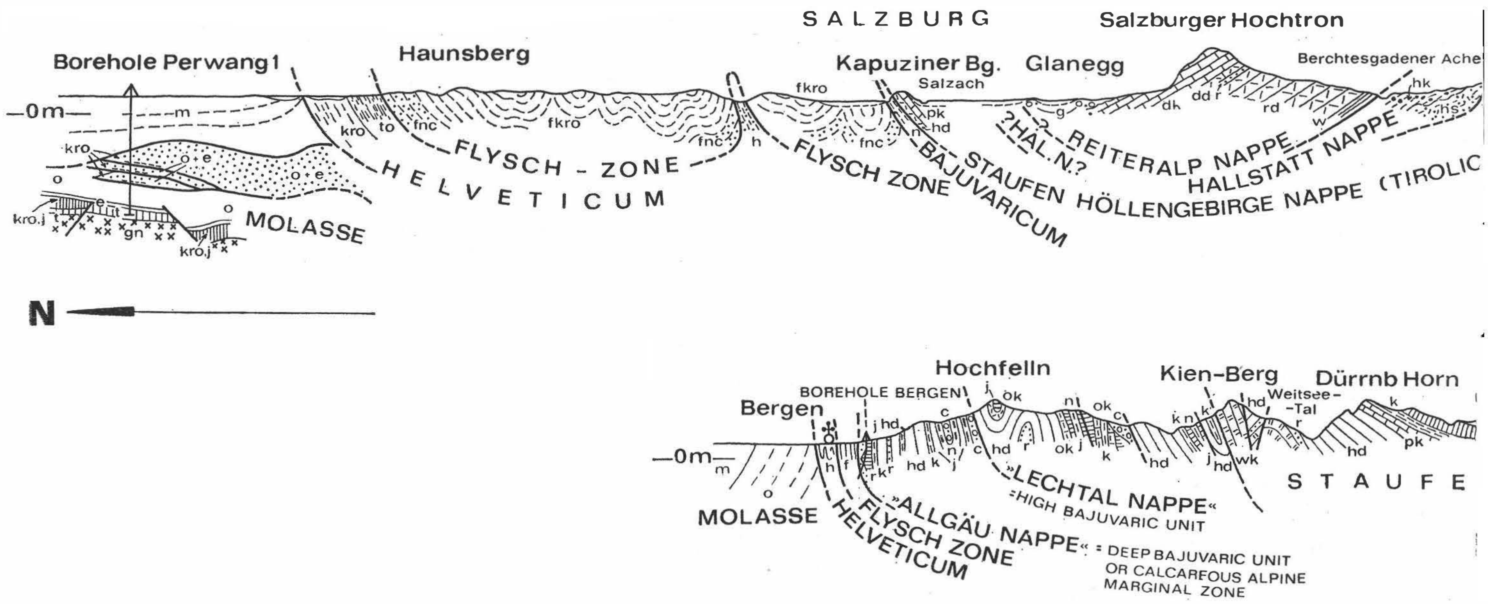


Fig. 4
Two geological cross sections through the Limestone Alps, Flysch Zone, Helveticum and the southernmost Molasse Zone west of Salzburg. H. Bögel, P. Schmidt Thomé, W. Zacher (1964)
Legend
Molasse and basement of molasse
vite = molasse, unfolded; dotted = "imbricate zone"; m = Miocene; o = Oligocene; e = Eocene; kro = Upper Cretaceous; d = Upper Jurassic; t = Trias Germanic facies; gn = crystalline rock of the Bohemian Massif
Flysch zone
h = Helveticum individed; fkro = Upper Cretaceous, undivided; fnc = Neocomian to Cenomanian.

Alps: the Allgäu-Ternberg-Frankenfels (deep Bajuvarian), the Lechtal-Reichramming-Lunz (high Bajuvarian) groups (L. Kober 1912, 1955; E. Spengler 1953, 1956, 1959; F. Trauth 1937; A. Tollmann 1967, 1969), the Inntal nappe, the Staufen-Höllengebirge (Tirolian) nappe, and the Ötscher nappe group ("Dachsteinkalkdecken"). The Juvavian nappes consist of the Hallstatt nappes (deep Juvavicum) and the Reiteralm-Dachstein-Schneeberg nappe (high Juvavicum); according to the facies, the latter can be ranged to the "Dachstein limestone nappes" of the Ötscher nappe group. Some partial nappes are also distinguishable (profiles III, IV, V).

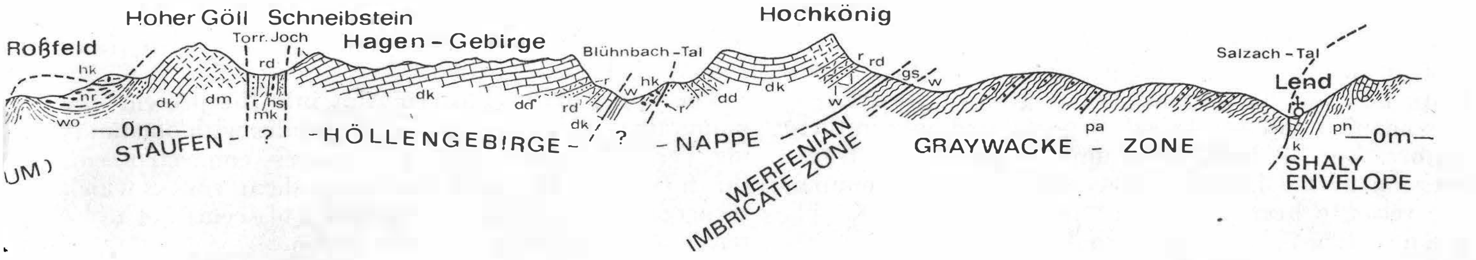
Particularly in the Norian-Rhaetic a pronounced relationship of the fore-reef zone to the rocks of the Hallstatt facies and of reef bodies to the lagoonal facies of the Dachstein Limestone is observed.

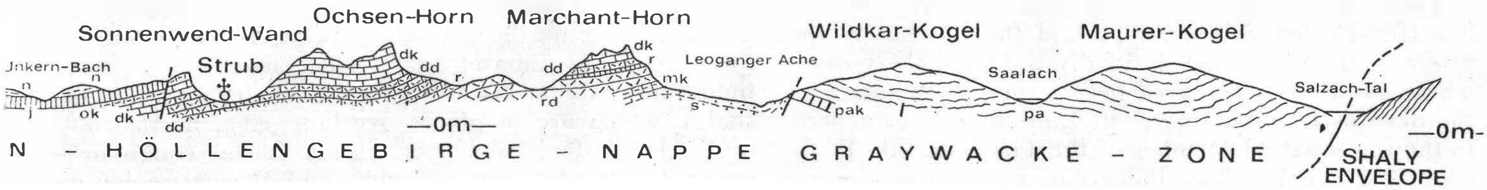
The Frankenfels-Allgäu nappe begins mostly with the Triassic rocks of the Carnian horizon: gypsum and rauhwacken below the bedded Hauptdolomit, which is overlain by thin-bedded limestone of small thickness and the fossil-rich Kössen Formation. In the south, the Lias of spotted-marl (Fleckenmergel) facies occasionally is replaced by cherty limestones; Vils (crinoidal-brachiopodal) Limestone occurs in the Dogger. Tithonian-Neocomian is developed as nodular limestones, spotted marls or Aptychus limestones. The Neocomian can be strictly differentiated stratigraphically from the Malm only rarely on petrographical grounds. The Aptian and Albian are present sporadically; the Cenomanian in conglomeratic and marly development ends the succession of strata. At the border against the flysch a "Cenomanian Klippen Zone" is locally in an advanced position. In the east this position is occupied by a quartz-limestone (Kieselkalk) zone, formed dominantly of Lias and Neocomian rocks. The Upper Cretaceous in the Gosau facies (Senonian) has so far not been recognized in these units.

Whereas in the Lechtal nappe, between Inn and Salzach, the Wetterstein Limestone and Dolomite form the deepest beds, shelly limestone (Muschelkalk) occurs in the basal part of the Lunz nappe; in the south the Werfen facies occurs at the base. A substantial difference between west and east consists in that the Cenomanian is represented in the Lechtal nappe, and the Gosau Formation in the Lunz nappe. In the east the Albian lies unconformably, and the Cenomanian sequence under the Gosau belongs to an earlier structural plan. The clastic facies of the Carnian horizon is weakly developed in the west; on the contrary, the Lunz Formation with arkosic sandstones and coal (above the Opponitz Limestone) represents an outstanding member of the sequence in the east. The Jurassic is also far more varied in development: Liassic cherty limestones, or Hierlatz, Klaus, and Acanthicus Limestones are added to the spotted-marl facies of the northern facies range (B. Plöchinger 1964, 1968).

According to A. Tollmann (1967), the southern part, which invariably shows an inverse succession of beds, is thrust over on the Lunz nappe s. s. from the south, and is termed as the Sulzbach nappe.

The Staufen-Höllengebirge nappe of the central sector pushes the Bajuvaricum in the east of the Inn progressively northwards, so that in the Salzburg area it appears as only subordinate slices at the boundary with the flysch. Southwards from the Staufen-Höllengebirge nappe there is a gradual transition to the Upper Triassic limestone of a great thickness, eastwards from the Loferer Steinberge. The transition, however, has nowhere been preserved undisturbed. The reef limestone of Hoher Göll (H. Zankl 1967; H. Zapfe 1969) is tectonically separated from that of Hochkönig, as is the limestone of Bischofsmütze from the Dachstein massif; the Tennengebirge intervenes between them. This southern tract of the Northern Limestone Alps is not strictly divided by the deep-reaching N-S cross fault of the Weyerer Bögen. Being disturbed by vertical faults, it stretches farther east, into the Hochschwab and Hohe Veitsch, where the Aflenz and Mürztal marly facies partly represents the





Limestone Alps
(Upper Ostalpin) g = Gosau (+ Lower Tertiary, partly); c = Cenomanian; n = Neocomian; nr = Neocomian of the Schrambach and Roßfeld beds; j = Jurassic undivided; wo = Malm of the Oberalm Beds; l = Lias Limestone; ok = Upper Rhaetic limestone; k = Kössen Beds; pk = platy limestone; dk = Dachsteinkalk, bedded; dm = Dachsteinkalk, massive; dd = Dachstein dolomite; hd = Hauptdolomit; r = Raibl Beds; wk = Wettersteinkalk; rd = Raumsau Dolomite; mk = Muschelkalk of the Alps; hk = Hallstatt Limestone and dolomite; s = Buntsandstein; w = Werfen Beds.
Greywacke Zone and Central Alpine rocks
pa = Paleozoic, undivided, mainly schistose; pak = Paleozoic limestone; k = Klammkalk („Schieferhülle" of the Hohe Tauern); ph = black phyllite („Schieferhülle" of the Hohe Tauern)

reef facies (Gesäuse units of P. Beck-Mannagetta 1955, 1970).

North-east of Windischgarsten, the transition of the Tirolicum into the Reichraming nappe is recognizable by the plunge of the Wetterstein-Limestone dome. In the east the Annaberg-Reisalpe nappe occupies an intermediate position, both in tectonic and facies respect, between the Lunz and Ötscher nappes; the Hauptdolomit of both nappe groups steadily increases at the expense of the Dachstein limestone facies, which is developed in the south (profile II).

As the Northern Limestone Alps swing north-eastwards, the Göller nappe reaches farther and farther northwards and additional partial nappes and slices are pushed down towards the Vienna Basin, until all parts disappear in the substratum of the Late Tertiary of the basin.

Division of tectonic phases

The tectonic phases that have modelled the structure of the Eastern Alps were interconnected in time and space.

The relics of the pre-alpine structure have been preserved only occasionally in the Central Zone. The structure and metamorphism of the Saualpe (Carinthia) have been dated by R. Schönenberg et al. (1967) as pre-Upper Carboniferous — Variscan. A Variscan nappe structure can be postulated. This presumption, however, does not justify us to assume the same age for the metamorphism and pre-alpine structure in other crystalline areas of the Central Zone, and consider it as the oldest, safely proved orogenic stage. The magmatic age of the central granite-gneiss and of its migmatized crystalline mantle is also thought to be Variscan (if not older) in the Penninicum.

The absolute age measurements of the crystalline schists and granites of the Central Zone (E. Jäger — H. Faul 1959; E. R. Oxbourgh et al. 1966; A. Kantor — H. Flügel 1964) show what care should be taken in their interpretation and what discrepancies can arise when only a small amount of data are available. Some data cannot be brought into agreement with the well-founded stratigraphic information. The morphological interpretation (cooling age) of the results of absolute age measurements appears to be a plausible approach to the solution; the concept of a "mixed age" is another one. However, they cannot be regarded as a satisfactory solution, as concerns the other crystalline central zones (e. g. Rhodope).

The absolute data of 19—25 m. y. obtained for the Penninic central granite-gneiss can be taken for granted. The abrupt increase to 80 m. y. for the old crystalline cover agrees with the tectonic boundary of the Tauern window (E. R. Oxbrough et al. 1966). The other values of the Altkristallin in the east fall readily within the scope of these results, but they cannot give us a reliable dating of metamorphism (H. Flügel 1964). On the contrary, the radiometric data of the Villach Granite (N. Grögler et al. 1965) and the Ötztal crystalline complex (E. Jäger et al. 1967; W. Harre et al. 1968) correspond better to the age values expected for the metamorphism and are evidently Variscan or earlier. The most recent measurements on the central granite-gneiss of the western Hohe Tauern fall better into the pattern of the Variscan age (C. Besang et al. 1968).

From the stratigraphic relations of the sedimentary complexes of the cover the time succession of the alpine orogenic phases can be deduced. The most relevant problem, i. e. the date of the overthrust of the Tauern window, however, cannot be solved as yet.

Irrespective of local indications of the uplifts and fault-type deformations of the Limestone Alps in Triassic and Late Jurassic times, the more extensive overthrusts can be confidently presumed to have occurred at the onset of the Neocomian (V. Medwenitsch 1958; B. Plöchinger 1956), but particularly during the pre-Cenomanian (pre-Gosau) period.

Since in the west, in the Bajuvaricum, and in the east, in the Frankenfels nappe, the Cenomanian represents the Upper Cretaceous, the orogeny of pre-Albian-Cenomanian date can be safely postulated only in these sectors. Yet, in both these units a continuous transgression of the Lower Cretaceous to the Cenomanian has recently been established in places (H. Kollmann 1968). In the eastern Lunz nappe the Cenomanian is covered with Gosau series (B. Plöchinger 1964). The pre-Cenomanian structure can thus be separated from pre- and post-Gosau structures.

The overthrusts of the Juvavian nappes on the Stauffen-Höllengebirge nappe and the Ötscher nappe group in the north had decidedly predated the Gosau. These overthrusts occurred before the Cenomanian, as the detritus from the Hallstatt Limestone is evidenced in the top Rossfeld Member of the Tirolicum (B. Plöchinger 1956). The Paleocene and Lower Eocene of the numerous Gosau synclines of the Northern Limestone Alps provide evidence of the post-Early Eocene age of the orogeny. The shift in the direction of material supply during the Gosau sedimentation (G. Woletz 1963) indicates prominent orogenic processes at Gosau time (before Campanian). As the sparse relics of the Upper Eocene (e. g. Willendorf — B. Plöchinger 1964) had not been dragged into the nappe structure, a Middle to Late Eocene age can be postulated to be the youngest phase of the nappe structure in the Northern Limestone Alps. The overthrust of the Limestone Alps as a whole on the Flysch Zone also took place at this time, as the stratal sequence of the flysch nappes extends into the Lower Eocene (into the Middle Eocene in the east). The overthrust of the Flysch Zone on the Helveticum is placed into the interval successive to the Late Eocene. In the latest Late Eocene the molasse sedimentation began in Bavaria and Upper Austria.

As these overthrust movements are synchronous with those at the Eastern/Western Alps boundary (after Early Eocene) and those of the Lower Engadin window (after Late Cretaceous), an Early Tertiary age should also be presumed for the overthrust of the pile of East Alpine nappes on the Hohe Tauern (R. Oberhauser 1968); no direct evidence, however, is so far available.

The Mesozoic stratal sequences of the Central Alps continue into the Lower Cretaceous. The Upper Cretaceous age of the Schwarzeck breccia of the Radstädter Tauern is so little substantiated as that of the Gams conglomerates near Frohnleiten (north-west of Graz). Therefore, no safe evidence is available for the Central Alps themselves which would date confidently the nappe structure of the Eastern Alps (A. Tollmann 1963). The area west of the Saualpe, Koralpe and the Gleinalpe in the Central Alps had not been incorporated into the alpine nappe structure of the Eastern Alps (P. Beck-Mannagetta 1967).

Local overthrusts of post-Late Eocene age have been proved in the lower Inn-river valley (W. Heissel 1956; H. G. Lindenberg 1965). Of major importance is the overthrust of the Helveticum and flysch on the molasse, during which the Limestone Alps were also shifted northwards as a nappe (A. Kröll — G. Wessely 1967). It is of interest that the overthrusting occurred earlier in the west (before Aquitanian — R. Janoschek — K. Götzinger 1969) than in the east (post-Burdigalian). The Waschberg Zone was thrust over only after the Lower Helvetian (R. Grill 1968), as is deduced from the fact that the Upper Helvetian (Karpatian = Laa Formation) had not been affected by the movement. The last overthrust movements of the Eastern Alps took place in the Karawanken, where they also involved isolated Triassic blocks with the Sarmatian (and Pliocene?) F. Kahler 1953).

The uplift of the Eastern Alps into the present-day mountains of high and medium altitudes with outstanding Tertiary depressions was a process connected with the formation of faults and steep shear zones, which recurred during the Late Tertiary and seems not to be terminated up to date (earthquake lines).

The northern Greywacke Zone

In the Tyrol the Greywacke Zone is divided into two parts. In the north it is the "Wildschönau" Schists (phyllites with diabase) and a superjacent complex of limestones, dolomites, calcareous shales, graptolite shales, which are in places overlain (e. g. north-west of Bischofshofen) by Upper Carboniferous conglomerate ("Gainfeld Conglomerate") and the entire basal Triassic "green" Werfen Shales. In the south the Wildschönau Schists are overridden by a quartz-phyllite nappe, which has granite-augengneiss at the base and is sliced with other units. In the Oberpinzgau (Salzburg) this tectonic structure terminates. The question of the age of the deformation remains open.

Towards the east the Upper Carboniferous (conglomerates and graphite-slates with phyllite) appears first above and then intercalated in the greywacke complex. The Early Paleozoic series was thrown over the Late Paleozoic ones along the "Norian line", which truncates all the older structures (K. Metz 1965). The encompassed Central Alpine Triassic relics (A. Tollmann 1959/1963) suggest the possibility of the Veitsch nappe (2b) being a part of the (Middle Ostalpin) central Alps. The upper Norian nappe bears the Northern Limestone Alps on its Early Paleozoic complexes. The crystalline complex at the base of the Norian nappe should be derived tectonically from the Gleinalm and Koralm Crystallines (A. Hauser 1939); it continues east-northeastwards in the Vöstenhof Crystalline (H. P. Cornelius 1941; B. Plöchinger 1964) (see profile III).

Above the clastic Silbersberg Formation there are phyllites with porphyroids (Blasseneck Porphyroid). Near Eisenerz they have been dated as Lower Silurian by G. Flajs (1964). The following Devonian sequence is partly calcareous, partly schistose Early Paleozoic, which in many places has preserved the Variscan structures (W. Fritsch 1960).

Paleozoic of Graz

The Paleozoic of Graz lies on the crystalline basement with a tectonic contact. In the Paleozoic three series have been differentiated as "nappes". The lowest is the Schöckel nappe, built up of banded limestones and dolomites, which alternate and interfinger with phyllites and sericite schists. In the area of Voitsberg and north-west of Weiz (Raasberg), H. Flügel and V. Maurin (1958, 1960) have separated the Raasberg Formation and matched it as the "Central Alpine Mesozoic" with the Semmering Mesozoic because of their petrographic similarity. As the authors themselves do not think this assignment to be unquestionable and the connection with the rocks called "Schöckel Limestone" is confidently proved, this conception has not generally been accepted (P. Beck-Mannagetta 1970). The Paleozoic of Graz does not contain any non-metamorphosed series fully equivalent to this zone, and the similarity with the strongly sheared Semmering-Mesozoic is doubtless. But why should not appear at the base of the Lower Paleozoic the rocks similar in facies to those that form the base of the Triassic?

(Ch. Exner 1965). Finally, the Schöckel Limestone has been thought to be Devonian(?) (H. Flügel 1961, 1963, 1972) due to that the limestone belt within the clayey shales NW of Parmaseggkogel was defined as Schöckel Limestone (profile I). The Hochlantsch facies could be considered as the nonmetamorphosed (schistosed) Schöckel Limestone facies or as a deeper slice of the Rannach nappe (H. Flügel 1961, H. Flügel — H. P. Schönlaub 1972). The greywacke facies of Breitenau over which the Hochlantsch nappe was thrust northwards could reveal the relationship of the Graz Paleozoic to the northern Greywacke Zone (H. Flügel 1961, 1972. Upper Carboniferous with plant remains occurs fragmentarily). While the Schöckel Limestone facies represents a deeper, tectonically strongly sheared structural layer of the Graz Paleozoic, the interfingering of the Rannach and Hochlantsch facies is observable in the north-west. In the Rannach facies the whole series from the Upper Ordovician (?) to Lower Carboniferous are developed. K. Metz et al. (1964) have reported that the Greywacke Zone is limited in the south by major fault zones, along which the Rannach Formation (not the Rannach facies!) is squeezed in at several places. The southern boundary of the Greywacke Zone should be therefore an important fault line (profiles II, III).

The Veitsch nappe

The Carboniferous of the Veitsch nappe cannot be decidedly assigned to the Upper Carboniferous overlying the western North Greywacke Zone, because the Upper Carboniferous conglomerates occur together not only with graphite and talc schists but also with the fossiliferous Lower Carboniferous limestones and schists. It is questionable whether some of the limestones are assignable to the Upper Carboniferous. The underlying Rannach Formation is transgressive on the Seckau Crystalline, and it cannot be everywhere proved that it belongs to the Triassic base (probably to the Semmering Quartzite), as it comprises a more varied clastic rock complex, even with limestone layers ("Seitnerberg marble"), which are nowhere found in the quartzites of the Central Alps. Therefore, K. Metz (1967) separates on the Kallwang map-sheet the Central Alpine quartzites north-east of Wald definitely from the Rannach Formation. The clastic sequences which accompany the quartzites are thought to be Permian by some modern authors (K. Metz et al. 1964).

The Carboniferous of the Veitsch nappe is connected with the carbonate Devonian only at Triebenstein, but the tectonic conditions are there so complicated that the picture of the structure is fully obscured. The magnesites of the eastern Greywacke Zone crop out only within the Veitsch nappe. The presumed migmatic contacts between the Seckau crystalline and the Rannach Formation (K. Metz 1947/1953) are a definite contra-indication of the Permo-Scythian age of this sequence.

According to K. Metz (1958) the Seckau Crystalline represents a re-mobilized Gleinalm crystalline mass, whose feldspar is present in the Seckau Granite. An analogous interpretation has been applied to the Bösenstein in the west, which in the Late Tertiary was separated from the Seckau Crystalline by the Pöls fault, one of the faults of the Lavanttal system. The tectonic slicing with the Rannach Formation has been described by K. Metz (1965/1967). It is to be decided by further study whether the term "Rannach Formation" covers a uniform sequence or rock groups of different age but of the same facies.

The Radstädter Tauern

The Radstädter nappes lie on the Permian crystalline envelope and plunge eastwards beneath the crystalline Schladming mass. The crystalline cores of the nappes are made up dominantly of diaphthoritic granite-gneiss mylonites (Tweng Crystalline); quartz phyllites reach a greater thickness in the north. The quartz phyllites are overlain by the Central Alpine Mesozoic sequence (ZA), which is disrupted into a number of erected nappes and slices. The Pleisling facies (Permian -Lias) makes up the upper nappe groups in the north of the Radstädter Tauern; the lower nappe group consists of breccia-rich Hochfeind facies (Permian — Cretaceous?). This rests on the Penninic crystalline envelope and is differentiable into individual nappe blocks (A. Tollmann 1964). On the northern border the Radstädter nappes wedge out westwards, east of Lend. The zone is traceable southwards as far as north of Spittal a. d. Drau; at Obervellach it turns to north-west and west and extends as the Matrei Zone along the southern margin of the Tauern window. From Mittersill the Radstädter Mesozoic continues impersistently westwards, as part of the "Lungaurides" arc (L. Kober 1938) through the Gerloss pass into the Tarntaler Berge (profile IV).

The Semmering nappes

In the Central Zone of the Eastern Alps, the Semmering nappes form the eastern counter-limb to the Radstädter nappes. The Jurassic is generally absent from the Semmering Mesozoic. The Upper Triassic is developed as variegated Keuper (bunter Keuper) with gypsum, similar to that of the Carpathians. In the area of Semmering the Mesozoic formations are disrupted into steep slices, in which the crystalline splinters represents the pierced cores of anticlines. These plunging nappes composed of Triassic carbonatites are presumably the translated up to overturned fold fronts (A. Tollmann 1964, 1968). The Mesozoic beds of the Semmering nappes pinch out westwards in the crystalline complex. This steep slice structure recedes west- and eastwards in favour of broad synclines with Triassic troughs. In the facies of Central Alpine Mesozoic (ZA) they overlie the crystalline segments and submerge together with them under the Paleozoic schists. The Upper Ostalpin gneiss nappe-blocks lie on the coarse-granite (Grobgneis) sequence, which is overlain by the Semmering Mesozoic (Sieggraben, Schäffern).

Between the Radstädter and the Semmering Mesozoic intervenes the Stangalm Mesozoic (H. Stowasser 1947, 1956; P. Beck-Mannagetta 1964), which is closer in facies to the Radstädter development than to that of Semmering. All Middle and partly also Upper Triassic rock complexes can be developed as "pyrite" shales (Bockbühel Shale) and primarily interfinger with Triassic limestones and dolomites. The oolites in the Carnian, tuffs in the Ladinian (or Anisian?) and Cidaris Limestone are similar to the Triassic of Krappfeld (P. Beck-Mannagetta 1964). The sparse Jurassic sequence in the uppermost pile of slices recalls the Jurassic facies of the Radstädter Tauern. The Mesozoic is invariably overridden by Carboniferous conglomerates and phyllites of the Gurktal nappe (from south to north), being partly wrapped up (Flattnitz), and partly squeezed into the complexes of the southern Greywacke Zone (Stolzalpe; Murau, S). The age of other tentatively Mesozoic elements cannot be stated with certainty because of the lack of fossils (K. Metz 1954; A.

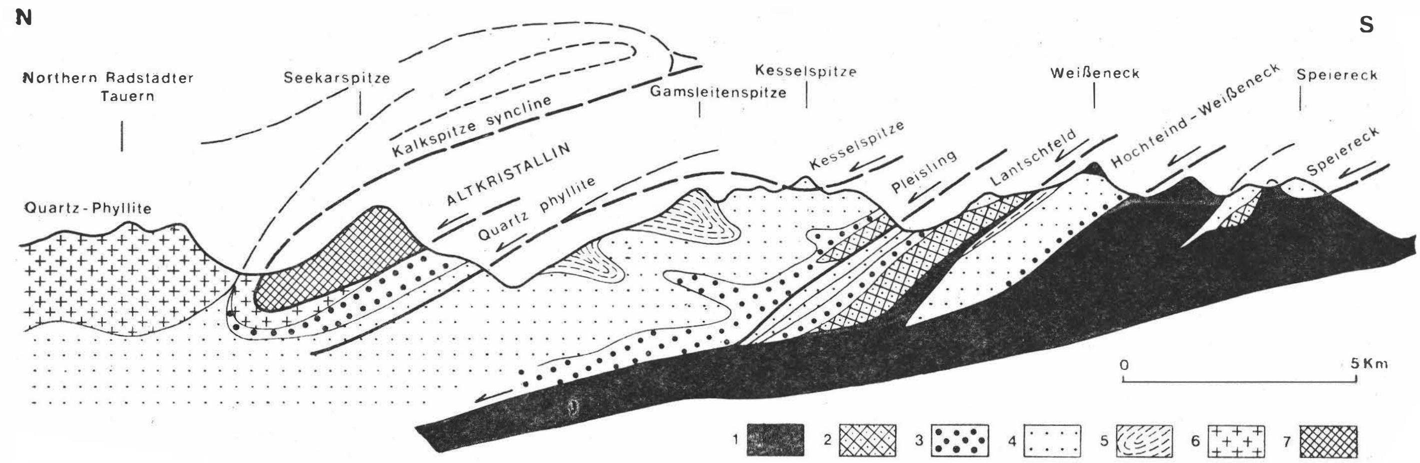


Fig. 5
Sketch section across the Radstädter Tauern to show the interpretation of A. Tollmann (1964)
1 — Schieferhülle (Penninicum), 2 — Tweng Crystallines, 3 — Permo-Scythian, 4 — Middle Upper Triassic, 5 — Jurassic to Neocomian, 6 — Paleozoic Quartz-Phyllite, 7 — Altkristallin Sht. metamorphics

Tollmann 1959; A. Thurner 1935, 1958; H. Flügel 1960; F. Kahler 1953/1962; P. Beck-Mannagetta 1964; K. Metz 1969; P. Beck-Mannagetta 1970).

Without any doubt, the basal Triassic of Zwischenberge should be ranged as a squeezed-in remnant to the Lienz Dolomites (Ch. Exner 1962); tectonically it represents a mirror-image of the Mandling sector branching off from the Northern Limestone Alps. The two last-named occurrences of the Triassic are unknown to have been overridden by older nappe units. For this reason they can be regarded as transitional tectonic units between the Radstadt-Stangalm Triassic and the true Upper Ostalpin sequences of the Eberstein Triassic.

The crystalline units of the Central Zone of the Eastern Alps are divided according to K. Metz (1965), just as they are in the attached sketch based on the "Tectonic Map of Styria" (P. Beck-Mannagetta 1970 — fig. 2).

Both the Schladminger Tauern and the western Niedere Tauern are built up of granodiorite cores which pass through migmatites into the pre-alpine crystalline envelope (profiles I, IV). It has been established that the amphibolite facies had been converted into greenschist facies (diaphthoresis) along the movement surfaces, in connection with the overthrust on the Lower Ostalpin complexes. The splinters of quartzite and phyllite divide the crystalline complex, from the base upwards, into several units (H. P. Formanek 1964). These conceptions are contrary to those propagated by the Graz geological school (K. Metz 1962, 1965), according to which the granites and their migmatite zones had undergone alpine mobilization. A well-defined boundary exists in the north against the Ennstal quartz phyllite, in which the greenschists (metadiabases) and marbles of Paleozoic (?) age, particularly in the west, are interlaid. The lower parts of the Wölz Mica-schists are thought to be the cover of the Schladming Crystalline. They contain pegmatites (pegmatoids) and can also be distinguished on the basis of their disthene or staurolite content. The superjacent sequence with graphitic quartzites or the Bretstein Marble might be metamorphosed Early Paleozoic rocks.

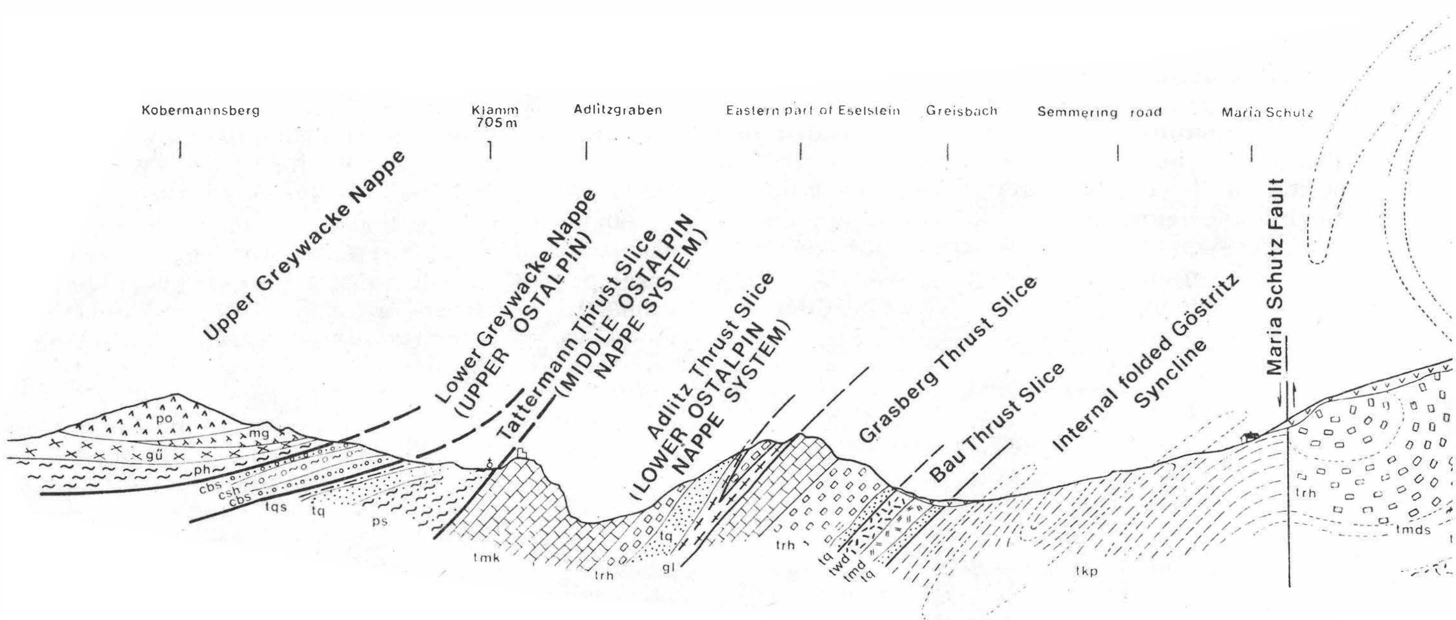


Fig. 6
Cross-section through the Semmering System and its border along the meridian of Sonnwendstein (A. Tollmann, 1966)

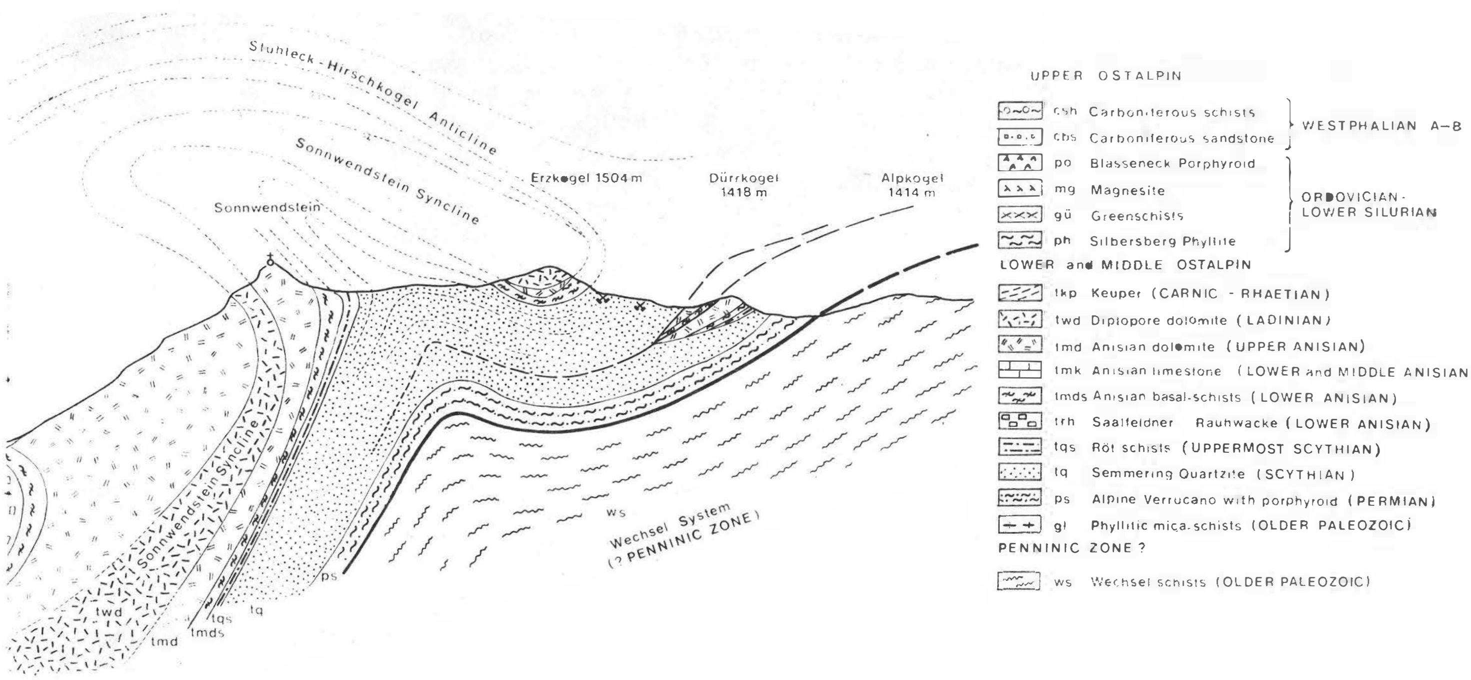
Farther in the east, the certainly proved Triassic beds are not incorporated in the crystalline of the Niedere Tauern (2f on schematic map, K. M e t z 1969).

The Gleinalm Crystalline

Towards the Bösenstein-Seckau massif and farther to the south-east the Gleinalm Crystalline predominates over the Wölz Mica-schists. The core is built up of Gleinalm Granodiorit-gneiss, which grades through migmatites into its amphibolite envelope (F. A n g e l 1925); the granite and augengneiss of the Amering massif form the other part of this core (F. H e r i t s c h — F. C z e r m a k 1923). The isolated occurrences of banded gneiss are south of Bösenstein, at the Gaaler Höhe, as well as the window-like outcrops of microcline granite gneiss south-west of Judenburg (A. T h u r n e r 1966; K. M e t z 1969) and south-east of Wolfsberg (P. B e c k - M a n n a g e t t a 1951). In the Gleinalpe the core is encompassed by an envelope of amphibolites (with serpentine: Kraubath, Hochgrößen, Utsch) and garnetiferous mica-schists. These rocks pass upwards into a marble-rich sequence. The garnetiferous mica-schists of the Graden Formation close the sequence which may extend upwards as high as the lower phyllite layer. These envelope members of the Gleinalm Crystalline compare well with the envelope members of the same facies of the Niedere Tauern (Wölz Mica-schists) and no sharp boundary can be drawn between the individual rock sequences (K. M e t z 1969). In contrast to the Schladming crystalline complex, the splitting of the mass by the Mesozoic rocks is not observable. In the north there is a transgressive contact with the conglomeratic quartzites which resemble closely both the quartzite of the Rannach Formation and the Semmering Quartzite. The envelope complexes pass into the Koralm Crystalline southwards (profile IV).

The Koralm Crystalline

As the Gleinalm Crystalline is invariably in tectonic contact with the demonstrably Paleozoic sedimentary series, the position of the Koralm Crystalline is of primary importance. In the north, it develops from the upper envelope member of the Gleinalm Crystalline in the Stubalpe through the pegmatoid (venoid) permeation of the rock mass, instead of by true migmatic gneissization or granitization. The primary disthene recedes and (several times crushed) disthene paramorphs after andalusite are typomorphic mineral forms (P. B e c k - M a n n a g e t t a 1960; O. H o m a n n 1962). Eclogite-amphibolites form instead of amphibolites (N. W e i s s e n b a c h 1963; P. B e c k - M a n n a g e t t a 1961), and eclogite-gabbros represent the gabbroid rocks (A. K i e s l i n g e r 1928; H. H e r i t s c h — F. B o s s e r t 1970). In the calc-silicate schists the group includes plagioclase as bytownite (W. F r i t s c h 1962). Within the large mass of venoid gneisses and mica-schists (P. B e c k - M a n n a g e t t a 1967) the gneisses dominantly occupy the middle layer above the marble complex. The "Plattengneis" extending from south-west to north-east shows a cataclastic N-S lineation, which displays post-tectonic recrystallization of different degree; in the north it is shifted to the north-east and in the south to the south-east, as can be demonstrated on metre- and kilometre scales (P. B e c k - M a n n a g e t t a 1954). The Koralm crystalline complex is above and below mantled by normal garnetiferous mica-schists and interfingers with them laterally. The upthrusts of underlying complexes (Gleinalm crystalline complex — 2i schematic map, fig. 2) are partly accompanied by diaphthoritic recrystallization (Wolfsberg window — A. K i e s l i n g e r 1929; P. B e c k - M a n n a g e t t a 1951; Kliening window — A. P i l g e r — N. W e i s s e n b a c h 1965; Auerling window — P. B e c k - M a n n a g e t t a 1967), and in places there exist transitions between the rock series (Stubalpe: F. H e r i t s c h — F. C z e r m a k 1923; west of Judenburg: A. T h u r n e r 1966; Trahütte upthrust; P. B e c k - M a n n a g e t t a 1968). No substantial difference between the under- and overlying garnetiferous mica-schists has been found yet. In trying to characterise these peculiar depositional conditions (P. B e c k - M a n n a g e t t a 1949, A. P i l g e r — N. W e i s s e n b a c h 1965), we can say that the two rock complexes (the Gleinalm to Koralm Crystalline; Murides and Korides, L. K o b e r 1938) occur persistently in an analogous position from the Eastern Tyrol to the Burgenland (F. H e r i t s c h 1932). The structural plan of the two crystalline series



is pre-alpine and predominantly Variscan (E. Clar et al. 1963); in its eastern autochthonous sector (roughly east of Krappfeld Triassic) it broadly represents the western end of the Pannonian mass (P. Beck-Mannagetta 1967).

The uppermost part of the Koralm crystalline complex in the Saualpe contains well-evidenced Early Paleozoic (G. Kleinschmidt 1966) in the Wandelitzen Formation (P. Beck-Mannagetta 1957). The Lower Paleozoic was affected by increasing Variscan metamorphism and the petrographic (sedimentary?) sequences are divided into 7 to 8-times repeated alternations of marble-rich and amphibolite-rich rocks (E. Clar et al. 1963, F. Thiedig 1966). Some rock types do not appear repeatedly, on the contrary, they are significant marker horizons (serpentinites). No "Plattengneis" horizon was formed in the Koralm crystalline complex in the Saualpe and west of it. The disthene-bearing flaser gneiss is there dominant, corresponding presumably to the mica-rich border zones of the "Plattengneis" in the Koralpe. The N-S lineation of the "Plattengneis" tectonics is not widely developed in the western area either. The axial rotations, however, have also been described from the southern Saualpe (F. Wurm 1968).

The Lower Paleozoic shows increasing metamorphism downwards and a Variscan nappe structure (metadiabase = Magdalensberg Formation, Ordovician?, on the calcareous phyllite of the Wandelitzen Formation (Devonian?). The transgressive Upper Carboniferous (G. Riehl-Herwisch 1965) or Permian, which lies on it, forms the base of the Triassic. Following is the conformable (probably North Alpine) Triassic sequence and, after a large hiatus, the Gosau Formation with Coniacian beds at the base (J. E. van Hinte 1963, P. Beck-Mannagetta 1964; R. Oberhauser 1963). In Krappfeld the Paleocene is missing and the Lower and (?) Middle Eocene occur immediately above. The fauna and the facies sequence gravitate rather southwards to Pohorje (Bacher) and into the Dalmatian region (Cuneolinen) than to the Gosau Formation of the Northern Limestone Alps.

West of Görtschitztal fault line, a crystalline complex of amphibolite facies is overlain by a sequence of the southern Greywacke Zone. North of the Glantal the Lower Paleozoic plunges somewhat obliquely into the crystalline mass (P. Beck-Mannagetta 1959, H. Hajek 1962). In the valleys Wimitz-, Gurk- and Metnitztal the schistose lower Paleozoic mantles this crystalline complex. The emplacement of the metadiabase complex on the Murau calcareous phyllites is presumed to correspond to a Variscan overthrust (A. Thurner 1958; P. Beck-Mannagetta 1960).

Between Friesach and Gurk, near Oberhof and in Wimitz the crystalline mass emerges without being accompanied by any Mesozoic slices. Farther westwards the flat-undulated structure of the Gurktal nappe stretches over the Central Alpine Mesozoic from Bad Kleinkirchheim to Flattnitz. The metadiabase complex extends below the Karawanken range, north of the Periadriatic suture and belongs to another formation (Lower Carboniferous; Ch. Exner — H. P. Schönlaub 1973).

Whereas the crystalline complexes similar to the Bundschuh mass emerge nowhere below the Early Paleozoic of Central Carinthia, in the Oberhof block it shows relations to the Niedere Tauern and in the Wimitz valley to the Seen Crystalline in south. The Variscan Villach Granite penetrated the Seen crystalline rocks, giving rise to pegmatites in the crystalline rocks (north of Wörthersee) between Tigring and Spittal a. d. Drau. The accessory components of these pegmatites cannot therefore be associated with the pegmatoids of the Koralm Crystalline (wollastonite; B. Plöchinger 1953; cassiterite: H. Schroll 1967). The Radenthein garnetiferous mica-schists represent a special contact zone. The interbedded spathic magnesite is primarily Devonian in age, as is that of Lanersbach in the Tux Alps (R. Höll et A. Maucher 1967).

The Bundschuh Crystalline (fig. 2) which continues west and northwards seems to possess an inverse position in many places, as the garnetiferous mica-schists submerge below the paragneisses and these, in turn, below the Bundschuh granite-gneiss. This underlies the Central Alpine Mesozoic of the Stangalm (ZA). In the western extension the East Alpine crystalline complex of the Kreuzeck group and the Defreggen area, south of the Tauern window, bears small granite and augengneiss bodies, which are embedded in a voluminous mass of paragneiss and mica-schists. Of importance is the pre-Triassic age of the "Schlingentektonik" (O. Schmidegg 1937; W. Senarclens-Gracy 1965), which is traversed by NW-SE striking Triassic limestone belt. The steeply pitching structure (Schlingentektonik) affected in the west the border of the Thurntal quartz phyllites, which represent the deeper part of the Lower Paleozoic.

The Lienz Dolomite and the Drauzug north of the Pustertal-Gailtal line (Periadriatic suture) contain Triassic rafts densely sliced and steep crected. The Triassic base is formed of "Gröden Beds" (Permo-Scythian sandstone); the Bellerophon beds (Upper Permian) are lacking (W. Schlager 1962). The Permo-Triassic of the Lienz Dolomite is transgressive on the crystalline basement. The Mesozoic sequence reaches as high as the Neocomian. The Gailtal Alps are built up solely of Permo-Triassic rocks and are disrupted into slices by steep faults. The Partnach Formation (clayey-marly Ladinian) locally replaces the Wetterstein Limestone and Dolomite in the western sector. The Pb-Zn mineralization of the Raibl Formation persists partly into the Hauptdolomit, where it occurs in traces. The Dobratsch massif presumably contains the Norian Dachstein Limestone (N. Anderle 1951), which is underlain by the terrigenous early Upper Carboniferous and marine Lower Carboniferous (Nötsch: K. O. Felser 1938).

The segment of the Gailtal Alps, which ends near Villach, continues from Festritz in the valley Rosental as the Northern Karawanken. The Mesozoic nappe structure, whose upper nappe consists of Permian to Hauptdolomit and the lower one of Hauptdolomit to Neocomian (J. Stiny 1938; F. Kahler 1953) was revived in Late Tertiary (Pliocene?). The Late Tertiary (Rosenbach coal beds: Lower Sarmatian, A. Papp 1951) forms steep slices in the Triassic blocks, irregularly limited. In the west emerges the basal Lower Paleozoic, and the Gailtal Crystalline (H. Heritsch — P. Paulitsch 1949, 1958) in the southern part of the Northern Karawanken, where it was hidden beneath the Triassic over long distances. The Upper Pliocene Bärental Conglomerate is still partly steeply erected. The Upper Pannonian Sattnitz Conglomerate, which occurs north of the Karawanken can be interpreted as molasse assignable to the youngest orogeny of the Eastern Alps.

Southern Alps

South of the Gailtal line (Periadriatic suture) there is an area of Variscan nappe structure in the Carnic Alps (F. Heritsch 1936). The nappe members built up of Upper Ordovician, Silurian and Devonian to basal Lower Carboniferous are divided by the Hochwipfel Formation (Lower Silurian to lower Upper Carboniferous), which is of synclinal disposition (profiles IV, V). The mapping of the presumable Silurian schist portions in the Hochwipfel Formation has not yet been completed. The disruption of the nappes invariably increases downwards, and the clayey shales are converted into quartz phyllites, particularly in the west. Marine Upper Carboniferous and Permian lie unconformably on the Variscan nappe structure. The Permian sea of the Southern Alps has been denoted as Paleotethys; it is evidenced, in some places of the south-eastern Dinarides, and left its traces throughout Hungary as far as the South Gemerides and farther to East Asia. In the north, all marine Permian is absent; traces of Permian volcanism appear as quartz porphyries and their tuffs in the clastic sediments farther northwards. The Bellerophon horizon with the Upper Permian dolomite is correlated with the "Haselgebirge" of the Northern Alps. The Gröden Formation overlying the Bozen Quartz-porphyry is partly represented by the Permo-Scythian sandstone or conglomerate north of the Alpine-Dinaric line (F. Kahler — S. Prey 1963, G. Riehl-Herwirsch 1970, 1972).

In the Southern Alps the remarkable unconformity between the Triassic beds and the underlying Upper Paleozoic is not at all developed.

A symmetrical flat fold-thrust of the South Alpine Triassic on the Paleozoic of the Carnic Alps recedes eastwards to an imbricate structure, slightly north-vergent and steadily more compressed. The east-west Triassic tracts had been by this process pinched steeply in the midst of it. Between the Southern Karawanken and the massif of the Steiner Alps, in the proximity of the Seeberg Pass and near Trögern, appears Lower Paleozoic (down to Silurian) beneath the Upper Paleozoic. The former is developed in the facies of the Carnic Alps (J. Rolser 1968).

The Eisenkappel Granite directly contacts the schists adjoining it in the south and bears metadiabase in the north (Ch. Exner 1972). No such contact forms are known from the flaser-tonalite in the south. Because of the tectonic limits on all sides, these Periadriatic granites and slightly older flaser-tonalites have not yet been unequivocally dated (H. P. Cornelius 1949; Ch. Exner 1960).

All mountain tracts of the Karawanken are in the east truncated at a sharp angle by the Donati fault, which is the southern continuation of the Lavanttal fault: at the same time they are shifted south-eastwards (A. Kieslinger 1928). The Lower Paleozoic of the southern Saualpe border is displaced along the Lavanttal wrench fault by about 20 km southwards relative to the southern margin of the Koralpe. The diaphthorite zone of the southern Koralpe is overlain by the Paleozoic phyllites and pebble-bearing banded limestones. In the Remschnigg-Possruck Mountains occur relics of Upper Carboniferous, Triassic and Upper Cretaceous, which compare in facies to the occurrences in the St. Paul Mts. South-west of Arnfels there is a broad ultramylonite zone between the Koralm Crystalline and the Paleozoic; along this zone the phyllites were overthrust in the north (A. Winkler-Hermaden 1933; F. Bauer 1965).

The Grobgneis (coarse-gneiss) series

The crystalline complex in the north-east of the Graz Paleozoic was denoted as Raabalpen Crystalline by R. Schwinner (1951). H. Flügel (1963) ranged this crystalline complex to the Pretul nappe. In addition to coarse-grained granite (gneiss), fine-grained gneiss and augengneiss occur in the form of lenses and irregular blocks. At their contact with the cover made-up of garnetiferous mica-schists, migmatites are partly developed. In the cover there are occasionally contact rocks (H. Wieseneder 1961), which are absent from all other East Alpine rock complexes. Associated with the alpine-increased diaphthoresis was a Mg-supply which gave rise to talc deposits of Rabenwald (O. M. Friedrich 1946).

North-east of Graz emerges the Radegunder Crystalline below the mylonite zone of the boundary phyllites of the Graz Paleozoic. The crystalline consists of a zone with staurolite-garnet mica-schists and a lower zone of pegmatoid mica-schists and gneisses of Koralm type. Apatite-bearing quartz veins and aplites invade the Paleozoic schists in places (O. Homann 1959).

In the Sieggraben nappe block appear the biotite gneisses above the Grobgneis series and are, in turn, overlain by disthene-bearing flaser gneiss with eclogite amphibolites (F. Kümel 1934, 1937; H. Wieseneder 1934). The sequence corresponds fully to the conditions of the Gleinalm and Koralm Crystallines: a north-south lineation is well observable in the gneisses, particularly of the latter complex (K. Lechner 1957). The eclogite of Schäffern and partly also the garnetiferous mica-schists near Vorau probably occur in the same position (H. Holzer 1960).

The Lower Ostalpin Grobgneis series with its cover of presumably Permo-Carboniferous conglomerates and the Semmering Mesozoic, extends eastwards into the Leitha Mountains. North-east of the Brucker Pforte the Mesozoic facies seems to change: Ballenstein Limestone and Dolomite in the Malé Karpaty Mts. contact the envelope of the autochthonous cores of the Tatrides.

The Wechsel window

The Grobgneis series lies on the rocks of the Wechsel window in the west, and on the Rechnitz Formation in the southeast (A. Tollmann 1967). In the upper parts the Wechsel rocks are greywackeous schists with graphite pigment. The alpine albitization of these schists increased downwards to such degree that albite gneisses and albite-rich greenschcists were formed. Their albite porphyroblasts contain inclusions, which show a syntectonic growth of albite. The metamorphism is thought to be alpine crystallization (P. Faupel 1967). The dying out of albitization and the lack of Mesozoic rocks southwards makes it difficult to draw a tectonic boundary against the Raabalpe Crystalline. Albitization has occasionally been established even in this crystalline complex (R. Schwinner 1940).

The Rechnitz Unit

It has been mentioned above that it is questionable whether the Wechsel crystalline should be assigned to the Lower Ostalpin or to the Penninicum. It is likewise uncertain whether the Rechnitz Unit is assignable to the Penninic crystalline envelope or to the greywacke-Paleozoic. New fossil finds point to a Cretaceous age of the calcareous phyllites; this is an other indication for the Penninic character of the Rechnitz Unit (profiles I, II; H. P. Schönlaub 1974).

The dominant composition of calcareous phyllites (with rauhwacke, quartzites and schistose conglomerate) is undoubtedly similar to the upper sequences of the Penninic crystalline envelope. The occurrence chiefly beneath the coarse gneisses confirms the "window" character: the Wechsel unit is overlain by the Rechnitz Unit in the east, and albitization or other alterations are unknown from the latter in the greenschist facies. From the Hungarian sector of this unit Devonian and Carboniferous fossils have been reported, in the south the units adjoin the Lower Paleozoic ferruginous rocks, which do not show any change in sedimentary or metamorphic facies. The tectonic conclusions inferable from these facts are of primary importance, as they would provide an additional reliable proof for the existence of a Penninic window (A. Pahr 1960, 1972; A. Erich 1961, 1966; H. P. Schönlaub 1973).

Lower Tertiary in the Inner Alpine Tertiary basins

Stratigraphically, the Inner Alpine Tertiary basins are considered to be an unconformable Inner Alpine Molasse, which had not been incorporated in the Cretaceous-Early Tertiary nappe structure of the Limestone and Central Alps. Therefore, the molasse formations appear as late as in the Late Eocene; the

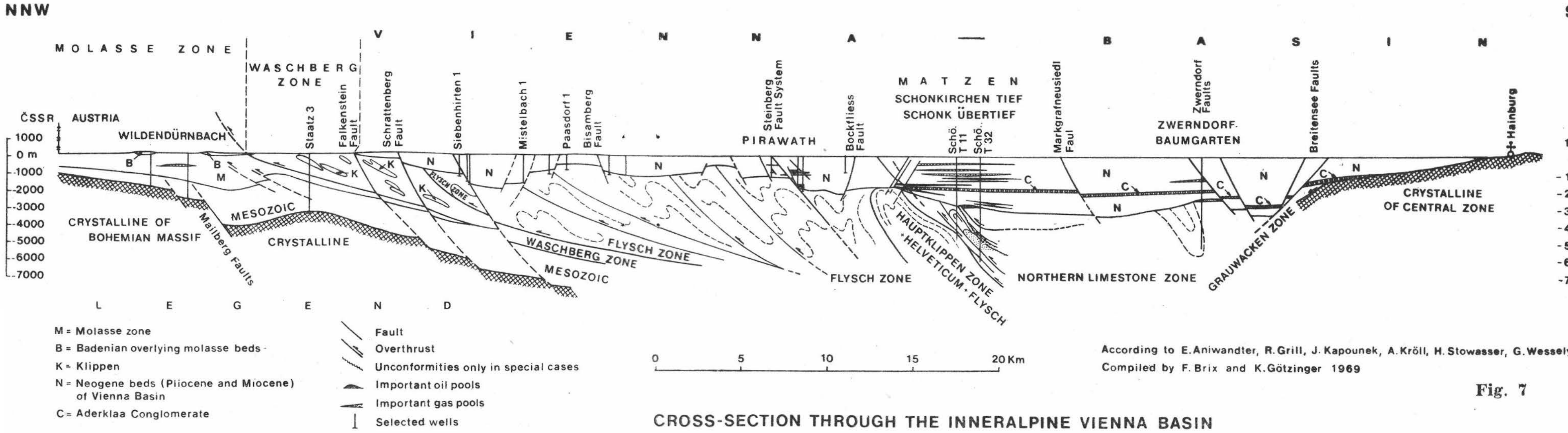


Fig. 7

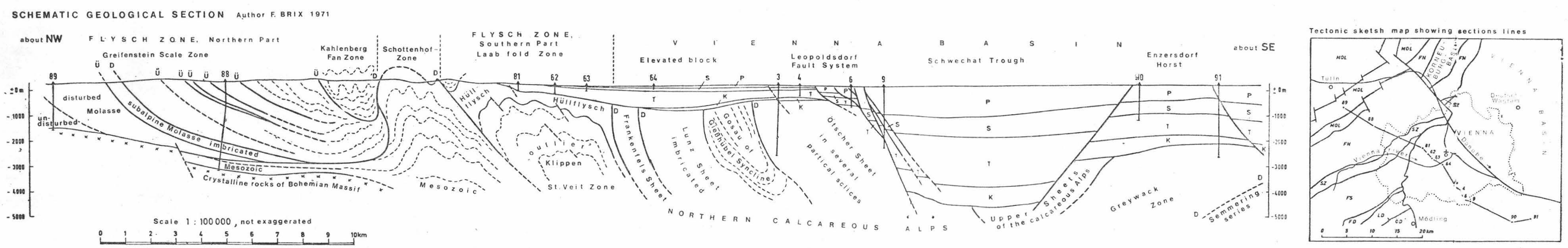


Fig. 8
Abbreviation of tectonical units and names of the formations as shown in the geological section and scale map

Mol	Molasse zone
FN	Flysch zone, northern part
FS	Flysch zone, southern part
SZ	Schottenhof zone
FD	Frankenfels nappe
LD	Lunz nappe
ÖD	Ötscher nappe
P	Pannonian
S	Sarmatian
T	Badenian („Tortonian")
K	Karpatian (Laa strata)
D	Line of outcrops of nappe boundaries
Ü	Line of outcrops of scale boundaries
90 ↑	bore-holes

Lower Eocene (when developed) joins the basins with Gosau Formations.

The oldest separate Tertiary basin is the so-called Inntal Molasse, which stretches from the lower reach of the Inntal east-northeastwards to Reit im Winkel.

The Oberaudorf Formation of Upper Eocene age is developed only in the north of the squeezed-off part of the Thiersee syncline of the Lechtal nappe. South of this disturbance, on the Inntal nappe, there are the Häring and Angerberg Formations, which comprise the entire Oligocene. Their Upper Eocene base cannot be defined. The Lower Oligocene Häring Formation is divisible into a northern marine part and a limnic (and brackish) southern part: their equivalent beds correspond to each other. Later on, the southern part became also marine, and the Angerberg Formation continues without break upwards (limnic Upper Oligocene — H. G. Lindenberg 1965).

In the Häring basin the transgressive contacts with the pre-Tertiary beds are exposed. The basin is dissected by SW-NE trending faults. From Kufstein to the south of Walchsee, the Kaisergebirge nappe had overridden the Inntal Tertiary as an overturned syncline: farther to east-northeast the overthrust passes into a flat synclinal structure.

Other Lower Tertiary relics occur near Willendorf (B. Plöchinger 1967), north-west of Untersberg (A. V. Hillebrandt 1962), Kirchberg am Wechsel, etc. Otherwise the Eocene rocks are found as pebbles embedded in the fillings of small Late Tertiary basins in the Enns valley and north of the Central Zone (R. Janoschek 1964). In Carinthia, the Eocene pebbles seem to be derived from the Southern Limestone Alps (F. Kahler 1949; A. Papp — F. Kahler 1968).

Inner Alpine Vienna Basin

The Inner Alpine Vienna Basin is the most important Late Tertiary basin within the Alps (R. Janoschek 1964).

In the north of the Vienna Basin stretches a complex of Burdigalian Schlier east-westwards across the present-day basin, and represents the tectonically interrupted connection between the Molasse Zone (Outer Alpine Vienna Basin) and the Schlier of the Slovak-Hungarian region. This sequence, which does not crop out anywhere in the Inner Alpine Vienna Basin, becomes freshened upwards in the Helvetian, chiefly north of the Spannberg Rücken. During the uplift of the Flysch Zone, the Korneuburg basin was downfaulted in the Upper Helvetian (Laa Formation-Karpatian; fig. 8). The uplift of the Flysch Zone persisted still in the lower Tortonian. At that time the deep marine beds of the lower and particularly the upper Lagenidae zone of the Baden Formation extended into the Vienna Basin, as far as the Semmering area (F. Brix 1972). The Vienna Basin was strongly downfaulted in the north-south direction along the eastern margin of the Limestone Alps; since the Middle Tortonian (Baden Formation — Spiroplectammina Zone) it was disrupted by step-like faults in the west and east, so that the facies in the marginal and inner parts of the basin differ. Great differences consequently also exist in the thicknesses of bed complexes of the same stratigraphic range (e. g. the thickness of the Baden Formation is 100—600 m in elevations and 1500 m in depressions). The extensive freshening and retreat of the sea was followed by the ingression of the brackish Sarmatian sea. In the Lower Sarmatian, the Tortonian beach deposits (Leitha Limestone and Conglomerate) were partly reworked.

The Sarmatian regression was followed by the ingression of a Caspian-brackish Pannonian "freshwater" sea, the sediments of which are higher replaced by purely limnic-fluviatile deposits. The tendency to subsiding along the faults decreased and the formation of faults was more and more restricted to the interior of the basin. As a result, the margins of the basin rose in the west and east and the supply of detritus became progressively less important. In the central parts of the basin the Early Pleistocene gravel in the Mitterndorf — Lassee depression are sunken to a depth of 100 m (J. Stiny 1932; R. Grill 1968). The total subsidence in the interior of the Vienna Basin must be more than 5500 m.

Other Inner Alpine basins

The Augenstein gravels on the plateau of the Northern Limestone Alps are presumably connected with the Burdigalian to Lower Helvetian basal gravel between Hieflau and Wagram (A. Winkler-Hermaden 1957; A. E. Tollmann 1962). The Augenstein gravels derived from the quartz gravels transported northwards from the Greywacke Zone and the Central Alps. A. Winkler-Hermaden (1957) connects them with the molasse gravel deposits near Salzburg, which are of the same age.

The disruption of the East Alpine central zone in the Late Tertiary occurred mainly on the tectonically predisposed planes of weakness, where Late Tertiary coal basins subsequently originated. They developed along the Mur-Mürz line, along the Lavanttal fault zone (A. Kieslinger 1928) on the northern and southern margins of the Niedere Tauern, and in the Klagenfurt area in the Helvetian and Tortonian. These extend as far as the Tauern window but did not get any sedimentary material therefrom, as is evidenced by the window itself, subsequently exposed by erosion.

Whereas in the Tertiary Central Alpine coal-bearing basins the fluviatile and Caspian-brackish (Fohnsdorf) sediments were deposited at that time, marine sedimentation extended to the Karawanken region (A. Papp — E. Weiss 1956) and especially to the lower course of the Lavant valley, and seems to have been connected with the Styrian Tertiary basin. All of the basins, however, are disrupted by faults. The Styrian coal basins (W. Petraschek 1922/1924, K. Metz 1972) are bounded by faults particularly in the north (asymmetrically). In the Karawanken area even major overthrusts occurred.

At the time of the Mediterranean II in the Laa Formation (Karpatian) and especially at the time of the Baden Formation, a large communication must have existed between the marine western Pannonian Basin and the Adriatic sea in the south-western direction (A. Papp — E. Weiss 1956).

The tectonic segmentation of the Styrian basin (K. Kollmann 1965) does not show the character of a downfaulted basin as does the Vienna Basin. It arose rather by extensive subsidences, and no faults are demonstrable in the interior of the basin. The local downfaulting at the boundary against the core mountains is not traceable inwards. However, the increase in tectonic intensity southwards can be presumed (A. Kieslinger 1929: Radl Conglomerate).

The coal-bearing Helvetian freshwater beds recede east of the Sausal sill to the marine Upper Helvetian (Karpatian) of a great thickness. The unconformity between the Helvetian and the Tortonian below (Schwanberg Gravel), which becomes more marked towards the west, disappears eastwards and can be only evidenced on microfaunal grounds. The marine Lower Tortonian with andesite-dacite tuffs completely fills the Florian basin and spreads westwards into the lower Lavanttal and into the Karawanken. In the Lower Sarmatian a wider connection with the lower course of the Lavanttal could have existed only west of Graz through and beyond the Koralpe (P. Beck-Mannagetta 1952/1960). The Lower Sarmatian in the limnic facies is included in the Karawanken range, so that the Pliocene gravel remnants occur in many places independent of the Lower Tertiary complexes (e. g. Gurktal gravel).

In the north of the Styrian basin the deeper Helvetian freshwater beds are overlain unconformably by the Tortonian sands and "Tegel". The area of the Neusiedler Lake is connected with the Vienna Basin via the Ebenfurth depression. Whereas the Pannonian sediments attain exceptionally great thicknesses, the Miocene sequences are sparse. The downfaulting of the area of Neusiedler Lake took place therefore in the Pannonian or later. The sedimentary and tectonic conditions persist into the Lesser Hungarian Plain, where the Pannonian, being tilted, attained a thickness of several thousand metres.

Two volcanic phases are distinguished in the Styrian Tertiary: The first, Helvetian-Lower Tortonian phase is associated with the volcanism of the Pohorje (Bachern) area, and andesites, dacites, latites and their tuffs were produced: the Weitendorf basalt from the southern vicinity of Graz is assigned to it (H. Flügel — H. Heritsch 1968). During the second phase the basalt effusions and tuffs penetrated into the Dacian-Levantinian horizon of the Upper Pannonian. The influence of both the volcanic phases reaches as far as the Lavanttal (P. Beck-Mannagetta 1957; E. Zirkl 1962). The dacite tuffs of Upper Helvetian date were first found in the Vienna Basin in 1969 (J. Kapounek — A. Papp), but in the Inner Alpine coal basins the Helvetian acid tuffs have already been recognized several times (W. Petraschek 1940).

REFERENCES

ANGEL, F. 1925: Das Gleinalpengebiet als metamorphe Einheit. — N. J. Min. Beil. Bd. 51. Stuttgart. S. 213 — 239.

ANGENHEISTER, G. — BÖGEL, H. — GIESE, P. — SCHMIDT-THOMÉ, P. 1972: Recent investigations of surficial and deeper crustal structures of the Eastern and Southern Alps. — Geol. Rdsch. Bd. 61, S. 349—395.

BECK-MANNAGETTA, P. 1965: Über geologische „Baueinheiten" und ihre Darstellung. — Carp. Balk. GA. VII Cong. Sofia. Reports I, S. 119 — 121.

BECK-MANNAGETTA, P. 1967: Die „venoide" Genese der Koralpengneise. — Mitt. Mus. Joanneum Abtg. Miner. Graz. S. 6 — 10.

BECK-MANNAGETTA, P. 1967: Über das Westende der Pannonischen Masse. — Mitt. Geol. Ges. in Wien Bd. 59. Wien. S. 139—150.

BECK-MANNAGETTA, P. 1969: 2. Versuch einer tektonischen Gliederung der östlichen Zentralzone der Ostalpen. — Anz. Österr. Akad. d. Wiss. math. nat. Kl. Wien S. 70—73.

BECK-MANNAGETTA, P. 1970: Tektonische Karte der Steiermark 1 : 300 000. Steiermarkatlas 1968. Graz. Akad. Verl.

BECK-MANNAGETTA, P. 1970: Über den geologischen Aufbau der Koralpe. — Verh. Geol. B. — A. Wien. S. 491 — 496.

BRIX, F. 1970/72: „Naturgeschichte Wiens", Geographie, Geologie, Erdgeschichte Bd. I. 1, S. 27—190; Bd. III, S. 5—32: Erläuterungen zur geologischen Karte der Stadt Wien; Jugend u. Volk; Wien.

CORNELIUS, H. P. 1952: Gesteine und Tektonik im Ostabschnittt der nordalpinen Grauwackenzone, vom Alpen- bis zum Aflenzer Becken. — Mitt. d. Geol. Ges. Wien. Bd. 42 — 43, 1949/50, S. 1 — 234.

EXNER, CH. 1954: Die Südost-Ecke des Tauernfensters bei Spittal an den Drau. Jb. Geol. B. — A. Wien. Bd. 97, S. 17 — 37.

EXNER, Ch. 1972: Geologie der Karawankenplutone östlich Eisenkappel, Kärnten. — Mitt. Geol. Ges. in Wien Bd. 64, S. 1—108.

EXNER, CH. — FAUPL, P. 1970: Die Anorthitgehalte der Plagioklase in einigen Gesteinsgruppen der zentralen Ostalpen. Verh. Geol. B. — A. Wien. S .245 — 266.

FAUPL, P. 1971: Zur Geologie des NW — Abschnittes des Wechselgebietes zwischen Rettenegg und Feistritz — Sattel (Steiermark, Österreich). — Mitt. Geol. Bergb. St. 19, 1970. Wien. S. 27 — 70.

FLAJS, G. 1967: Conodontenstatigraphische Untersuchungen im Raum von Eisenerz, Nördliche Grauwackenzone. — Mitt. Geol. Ges. in Wien. Bd. 59/1966, S. 157 — 212.

FLÜGEL, H. 1961: Die Geologie des Grazer Berglandes. Mitt. Mus. Berg. Geol. Tech. Joann. Geol. H. 23. Graz. S. 1 — 212.

FLÜGEL, H. 1972: D. Das Paläozoikum von Graz. — Führer zu den Exkursionen der 42. JV. Pal. Ges. in Graz, Joan. Geol-Pal. Abt. Graz, S. 117—140.

FLÜGEL, H. — SCHÖNLAUB, H. P. 1972: Geleitworte zur stratigraphischen Tabelle des Paläozoikums von Österreich. — Verh. Geol. B. A. Wien. S. 187—198.

FRITSCH, W. 1962: Erläuterungen zu einer neuen geologischen Übersichtskarte von Kärnten 1 : 500 000. Klagenfurt. Car. II Jg. 72. S. 14—20.

GAAL, G. 1965, 1966: Geologie des Rosskogelgebietes W Mürzzuschlag (Steiermark). Mitt. Geol. — Bergb. St. Wien. 16, S. 105 — 148.

HERITSCH, F. 1932: Die Stellung der Eklogitfazies im oberostalpinen Kristallin der Ostalpen. — Centralbl. Abtg. B. Stuttgart. S. 27 — 31.

JAEGER, E. — METZ, K. 1971: Das Alter der Pegmatite des Raumes Bretstein-Pusterwald (Wölzer Tauern, Steiermark). — Schweiz. Min. Petr. Mitt. Bd. 51. Zürich. S. 411 — 414.

KOBER, L. 1938: Der geologische Aufbau Österreichs. — J. Springer. Wien. S. 204.

METZ, K. 1962: Das ostalpine Kristallin der Niederen Tauern im Bauplan der NE-Alpen. — Geol. Rundsch, 52. Stuttgart. S. 210—226.

METZ, K. et al. 1964: Beiträge zur Geologie der Rottenmanner und östlichen Wölzer Tauern. — Vh. Geol. B. — A. Wien. S. 65 — 163.

METZ, K. 1965: Das ostalpine Kristallin im Bauplan der östlichen Zentralalpen. Sb. Österr. Ak. Wiss. Math. nat. Kl. I 174. Wien. S. 229 — 278.

METZ, K. 1969: Geologische Karte der Steiermark 1 : 300 000 (1968); 2. Auflage. Stmk. LLL. Graz. Ak. Druck Verl. Anst.

NEUGEBAUER, J. 1970: Alt-paläozoische Schichtfolge, Deckenbau und Metamorphose — Ablauf im südwestlichen Saualpen-Kristallin (Ostalpen). — Geotekt. Forsch. 35. Stuttgart. S. 23 — 93.

PAPP, A. 1972: Die stratigraphischen Grundlagen des Miozäns der zentralen Paratethys und die Korrelationsmöglichkeiten mit dem Neogen Europas. — Verh. Geol. B. A. Wien, S. 59—65.

PAPP, A. — WEISS, E. 1956: Ein Tortongerölle am Nordrand der Petzen. — Car. II Bd. 66, Klagenfurt, S. 31—33.

PILGER, R. — WEISSENBACH, N. 1965: Tektonische Probleme bei der Gliederung des Altkristallins der östlichen Zentralalpen. — Verh. Geol. B.—A. Wien. Sdh. G. S. 191—198.

PILGER, A. — WEISSENBACH, N. 1970: Stand und Aussichten der Forschung über Stratigraphie, Tektonik und Metamorphose in der Saualpe in Kärnten. Clausth. geol. Abh. 5 Cl. Zel. S. 1 — 39.

PLÖCHINGER. B. 1964: Die tektonischen Fenster von St. Gilgen und Strobl am Wolfgangsee (Salzburg, Österreich). — Jb. Geol. B. — A. Wien. Bd. 107, S. 11 — 69.

PLÖCHINGER, B. 1970: Erläuterungen zur Geologisch-Geotechnischen Karte 1 : 10 000 des Schwechattal-Lindkogel-Gebietes W Baden (Niederösterreich). Verl. Geol. B. — A. Wien. S. 1 — 58.

PLÖCHINGER, B. — PREY, S. 1968: Profile durch die Windischgarstener Störungszone im Raume Windischgarsten — St. Gallen. — Jb. Geol. B. A. Wien. Bd. 111, S. 175 — 211.

PREY, S. 1972: Mehrmalige Schweregleitungen als Denkmöglichkeit zur Auflösung der Strukturen der Haupt-

klippenzone des Wienerwaldes. — Anz. Öst. Ak, Kin. math. nat. Kl. Wien 1971.
RUTTNER, A. 1960: Das Flyschfenster von Brettl am Nordrand der niederösterreichischen Kalkalpen. — Vh. Geol. B. — A. Wien. S. 227 — 236.
SCHMIDEGG, O. 1937: Der Triaszug von Kalkstein im Schlingengebiet der Villgrater Berge. — Jb. Geol. BB — A. Wien. Bd. 87, S. 111 — 132.
SCHÖNENBERG, R. 1970: Das variszische Orogen im Raum der Südost-Alpen. — Ostalpentektonik II. Geotekt. Forsch. H. 35. 1 — 22. E. Schweizerbarth. Stuttgart.
TOLLMANN, A. 1959: Der Deckenbau der Ostalpen auf Grund der Neuuntersuchungen des zentralalpinen Mesozoikums. — Mitt. Ges. Geol. Bergb. stud. Wien. Bd. 10, S. 3 — 62.
TOLLMANN, A. 1969: Tektonische Karte der Nördlichen Kalkalpen 1. Teil: Der Ostabschnitt. — Mitt. Geol. Ges. Bd. 59, 1966 Wien, S. 231—253.
TOLLMANN, A. 1969: Tektonische Karte der Nördlichen Kalkalpen 2. Teil: Der Mittelabschnitt. — Mitt. Geol. Ges. in Wien Bd. 61, S. 124—181.
TOLLMANN, A. 1970: Der Deckenbau der westlichen Nord-Kalkalpen. — N. Jb. Geol. Pal. Abh. 136 Stuttgart, S. 80—133.

EXTERNAL ZONES

SIGMUND PREY

The Flysch Zone of the Eastern Alps consists of several tectonic units, which were derived from the following depositional areas; the Klippen Zone of St. Veit near Vienna, the flysch nappes and Helveticum including the Gresten Klippen Zone. There source areas will be dealt with separately.

One of the most important facts is the facies contrast between the Helveticum and flysch. The Helveticum and Ultrahelveticum are composed prevalently of sediments in marly to clayey-marly foraminiferal facies of small thickness, whereas the flysch is represented by thick complexes of marls, shales and sandstone beds. The sedimentary area of the Helveticum which was located farther in the north belonged to the epicontinental part of the sea. The calcareous faunas of the northern region recede southwards to the characteristic arenaceous faunas consistently with the deepening of the sea. The flysch trough — to which no transitions are known — can be visualized as the deepest furrow in the sea floor. From the northern slope of the trough the rocks underlying the Cretaceous and Early Tertiary beds of the Ultrahelveticum were probably torn off later by tectonic forces (Gresten Klippen Zone). The original site of the St. Veit Klippen Zone, however, must be presumed to have lain farther south as the basement of the flysch trough. The axis of the flysch trough travelled slowly northwards in the Cretaceous and Paleocene.

Certain analogies are inferable between this paleogeographic distribution of the depositional areas and that of the Silesian Carpathians: The Subsilesicum (with the Wadowice Klippen) in the north occupies an analogous position to that of the Helveticum: the outer flysch nappes can be broadly compared to the Silesian units; the Laab nappe to the Magura nappe; the St. Veit Klippen Zone to the zone of Pieniny klippen in the Carpathians. A precise parallelization is, of course, still questionable.

The St. Veit Klippen Zone near Vienna

(The succession of strata is given in Table I)

No substantial breaks have been recognized in the stratal sequence between Rhaetic and Neocomian. The foraminifer-rich beds that in the Pieniny Klippen Zone of Moravia pass from the klippen complexes into the klippen envelopes have so far not been found in this sector of the Klippen Zone either. Only the Cenomanian beds yield a greater amount of fauna at a few places. The bulk of the klippen envelope is made up of Albian-Cenomanian variegated claystones, which bear arenaceous fauna, frequently very poor. An interruption of sedimentation in the middle Lower Cretaceous is very likely. The variegated claystones are connected with sandstones of Reiselsberg type.

The variegated marls with the Senonian and Early Tertiary faunas, which are numerous and characteristic of the Gresten Klippen Zone, have not been recovered from the St. Veit Klippen area. This feature differentiates the individual Klippen areas of the Eastern Alpine Flysch Zone.

Of interest are the traces of volcanic activity. The picrite lavas and tuffs are clearly joined with the Albian-Cenomanian red shales and must have been piled up synchronously.

The St. Veit Klippen Zone does not differ essentially in its structural style from the Pieniny Klippen Zone of the Carpathians. It is intensively folded and sliced and contains lenticular disrupted bodies, especially of limestone. However, any strong mixing of the klippen with the "flysch of the klippen envelope", as has been presumed hitherto (F. Trauth 1930), is out of question. The spaces between the protruding klippen limestones are most likely formed of soft rocks with scarce Dogger sandstones. The variegated Albian-Cenomanian shales and flysch sandstones were incorporated in the imbricate structure quite exceptionally.

In the area of the Lainz Tiergarten a flysch Upper Cretaceous sequence divides the klippen belt into two parts. It is truncated together with the klippen belts by faults in the west.

The renowned Antonshöhe Klippe south-west of Vienna is encompassed by marl-sandstone sequences, which suggest the assignment to the marginal parts of the Limestone Alps.

The relationships of the St. Veit Klippen Zone to the adjacent tectonic units have not yet been decidedly stated. Yet the fact that the Klippen Zone contacts in the west and south only the upper parts of the Laab stratal sequence indicates that the Klippen Zone unit is thrust on the Laab nappe. This would correspond broadly with the conception of T. Trauth (1930). Traces of the Cretaceous Buntmergelserie have been established only here. The Upper Cretaceous formations of the Klippen area rest on the Albian — Cenomanian complex as a continuation of sedimentation comparable to the Kahlenberg nappe. According to new investigations of S. Prey (1968) the St. Veit Klippen Belt remained as a part of the flysch trough undergraund.

From the above-said it follows that a pre-Albian folding is possible, maybe probable but not demonstrable. The structure, as far as it is known today, originated chiefly in a Tertiary phase, presumably in the Upper Oligocene-Burdigalian, when the overthrust of the Flysch Zone on the molasse also took place. The movements ended unquestionably before the development of the Vienna Basin, as the Miocene Baden Formation is transgressive on the completed structure. The St. Veit Klippen Zone as well as the Flysch Zone and the Limestone Alps had sunk into depth in the Vienna Basin. The faults at the western margin of this basin run east of the area where the Klippen Zone comes to the surface.

THE FLYSCH NAPPE

The sequence of the flysch beds is shown in Table I—Ia. Contrary to the Helveticum, the thickness of the flysch sequence is estimated at several thousand

Stratigraphy of the Flysch zone in the Wienerwald area (S. Prey 1967)

Tab. I/a

		Northern zone Greifenstein nappe	Central zone Kahlenberg nappe and Satzberg unit	Main Klippen Zone	Southern zone Laab nappe	Klippen Zone of St. Veit	
Tertiary	Middle — Lower Eocene	Greifenstein sandstone accompanied by often sandy shales, alternating with glauconitic sandstones (current bedding, convolute bedding, hieroglyphs)			Laab Beds: Agsbach Beds: Hard dark shales, scarcely marls, siliceous sandstones		Middle — Lower Eocene
	Paleocene — Danian	Altlengbach Beds: Calcareous sandstones with graded bedding, coarser grained micaceous sandstones,	Sievering		Hois Beds: Numerous fine to coarse grained partly siliceous sandstones, shales		Paleocene — Danian
Cretaceous	Maastrichtian	partly with clayey cement and softly weathering („Mürbsandsteine") alternating with grey marls and grey or black shales (rarely Fucoids and Helminthoids)	Sievering Beds are a facies of Altlengbach Beds, richer in marls		Black shales, dark glauconitic quartzites Thin bedded quartzites, thin shales (seldom Rzehakina)		Maastrichtian
	Campanian	Traces of variegated shales Kahlenberg Form	Kahlenberg Beds: Grey marls (partly with Fucoids,	„Buntmergel" series Series of variegated marls and clays with few agglutinating, sometimes also calcareous foraminifera	Kaumberg Beds:		Campanian
	Santonian		Helminthoids), marly shales, greenish shales; mainly fine-grained				Santonian
	Coniacian	Interruption	calcareous sandstones and sandy limestones (current bedded) Variegated shales?		Greenish-grey, red and grey shales and marls with thin layers of calcareous sandstones	Sandstones with Orbitolina	Coniacian
	Turonian					Sandstones with Inoceramusl	Turonian
	Cenomanian		Red shales with Reiselsberg sandstone			Variegated beds	Cenomanian
	Lower Cretaceous	Gault Flysch: Black and green, locally red shales with beds of dark sandstones, often siliceous and glauconitic. Neocomian Flysch: Detritic or sandy limestone beds and layers of shaly marls	Black and green shales with quartzitic layers	Stollberg Beds: Marls Marly limestones Aptychus limestone		Variegated beds? (Cretaceous of the lowermost unit of the limestone Alps)	Lower Cretaceous
Jurassic	Malm	Basement unknown	Basement: Klipen zone of St. Veit	Variegated limestones	Basement unknown	Aptychus limestone Cherty limestone Crinoidal limestone Radiolarite clays and siliceous clays	Malm
	Dogger			Radiolarite Siliceous clays Micaceous sandy marls and sandy limestones, marly sandstones Black clay?		Sandy limestone Marls and marly limestones	Dogger
	Liassic			Gresten Beds		Spotted Marls	Liassic
Trias	Rhaetic					Kössen Beds: Marls and limestones Keuper quartzites	Rhaetic

metres. In the major part of the Flysch Zone it can be regarded as a uniform complex and the same division can be applied (S. Prey 1968). Over large parts it extends from the Neocomian to the Paleocene, and in the Wienerwald to the Middle Eocene. No younger members have been recognized. Some deviations from the normal sequence have been established west of Vienna: a break exists in the outer Greifenstein nappe covering the Cenomanian to Campanian; in the Laab nappe the Upper Cretaceous is developed in a variegated facies (Kaumberg Formation) und the Early Tertiary occurs in the form of sandstone-rich Hois Formation and shale-rich Agsbach Formation. The flysch sequences in the windows in the Limestone Alps are the same as in the Flysch Zone itself (S. Prey 1962).

The characteristic features are most readily explicable by the theory of Ph. Kuenen — A. Carozzi (1953), according to which the flysch formed in the deeper sea troughs under the activity of the turbidity currents (see S. Prey 1968). The source areas are unknown. The streams supplying the material flowed predominantly from the west, but they altered their courses up to the opposite direction. During the Upper Cretaceous-Paleocene the through moved slowly northwards, as is inferable from the increasing thickness of the progressively younger sediments in this direction.

The sequence of strata begins with the Neocomian beds, which often show only feebly distinct flysch features and are partly of detrital calcareous character. They grade rapidly into quite typical flysch with distinctive glauconite-bearing quartzites (Gault flysch). In the overlying normal flysch an increased supply of sand is observable in the Cenomanian-Turonian (Reiselsberg Sandstone), in the Maastrichtian-Paleocene (Upper Cretaceous and Lower Tertiary with Mürb Sandstone), in the Paleocene of the Laab nappe (Hois Formation) and in the Lower to Middle Eocene of the outer Greifenstein nappe (Greifenstein Sandstone). In the sandstone complexes there are more frequent fluxoturbidites. The deposition of red mud (Variegated Shales) was more intensive in places where the supply of material has changed. In the flysch of Austria the youngest sediments are of Middle Eocene age. By that time the stratal sequence was terminated. No transition exists to the molassoid sedimentation. In the latest Upper Eocene, the newly formed molasse trough became the site of further sedimentation. In the deepest southernmost part the flysch facies formed at first, which receded upwards to the molasse sedimentation. In this feature the structural pattern of the East Alpine Flysch Zone differs from that of the Carpathians, where the Krosno Formation persists in the flysch facies until the Oligocene.

The Flysch nappe of varying breadth accompanies the northern border of the Eastern Alps. It is narrow in places and west of Salzburg it disappears totally over short distances to re-appear farther east. Near Salzburg and in Upper Austria it is as much as 15 km broad and in the Wienerwald 20 km. The allochthonous position of the whole flysch nappe on the Helveticum is particularly well-defined, especially between the rivers Salzach and Steyr (S. Prey 1962). The translation was facilitated, on the one hand, by the high deformability of the underlying Helveticum marls and on the other hand, by the mobility of the shale-rich formations of the lower Cretaceous flysch. These are mostly strongly stressed tectonically ("Reibungsteppich") and consequently tectonically reduced, occasionally to almost complete disappearance.

The greater part of the Flysch Zone shown in the map is not divided into nappes, except for the region west of Vienna. The flysch mass as a whole is thrust rather flatly over the foreland molasse, together with the underlying Helveticum. These two units were in turn overridden by the Limestone Alps, as is documented by the flysch windows in the Limestone Alps and by Urmannsau 1 borehole (A. Kröll — G. Wessely 1967). It has been established by boring that the flysch nappes extend to a relatively small depth (F. Brix — K. Götzinger 1964). Rafts of basic igneous rocks (mostly ophicalcite) are known to occur beneath the overthrust of the Limestone Alps in Upper Austria (fig. 9, 10).

The structural style of the flysch nappe is distinguished by intensive folding and slicing. The intensity of folding was controlled by the properties of the rocks, chiefly by the content of shales and by the small thickness of beds. The style is clearly seen from the generalized and detail sections (fig. 11). Where the whole nappe was disrupted by slicing, the Helveticum often crops out on the surface as narrow elongated tectonic windows. Inside the flysch complex they are frequently accompanied by the deeper Cretaceous flysch. In many places the windows originated evidently from the anticlines (S. Prey 1968; fig. 12).

The structure of the flysch nappe is dominated by the anticlines and synclines overturned to the north and occasionally disrupted, which are very often separated from one another and some of them steeply plunge beneath the surface as do the brachyanticlines. The structures formed as a result of the northward thrust or gliding, not being loaded by the higher tectonic units. In this way arcuate structures also were generated, some of which clearly show the influence of the configuration of the northern border of the Limestone Alps (e. g. south-west of Steyr; S. Prey 1950).

The slice structures at the southern border of the Flysch Zone are shown in figs. 14, 15.

Of the three nappes occurring west of Vienna, which were recognized by G. Götzinger (e. g. 1954), the two northerly ones show close relations to each other, so that they are regarded as partial nappes in the further text. The Laab nappe in the extreme south possesses a different structure and can therefore be considered as a separate nappe (S. Prey 1965; fig. 13).

If the Cretaceous flysch occurrence located southeast of the Main Klippen Zone, at the western periphery of Vienna, is assigned to the system of the Kahlenberg nappe, the Main Klippen Zone is in this part of similar character as are the strip-forming Helveticum windows in the west. In the western part it was overridden by the northern border of the Laab nappe (S. Prey 1968) (fig. 13).

The Lower Cretaceous beds of the northernmost Greifenstein partial nappe are thrust together into a thick mass at the northern border of the Flysch Zone, but the Mauerbach 1 borehole provides evidence (F. Brix — K. Götzinger 1964) that they are strongly reduced under the flysch nappe. It has also been revealed by this borehole that the nappe consists of a number of slices. The Kahlenberg partial nappe can be likewise subdivided into several portions, whereas the Laab nappe, irrespective of the bordering strip against the main Klippen Zone, displays a monotonous fold structure. There is a large east plunging anticline in the west and a major syncline, slightly folded, in the east. A fault of north-northeast strike separates the latter from the St. Veit Klippen Zone.

The map shows distinctly that the southern nappes near Vienna trend south-west beneath the Limestone Alps and do not emerge any more.

West of Vienna, the strike of the units turns progressively to NE and NNE and keeps this direction to a short distance northwards of the Danube. Farther

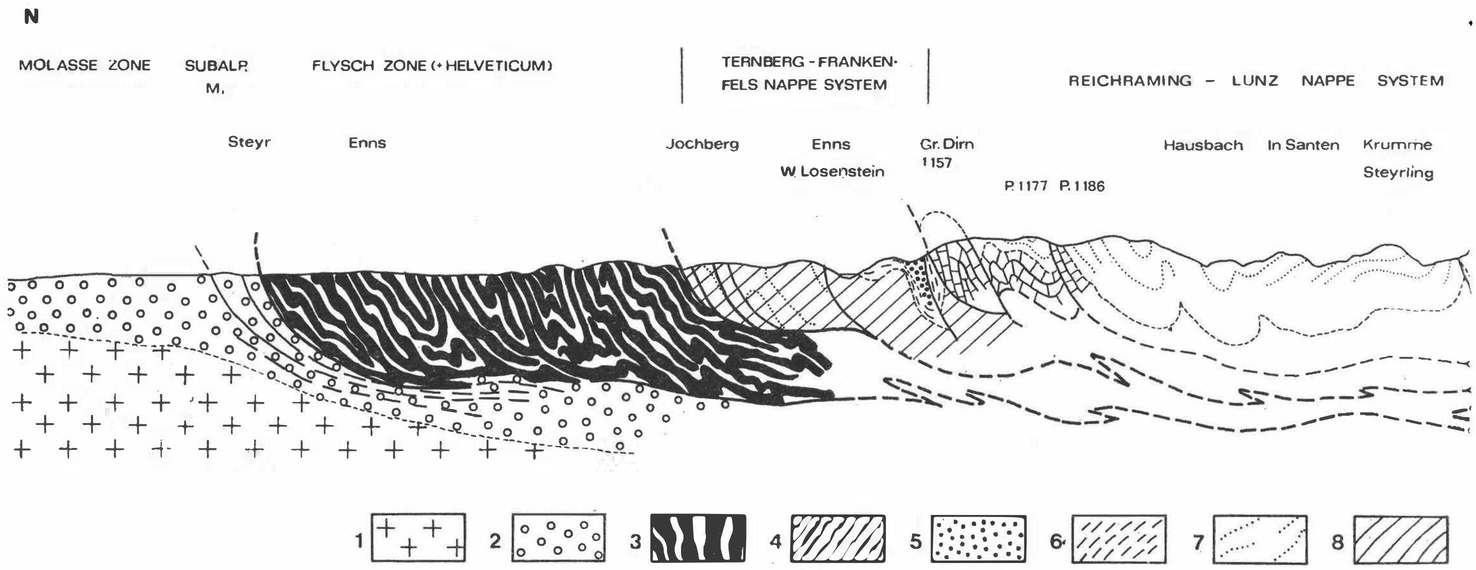


Fig. 9
Generalized geological section across the Limestone Alps between Steyr, Windischgarsten and west of Admont (S of Linz, Upper Austria) S. Prey. The position of the flysch window.
Bohemian Massif: 1 — Crystalline — Mesozoic complexes; Molasse Zone: 2 — Molasse (Tertiary); Flysch Zone: 3 — Lower Cretaceous — Eocene; Northern Limestone Alps (the Ternberg — Frankenfels nappe system is hatched diagonally): 4 — Gosau Formation and Lower Tertiary (Coniacian — Eocene); 5 — Albian — Cenomanian; 6 — Jurassic — Neocomian; 7 — Upper Triassic, Hauptdolomit — Plattenkalk facies; 8 — Upper Triassic, Dachstein limestone facies; 9 — Middle Triassic (Wetterstein — Reifling — Gutenstein limestone); 10 — Middle Triassic Ramsau Dolomite; 11 — Lower Triassic, Haselgebirge, rauhwacken; 12 — Werfen Formation; 13 — Greywacke Zone; 14 — Quaternary

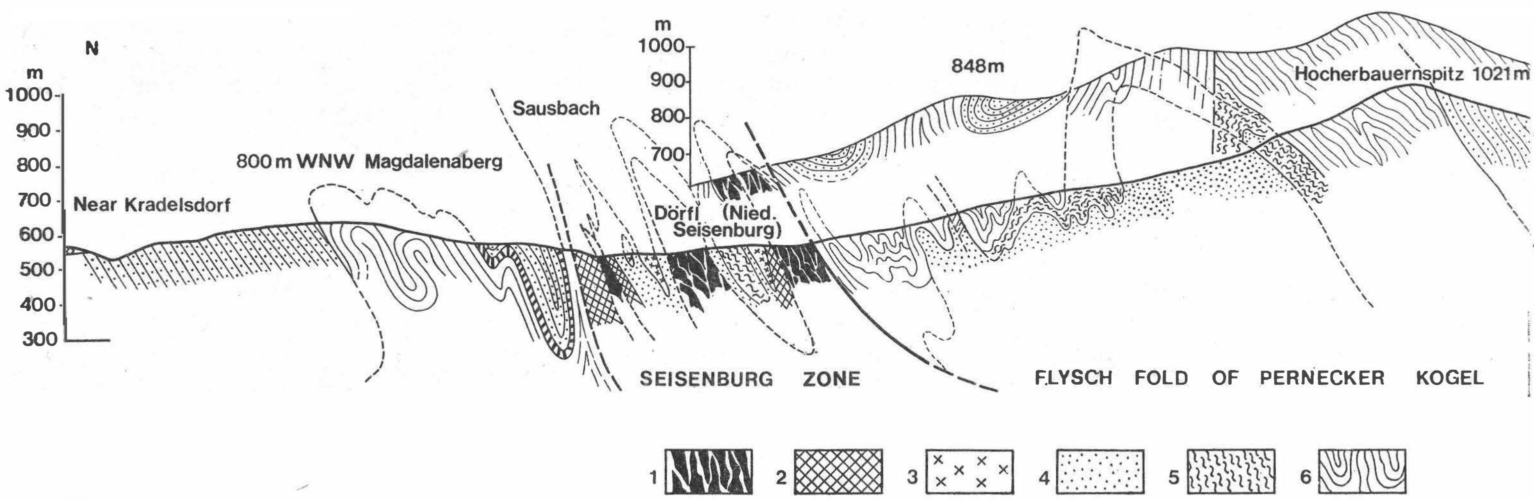
away the east-west trend becomes more spectacular in the flysch complexes, as far as they crop out. The outer border falls into a number of nappe slices, which are composed of the youngest beds of the sequence (mostly Greifenstein Sandstone). We can, however, deduce from the subsurface exposures and the morphology of the sunken and buried flysch complexes beneath the Neogene of the Vienna Basin that the structures re-assume the north-eastern strike towards the Moravian Flysch Zone. The sunken parts of the Flysch Zone have so far not been drilled through by boreholes.

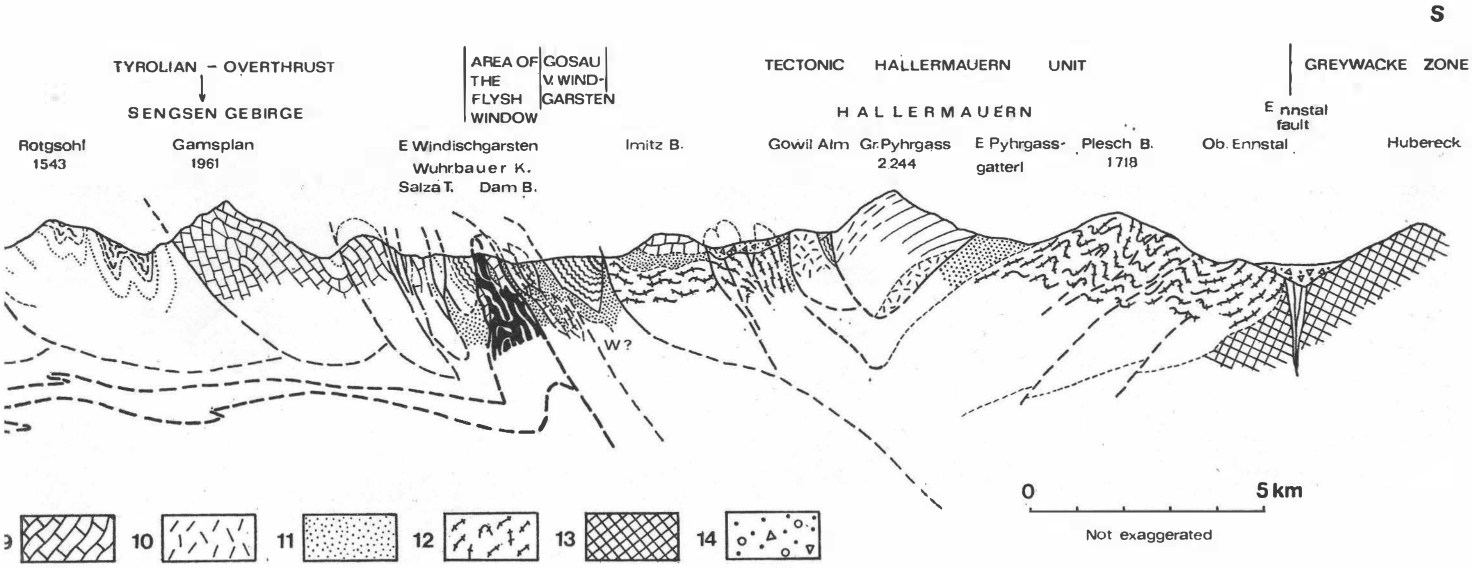
In the Cretaceous flysch occurrence at the western margin of Vienna the WNW-overturned structures intervere with the elements of east-west trend. The south-eastern border is accompanied by Albian-Cenomanian of the area of the St. Veit klippen thus formation continues in their extension. The intricate relations are undoubtedly due to that the strike swings into the Carpathian direction and that the Tertiary gliding of the North Limestone Alps away from the Central Alps had begun there.

The whole Flysch Zone is transected by cross faults. They strike north to north-northeast and in the east also north to north-northwest, and mostly the eastern limbs are shifted northwards along them. Their effects are almost invariably slight.

Helveticum, Ultrahelveticum and the Gresten Klippen Zone

The sequence of strata is listed in Table II. The "South Helveticum" of the Bavarian geologists occurs only on the northern border of the Flysch Zone near Salzburg and north of Gmunden. The bulk of the complex in Salzburg and Upper Austria is made up of calc-rich marls abounding in calcareous foraminifers (Ultrahelveticum). Only in the extreme south does appear the facies of "Buntmergel" Series rich in arenaceous microfauna. The Eocene complex distinguished in the north by clastic and calcareous rocks is replaced farther south by a variegated facies (Buntmergelserie) bearing both calcareous and arenaceous foraminifers. In the southern facies occasional block accumulations of local and partly exotic material formed during Maastrichtian-Early Tertiary, which suggest a





short increase of movement intensity. Flysch is absent from these formations.

The Helveticum forms a separate tectonic unit, which is nowadays covered by a flysch nappe to a large extent. The dominating marly character of the sediments makes them liable to a greater mobility so that they are strongly kneaded and sheared, and secondary calcite forms abundantly. The harder rocks, such as nummulitic and lithothamnion limestones occur mostly as lens-shaped bodies. Therefore, the Helveticum often acted as a slide surface for the flysch nappe to glide over it.

The two nappes were together thrust over the foreland molasse and folded, and the Helveticum was thrust high up as narrow tectonic windows arranged into strips.

In many cases it is clearly seen that the narrow windows originated from the anticlines of the flysch nappe. The large scale of movements is also indicated by the fact that north of Salzburg occur slices of the

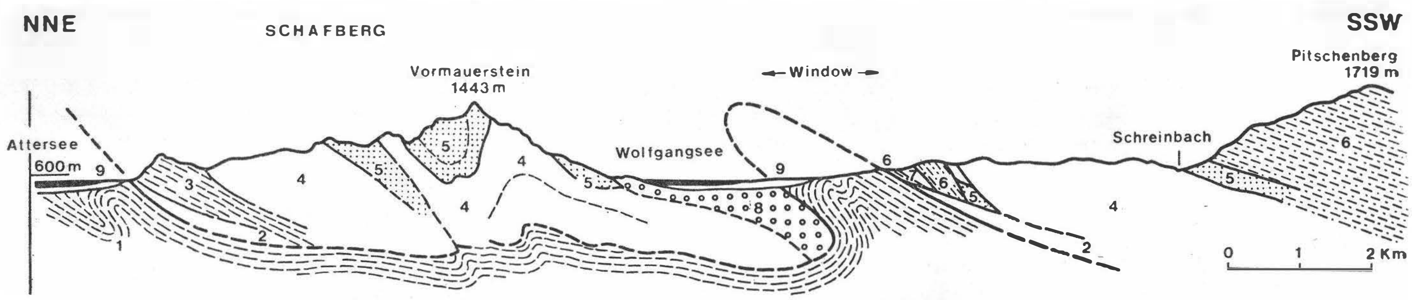
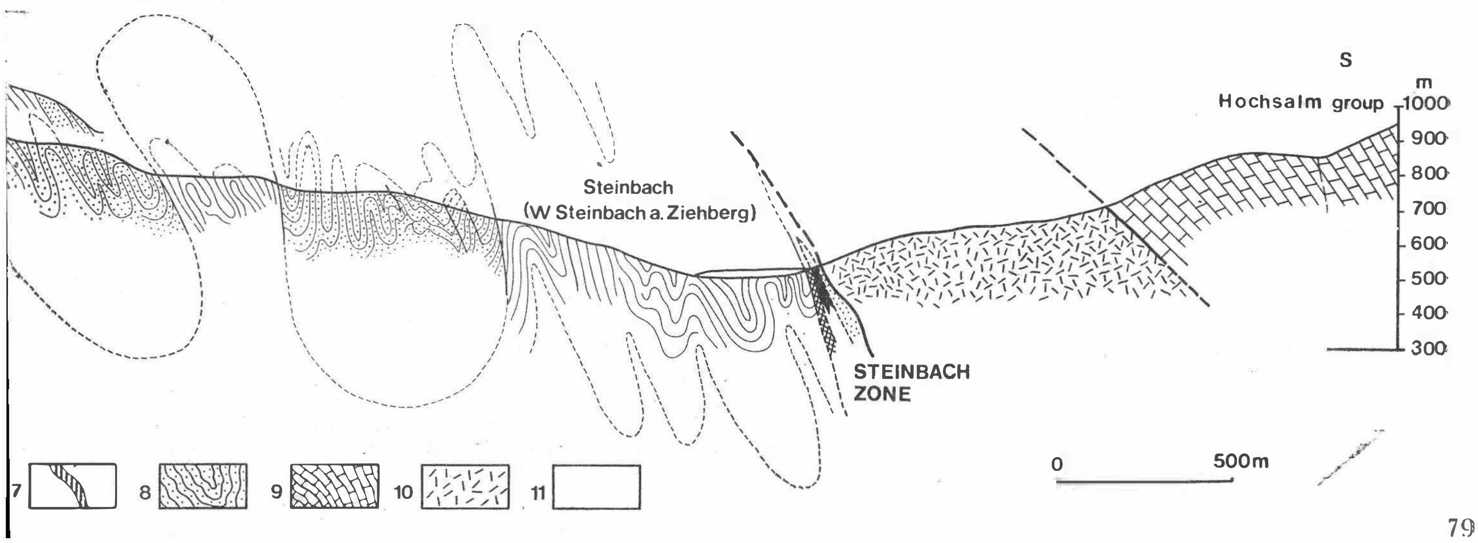


Fig. 10
The position of the window composed of the Flysch and Klippen Zones within the Limestone Alps. Wolfgang Lake, E of Salzburg. B. Plöchinger.
1 — Rocks of the Flysch, Klippen and Buntmergel; 2 — Lower Cretaceous — Bajuvaricum; 3–7 Tirolicum: 3 — Middle Triassic; 4 — Upper Triassic; 5 — Lower Jurassic; 6 — Middle Upper Jurassic; 7 — Lower Cretaceous; 8 — Gosau Beds; 9 — Quaternary

Fig. 11
Detailed geological profile showing the complicated fold structures of Flysch and Helveticum near Kirchdorf/Krems (S of Linz, Upper Austria). S. Prey
Helveticum: 1 — Cretaceous marls, subordinate Lower Tertiary; Flysch: 2 — Gault flysch; 3 — Reiselsberg Sandstone and accomp. rocks; 4 — Variegated shales (Turonian); 5 — Thin-bedded basal complex of Zementmergelserie; 6 — Zementmergelserie; 7 — Uppermost variegated shales; 8 — Upper Cretaceous with friable sandstones; Limestone Alps: 9 — Triassic, mainly Hauptdolomit; 10 — Cenomanian with breccias containing exotic pebbles; Pleistocene: 11 — Alluvium



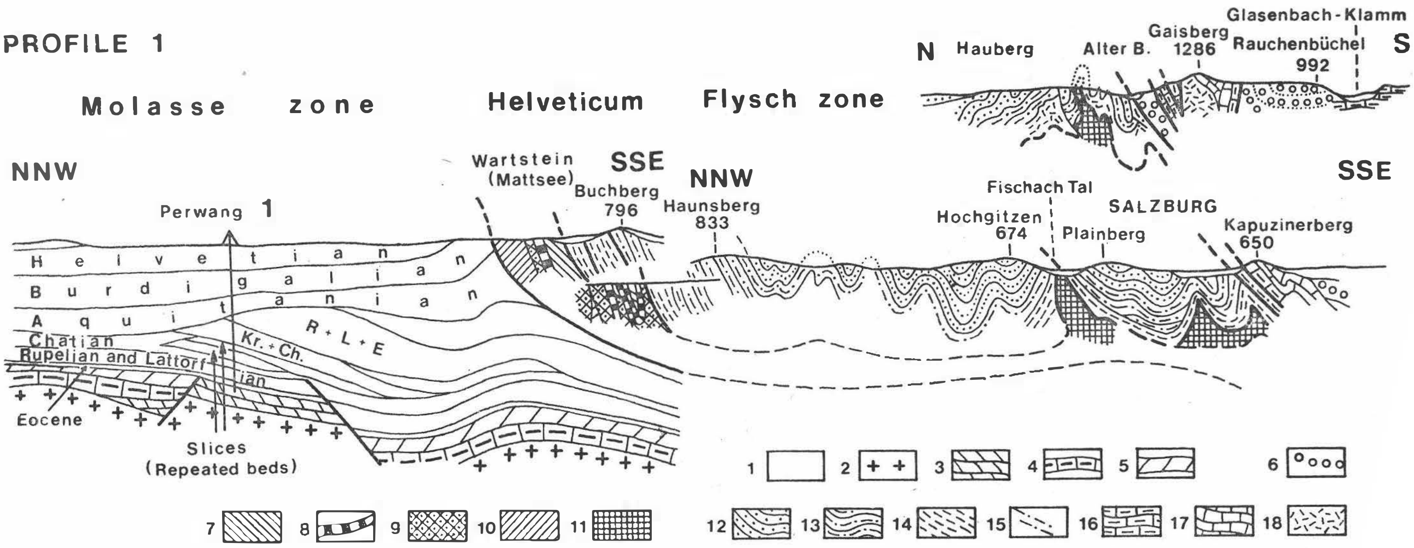


Fig. 12

Geological sections across the Flysch Zone and the southernmost Molasse Zone north-east of Salzburg (after R. Janoschek, S. Prey). S. Prey. Structures of Perwang and the Helveticum and Flysch nappes.
Alpine foreland: 1 — Molasse, undivided by signs; basement of the molasse: 2 — Crystalline of the Bohemian Massif; 3 — Triassic 4 — Upper Jurassic; 5 — Upper Cretaceous;
Northern Limestone Alps: 6 — Gosau Formation (U-Cretaceous, marls sandstones, conglomerates, limestones); Helveticum: 7 — Middle-Upper Eocene argillites; 8 — Middle Eocene, nummulitic limestones, sands, sandstones, partly Lower Eocene; 9 — Paleocene-Lower Eocene, sandy-marly, glauconitic; 10 — Upper Cretaceous marls; 11 — Helveticum, undivided (in S) with klippen in the Wolfgangsee window;
Flysch Zone: 12 — Upper Cretaceous with friable sandstones (Maast); 13 — "Zementmergel" complex (mainly Santon-Campanian); 14 — Lower Cretaceous flysch (Neocom-Coniacian); 15 — Schrambach and Rossfeld Form. Neocomian; 16 — various limestones, Oberalm B. Jurassic, undivided; 17 — Dachstein limestone, platy limestones, partly Kössen Form. (Upper Triassic, Norian Rhaetian); 18 — Hauptdolomit, Dachstein dolomite (Norian stage)

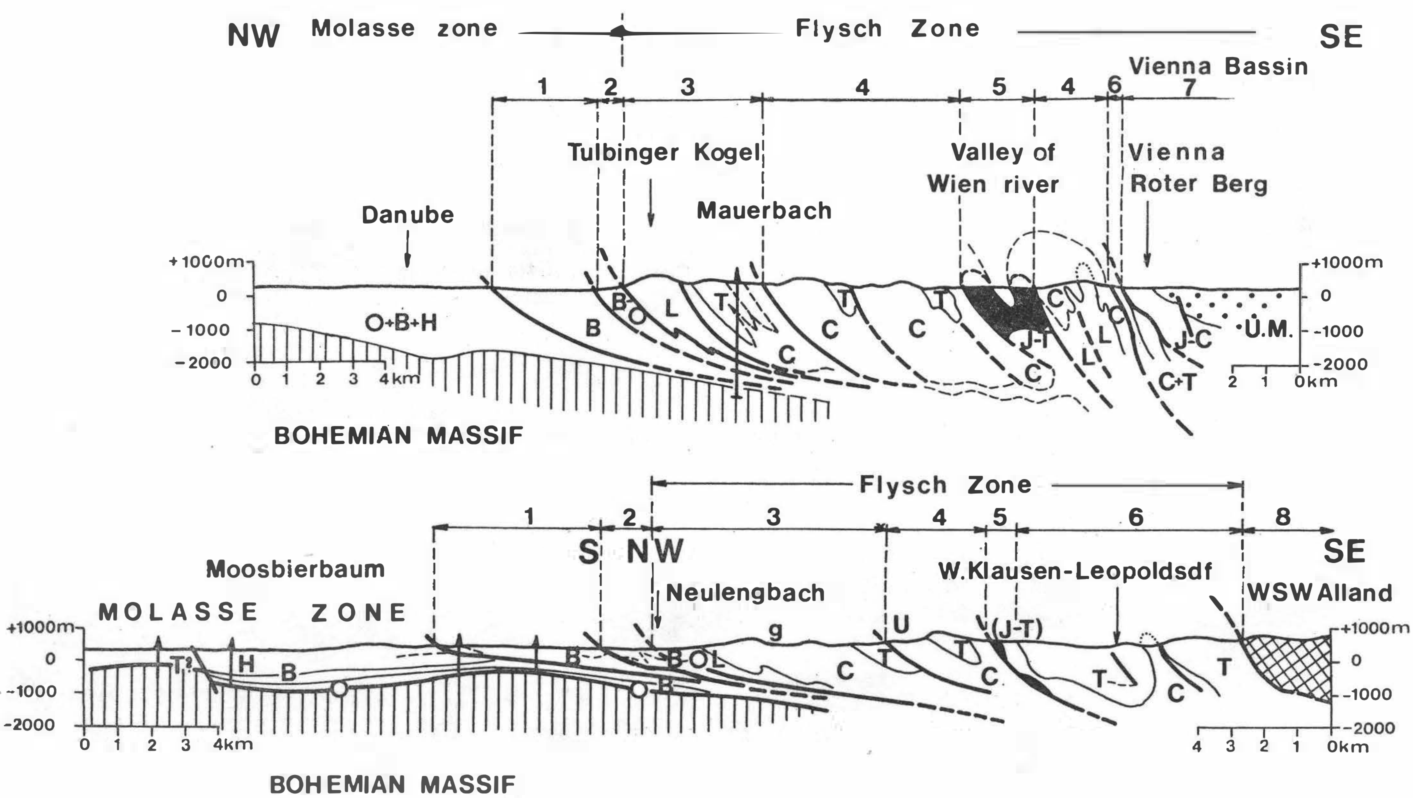


Fig. 13

Geological cross sections through the Flysch Zone west of Vienna (according to G. Götzinger, F. Brix and K. Götzinger, J. Kapounek et al.) by S. Prey 1967
1–2 Molasse: 1 — Disturbed Molasse; 2 — Subalpine Molasse; 3–7 Flysch Zone: 3 — Greifenstein nappe; 4 — Kahlenberg nappe; 5 — Klippen Zone, Ultrahelvetic; 6 — Laab nappe; 7 — Klippen Zone of St. Veit, Pieninic; 8 — Limestone Alps; J — Jurassic; L — Lower Cretaceous; C — Upper Cretaceous; T — Lower Tertiary; O — Oligocene; B — Burdigalian; H — Helvetian; UM — Upper Miocene
According to new investigations of S. Prey, the St. Veit Klippen Area (7) necessarily must be drawn otherwise: The Laab nappe does not exist there. The klippen form the basement of the Lower (better Middle) Cretaceous complexes and at least of the Kahlenberg nappe (see S. Prey 1972).

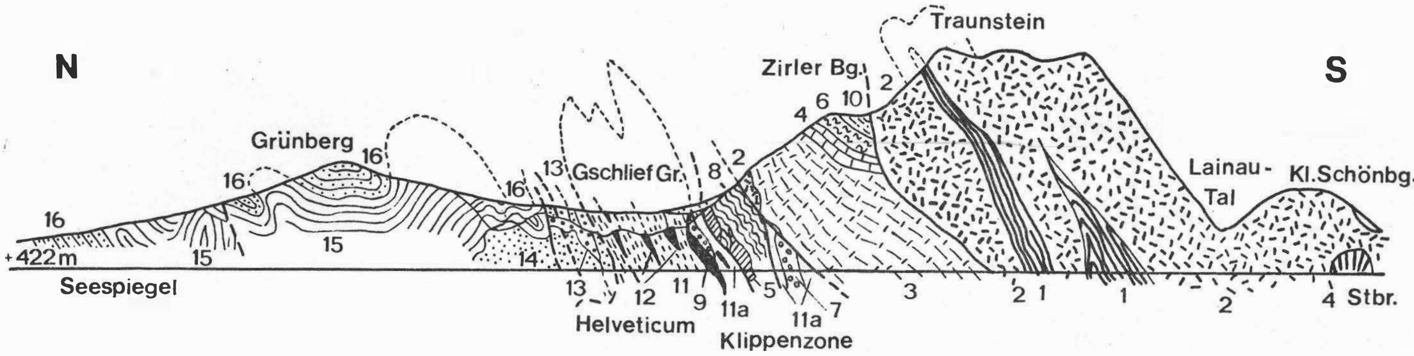


Fig. 14

Section through the Traunstein — Geschliefgraben-Grünberg area, after S. P r e y
L i m e s t o n e A l p s: 1 — Gutenstein limestone; 2 — Wetterstein limestone; 3 — Hauptdolomit; 4 — platy limestone; 5 — Rhaetic limestones (?); 6 — Liassic spongolite; 7 — Gresten Formation (Lias); 8 — Liassic spotted marls; 9 — Upper Jurassic and Neocomian of the Klippen Zone; 10 — Neocomian (Langbath zone);
H e l v e t i c u m: 11 — Cretaceous marl, 11a — red marl of the Klippen Zone (Upper Cret.); 12 — Eocene; F l y s c h Z o n e: 13 — Cenomanian complex of friable sandstone; 14 — dominantly variegated shales, little Neocomian and Gault flysch; 15 — Upper Cretaceous flysch — "Zementmergel" complex; 16 — Upper Cretaceous flysch with friable sandstones.
The complex delimited by heavy lines within the Klippen Zone is conceived as an in folded deep-Bajuvarian element

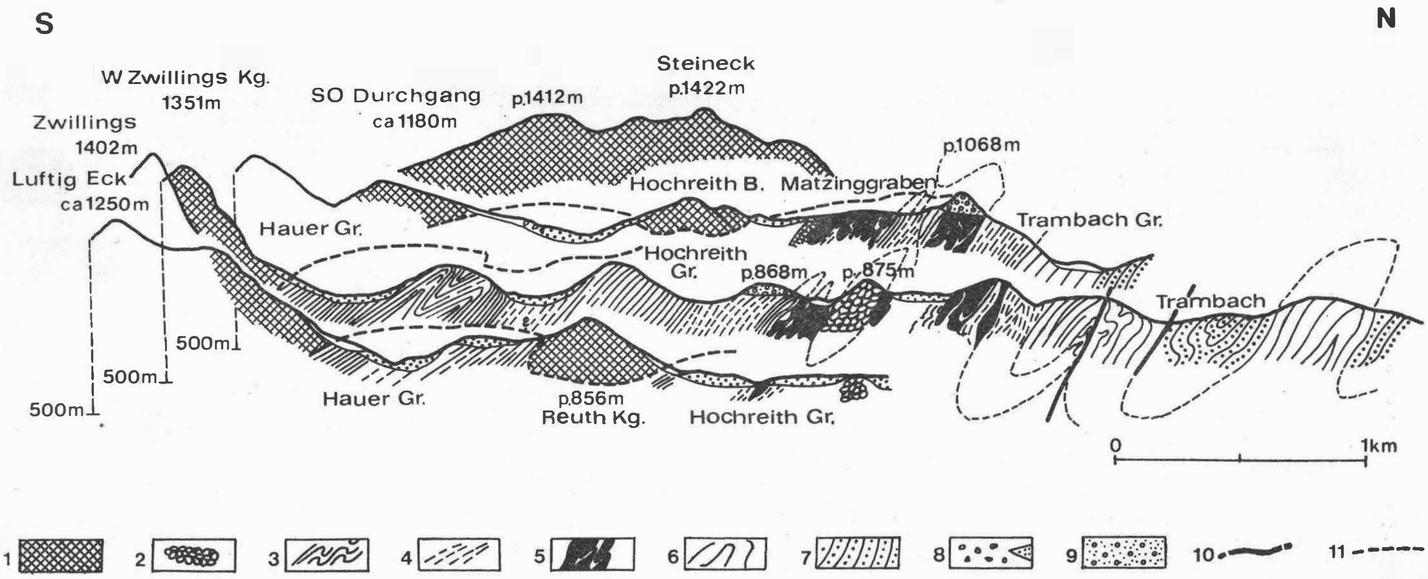


Fig. 15

Geological profiles through the frontal overthrust of the Limestone Alpes on the Flysch, Klippen Zone and Helveticum. Alm Valley, ESE of Gmunden. S. P r e y.
L i m e s t o n e A l p s: 1 — Triassic, undivided; 2—5 K l i p p e n Z o n e: 2 — Gresten Formation; 3 — Tithonian and Neocomian Klippen, Neocomian marls and limestones; 4—7 F l y s c h Z o n e a n d H e l v e t i c u m: 4 — Lower Cretaceous flysch (Albian — Turonian); 5 — Buntmergelserie and Helveticum; 6 — Zementmergelserie; 7 — Upper Cretaceous with friable sandstones; 8—9 P l e i s t o c e n e d e p o s i t s: 8 — Young and older moraines, gravel terraces; 9 — Talus breccia; 10 — Faults; 11 — Overthrust of Limestone Alps

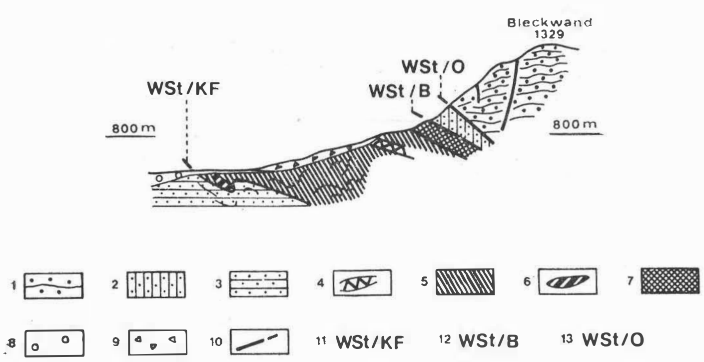


Fig. 16
Geological cross section through the tectonic window of the Flysch and Klippen Zone south of St. Wolfgang (E of Salzburg). B. P l ö c h i n g e r.

1—3 R o c k s o f L i m e s t o n e A l p s: 1 — Variegated limestones of Oberalm Formation and Barmstein Limestone; 2 — Sandy Neocomian marl of Bajuvaricum; 3 — Grey Gosau marls and sandstones; 4—7 R o c k s o f t h e K l i p p e n — B u n t m e r g e l s e r i e — F l y s c h w i n d o w s a n d t h e F l y s c h Z o n e; a) Klippen — Buntmergelserie complex: 4 — Tithonian limestone and red radiolarite with thin limestone intercalations; 5 — Variegated marls (Buntmergel); b) Flysch: 6 — Gault flysch; 7 — Cenomanian — Turonian friable sandstone (Reiselsberg Sandstone); 8 — Q u a t e r n a r y: 8 — Moraine deposits; 9 — Slope detritus; 10 S i g n i f i c a n t d i s l o c a t i o n s: 11 — WSt/KF — Overthrust and imbrications of the Klippen Buntmergelserie and Flysch; 12 — WSt/B — Overthrust of the Bajuvaricum; 13 — WSt/O — Overthrust and faults of the Osterhorn Tirolicum.

	Geological major units	Helveticum	Ultrahelveticum		
	Areas, nappes or groups of nappes	Oberbayern, Salzburg	Northern Ultrahelveticum (Helv. in Upper Austria)	Southern Ultrahelveticum („Buntmergel" series) including the Gresten Klippen Belt	Vorarlberg Bayern
	Lover Tertiary	Globigerine marls and Lithothamnium sandstone **Schwarzerz (Adelholzen Bed with nummulites),** partly Roterz Beds (nummulitic limestones) Lower Lithothamnium lms, or nummulitic limestones Clay-marls and glauconitic sandstones or Oiching Beds	Globigerine marls with Lithothamnium limestones nummulitic limestone in Adelholzen facies, sandy marls, sandstones Lithothamnium limestones dark clayey marls and glauconitic sandstones	light-col. spotted marls partly with breccia beds congl. sandstones or red marls variegated marls and greenish spotted marls very rare calcic intercalations	
Upper Cretaceous	Maastrichtian	Hachau Beds (lacking in the east?) Gerhardsreut Beds	dark-coloured marls		Fanola Form. or Bleicherhorn Form.
	Campanian	Pattenau marls **Pinswang Beds** **Stallau** green sandstone	light-grey marls	Variegated marls and greenish spotted marls sporadic intercalations of clastic rocks	Planknerbrücke Form. or Hällritz — and Zementmergel series
	Santonian	Amden	variegated		Plankner Form.
	Coniacian	Beds pre-Campanian beds are lacking in Salzburg	marls		or Piesenkopf Beds
	Turonian	Seewer —	red marls with white and reddish limestone beds		Schwabbrünnen Form. or
	Cenomanian	limestones Kletzen Bed	spotted limestones with marl intercalations	grey spotted marls dark-grey clayey marls	Reiselsberg sandstone basal complex of Ofterschwang
	Lower Cretaceous	Gault green sandstones Schratten limestone Drusberg Beds	dark fine-sandy marls (partly with ammonites)	dark shales and glauconite sandstones? Stollberg Beds of the Main Klippen Zone of the Wiener Wald Aptychus limestones of the Klippen	Form. quartzite complex
	Malm			Klippen series below	
		F. Aberer and E. Braumüller (1958), expl. Bayern (1964)	S. Prey (1962)	S. Prey (1962), H. Küpper (1962), expl. Wien (1954)	F. Allemann et al. (1951), M. Richter (1957)

Flysch Zone				St. Veit Klippen Zone (Pienides)
Central Flysch Zone Salzburg, Upper and western Lower Austria	Wienerwald			
	Northern Zone (Greifenstein partial nappe)	Central Zone (Kahlenberg partial nappe)	Southern Zone (Laab nappe)	
friable sandstone-bearing Upper Cretaceous to Lower	Greifenstein sandstone (with sandy shales, clayey shales, glauconitic sandstones) and Gablitz Formation Altleng —	Altleng —	Laab Form.: Agsbach Formation (shales, rel. little quartz-sandstone beds) Hols Formation (thickbedded sandstones, shale beds) black shales, glauconite quartzite beds	
Paleocene of the same facies (beds of calc-sandstone, clayey shales and marl beds, partly with chondrites and helmintoids, coarser friable sandstone beds	bach Formation (rocks as in Upper Cretaceous friable-sandstone facies)	bach and Sievering Formation (rocks as in Upper Cretaceous friable-sandstone facies)	thin-bedded quartzites, thin shale beds	
variegated shales with thin calc-sandstone beds (mostly lacking in the S) Zementmergel series (marls and marly shales,	traces of variegated shales	Kahlen — berg	Kaumberg	
partly with chondrites and helminthoids, clayey-marly shales calc-sandstone beds)	hiatus?	Formation (rocks as in the	Formation (green and red shales	
			thin	
variegated shales with thin calc-sandstone and marl Reiselsberg sandstone and grey and green shales		Zementmergel complex) variegated shales	calc-sandstone beds)	sandstone with inocerami?
with sandstone beds mostly variegated shales				variegated marly clays partly with thin sandstone beds (evidenced Cenomanian)
Gault flysch (black and green clayey shales, dark calc-sandstones and quartzites, glauconite-quartzite, local breccia beds) Neocomian flysch (calc-sandstones, shale beds, detrital and spotted limestone, breccia beds)	Gault flysch (black and green clayey shales, quartzites, glauconite quartzite, banded sandstone) Neocomian flysch (detrital limestones, sandy limestones, calc-sandstones, marly shales)	Red shales with Reiselsbeg sandstone black and greenish shales, quartzite beds relics of Lower Cretaceous flysch? Klippen Zone of St. Veit		(Cretaceous of the lowermost unit of the Limestone Alps Aptychus limestones etc.
S. Prey (1962)	Expl. Wien area (1954), S. Prey 1962, 1966, 1972			H. Küpper (1965) R. Janoschek et al. (1956)

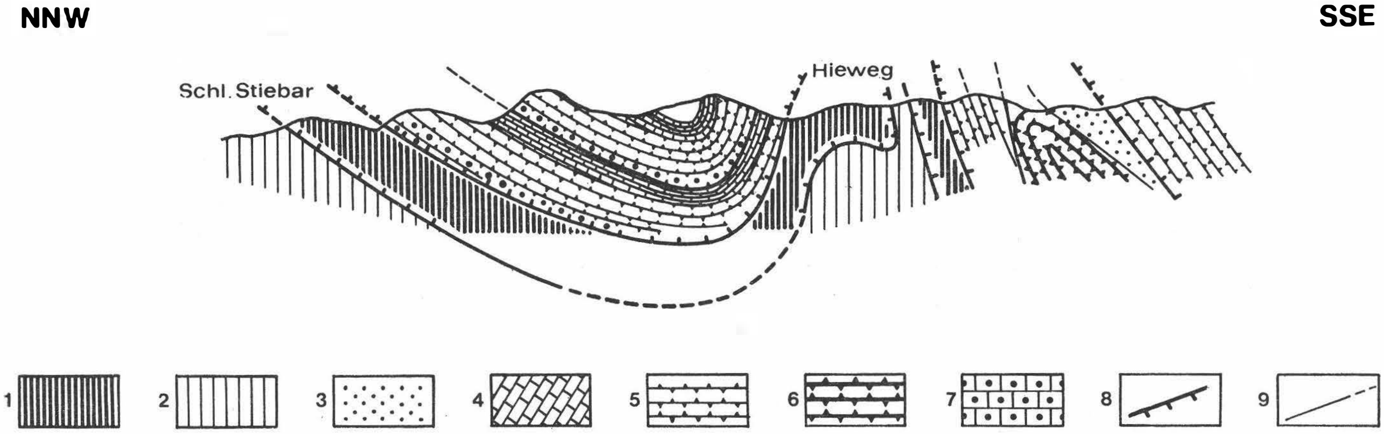


Fig. 17
Geological cross section through the flysch window of Brettl near Gresten SE of Amstetten (A. Ruttner.)
The Buntmergelserie nappe is overridden by the Flysch nappe and both by the Frankenfels nappe, consisting of two sheets.
1 — Flysch; 2 — Klippen Zone incl. "Buntmergel" complex; 3 — Neocomian; 4 — Jurassic; 5 — Triassic: Hauptdolomit and Rhaetic; 6 — Triassic: Reifling limestone, Lunz Formation, Opponitz limestone; 7 — Shattered Hauptdolomit; 8 — Boundaries of major nappes; 9 — Overthrusts, faults

"Buntmergel" Series which had been dragged along from the southern Helveticum trough as far as the northern margin (F. Aberer — E. Braumüller 1958). The slices of the Helveticum lie side by side with various Eocene formations at the northern border of the flysch north of Gmunden and in the Gschlief graben near Gmunden at the southern border. When the Flysch Zone was being thrust forwards in front of the Limestone Alps, the anticlines with the core made up of Helveticum were occasionally folded, their southern limb being torn off (fig. 14). In the large Rogatsboden anticline the Inner Alpine molasse was also squeezed between the "Buntmergel" Series and the Gresten Klippen Zone (fig. 20).

The major Helveticum windows have been plotted on the map, but they had to be drawn on a very enlarged scale. With the exception of the Helveticum north of Salzburg, which is exposed over almost 3 km, the other windows are only several hundred metres broad. The breadth of 1 km is quite exceptional.

As there are no younger sediments than lower Upper Eocene in the Helveticum, the movement of the nappe could have begun in the Late Eocene. The principal movements, however, were undoubtedly active in the Late Oligocene and Aquitanian, when the Inner Alpine molasse was also drawn into the nappe structure.

The Gresten Klippen Zone (Tab. Ia) consists of the blocks of Jurassic rocks and the envelope composed of the Cretaceous-Paleogene Buntmergel Series. The structural style of this zone is distinguished by tectonic crushing and kneading. The contacts between the klippen and the envelope are almost invariably tectonic. As a result the indications of the pre-Senonian movements are observable only sporadically, and their intensity is so far unknown. The tectonic unrest during the Late Senonian-Paleocene is likewise inferable from the block accumulations of Klippen rocks in the Buntmergel Series.

The first occurrence of the Klippen Zone is between the lake Traunsee and the river Alm (fig. 14, 15) and another one of larger extent east of the river Enns, both of them on the southern margin of the Flysch Zone. The "Main Klippen Zone" (Götzinger 1954) of the Wienerwald, which also belongs to them, is located in the midst of the Flysch Zone. Their tectonic position and the grouping with the Helveticum is based on the following observations: south of the Gresten Klippen Zone the flysch is still widespread (window at the lake Wolfgangsee, east of Salzburg — B. Plöchinger 1964; Windischgarsten flysch window — B. Plöchinger — S. Prey 1968; Brettl flysch window — A. Ruttner 1960; half-window of Grünau — S. Prey 1953) within the Limestone Alps, but near Rogatsboden also at the southern border of the Gresten Klippen Zone. Moreover, some close relationships between the envelope of the klippen and the Buntmergel Series suggest their deposition in the same sedimentary area. The separation of the St. Veit Klippen Zone is based on the widely different character of the envelope of klippen. As concerns the flysch windows see figs. 9, 16, 17.

Regional position of the Flysch Zone

The performed investigations make it possible to postulate the following order of the sedimentary areas of the individual units of the Flysch Zone (from north to south): Helveticum (in the west), Ultrahelveticum, Gresten Klippen Zone, the flysch sequence which was laid down in the deepest part of the sea, and the St. Veit Klippen Zone. The Pieniny Klippen Zone may be compared with the Arosa Zone which is located near the boundary between the Eastern and Western Alps. In the Upper Cretaceous and Early Tertiary the flysch area was thus flanked on either side by the areas of marly, partly foraminifer-rich sedimentation.

At the boundary between the Western and Eastern Alps, the derivation of the Flysch Zone of the Eastern Alps from the Pennine region, in the broader sense, is given by its position between the underlying Ultrahelveticum and the overlying Unterostalpin (R. Oberhauser 1963, S. Prey 1965, 1968). In the east this succession is debatable, because no unquestionable Penninicum is known there. When, however, the main supply of sediments is presumend to have occurred from the western border of the trough (Ph. H. Kuenen 1957), this problem becomes less important for the eastern part.

An interesting conception of the development of flysch troughs is given in the publication of R. Oberhauser (1968).

REFERENCES

ABERER, F. — BRAUMÜLLER, E. 1958: Über Helvetikum und Flysch im Raume nördlich Salzburg. — Mitt. Geol. Ges., Bd. 49. Wien.

BRIX, F. — GÖTZINGER, K. 1964: Ergebnisse der Aufschlussarbeiten der ÖMV AG in der Molassezone Niederösterreichs in den Jahren 1957—1963. Teil I, Zur Geologie der Beckenfüllung, und des Untergrundes. — Erdöl-Zeitschrift, Wien-Hamburg.
GRILL, R. 1953: Der Flysch, die Waschbergzone und das Jungtertiär um Ernstbrunn (Niederösterreich). — Jahrb. G. B. A., Bd. 96. Wien.
GRILL, R. 1968: Erläuterungen zur Geologischen Karte des nordöstlichen Wienviertels und zu Blatt Gänserndorf. — G. B. A. Wien.
GÖTZINGER, G. 1954: Die Flyschzone. — In: Erläuterungen zur geologischen Karte der Umgebung von Wien, 1:75 000. G. B. A. Wien.
JANOSCHEK, R. — KÜPPER, H. — ZIRKL, E. J. 1956: Beiträge zur Geologie des Klippenbereiches bei Wien. — Mitt. Geol. Ges., Bd. 47. Wien.
JANOSCHEK, W. 1964: Geologie der Flyschzone und der Helvetischen Zone zwischen Attersee und Traunsee. — Jb. G. B. A., Bd. 107. Wien.
KAPOUNEK, J. — KRÖLL, A. — PAPP, A. — TURNOVSKY, K. 1965: Die Verbreitung von Oligozän, Unter- und Mittel miozän in Niederösterreich. — Erdöl-Zeitschrift. Wien—Hamburg.
KRÖLL, A. — WESSELY, G. 1967: Neue Erkenntnisse über Molasse, Flysch und Kalkalpen auf Grund der Ergebnisse der Bohrung Urmannsau 1. — Erdöl-Erdgas-Zeitschrift. Wien—Hamburg.
KUENEN, Ph. H. 1957: Longitudinal filling of oblong sedimentary basins. — Verh. Koninkl. Nederl. Geol. Mijnbouwk. Genoot. Gedenkboek F. A. Vening-Meinesz. Geol. Ser., Dell. 18. Gravenshage.
OBERHAUSER, R.: 1963: Die Kreide im Ostalpenraum Österreichs in mikropaläontologischer Sicht. — Jahrb. G. B. A., Bd. 106. Wien.
OBERHAUSER, R. 1968: Beiträge zur Kenntnis der Tektonik und der Paläogeographie während der Oberkreide und dem Paläogen im Ostalpenraum. — Jahrb. G. B. A., Bd. 111. Wien.
PLÖCHINGER, B. 1964: Die tektonischen Fenster von St. Gilgen und Strobl am Wolfgangsee (Salzburg, Österreich). — Jahrb. G. B. A., Bd. 107. Wien.
PLÖCHINGER, B. — PREY, S. 1968: Profile durch die Windischgarstener Störungszone im Raume Windischgarsten — St. Gallen. — Jahrb. G. B. A., Bd. 111. Wien.
PREY, S. 1951: Geologie der Flyschzone im Gebiete des Pernecker Kogels westlich Kirchdorf an der Krems (Oberöstereich). — Jahrb. G. B. A., Bd. 94. Wien.
PREY, S. 1953: Flysch, Klippenzone und Kalkalpenrand im Almtal bei Scharnstein und Grünau (O. Ö.). — Jahrb. G. B. A., Bd. 96. Wien.
PREY, S. 1960: Gedanken über Flysch und Klippenzonen in Österreich anlässlich einer Exkursion in die polnischen Karpaten. — Verh. G. B. A. Wien.
PREY, S. 1962: Flysch und Helvetikum in Salzburg und Oberösterreich. — Zeitschrift Deutsch. Geol. Ges., Bd. 113. Hannover.
PREY, S. 1965: Neue Gesichtspunkte zur Gliederung des Wienerwaldflysches (Fortsetzung). — Verh. G. B. A. Wien.
PREY, S. 1968: Probleme im Flysch der Ostalpen. — Jahrb. G. B. A., Bd. 111. Wien.
PREY, S. 1972: Mehrmalige Schweregleitungen als Denkmöglichkeit zur Auflösung der Strukturen im Bereich der Hauptklippenzone des Wienerwaldes. — Anz. öst. Akad. Wiss. math-nat. wiss. Kl, Ig. 1971.
RUTTNER, A. 1960: Das Flyschfenster von Brettl am Nordrand der niederösterreichischen Kalkalpen. — Verh. G. B. A. Wien.
TRAUTH, F. 1930: Geologie der Klippenregion von Ober—St. Veit und des Lainzer Tiergartens. — Mit. Geol. Ges., Bd. 21. Wien.
GUIDE TO EXCURSION 26 AC — XXIII. Inter. Geol. Congr. Prague. 1968.
GUIDE TO EXCURSION 33 C — XXIII. Inter. Geol. Congr. Prague. 1968.

MOLASSE ZONE

SIGMUND PREY

The Molasse Zone accompanies the Eastern Alps in the north. The molasse sediments filled the foredeep of the originating Alps chiefly in the Oligocene and Miocene. Sedimentation began in the latest Upper Eocene and ended in the Late Miocene.

The Molasse Zone is broadest in the west, narrows eastwards to a few kilometres near the projection of the Bohemian Massif, and extends farther north-northeastwards to Moravia at a moderate breadth. It lies transgressively on the basement complexes, which are largely made up of crystalline rocks of the Bohemian Massif, occasionally overlain by the autochthonous Mesozoic. The gradual plunging of the substratum of the molasse below the Alps has been evidenced by boring to a distance of 16 km, but it evidently reaches still farther.

The bulk of the sedimentary material had been washed down from the Alps. Therefore, the thickness and the frequency of detrital, especially coarse detrital sediments increase southwards (fig. 18).

The sequence of molasse beds

The stratal sequences are listed in Table I. The outstanding unconformities that make it possible to date movements of greater intensity occur in the latest Upper Eocene (molasse transgression), in the Aquitanian (Egerian) and at the base of the Burdigalian (Eggenburgian) and the Tortonian (Badenian) (A. Papp et al. 1968).

Tectonics of the Molasse Zone

In the Molasse Zone three structures can be differentiated: (a) Undisturbed molasse, (b) Disturbed molasse and (c) Subalpine (transported) molasse. In this sequence they reflect the increasing influence of the thrust movements of the Alpine nappes which had overridden the southern part of the molasse. Therefore, these structures are also thought to be superposed in this order even beneath the Alpine nappes. Parts of the Subalpine molasse can also be transgressively overlain by weakly disturbed molasse beds. The unconformities reveal the existence of tectonic processes which are also inferable from coarse detrital accumulations.

(a) The undisturbed molasse represents that part of the basin filling which is so far from the Alps that it could not have been affected by the Alpine nappe movements. It covers the marginal parts of the exposed areas of the Bohemian Massif with their littoral formations, which generally submerge beneath the basin filling.

The older complexes of the molasse are, however, displaced by antithetic faults with uplifts of up to several hundred metres. They have been established by the exploration for oil and natural gas, particularly in the Alpine foreland. Their activity ended in the Chattian (Lower Egerian), at the latest in the Aquitanian (Upper Egerian). The younger beds are virtually undisturbed (R. Janoschek 1959, 1961; fig. 18).

In the segment of the Alps, which extends east of the projection of the crystalline Bohemian Massif and of the Carpathian foreland, there is the Mailberg fault system. It trends north-northeast and separates the shallower part of the molasse basin in the west from the eastern part of a greater depth. The movements ended here considerably later than in the western Alpine foreland, i. e. at the Lower/Upper Helvetian (Ottnangian-Karpatian) boundary. The fault system is partly a revived Jurassic synsedimentary fault, which was responsible for the increase in the thickness of the autochthonous Mesozoic eastwards and controlled its boundary against the crystalline complex (J. Kapounek 1968).

(b) The disturbed molasse. This term designates molasse beds that were weakly folded, or erected and slightly disturbed but were not displaced. This molasse

	Areas, Geological units	Bohemian Massif, Albian marginal facies of the molasse		Eastern Bavaria, Upper Austria, western Lower Austria, incl. Subalpine molasse	Outer Alpine Vienna Basin	Subalpine molasse in the east
	Pliocene	Clays, sands, gravels	southern Bohemia: clays, sands (limnic)	Hausruck gravels clays with coal	Hollabrun gravel fan	
Miocene	Sarmatian			gravels and clays with	Rissoa Beds	
	Badenian („Tortonian")	coal-bearing clays, sands	Budějovice and Třeboň basins: sand (partly silicified), clay, lignite, diatomite	coal	Grund Beds s. s.	
	Carpathian Ottnangian („Helvetian")	clays, sandy clays, micaceous sands		Oncophora Beds, glauconitic complex, schlier, Treubach and Mehrnbach Sands Rotalia schlier Robulus schlier with Atzbach sand	Laa Formation and Oncophora Beds	
	Eggenburgian („Burdigalian")	marine Ortenburg Sand	Eggenburg Formation, Langau coalbearing Formation	group of sand and gravel Hall schlier Subalpine molasse	schlier marls and sands („Sandstreifen-schlier" and Eggenburg Formation	schlier marls with Buchberg Conglomerate and blocky sands
	Aquitanian	Linz Sands dark schlier	Melk Formation or dark schliery clay	clayey marls, gravel sandstones	Upper Melk Sand or dark schlier clay	Melk Sand with Ollersbach Conglomerate, Königstetten blocky marl
Oligocene	Chattian	In the Třeboň Basin: sands and gravels clay, quartzite (Oligocene? limnic)		clayey marl with sandstones and partly conglomerates	Lower Melk Sand or schlier	coaly clays
	Rupelian			clayey-marl beds banded marls light-coloured marly limestone		
	Lattorfian			„Fischschiefer" Nullipora limestone sandstones and basal limnic sequence		
	Eocene					
	Danian-Paleocene					
		R. Janoschek (1964), Expl. Geol. map of Bavaria (1964)		F. Aberer (1958), R. Janoschek (1964)	R. Janoschek (1964) J. Kapounek (1965)	Explanations Wien (1954)

Tab. II

Subcarpathian molasse Waschberg Zone	Vienna Basin (Inner Alpine Vienna Basin)	Basin at the margin of the Eastern Alps	Tertiary in the Alps
	Rohrbach Conglomerate, Variegated a. blue complex, lignite, Congeria Beds (tegel, sands)	locally basalt and tuff	Sattnitz Conglomerate clays with coal (southern Carinthia)
	tegel, sands, detrital Nullipora limestones, beach conglomerates	similar as in the Inner Alpine Vienna Basin	Bärental Conglomerate, Rosenbach coal beds (s. Carinthia); gravel, sand, clay coal (Lavanttal)
	Baden Formation (tegel, sands, Leitha Limestone, beach complexes, etc.)		
ferruginous clays and sands	Laa Formation (Carpathian complex) (marine, limnic in the south)	Eibiswald Beds or freshwater deposits, gravel; trachy-andesite; Styrian schlier	coal-bearing form. of the Norian depression, and others
slaty clays and clayey marls (Auspitz Marl)	Oncophora Beds and schlier, basal detritus accumulation (Luschitz Formation)	Northern Slovenia: schlier deposits with breccias and reef limestones on the basis	Ennstal Tertiary and „Augensteine“
Michelstetten			Inn Valley Angerberg Formation
Formation		Socka Formation (sandy clayey marls conglomerates, coal)	
		Oberburg Formation (clayey marls) and „Fischschiefer“	„Zementmergel“
		conglomerates, Lithothamnium and coral limestones	Lithothamnium limestone complex
Reingrub Formation Haidhof Beds Waschberg Limestone			bituminous marls (with coal) basal complex
Reingruberhöhe „tegel“ sands			
R. Janoschek (1964)	R. Janoschek (1964), J. Kapounek, (1965), E. Thenius (1962)	R. Janoschek (1964), A. Winkler-Hermaden (1959) F. Heritsch and Kühn (1951)	R. Janoschek (1964)

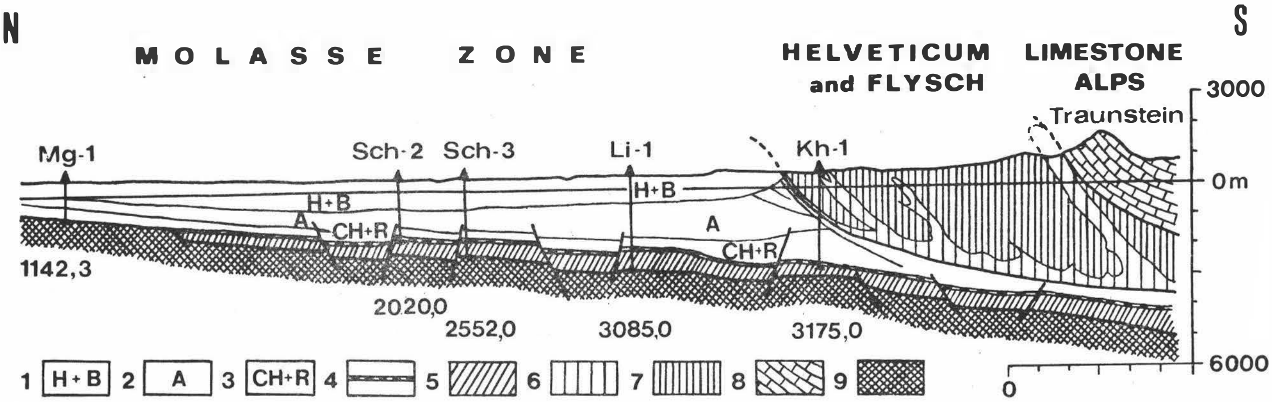


Fig. 18
Geological cross-section through the Molasse Zone (Upper Austria) Peuerbach — Meggenhofen — Schwanenstadt — Lindach — Kirchham — Traunstein (F. Aberer — K. Kolmann)
1 — Helvetian — Burdigalian; 2 — Aquitanian; 3 — Chattian — Rupelian; 4 — Lattorfian — Upper Eocene; 5 — Upper Cretaceous — Upper Jurassic; 6 — Helveticum; 7 — Flysch; 8 — Limestone Alps; 9 — Crystalline complex of the Bohemian Massif; Deep wells: Mg-1 — Meggenhofen-1; Sch-2, 3 — Schwanenstadt-2, 3; Li-1 — Lindach-1; Kh-1 — Kirchham-1

type, however, cannot be sharply distinguished from the Subalpine molasse, particularly because these structures are very little known thus far.

In the greater part of the southern molasse border against the Flysch Zone, the present-day exposures only display the erection of strata towards south as, for example, north of Salzburg, near Gmunden and Amstetten. These outcropping parts should be ranked with the disturbed molasse, as well as some parts of the autochthonous molasse overlain by the Alpine nappes. In the Wienerwald-foreland occurs a wide "fore-fold zone", which begins near St. Pölten east of the constriction of the Molasse Zone, widens northeastwards and passes into the outer belt of the Waschberg zone. As, however, a minor overthrust has been established there (R. Grill 1953; J. Kapounek et al. 1965), it is regarded as a transition into the transported molasse.

(c) Subalpine molasse and Waschberg zone (Subcarpathian molasse) were more or less affected by the Alpine nappe overthrusts. Tectonic slices, partly with internal folds and minor nappe forms are the most important structures. They are developed in front of and under the Alpine nappes and were dragged into the marginal nappes to a very small extent (fig. 13, 19).

Of interest is the structure that was revealed by Perwang 1 borehole, north of Salzburg (R. Janoschek 1959, 1961). A series of slices comprising Campanian and Upper Eocene in the foreland facies and Oligocene molasse, lies on the autochthonous molasse, which is of the latest Eocene to early Chattian age and transgressively overlain by the Upper Aquitanian. The superjacent Aquitanian, Burdigalian and Helvetian beds (Upper Egerian-Eggenburgian-Ottnangian) are erected against the Alps as is the "disturbed" molasse. The formation of the imbricate structure can be strictly dated in this area (fig. 12).

Analogously to this case, the presence of such older slices at depth is presumable at many places along the Alps.

The unconformity at the base of the Burdigalian of the Subalpine molasse at Bad Hall in Upper Austria is very prominent, so that part of the structures might closely predate the Burdigalian (E. Braumüller 1959). It is also noteworthy that a breccia with blocks of the Helveticum and flysch occurs in the Aquitanian (Upper Egerian) dating thus the arrival of the Flysch Zone (nappe) in this part of the molasse trough.

The moved Subalpine Molasse accompanies the external border of the East Alpine Flysch Zone.

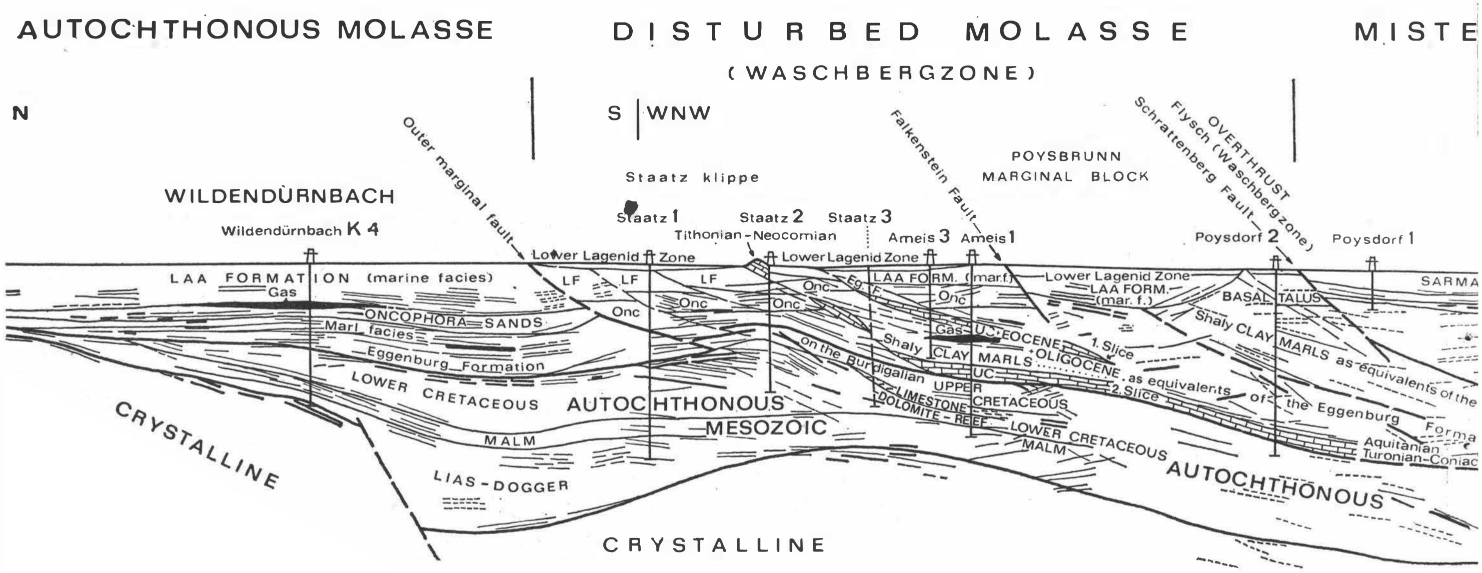


Fig. 19
Geological profile through the foredeep, the Waschberg Zone (Subalpine resp. Subcarpathian Molasse), the Flysch Zone and the western Vienna Basin north of the Danube, Lower Austria. J. Kapounek, A. Kröll.

Because of a small depth of the molasse basin in this area, the rocks forming the base of the molasse, such as Melk Sands and Coal Series east of Neulengbach were moved along. In addition, the Lower Miocene conglomerates and beds with flysch blocks from the flysch nappe (e. g. Buchberg Conglomerate) are interlaid into the Schlier-marlstone, being absent farther north.

The north-eastern extension of this zone becomes a broad and complicated structural component in the Waschberg Zone. The bulk of the rock mass is made up of Burdigalian and Helvetian showing indications of an unconformity below the Upper Helvetian (Karpatian) Laa Series. The rocks are strongly sliced, and the prospection oil wells (J. Kapounek et al. 1965) proved the displacements of at least 10—15 km. These nappe overthrusts tore away blocks of Jurassic limestones and various rocks of the Upper Cretaceous and Lower Tertiary from the basement parts lying farther south-east. The front of the flysch nappe travelling from south-east and the dragged-along rafts and masses of crystalline and granitoid rocks supplied the material of the characteristic "Blockschichten" (R. Grill 1953). The Laa Series is the first to be transgressive on the complicated structure of the Waschberg Zone. The faulting that was connected with the downfault of the Vienna Basin began in Badenian time and was partially active until the Pannonian (fig. 19), locally even until the Pleistocene.

The Waschberg Zone continues in the Ždánice Formation on Czechoslovak territory.

The special form of the Subalpine Molasse is observable near Rogatsboden and Texing, where the occurrences of the so-called Inner-Alpine Molasse are intercalated in the Flysch Zone. The strata of the upper Upper (Eocene (?) and Lower Oligocene, which are mostly developed in the flysch facies, had been squeezed steeply into the Buntmergel Serie of the Ultrahelveticum, which is strongly sliced together with the flysch beds, particularly in the north. Many geologists (F. Brix — K. Götzinger 1964) presume that this molasse had been deposited on the Serie and together with it was subsequently kneaded into the Flysch Zone. According to S. Prey (1957), there are more reasons speaking for its being incorporated into the two units separately (fig. 20).

The occurrences at Rogatsboden and Texing show that the tectonic movements that led to the incorporation of this molasse into the Flysch Zone must have been active at the earliest in the Chattian. The breccia formations near Bad Hall suggest that the Flysch Zone was thrust onto the molasse chiefly in the Chattian-Aquitanian (Egerian). The later movements were much weaker.

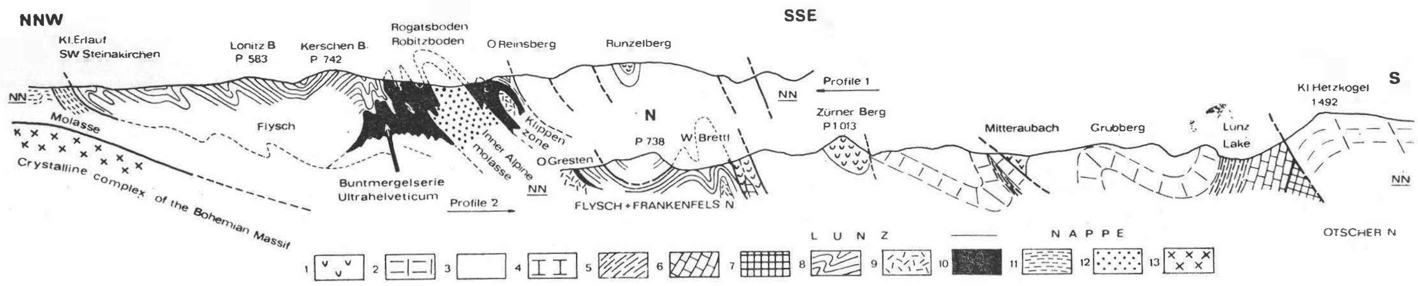
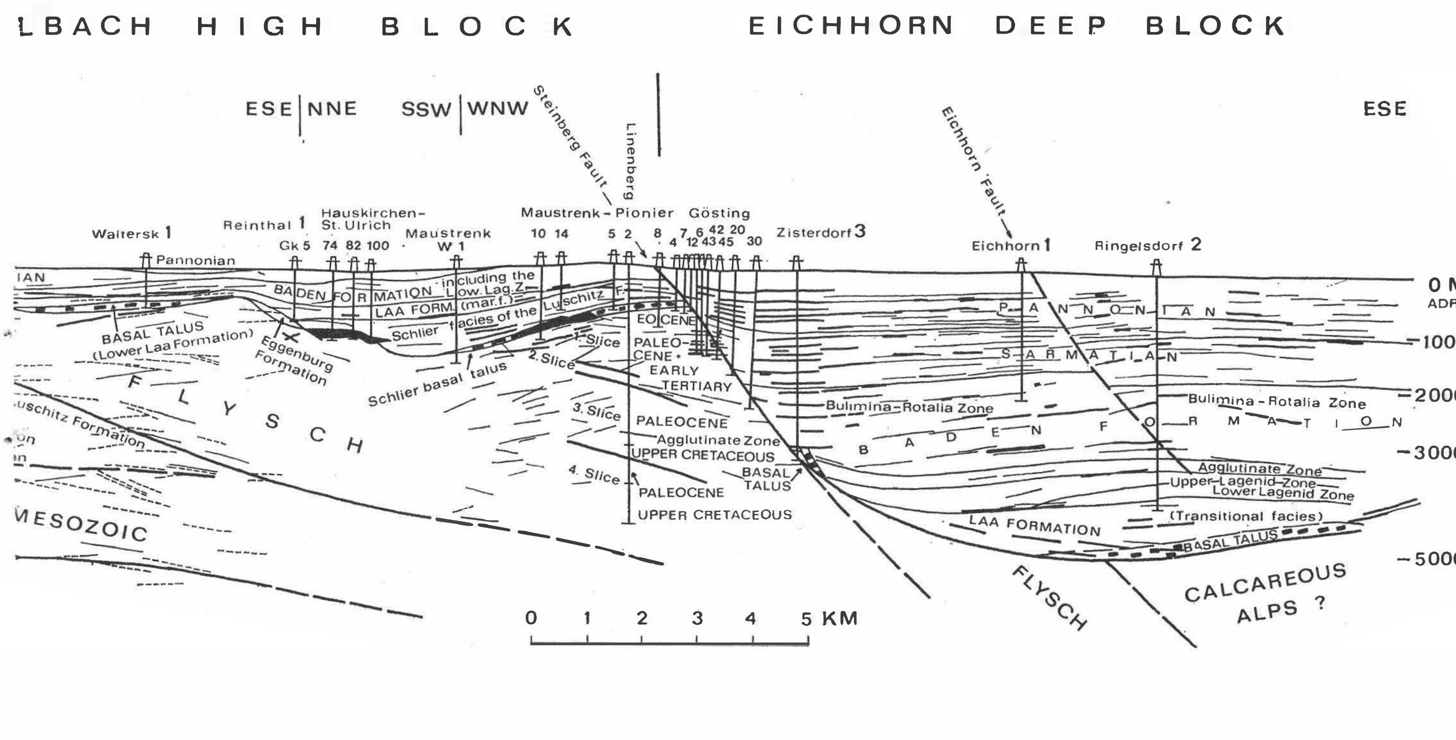


Fig. 20

Geological cross sections of the Scheibbs — Rogatsboden — Gresten — Brettl — Gaming — Lunz area SE of Amstetten, Western Lower Austria. (S. Prey, A. Ruttner)

The section shows the Molasse Zone and its basement, the Flysch Zone, the tectonic Molasse window of Rogatsboden and the Klippen Zone, farther the Flysch window of Brettl and nappes and structures of the Limestone Alps.

1—7 Rocks of the Limestone Alps: 1 — Jurassic-Cretaceous synclines; 2 — Dachstein Limestone; 3 — Hauptdolomit with Dachstein Limestone; 4 — Opponitz Limestone; 5 — Lunz Formation; 6 — Middle Triassic limestone; 7 — Werfen Formation; 8—10 — Flysch-Ultrahelveticum. 8 — Flysch; 9 — Klippen Zone; 10 — Buntmergelserie; 11—12 Molasse: 11 — Molasse, autochthonous or transported; 12 — Inner Alpine Molasse; 13 — Basement of the foredeep



REFERENCES

ABERER, F. 1958: Die Molassezone im westlichen Oberösterreich und in Salzburg. — Mitt. Geol. Ges., Bd. 50. Wien.

BRAUMÜLLER, E. 1959: Der Südrand der Molassezone im Raume von Bad Hall. — Erdöl-Zeitschrift. Wien—Hamburg.

BRIX. F.—GÖTZINGER, K. 1964: Ergebnisse der Aufschlußarbeiten der ÖMV AG in der Molassezone Niederösterreichs in den Jahren 1957—1963. Teil I. Zur Geologie der Beckenfüllung und des Untergrundes. — Erdöl-Zeitschrift. Wien—Hamburg.

GRILL, R. 1953: Der Flysch, die Waschbergzone und das Jungtertiär um Ernstbrunn (Niederösterreich). — Jahrbuch G. B. A., Bd. 96. Wien.

GRILL, R. 1968: Erläuterungen zur Geologischen Karte des nordöstlichen Weinviertels und zu Blatt Gänserndorf. — G. B. A. Wien.

JANOSCHEK, R. 1959: Oil Exploration in the Molasse Basin of Western Austria. — 5. World Petroleum Congr.

JANOSCHEK, R. 1961: Über den Stand der Aufschlussarbeiten in der Molassezone Oberösterreichs. — Erdöl-Zeitschrift. Wien—Hamburg.

KAPOUNEK, J.—KRÖLL, A.—PAPP, A.—TURNOVSKY, K. 1965: Die Verbreitung von Oligozän, Unter- und Mittelmiozän in Niederösterreich.—Erdöl-Zeitschrift. Wien—Hamburg.

PAPP, A. in cooperation with GRILL, R. — JANOSCHEK, R. — KAPOUNEK, J. — KOLLMANN K. — TURNOVSKY, K. 1968: Nomenclature of the Neogene of Austria. —Verh. G. B. A. Wien.

PREY, S. 1957: Ergebnisse der bisherigen Forschungen im Molassefenster von Rogatsboden (Niederösterreich). — Jahrb. G. B. A., Bd. 100. Wien.