

Large-scale strike-slip displacement of the Drauzug and the Transdanubian Mountains in early Alpine history: evidence from Permo-Mesozoic facies belts

Thomas Schmidt ^a, Joachim Blau ^a and Miklós Kázmér ^b

^a Institut für Angewandte Geowissenschaften der Justus Liebig-Universität, Fachgebiet Paläontologie, Diezstrasse 15, D-6300 Giessen, Germany

^b Eötvös University, Department of Paleontology, Kun Béla tér 2, H-1083 Budapest, Hungary

(Received August 18, 1989; revised version accepted August 14, 1991)

ABSTRACT

Schmidt, T., Blau, J. and Kázmér, M., 1991. Large-scale strike-slip displacement of the Drauzug and the Transdanubian Mountains in early Alpine history: evidence from Permo-Mesozoic facies belts. *Tectonophysics*, 200: 213–232.

Both the Drauzug (Italy, Austria) and the Transdanubian Mountains (Hungary) show great differences in facies compared to the geological units that presently surround them, i.e. proximal facies contrast with distal facies in the Permo-Triassic. Lower Liassic strata in the Drauzug and the Transdanubian Mountains indicate an extensional regime causing typical structural features such as tilted blocks, fault scarps, and drowned carbonate platforms.

The Permo-Mesozoic facies zones provide markers for the paleogeographic fitting of the Drauzug and the Transdanubian Mountains with areas today lying some 300–400 km to the west: the Drauzug corresponds to the Lombardian basin and the westernmost part of the Northern Calcareous Alps while the Transdanubian Mountains correspond to the westernmost part of the Lombardian basin, the Trento platform, and the Belluno trough.

The Drauzug and the Transdanubian Mountains (together with the South Alpine realm) were displaced to the east along strike-slip faults during the Middle Jurassic to Early Cretaceous opening of the Central Atlantic and Ligurian–Piemont oceans and the simultaneous subduction of the Vardar ocean at the eastern margin of Apulia. Finally in Late Oligocene and Miocene times the Southern Alps were displaced back to the west along the dextral Periadriatic fault system.

Introduction

The Drauzug and the Transdanubian Mountains (TDM) belong to the internal parts of the Alpine–Carpathian mountain chain created by the Cenozoic collision of Apulia with Eurasia. One of the problems of reconstructing the paleogeography of this area is the discontinuity between Permo-Mesozoic isopic zones. Striking examples of this phenomenon are the Drauzug and the TDM. These mountain ranges exhibit Permo-Mesozoic facies, which is inconsistent with the widely accepted concepts of top to north (e.g., Tollmann, 1963) or top to west-northwest (Ratschbacher, 1986) stacking of Austroalpine cover nappes, unless a lateral dislocation of the Drauzug and the TDM is accepted.

The aim of this paper is to propose a model that solves the above mentioned problem and stresses the necessity to distinguish between the Ligurian–Piemont and Vardar oceans. The connection of these two oceans is one of the major reasons for incorrect paleogeographic reconstructions, which originate from inadmissible extrapolation of West Alpine relationships to the east not considering sufficiently the East Alpine/West Carpathian facies distributions. Both possible resulting reconstructions of this West Alpine point of view cannot be accepted: The first model places the West Carpathian realm onto the northern margin of Apulia, which raises severe problems in establishing cross sectional palinspastic restorations (the Alps–Dinarides problem of Laubscher, 1971; 1988); the second places the West Carpa-

thian realm onto the southern margin of Eurasia but it is then incorrectly separated from the Austroalpine realm (e.g., Dercourt et al., 1986).

Outline of the paleogeographic and tectonic development of the East Alpine/West Carpathian domain

The Eastern Alps are composed of different crustal units stacked upon each other by southward subduction of the Penninic realm and the subsequent collision of its Eurasian and African/Apulian margins. The Penninic oceanic basin was created after a Liassic rifting phase in the Late Lias/Dogger (e.g., Trümpy, 1980). The effects of crustal stretching resulted in the breakdown of Late Triassic carbonate platforms, as shown by the development of tilted crustal blocks and the subsidence of halfgrabens controlled by steep normal faults. Displacement along these faults, which strike subparallel to the margins of the later oceanic basin, caused the deposition of major scarp breccias (e.g., Winterer and Bosellini, 1981; Trümpy, 1983; Eberli, 1985; Häusler, 1987).

The Penninic realm is divided into the North Penninic basin (Valais), the Middle Penninic swell (Briançonnais), and the South Penninic oceanic basin (Ligurian–Piemont ocean). The North and Middle Penninic areas were part of the distal Eurasian continental margin south of the Helvetic realm (e.g., Dercourt et al., 1986). To the east, the North Penninic trough continued into the Carpathian flysch basin, partly floored by oceanic crust (e.g., Dercourt et al., 1986). The Middle Penninic swell can be traced into the Tatrídes of the West Carpathians (Tollmann, 1969). More important, the South Penninic ocean discontinued east of the East Alpine domain (e.g., Tollmann, 1986).

During the Early Cretaceous to Neogene Alpine orogeny, the southern margin of the Penninic realm, represented by the Austroalpine/West Carpathian domain, became the upper plate overriding the Penninic and finally the Helvetic domain of the Eurasian foreland. As a consequence the resulting nappe pile, from top to

bottom, consists of the Austroalpine/West Carpathian, the Penninic, and the Helvetic units.

General geologic setting

Penninic units outcropping in the tectonic windows of the Central Alps (e.g., Lower Engadine, Tauern, and Rechnitz windows) prove the allochthony of the Austroalpine domain (Fig. 1). The Austroalpine unit is divided into the Lower, Middle, and Upper Austroalpine subunits (Tollmann, 1963). The Lower Austroalpine unit, which originally bordered the Ligurian–Piemont ocean, and the Middle Austroalpine unit consist of medium grade metamorphic basement nappes with relicts of Permo-Mesozoic cover sediments (e.g., Tollmann, 1977).

On the other hand, the Upper Austroalpine unit comprises nappes of mostly unmetamorphosed Permo-Mesozoic and low grade metamorphic Paleozoic sedimentary rocks. The Northern Calcareous Alps (NCA) are the most prominent example of the Upper Austroalpine unit, consisting of a large number of nappes. These can be grouped into three nappe systems, which are from north to south and bottom to top: the Bajuvaricum (external), the Tirolicum, and the Juvavicum (internal). Each of these nappe systems has its own tectonic style, due to the rheology of the different Triassic facies (e.g., Tollmann, 1976b).

The Gurktal nappe and the Paleozoic of Graz represent Upper Austroalpine thrust systems of low-grade metamorphic Paleozoic rocks (e.g., Tollmann, 1977; Neubauer, 1987; Von Gosen, 1989). On top of the Gurktal nappe, remnants of its Permo-Mesozoic cover (Krappfeld, St. Paul) are preserved.

The Upper(?) Austroalpine Engadine Dolomites occupy an uncertain tectonic position in relation to the NCA. This is controversially discussed between Swiss (e.g., Trümpy, 1980) and Austrian (e.g., Tollmann, 1977) geologists.

The southernmost part of the Upper Austroalpine unit is represented by the Drauzug. Its bearing on Alpine geology is the topic of this paper. To the south, the Austroalpine units are separated from the Southern Alps by the Peri-

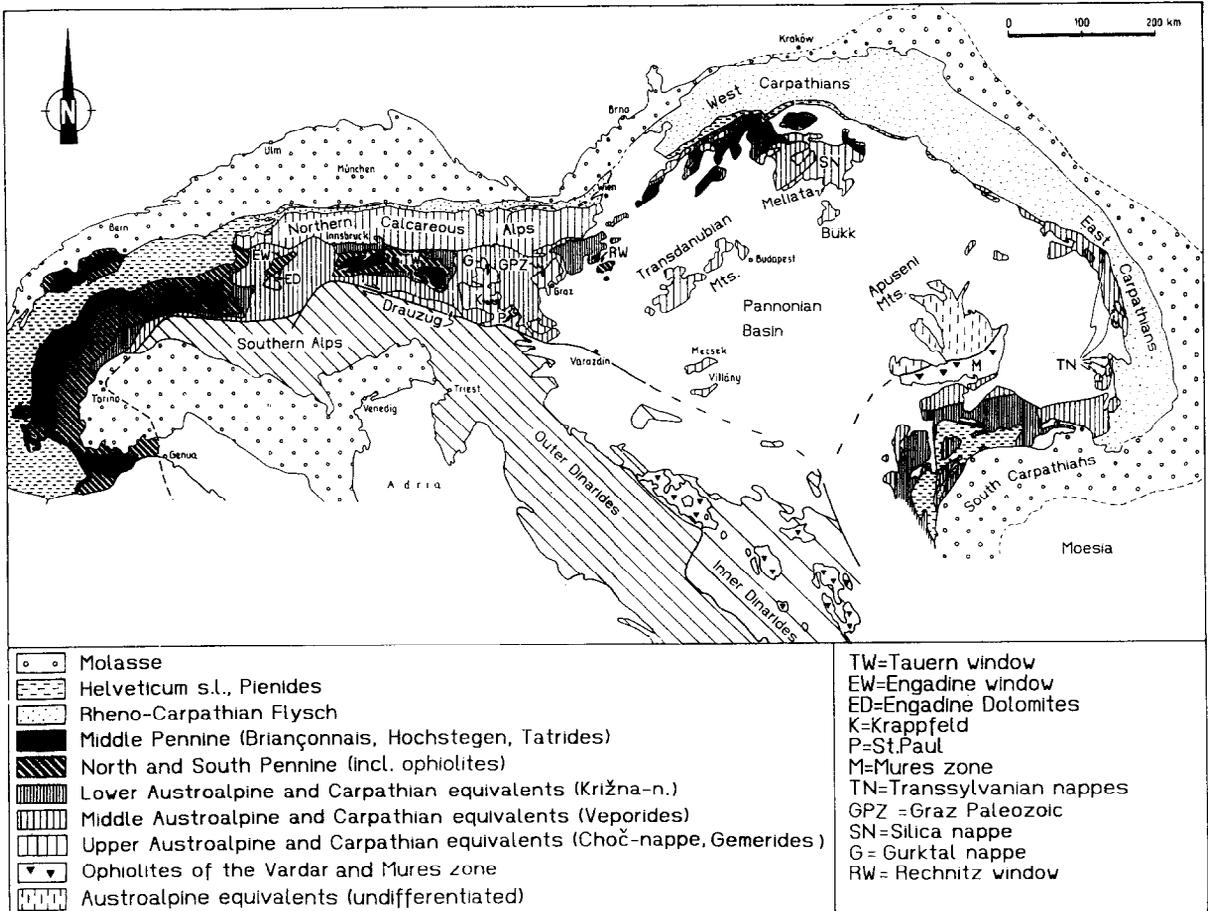


Fig. 1. Schematic tectonic map of the Alps, Carpathians and Dinarides. Alps and Carpathians modified after Tollmann (1969), Dinarides modified after Channell et al. (1979).

adriatic Lineament, which itself can be divided into several fault segments (e.g., Schmid et al., 1989).

The Lower, Middle, and Upper Austroalpine units can be traced into the West Carpathians, whereas the Southern Alps continue into the Dinarides (Fig. 1). Between the Dinarides and the Carpathians, the TDM occupy an isolated position inside the Neogene intra-Carpathian (Pannonian) basin (e.g., Burchfiel and Royden, 1982). As with the Drauzug, they are considered to be part of the southern Upper Austroalpine domain.

Paleogeographic development of the Alpine/Carpathian realm in the Permo-Triassic

In the late Paleozoic and Triassic the Alpine-Carpathian realm was part of Pangaea. From the

east this continental mass was separated by an embayment of Panthalassa, called Paleo-Tethys by Laubscher and Bernoulli (1977). This ocean disappeared later in the Cimmerian-Indosinian suture zone, due to the northward drift of Gondwanian microcontinents (Sengör, 1979; Dercourt et al., 1986). This northward drift of Gondwanian fragments created the space for a new oceanic domain called Neo-Tethys (Dercourt et al., 1986), which influenced the Alpine-Carpathian region from the southeast (Fig. 2). Throughout the Permo-Triassic, increasing marine influence from the southeast is documented in the Alpine-Carpathian area, whereas to the west and north, the occurrence of terrestrial sediments (e.g., Alpine Verrucano) and detrital influenced facies types (e.g., Buntsandstein, Keuper) is evidence of epicontinental conditions (e.g., Oberhauser, 1980; Tollmann, 1963, 1986).

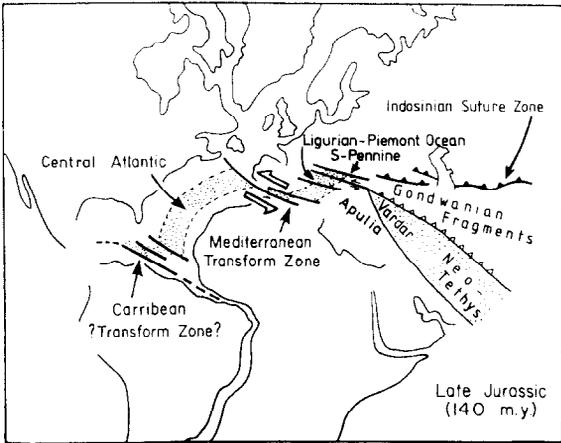


Fig. 2. Plate tectonic scenario in the Late Jurassic. The opening of the Central Atlantic ocean implied left-lateral transcurrent movements between Africa/Apulia and Eurasia. The creation of the Piemont-Ligurian ocean resulted in the simultaneous subduction of the northwestern branch of the Neo-Tethys (Vardar ocean). Dots = oceanic crust. Modified after Lemoine (1980).

The disintegration of Pangea and the north-westward propagation of the Tethys sea, which controlled the development of the Mediterranean

area, is documented by the progression of the deep water environment (Hallstatt facies) combined with synsedimentary tectonics: it reached Turkey in the Late Permian, the Dinarides in the early Anisian, and the Alpine region in the middle to late Anisian (e.g., Bechstädt et al., 1976; Bechstädt, 1978). This process of crustal thinning must be distinguished from the total breakup of Pangaea in the Late Lias and Dogger, which created the Central Atlantic and Ligurian-Piemont (South-Penninic) oceans and influenced the Austroalpine and South Alpine regions from both the west and north (Fig. 2).

In the Late Triassic the rifting processes ceased and a giant carbonate platform expanded over the formerly rifted areas ("aborted rifting" sensu Bechstädt et al., 1978). However, in the Hallstatt zone the deep-water environment persisted and formed a "gulf-like" embayment of the Vardar ocean (Kovács, 1982; 1984; Lein, 1985; 1987; Tollmann, 1987a). The resulting distinct Late Triassic facies zonation of distal (outer shelf) and proximal (inner shelf) facies types leads to the following paleogeographic reconstruction (Fig. 3): a

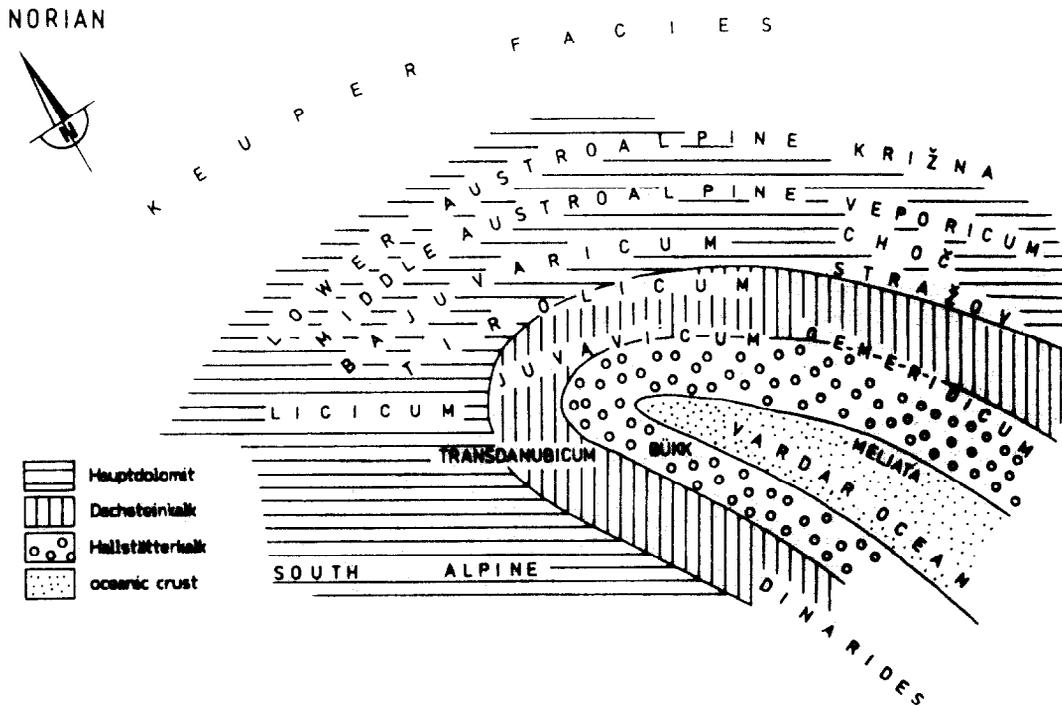


Fig. 3. Reconstruction of the Late Triassic (Norian) facies zonation in the Alpine-Carpathian region. Note that the Lower Austroalpine unit in its eastern part and the Križna nappe developed Keuper facies. Modified after Prey (1980) and Kovács (1982).

shelf slope and base of slope deep water zone (Hallstatt facies) is rimmed by a belt of Dachstein reefs and the backreef facies of Dachsteinkalk (Dachstein limestone), and eventually by the restricted inner shelf facies of the Hauptdolomit, with intercalations of Keuper facies to the north (e.g., Prey, 1980; Kovács, 1982, 1984; Lein, 1985, 1987). The Late Triassic deep water zone of the Austroalpine (Hallstatt facies) area can be traced in the north (southern European margin) to the Inner West Carpathians and farther southeast to the Transylvanides of the Inner East Carpathians (Tollmann, 1969, 1984; Kovács, 1982). In the south (northern Apulian margin), there was a deep water connection from the South Alpine realm to the Inner Dinarides (e.g., Kovács, 1982).

Whether this Triassic deep water seaway was associated with real oceanic crust is still in discussion, but it is strongly suggested by the Middle Triassic radiolarites which interfinger with huge masses of pillow lavas in the Meliata unit of the innermost West Carpathians (Kozur and Mock, 1987). Reworked ophiolites at the base of the overthrust Silica nappe contain serpentinites, gabbros, and pillow lavas with an ocean floor tholeiite affinity (Reti, 1985). Probably these ophiolites originate from the Meliata unit, which is supposed to constitute the northwestern prolongation of the Vardar ocean.

We postulate a Triassic Vardar ocean (at least an area with very thinned continental crust) which

reached between the Austroalpine–West Carpathian and the South Alpine realms (cf. Lein, 1985, 1987). This ocean was not connected with the later Ligurian–Piemont (South-Penninic) ocean, for reasons which will be shown later.

Contrasts in Permo-Triassic isopic zones between Drauzug, Transdanubian Mountains, and related geological units

The Late Permian and Late Triassic sedimentary record provides good examples for the problem stated in the introduction (e.g., Bechstädt, 1978; Niedermayr et al., 1978; Tollmann, 1978; Prey, 1980; Kovács, 1982, 1984; Dercourt et al., 1984). In the Southern Alps, the marine facies of the Bellerophon beds reaches from the east into the area of Bozen. West of Bozen, the Late Permian sediments are terrestrial (e.g., Assereto et al., 1973; Buggisch et al., 1978).

In the NCA the original internal areas (Juvavicum and parts of Tirolicum) accommodated the evaporites of the Haselgebirge. In the external areas (Tirolicum, Bajuvaricum), terrestrial red bed sediments were deposited (e.g., Tollmann, 1976a, 1985). In contrast, the Drauzug and the western TDM were the site of terrestrial red bed sedimentation (e.g., Niedermayr et al., 1978). Only in the eastern parts of the TDM marine influence is documented by evaporites and

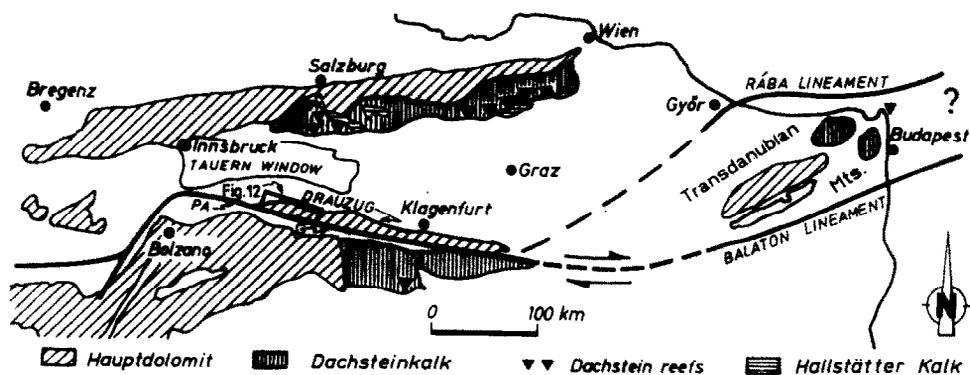


Fig. 4. Distribution of the Late Triassic (Norian) facies zones in the Alpine–Pannonian region. Drauzug and Transdanubian Mountains appear as exotic. The boundary between Hauptdolomit (incl. dolomitic Lofler cyclothems in the Bakony) (Haas, 1988) and Dachsteinkalk in the Transdanubian Mountains is displaced 450 km to the east. Modified after Prey (1980). *G* = Gailtal line (is a part of *PA*), *PA* = Periadriatic lineament. Dashed lines: connection of faults according to Kázmér and Kovács (1985).

dolomites (e.g., Majoros, 1980, 1983; Kázmér and Kovács, 1985).

We conclude that the Drauzug and the western TDM, with their terrestrial facies, do not fit in the surrounding pattern of the Late Permian marine sedimentation.

The Late Triassic facies zonation (Fig. 3) is presently reflected in the nappe pile of the NCA. The original internal Hallstatt and Dachsteinkalk facies is represented by the highest nappes (Juvavicum), whereas the more external areas of the Dachsteinkalk and Hauptdolomit facies are occupied by the Tirolicum, and eventually the most external areas of exclusively Hauptdolomit facies by the Bajuvaricum (Fig. 4). It has to be reminded that this is a simplified outline of the more complicated internal facies distribution of the NCA (detailed information in Tollmann, 1976b; 1985).

In the Southern Alps, these transitions from distal to proximal facies regions are developed in an east-west direction: Hallstatt-type limestones and Dachstein reefs in northwest Jugoslavia (Wochein), Dachsteinkalk to the west, and finally Hauptdolomit (*Dolomia principale*) to the west of the meridian of Udine (e.g., Ramovš, 1974; Prey, 1980).

The Drauzug, however, shows exclusively Hauptdolomit facies. Even the western parts of the TDM are developed in Hauptdolomit facies. In the eastern parts of the TDM, Dachsteinkalk and Hallstatt-type limestones with debris of Dachstein reefs have been found (Kozur and Mostler, 1973; Kázmér and Kovács, 1985; Kázmér, 1986). Again the Drauzug and the western TDM with their proximal facies-types appear as an exotic block in their present day framework (Fig. 4).

The Triassic of Krappfeld and St. Paul on top of the Gurktal nappe is also developed in Hauptdolomit facies, which in addition to other affinities was the reason for Tollmann (1977) to see it as a unit with the Drauzug. This facies unit was named Licicum and is considered as the southernmost part of the Upper Austroalpine (Tollmann, 1977) domain.

In summary we conclude that the Permo-Triassic sedimentary record of the Drauzug (including Krappfeld and St. Paul) and of the western

TDM shows a proximal facies character and does not fit to the distal facies zones of the surrounding Alpine and Carpathian areas. Drauzug and TDM show close affinities to the more western parts of the Alpine realm.

Early Liassic rifting related facies differentiation of the Transdanubian Mountains and the Drauzug

Transdanubian Mountains

The Early Liassic sedimentary record of the TDM documents the disintegration of the Late Triassic carbonate platform and allows to distinguish three different facies zones. These are from east to west: the Gerecse platform, the Bakony platform, and the Zala basin (Kázmér, 1987).

The Gerecse platform is characterized by red limestones of reduced thickness which paraconformably overlie the Rhaethian Dachsteinkalk. The uppermost part of the Dachsteinkalk is missing. The drowning of the Late Triassic carbonate platform occurred between the Rhaethian and middle Hettangian (Kázmér, 1987). Contrary to Kázmér (l.c.), we here prefer the term platform because the sediments represent rather the environment of a drowned carbonate platform than of a basin in Liassic times.

To the west, on the Bakony platform, the carbonate platform development was not interrupted at the Triassic/Jurassic boundary, but persisted until the late Hettangian. This is documented by shallow-water oncoid limestones (Kardosrét limestone).

Subsurface data from the Zala basin reveal a complex internal structure. Local highs in Early Liassic time (e.g., Szilvagy) are characterized by shallow-water oncoid limestones, troughs between the highs contain thick sequences of black marls deposited in restricted environments (for more information see Kázmér, 1986, 1987).

Drauzug

The Drauzug is divided into the Nordkarawanken, the Gailtaler Alpen, and the Lienzer Dolomiten (from east to west). West of the Lienzer Dolomiten several isolated slices of

Mesozoic sediments, such as the Winnebacher Kalkzug, belong to the Drauzug (Furlani, 1912; Tollmann, 1977; Hippenstiel, 1985). During the Lias, the Nordkarawanken were characterized by reduced sedimentation of red biosparitic limestones (Hierlatzkalk), interfingering with red nodular limestones (Adneter Kalk) (Schröder, 1988). They are interpreted as a drowned carbonate platform.

Whereas no Jurassic sediments are preserved in the Gailtaler Alpen, Early Liassic sediments of the Lienzer Dolomiten indicate two troughs filled with hemipelagic basin sediments. These are separated by a presently N–S striking swell with shallow-water limestones (Fig. 5) (Blau and Schmidt, 1988). The sedimentary record is the result of two westward tilted crustal blocks. The synsedimentary fault scarp, which bordered the downthrown western part of the eastern block, shed megabreccias into the eastern trough. The sediments deposited on the western block reflect a gradual deepening of the trough to the west. The upthrown eastern part of the block was affected by synsedimentary faulting, which produced in situ brecciation of the shallow-water limestones (Lavanter Breccie) and neptunic dykes

in the underlying Oberrhätkalk. These were filled with Early Liassic red biomicritic limestones (Blau, 1987a, b). The effects of faulting disappear towards the west, where the breccia passes into variegated limestones (Bunte Kalke) and eventually Liasfleckenmergel (Allgäuschichten), thickening towards the west.

Liassic facies relations between Drauzug, Transdanubian Mountains, and other Alpine units

Relations between Drauzug and Austroalpine units

Like the Drauzug and the TDM, other parts of the Alpine realm were affected by active rifting processes in Liassic times. As a consequence, the Late Triassic spacious arrangement of facies zones was destroyed and replaced by a highly differentiated facies pattern.

The NCA are characterized by Liasfleckenmergel basin(s), which can be divided into several troughs by long E–W trending intra-basinal swells on which red crinoidal limestones (Hierlatzkalk) and red nodular limestones (Adneter Kalk) were deposited (Jacobshagen, 1965; Tollmann, 1976a). Difficulties are raised, when one attempts to re-

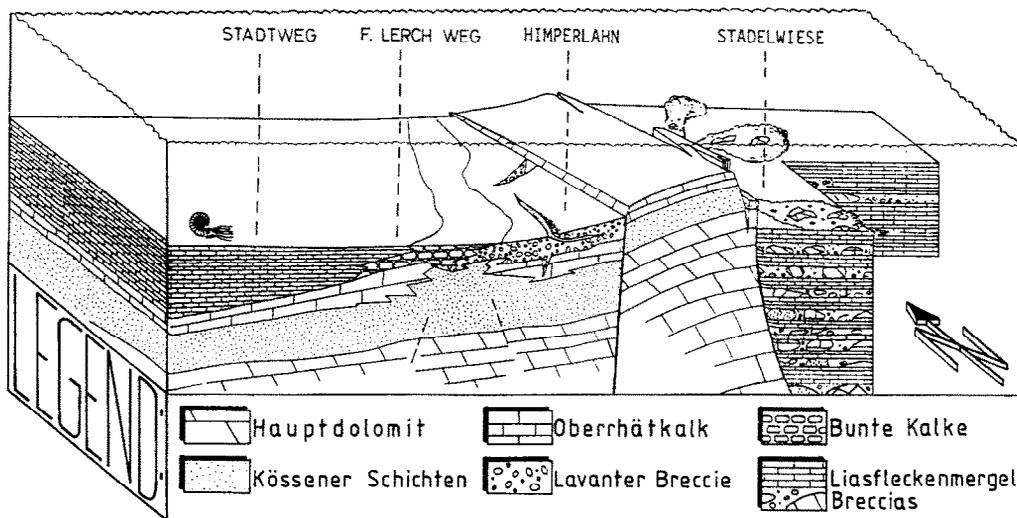


Fig. 5. Paleogeography of the Lienzer Dolomiten in the Early Lias. It shows the typical situation of two tilted blocks which created a today N–S striking horst/halfgraben structure. The Stadelwiese represents the western part of the westward tilted eastern block. It is bordered to the west by a Liassic fault scarp with a displacement of at least 2000 m. From the western block megabreccias poured into the basin of the Stadelwiese. The Lavanter Breccie of the Himperlahn area marks the upthrown eastern part of the western block. In situ brecciation occurred on minor faults presumably parallel to the main fault of the Stadelwiese. To the west the Lienz trough deepens gradually, documented by the increasing thickness of Liasfleckenmergel (compare with Fig. 6).

late the Liassic sediments to their former neighbouring depositional areas. In particular, the absence of accurately determined proximal and distal facies zones complicates a paleogeographic reconstruction.

As these facies relationships are not sufficiently clear, palinspastic reconstructions must be based on other criteria, as could be provided by syndimentary tectonics and the trend of major structural features.

The complex primary situation (Liassic) is further complicated by the later Alpine orogeny. It is likely that many of the Liassic extensional faults became transformed into thrust planes or strike-slip faults (e.g., Dewey et al., 1986; Tricart and Lemoine, 1986). Additionally, different parts of the NCA have been rotated in opposite directions as is evident from paleomagnetic investigations (Mauritsch and Becke, 1987; Heller et al., 1989). Under these circumstances it is problem-

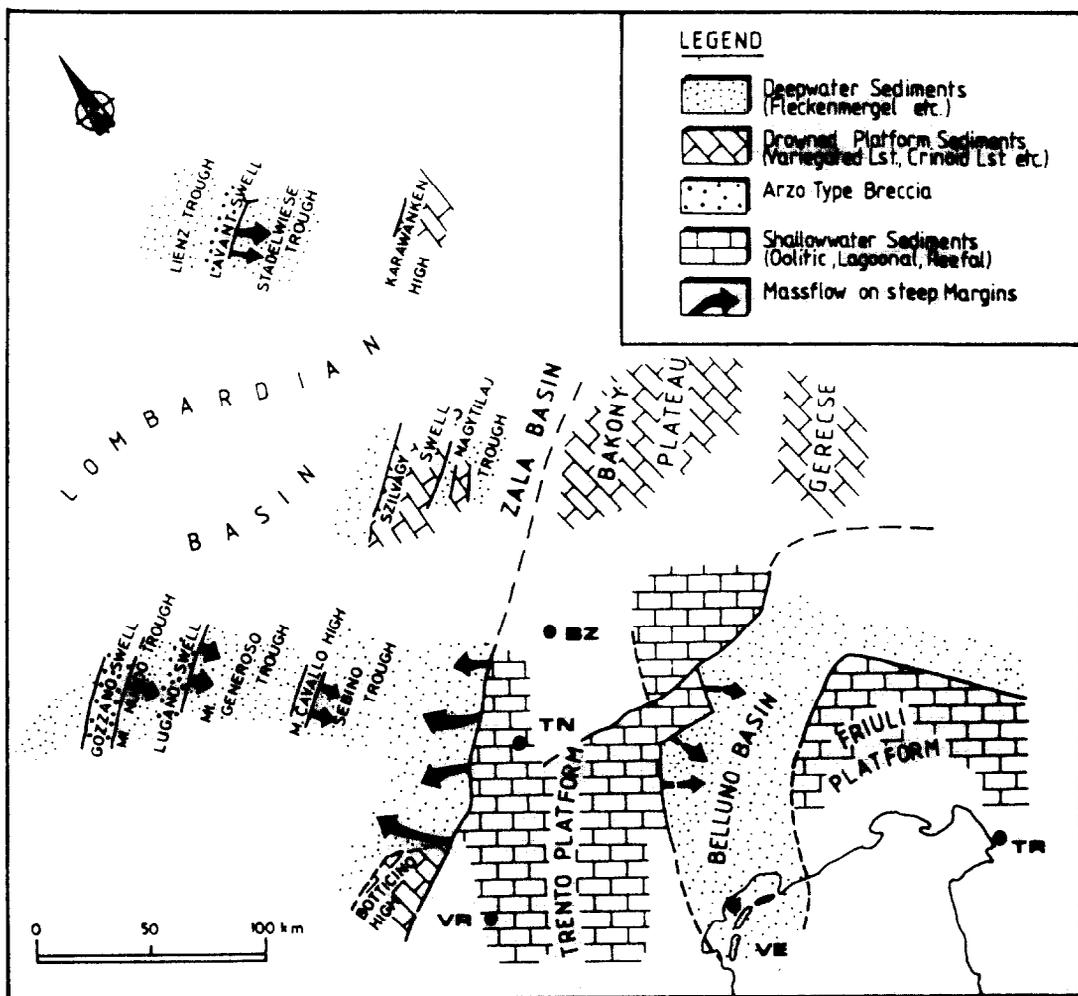


Fig. 6. Paleogeographic reconstruction of the Early Liassic South Alpine realm and its northern prolongation. After shifting back the Drauzug and the Transdanubian Mountains to their proposed original position a good correlation of facies and structural elements is given. The today N-S striking swell/halfgraben structure of the Lienz Dolomiten fits to the western part of the Lombardian basin which shows the same facies association. The Karawanken-high and the highs of the Zala basin represent isolated elevations in the eastern part of the Lombardian basin. The Bakony platform appears as the northern prolongation of the Trento platform with its typical shallow-water carbonates. Modified after Winterer and Bosellini (1981). (BZ = Bozen, TR = Trieste, TN = Trento, VE = Venice, VR = Verona).

atic to use the Liassic sedimentological and structural pattern of the NCA for palinspastic reconstructions.

The Upper(?) Austroalpine Engadiner Dolomiten show a structural and sedimentary record closely resembling that of the Lienzer Dolomiten: a presently N–S striking swell and halfgraben configuration with eastward dipping fault scarps, in situ brecciated shallow-water limestones on the swells, and Lower Liassic scarp breccias in the basins (Eberli, 1985). In the Lower Austroalpine realm of this area (e.g., Err nappe) sedimentological and stratigraphic data indicate Late Liassic to Dogger rifting activity with westward (i.e. oceanward) dipping fault scarps (e.g., Froitzheim and Eberli, 1990). The authors interpreted this configuration as the result of two low-angle detachment fault systems. The first was active in the Early Lias dipping eastward, the second in the Late Lias to Dogger dipping westward. The striking similarities of the Engadiner Dolomiten and the Lienzer Dolomiten point to a close relationship.

Relations between Drauzug and Southern Alps

The Jurassic setting of the South Alpine domain is interpreted as an analogue to modern passive continental margins (Bernoulli, 1981; Winterer and Bosellini, 1981). Due to the weak Alpine overprinting, the Jurassic configuration can still be clearly reconstructed (Wiedenmayer, 1963; Bernoulli, 1964; Aubouin et al., 1965; Castellarin, 1972; Kälin and Trümpy 1977; Bernoulli et al., 1979; Winterer and Bosellini, 1981).

The Southern Alps are divided into four N–S trending paleogeographic elements known as the Friuli platform, the Belluno trough, the Trento platform, and the Lombardian basin (Fig. 6). Each element is characterized by a different sedimentological and structural development.

The Lombardian basin is subdivided into several troughs by N–S striking rises (Gaetani, 1975; Kälin and Trümpy, 1977; Winterer and Bosellini, 1981); the sedimentary and stratigraphic record resembles that of the Drauzug. Large tilted blocks, bound by normal faults with a displacement of up to several thousands of metres, were

recorded by Bernoulli (1964) and Castellarin and Sartori (1972). Scarp breccias associated with these faults occur frequently in the basinal areas; in situ brecciated shallow-water limestones are characteristic of the intra-basinal swells (Wiedenmayer, 1963, Bernoulli, 1964; Winterer and Bosellini, 1981). The stratigraphic and structural record of the Drauzug differs from that of the South Alpine region with the exception of the Lombardian basin. For example, the Trento platform was also drowned, but not before the Late Lias to Dogger (Gaetani, 1975; Bosellini et al., 1981; Winterer and Bosellini, 1981).

We conclude that the Drauzug can only be compared with the Lombardian basin. The swell and halfgraben structure of the Lienzer Dolomiten can be correlated with the Monte Nudo trough, the Lugano swell and the Monte Generoso trough; the Nordkarawanken may represent an isolated high in the eastern part of the Lombardian basin like the Botticino high (Fig. 6). Compare data presented here with those of Gaetani (1975) and Winterer and Bosellini (1981).

Paleomagnetic data prove the absence of larger rotations between the Drauzug and the Southern Alps since the Carboniferous (Heinz and Mauritsch, 1980). This is a good confirmation of the geologic data.

Relationships between the Transdanubian Mountains and the Southern Alps

Based on the Liassic sedimentary record, the TDM can be divided into three paleogeographic units (see above). According to Kázmér and Kovács (1985) and Kázmér (1987) these units can be correlated with the South Alpine paleogeographic units in the following way: the Gerecse platform corresponds to the Belluno trough, the Bakony platform to the Trento platform, and the Zala basin to the Lombardian basin (Fig. 6).

Tethyan margins and their plate tectonic framework in post-Triassic time

After the Liassic rifting period the creation of the Ligurian–Piemont ocean (South-Penninic) in Late Liassic to Dogger times separated the Aus-

troalpine and South Alpine domains from the European continent (Bernoulli, 1981; Dercourt et al., 1986). They now belong to Apulia (forming its northwestern margin), which is still part of Africa (Channell and Horváth, 1976). Along the eastern margin of Apulia new oceanic crust was also created in the Vardar ocean (Dercourt et al., 1986; Knipper et al., 1986).

However, Apulia remained linked to Eurasia via the West Carpathian realm, and the Ligurian–Piemont ocean and the Vardar ocean never merged (Dercourt et al., 1984; Tollmann, 1987a) (Figs. 2, 7). This is shown by the surrounding facies belts of the two oceans. The Vardar ocean was surrounded by the Hallstatt facies (distal facies) in the Austroalpine and West Carpathian realms (Kovács, 1982, 1984; Tollmann, 1987a) (Fig. 3). This area was separated from the realm of the later Ligurian–Piemont ocean by the vast regions of Dachsteinkalk and Hauptdolomit facies of the Upper, Middle, and Lower Austroalpine domains. The Lower Austroalpine

realm, which bordered the Ligurian–Piemont ocean to the south (Tollmann, 1977; Häusler, 1987), even developed Keuper facies in its eastern parts (Semmering) (Tollmann, 1977), emphasizing its proximal facies character.

The Rechnitz window is the easternmost outcrop with remnants of the Ligurian–Piemont ocean. Even if the Ligurian–Piemont ocean reached far to the east into the realm of the West Carpathians (Trümpy, 1988) (in this case its remnants would lie hidden below the West Carpathian nappes), this would not contradict the following conclusion: the Ligurian–Piemont ocean must have cut through the Austroalpine domain or the corresponding West Carpathian units if a connection between the two oceans existed. The lack of such evidence in the NCA and the West Carpathians is the best objection against this idea.

The opening of the Ligurian–Piemont ocean was closely linked with the development of the Central Atlantic ocean; this had consequences for the evolution of the Apulian margins (Fig. 2). The

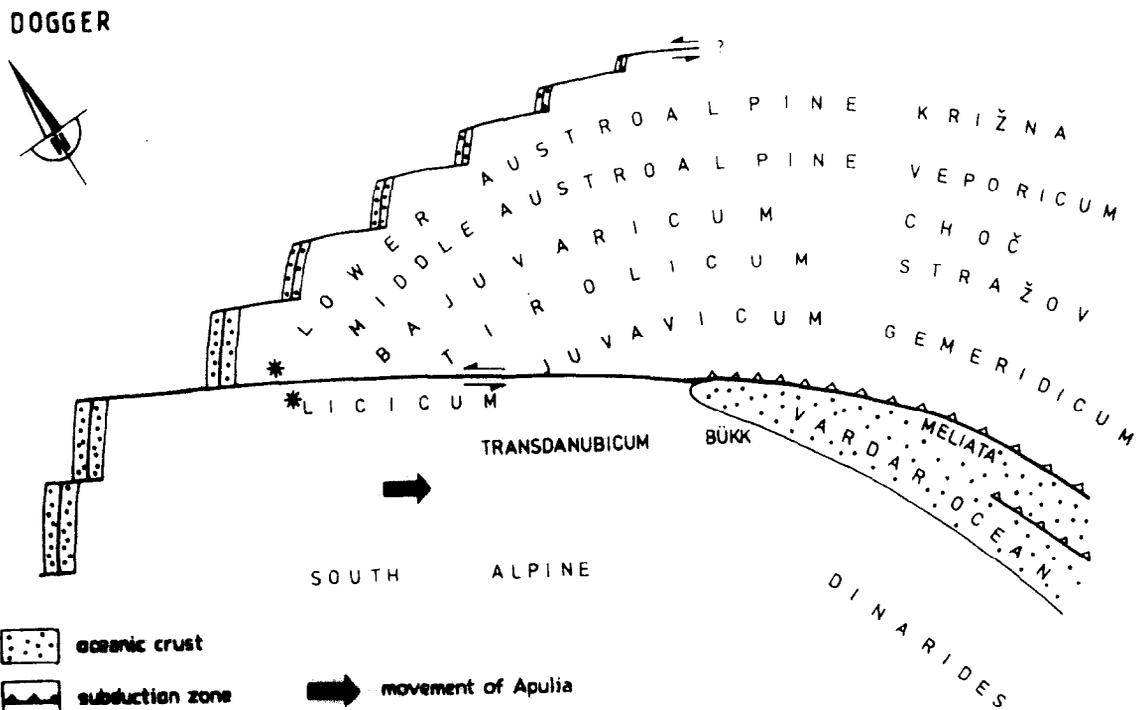


Fig. 7. Beginning of the spreading of the Ligurian–Piemont ocean. The plate tectonic situation (cf. Figure 2) implied left-lateral translation between Africa/Apulia and Eurasia causing the simultaneous subduction of the Vardar ocean. Note that the Ligurian–Piemont and Vardar oceans were separated by the Austroalpine and West Carpathian realms which implies the proposed transform faulting.

opening of these oceans necessarily implied sinistral transcurrent movements between Africa/Apulia and Eurasia (Dercourt et al., 1986; Ziegler, 1988). Since the Ligurian–Piemont ocean probably did not attain the width of the contemporaneous Central Atlantic ocean, these movements must have been compensated elsewhere. Therefore, the northern and western margins of Apulia are presumed to be of a transform type (Figs. 7, 8). This is suggested by the occurrence of serpentinites and ophicalcites that are similar to rocks retrieved from recent oceanic fracture zones (Lemoine, 1980; Weissert and Bernoulli, 1985).

On the other hand the Vardar ocean, which paralleled the eastern margin of Apulia, must have started to close at the same time (Dercourt et al., 1986; Knipper et al., 1986; Ricou et al., 1986; Kazim et al., 1986) (Figs. 7, 8, 9). Evidence for subduction is given by the Aalain flysch deposits in the Meliata unit (Kozur and Mock, 1987) and last not least by the calc-alkaline volcanism at the southeastern margin of Eurasia (Dercourt et al., 1986; Knipper et al., 1986).

This overall situation persisted throughout the Jurassic until the Early Cretaceous when Apulia's northeastern leading edge collided with the southern margin of Eurasia. As a result Apulia was partly decoupled from Africa along the Gibraltar–Maghreb–South Anatolian fracture zone (Ziegler, 1988) and began an anticlockwise rotation (Figs. 9, 10). The former sinistral transpressive regime was replaced by a dextral transpressive one, which marked the onset of the Alpine orogeny (Dercourt et al., 1986; Tollmann, 1986; Ziegler, 1988) (Figs. 9, 10).

Although the sinistral translation between Africa and Eurasia persisted throughout the Cretaceous, the opening of the South Atlantic–Indian ocean forced Africa to rotate anticlockwise and to converge with Eurasia (Savostin et al., 1986; Westphal et al., 1986; Ziegler, 1988). This movement of Africa induced the progressive closure of the Ligurian–Piemont ocean and the continuation of Alpine orogeny (Tollmann, 1980; Trümpy, 1980). In the Early Tertiary, the former left-lateral movements between Africa and Eura-

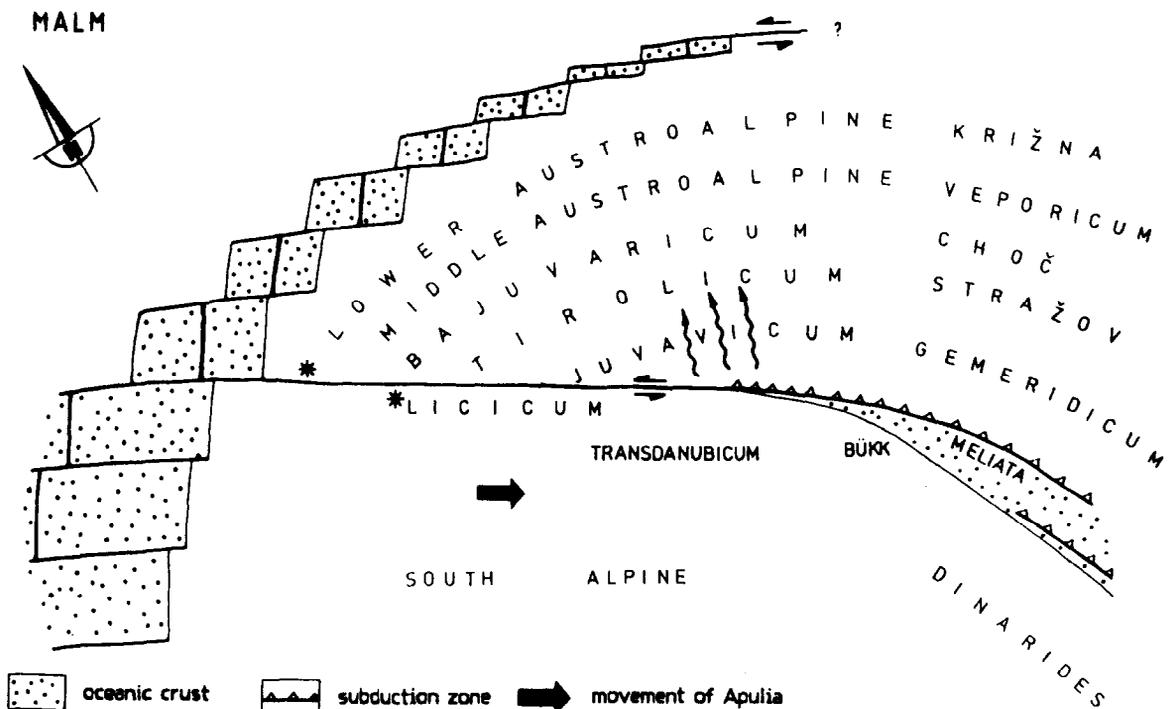


Fig. 8. While the Ligurian–Piemont ocean opened continuously, Loricum and Transdanubium (together with the southern part of Apulia) were displaced to the east. The Vardar ocean got still subducted beneath Eurasia. Transcurrent movement may have induced gravitational sliding tectonics in the Juvavicum.

BARREMIAN

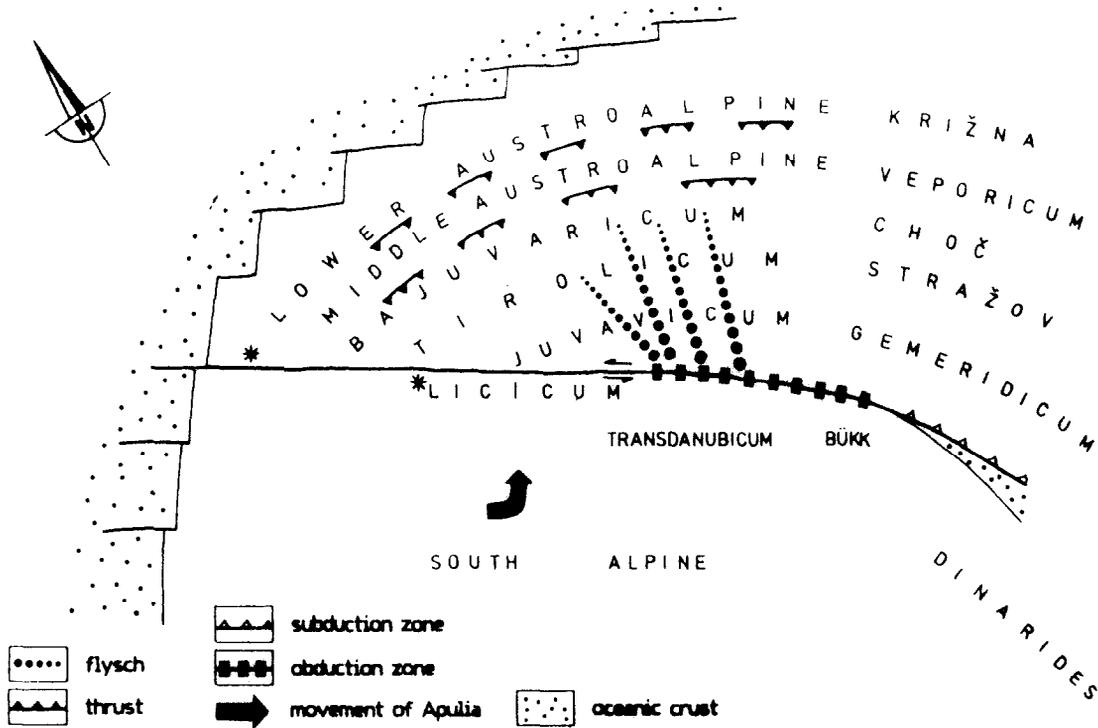


Fig. 9. Continuous displacement of Loricum and Transdanubium to the east. The northwestern branch of the Vardar ocean was closed causing ophiolite obduction. Collision induced the beginning of anticlockwise rotation of Apulia. The Rossfeld beds in the NCA derived their ophiolitic detritus from the south. First thrusting of Apulias northern margin.

sia turned into right-lateral direction. This was due to the progressive opening of the North Atlantic ocean and a simultaneous drop in the spreading rate between North America and Africa (Dercourt et al., 1986; Savostin et al., 1986).

The Drauzug and the Transdanubian Mountains as displaced crustal units

The Permo-Triassic and (to some extend) Early Jurassic sedimentary record of the Drauzug and of the TDM characterizes them as crustal units that have strong western affinities compared to structural units that presently surround them. This complicates paleogeographic reconstructions.

These difficulties are avoided if the Drauzug and the TDM are interpreted as displaced crustal units that were transported from their original western position to the east.

After the attempts of Bechstädt (1978) and Prey (1978) concerning the Drauzug, Kázmér and Kovács (1985) were the first to take such a possi-

bility into consideration and proposed their "continental escape" model. According to this model the TDM originally were located between the South Alpine domain and the NCA, and the Drauzug even farther west. These blocks were squeezed out towards the east along the DAV (Deferegental–Anterselva–Valles)–Raba lineament in the north and along the Gailtal–Balaton lineament in the south, during the Middle Eocene to Late Oligocene main phase of the Alpine orogeny that involved the collision of Apulia with Eurasia (Fig. 4).

This model solves many problems but also raises new difficulties as pointed out by Tollmann (1987a). He agrees with the original position of Drauzug and TDM but disagrees with the timing of their displacement. Because the escape is postulated after the emplacement of the Austroalpine nappes, Tollmann (1987a) demands a northern analogue to the obvious Periadriatic lineament to the south. After Tollmann (l.c.) the authors constructed this necessary fracture zone

by adding several individual, differently striking and partly not even existing fault segments. According to Tollmann (l.c.) the DAV–Rába lineament cannot be accepted as a northern equivalent of the Periadriatic lineament. Another problem is the Triassic of Krappfeld and St. Paul (Fig. 1) on top of the Gurktal nappe. This Triassic (with Hauptdolomit facies) is interpreted as a facies unit together with the Drauzug (Licicum) (Tollmann, 1977). The fact that the Gurktal nappe was thrust in its position during the early Late Cretaceous (pre-Gosau) also necessarily implies a pre-Gosau eastward displacement of the Gurktal nappe. Otherwise, the Gurktal nappe could not have been transported into its location by top-to-north (Tollmann, 1987a) or even top-to-west-northwest thrusting (Ratschbacher, 1987; Neubauer, 1987).

Tollmann (1987a) proposes a Jurassic to Lower Cretaceous displacement of the Drauzug (together with the other parts of the Licicum) and

separately of the Transdanubicum (the facies unit of which the TDM are part of) along transform faults. Additionally, he postulates that the TDM are part of a big nappe, called Ultrastyrian nappe, which was thrust to the north over the Licicum in the early Late Cretaceous (pre-Gosau). According to Tollmann (l.c.) this uppermost nappe is necessary to explain the South Alpine clasts in the Gosau sediments (“Mittelsteirische Gosau”) of the Graz Paleozoic (Gollner et al., 1987).

As to the Drauzug, we cannot confirm this idea because there are no signs that the Drauzug was overthrust by a large nappe. We agree with Tollmann (l.c.) that the eastward displacement of the Licicum and the TDM took place before the emplacement of the Austroalpine nappes. But in our model these movements took place at the same time and involved the Licicum, the Transdanubicum (the facies unit of which the TDM are part of), and the South Alpine realm. This is in agreement with the movements of Apulia de-

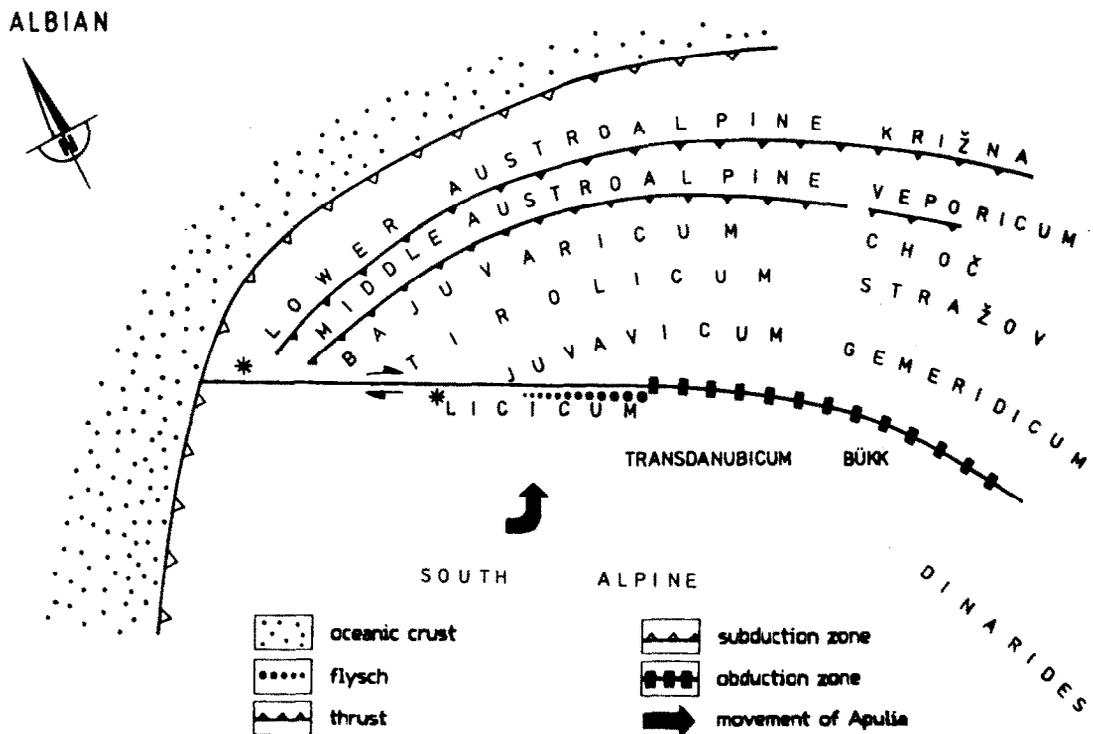


Fig. 10. Apulias northeastern margin has collided with Eurasia. Consequently Apulias eastward movement has ceased and Licicum and Transdanubicum have reached their eastern position. Apulia continued to rotate counterclockwise and moved to the north causing subduction of the Ligurian–Piemont ocean and advanced thrusting in the Austroalpine realm. The Lavant flysch derived its detritus from the obduction zone in the east. Note inversion of the former sinistral into a dextral strike-slip fault.

scribed by Dercourt et al. (1986) and Savostin et al. (1986).

The displacement of the Drauzug and the Transdanubian Mountains

With the beginning of spreading in the Central Atlantic and Ligurian–Piemont oceans in the Late Lias/Dogger Apulia moved to the southeast in respect to Eurasia until the Early Cretaceous (Fig. 2). From then on Apulia's northeastern margin began to collide with Eurasia and started an anticlockwise rotation (Dercourt et al., 1986; Ziegler, 1988).

Because in our model Apulia was connected with Eurasia via the West Carpathians (Dercourt et al., 1984), only the areas south and west of the Vardar ocean could move easily to the east, while the Vardar ocean itself was subducted under the southeastern margin of Eurasia (Figs. 7, 8, 9).

On the other hand, the areas north of the Vardar ocean, i.e. the Austroalpine (except Liticum) and the West Carpathians, were hindered in their eastward movement. This scenario implies left-lateral transcurrent movements in the area between Liticum, Transdanubicum on one side and Upper Austroalpine, West Carpathians on the other side (Figs. 7, 8, 9).

Beside the proposed strike-slip fault of Figs. 7–9 other corresponding faults might have dissected Apulia like the Emilia fault (Bosellini, 1981). Because pure strike-slip is probably very rare we prefer to think of a broad oblique-slip mobile zone (*sensu* Ballance and Reading, 1980).

Recently Spieler (1990) and Channell et al. (1990) interpreted a Liassic basin of the NCA (close to the Achensee (Achen Lake), 40 km northeast of Innsbruck) as a sinistral pull-apart basin. This would imply that the proposed sinistral transcurrent movements occurred even earlier (late Hettangian/Sinemurian).

Strike-slip movements might also have induced the Late Jurassic gravitational sliding tectonics in the Juvavicum of the NCA (Fig. 8) (Tollmann, 1987a, b; Lein, 1987), since extensional as well as compressional features are typical for strike-slip systems (Reading, 1980; Christie-Blick and Bidle, 1985).

In this context, it must be considered that the Late Jurassic breccias of the NCA (Schwarzbergklamm breccia, Hornstein breccia, Rofan breccia) can be interpreted as rifting related massflow movements (*sensu* Wächter, 1987), because the Late Jurassic was the time of advanced spreading in the Ligurian–Piemont ocean (Dercourt et al., 1986), i.e. the time of thermal subsidence of the whole shelf. The breccias could also have been deposited in pull-apart basins, which received their detritus from fault scarps and adjacent elevated areas. These elevated areas are indicated by clasts of Upper Jurassic shallow-water carbonates in the breccias (Wächter, 1987). Such an origin of the breccias would fit well into the plate tectonic scenario.

In the earliest Cretaceous Apulia's eastern margin collided with an intra-oceanic volcanic arc, and ophiolites were thrust over Apulia's eastern margin in the Dinarides and Hellenides (Dercourt et al., 1986; Knipper et al. 1986). The following anticlockwise rotation of Apulia caused the first thrusting in the Austroalpine domain, as indicated by the Early Cretaceous Rossfeld beds of the NCA (Fig. 9). These early orogenic sediments derived their ophiolitic detritus from the south, indicating that oceanic crust was obducted south of the NCA (Faupl and Tollmann, 1979; Decker et al., 1987). From this ophiolitic detritus we can constrain the proposed western prolongation of the Vardar ocean, as well as the evidence that the Aptian/Albian flysch of the Lienzer Dolomiten (Fig. 10) was transported in a western direction (Mariotti, 1972; Faupl, 1977).

In the middle Cretaceous, Apulia's eastern margin was in full collision with Eurasia and was stopped in its eastward movement (Dercourt et al., 1986); i.e. together with the Drauzug, the TDM and the Southern Alps must have reached their eastern position.

Based on paleomagnetic data, Channell et al. (1990) argued that the NCA did not take part in the anticlockwise rotation of Apulia and concluded that the NCA were decoupled from Apulia by an oceanic branch of the Tethys (connection between the Ligurian–Piemont and Vardar oceans). Although we cannot see evidence for this ocean, the proposed decoupling of the NCA

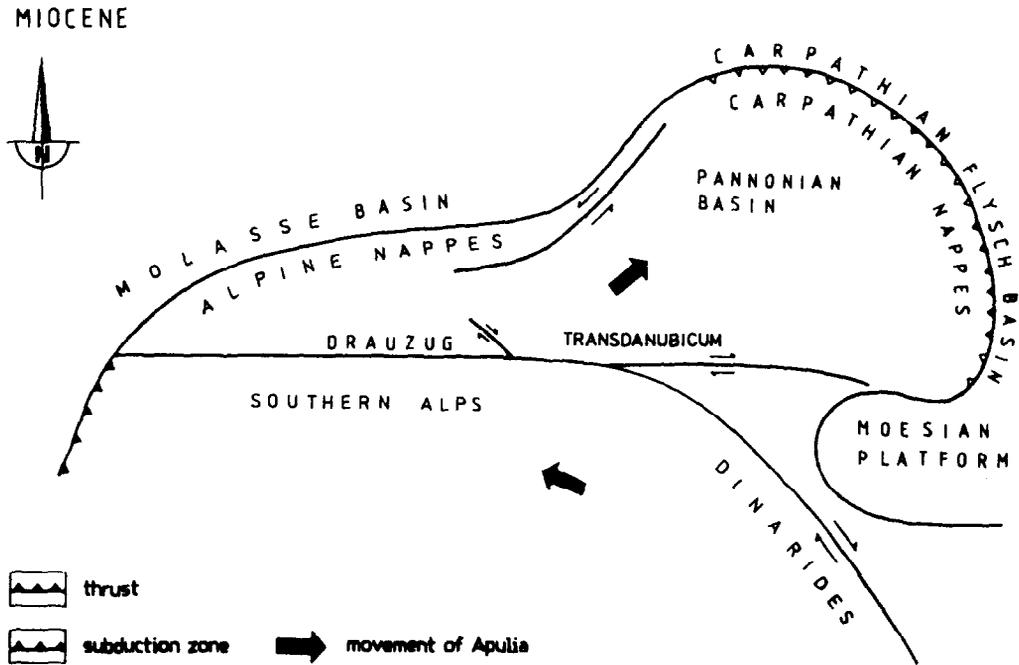


Fig. 11. Due to the overall plate tectonic situation, the relative motion between Africa and Eurasia has become right-lateral. The Southern Alps were shifted back to the west into their recent position. The Transdanubicum experienced additional eastward displacement due to continental escape of the Intra-Carpathian region (see text for discussion).

could be accomplished simply by the strike-slip fault zone shown in Figs. 7-9. Due to the collision in the east (Fig. 10), the former sinistral fault zone could have been converted into a dextral strike-slip zone. This then became the northern boundary of the anticlockwise rotating Apulia plate.

In the Miocene the now right-lateral translation between Africa and Eurasia reached its maximum causing a complex system of en echelon arranged right-lateral strike-slip faults, along which Apulia glided to the northwest (Dercourt et al., 1986; Savostin et al., 1986). During this time the Southern Alps were displaced back to

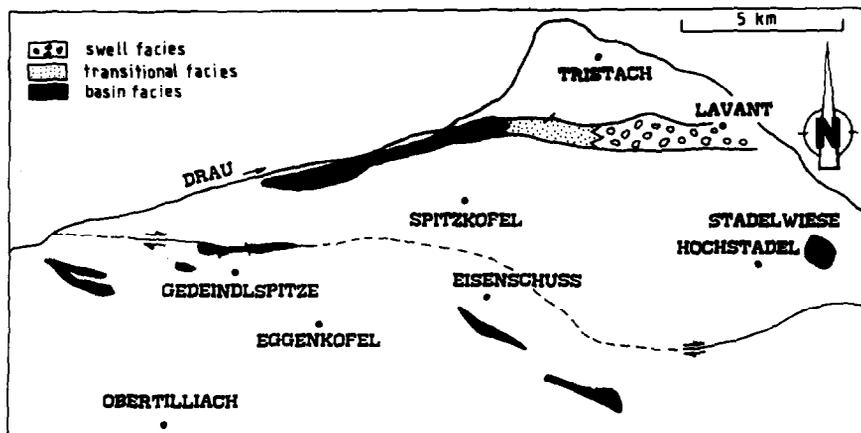


Fig. 12. Distribution of Early Liassic facies zones in the Lienzer Dolomiten. The location of basin facies in the south against swell facies in the north indicates the dissection of the original Jurassic facies pattern, due to strike-slip faulting (compare with Figs. 5, 6).

the west along the right-lateral Periadriatic fault, leaving Licio and TDM in the east (Fig. 11).

The distribution of Jurassic facies zones in the Lienzer Dolomiten indicates that the original facies pattern (compare with Figs. 5, 6) was dissected by dextral strike-slip faulting (Fig. 12). This was probably contemporaneous with the movement along the Periadriatic fault. Periadriatic tonalite bodies with an intrusion age of 20–30 Ma provide evidence for movement during this time (Exner, 1976; Mager, 1985).

From Mesozoic paleogeographic reconstructions, it is probable that the TDM have been transported even farther to the east than the Drauzug. The mechanism for this additional displacement could have been provided by continental escape of the Intra-Carpathian region toward the Carpathian flysch basin, where oceanic crust was subducted (Burchfiel and Royden, 1982; Royden et al., 1982). This east to northeastward escaping block was decoupled from Apulia by the dextral Periadriatic–Vardar fault system and related faults. Sets of contemporary sinistral ENE trending strike-slip faults in the eastern Eastern Alps and the western West Carpathians provided the conjugate fault system (Ratschbacher et al., 1989, 1990) (Fig. 11). The creation of pull-apart basins along these faults, such as the Vienna Basin, occurred between 17.5 and 13 m.y. and dates the active strike-slip faulting in the Intra-Carpathian region (Burchfiel and Royden, 1982; Royden et al., 1982).

Conclusions and outlook

The proposed model tries to solve problems which arise from the discontinuity of isopic zones in the Alpine-Carpathian region. Based on Permo-Triassic facies zones, the Drauzug as well as the TDM must be interpreted as displaced crustal units shifted to the east from their original western position. The mechanism for this eastward transport is provided by the sinistral translation between the Africa/Apulia and Eurasia plates due to the opening of the Central Atlantic and Ligurian–Piemont oceans in the Middle Jurassic to Early Cretaceous. During this process the Vardar ocean at Apulias eastern margin was

closed. Because the Vardar ocean was separated from the Ligurian–Piemont ocean by the northern Austroalpine and West Carpathian realms, the area between these two oceans must have been the site of intensive sinistral strike-slip faulting. After this time of eastward displacement, the South Alpine realms were shifted back to the west along the dextral Periadriatic fault system in the Late Oligocene and Miocene. During this time, the TDM experienced an additional eastward displacement due to continental escape of the Intra-Carpathian region.

The Drauzug and the TDM are good examples for crustal units in an exotic position but by no means do they represent the only ones, as two examples may demonstrate. The Bükk Mountains, now situated north of the TDM in northern Hungary, show close affinities to Dinaric facies zones (Kovács, 1982, 1984; Kozur and Mock, 1987). On the other hand, south of the TDM, the Mecsek and Villány Mountains definitely resemble the facies of the European margin, such as Liassic Gresten facies, detritically influenced from the north (Kovács, 1982, 1984; Dercourt et al., 1984).

In our opinion the displacements of these units must be seen in context with the lateral movements of Drauzug, TDM, and Southern Alps, but these problems are beyond the scope of this paper. The advantage of our model is that the eastward displacement of Drauzug, TDM, and Southern Alps and the later westward displacement of the Southern Alps is in good agreement with the movements of the Apulia plate and the corresponding orogenic processes.

Acknowledgements

This paper is part of T. Schmidt's Ph.d. thesis. We thank W. Blind and J. Behrmann for fruitful discussions. The reviewers of *Tectonophysics* gave critical comments and helped to improve the paper. D. Tanner corrected the English text.

References

- Assereto, R., Bosellini, A., Fantini Sestini, N. and Sweet, W.C., 1973. The Permian–Triassic boundary in the South-

- ern Alps. In: A. Logan and V. Hills (Editors), *The Permian and Triassic Systems and their Mutual Boundary*. Mem. Can. Soc. Pet. Geol., 2: 176–199.
- Aubouin, J., Bosellini, A. and Cousin, M., 1965. Sur la paléogéographie de la Venetie au Jurassique. Mem. Geopal. Univ. Ferrara, 1, II, (5): 149–158.
- Ballance, P.F. and Reading H.G. (Editors), 1980. Sedimentation in oblique-slip mobile zones. Int. Assoc. Sedimentol. Spec. Publ., 4: 265 pp.
- Bally, A. W., 1981. Atlantic-type margins. In: A.W. Bally, A.B. Watts, J.A. Grow, W. Manspeizer, D. Bernoulli, C. Schreiber and J.M. Hunt, *Geology of Passive Continental Margins: History, Structure and Sedimentologic Record (with special emphasis on the Atlantic margin)*. Am. Assoc. Pet. Geol., Educ. Course Note Ser., 19: (1)1–(1)48.
- Bechstädt, T., 1978. Faziesanalyse permischer und triassischer Sedimente des Drauzugs als Hinweis auf eine grossräumige Lateralverschiebung innerhalb des Ostalpins. Jahrb. Geol. Bundesanst. (Austria), 121(1): 1–121.
- Bechstädt, T., Brandner, R. and Mostler, H. 1976. Das Frühstadium der alpinen Geosynklinalentwicklung im westlichen Drauzug. Geol. Rundsch., 65 (2): 618–648.
- Bechstädt, T., Brandner, R., Mostler, H. and Schmidt, K., 1978. Aborted rifting in the Triassic of the Eastern and Southern Alps. Neues Jahrb. Geol. Paläontol. Abh., 126: 157–178.
- Bernoulli, D., 1964. Zur Kenntnis der Geologie des Monte Generoso (Lombardische Alpen). Ein Beitrag zur Kenntnis der südalpinen Sedimente. Beitr. Geol. Karte Schweiz, N.F., 118: 134 pp.
- Bernoulli, D., 1981. Ancient continental margins of the Tethyan ocean. In: A.W. Bally, A.B. Watts, J.A. Grow, W. Manspeizer, D. Bernoulli, C. Schreiber and J.M. Hunt, *Geology of Passive Continental Margins: History, Structure and Sedimentologic Record (with special emphasis on the Atlantic margin)*. Am. Assoc. Pet. Geol., Educ. Course Note Ser., 19: 5(1)–5(36).
- Bernoulli, D., Caron, C., Homewood, P., Kälin, O. and Van Stuivenberg, J., 1979. Evolution of continental margins in the Alps. Schweiz. Mineral. Petrogr. Mitt., 59: 165–170.
- Biju-Duval, B., Dercourt, J. and Le Pichon, X., 1977. From the Tethys Ocean to the Mediterranean Seas: a plate tectonic model of the evolution of the western Alpine system. In: B. Biju-Duval and L. Montandert (Editors), *Int. Symp. Struct. Hist. Mediterranean basins, Split (Yugoslavia)*, 1976. Editions Technip, Paris, pp. 143–164.
- Blau, J., 1987a. Neue Foraminiferen aus dem Lias der Lienzer Dolomiten. I. Die Foraminiferenfauna einer roten Spaltenfüllung in Oberrhätalken. Jahrb. Geol. Bundesanst. (Austria), 129 (3–4): 495–523.
- Blau, J., 1987b. Neue Foraminiferen aus dem Lias der Lienzer Dolomiten. II (Schluss). Foraminiferen (Involutinina, Spirillina) aus der Lavanter Breccie (Lienzer Dolomiten) und der Nördlichen Kalkalpen. Jahrb. Geol. Bundesanst. (Austria), 130(1): 5–23.
- Blau, J. and Schmidt, Th., 1988. Tektonisch kontrollierte Sedimentation im Unterlias der Lienzer Dolomiten (Österreich, Osttirol, Kärnten). Mitt. Ges. Geol. Bergbaustud. Österr., 34/35: 185–207.
- Bosellini, A., 1981. The Emilia fault: a Jurassic fracture zone that evolved into a Cretaceous-Paleogene sinistral wrench fault. Boll. Soc. Geol. Ital., 100: 161–169.
- Bosellini, A., Masetti, D. and Sarti, M., 1981. A Jurassic “Tongue of the Ocean” infilled with oolitic sands: the Belluno Trough, Venetian Alps, Italy. Mar. Geol., 44(1/2): 59–95.
- Buggisch, W., Flügel, E., Leitz, F. and Tietz, G.F., 1978. Paleogeography of the Permian in the Southern Alps. Perm der Karnischen Alpen und den Randgebieten. In: H. Closs, D. Röder and K. Schmidt (Editors), *Alps, Apennines, Hellenides*. Schweizerbart, Stuttgart, pp. 108–112.
- Burchfiel, B.C. and Royden, L., 1982. Carpathian foreland fold and thrust belt and its relation to Pannonian and other basins. Am. Assoc. Pet. Geol. Bull., 66: 1179–1195.
- Castellarin, A., 1972. Evoluzione paleotettonica sinsedimentaria del limite tra piattaforma veneta e bacino lombardo al nord di Riva. G. Geol., 38(1): 11–212.
- Castellarin, A. and Sartori, R., 1982. Geologia della linea delle Giudicarie Sud (tra Piave di Bono e Tione). In: A. Castellarin and G.B. Vai, (Editors), *Guide Geologiche Regionali*. Soc. Geol. Ital., Bologna, pp. 103–114.
- Channell, J.E.T. and Horváth, F., 1976. The African/Adriatic promontory as a paleogeographical premise for Alpine orogeny and plate movements in the Carpatho-Balkan region. Tectonophysics, 35 (1–3): 71–101.
- Channell, J.E.T., D’Argenio, B. and Horvath, F., 1979. Adria, the African promontory, in Mesozoic Mediterranean palaeogeography. Earth-Sci. Rev., 15: 213–292.
- Channell, J.E.T., Brandner, R., Spieler, A. and Smathers, N.P., 1990. Mesozoic paleogeography of the Northern Calcareous Alps—Evidence from paleomagnetism and facies analysis. Geology, 18: 828–831.
- Christie-Blick, N. and Biddle, K.T., 1985. Deformation and basin formation along strike-slip faults. In: K.T. Biddle and N. Christie-Blick, (Editors), *Strike-slip Deformation, Basin Formation, and Sedimentation*. Soc. Econ. Paleontol. Mineral., Spec. Publ., 37: 1–34.
- Decker, K., Faupl, P. and Müller, A., 1987. Synorogenic sedimentation on the Northern Calcareous Alps during the early Cretaceous. In: H.W. Flügel, and P. Faupl, (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 126–141.
- Dercourt, J., Geysant, J., Lepvrier, C., Bergerat, F., Bignot, G., Clos, P., De Wever, P., Géczy, B., Guernet, C. and Lachkar, G., 1984. Hungarian mountains in Alpine framework. Acta Geol. Hung., 3–4: 213–221.
- Dercourt, J., Zonenshain, L.P., Ricou, L.-E., Kazmin, V.G., Le Pichon, X., Knipper, A.L., Grandjacquet, C., Sbertshikov, I.M., Geysant, J., Lepvrier, C., Pechersky, D.H., Boulin, J., Sibuet, J.C., Savostin, L.A., Sorokhtin, O., Westphal, M., Bazhenov, M.L., Lauer, J.P. and Biju-Duval, B., 1986. Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias. Tectonophysics, 123: 242–315.
- Dewey, J.F., Hempton, M.R., Kidd, W.S.F., Saroglu, F. and

- Sengör, A.M.C., 1986. Shortening of continental lithosphere: the neotectonics of Eastern Anatolia—a young collision zone. In: M.P. Coward and A.C. Ries (Editors), *Collision Tectonics*. Geol. Soc. London, Spec. Publ., 19, 3–36.
- Eberli, G.P., 1985. Die jurassischen Sedimente in den ostalpinen Decken Graubündens. Relikte eines passiven Kontinentalrandes. Diss. ETH/Univ. Zürich, Zurich, 203 pp.
- Exner, C., 1976. Die geologische Position der Magmatite des periadriatischen Lineaments. Verh. Geol. Bundesanst. (Austria), 1976(2): 3–64.
- Faupl, P., 1977. Sedimentologische Studien im Kreideflysch der Lienzer Dolomiten. Anz. Österr. Akad. Wiss., Math.-Nat. Kl., 113 (1976): 131–134.
- Faupl, P. and Tollmann, A., 1979. Die Rossfeldschichten: Ein Beispiel für Sedimentation im Bereich einer tektonisch aktiven Tiefseeerinne aus der kalkalpinen Unterkreide. Geol. Rundsch., 68: 93–120.
- Froitzheim, N. and Eberli, G.P., 1990. Extensional detachment faulting in the evolution of a Tethys passive continental margin, Eastern Alps, Switzerland. Geol. Soc. Am. Bull., 102: 1297–1308.
- Furlani, M., 1912. Der Drauzug im Hochpustertal. Mitt. Geol. Ges. Wien., 5: 252–271.
- Gaetani, M., 1975. Jurassic stratigraphy of the southern Alps: a review. In: C.H. Squyres, (Editor), *Geology of Italy, I*. Earth Sci. Soc. Libyan Arab. Repub., Tripolis, pp. 377–402.
- Gollner, H., Schirnik, D. and Tschelaut, W., 1987. The problem of the Southalpine clasts in the “Mittelsteirische Gosau”. In: H.W. Flügel and P. Faupl (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 156–163.
- Haas, J., 1988. Upper Triassic carbonate platform evolution in the Transdanubian Mid-Mountains. Acta Geol. Hung., 31: 299–312.
- Häusler, H., 1987. The northern Austroalpine margin during the Jurassic: breccias from the Radstädter Tauern and Tarntaler Berge. In: W. Flügel and P. Faupl (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 103–111.
- Heinz, H. and Mauritsch, H.J., 1980. Paläomagnetische Untersuchungen an der “Periadriatischen Naht”. Mitt. Österr. Geol. Ges., 71/72: 269–274.
- Heller, F., Lowrie, W. and Hirt, A.M., 1989. A review of paleomagnetic anisotropy results from the Alps. In: M.P. Coward, D. Dietrich and R.G. Park (Editors), *Alpine Tectonics*. Geol. Soc. London, Spec. Publ., 45: 399–420.
- Hippenstiel, G., 1985. Zur Stratigraphie und Fazies des Winnebacher Kalkzuges. Thesis, Giessen (unpublished).
- Jacobshagen, V., 1958. Zur Stratigraphie und Palaeogeographie der Jura-Fleckenmergel im südöstlichen Allgäu. Notizbl. Hess. Landesamt Bodenforsch., 87: 208–226.
- Jacobshagen, V., 1965. Die Allgäu-Schichten (Jura-Fleckenmergel) zwischen Wettersteingebirge und Rhein. Jahrb. Geol. Bundesanst. (Austria), 108: 1–114.
- Kälin, O. and Trümpy, M., 1977. Sedimentation und Palaeotektonik in den westlichen Südalpen: zur triasisch-jurassischen Geschichte des Monte Nudo-Beckens. *Ecol. Geol. Helv.*, 70(2): 295–350.
- Kazim, V.G., Sborshikov, I.M., Ricou, L.-E., Zonenshain, L.P., Boulin, J. and Knipper, A.L., 1986. Volcanic belts as markers of the Mesozoic–Cenozoic active margin of Eurasia. *Tectonophysics*, 123: 123–152.
- Kázmér, M., 1986. Tectonic units of Hungary: their boundaries and stratigraphy (a bibliographic guide). *Ann. Univ. Sci. Budap. Rolando Eötvös Nom.*, 26: 45–120.
- Kázmér, M., 1987. Lower Liassic facies zones in the Bakony unit of Hungary. *Ann. Univ. Sci. Budap. Rolando Eötvös Nominatae, Sect. Geol.*, 27: 89–100.
- Kázmér, M. and Kovács, S., 1985. Permian–Paleogene paleogeography along the eastern part of the Insubric–Periadriatic Lineament System: evidence for continental escape of the Bakony-Drauzug Unit. *Acta Geol. Hung.*, 28 (1–2): 69–82.
- Knipper, A., Ricou, L.-E. and Dercourt, J., 1986. Ophiolites as indicators of the geodynamic evolution of the Tethyan ocean. *Tectonophysics*, 123: 213–240.
- Kovács, S., 1982. Problems of the ‘Pannonian Median Massif and the plate tectonic concept. Contributions based on the distribution of Late Paleozoic–Early Mesozoic isopic zones. *Geol. Rundsch.*, 71(2): 617–640.
- Kovács, S., 1984. North Hungarian triassic facies types: a review. *Acta Geol. Hung.*, 27(3–4): 251–264.
- Kozur, H. and Mock, R., 1987. Deckenstrukturen im südlichen Randbereich der Westkarpaten (vorläufige Mitteilung). *Geol. Paläontol. Mitt. Innsbruck*, 14(6): 131–155.
- Kozur, H. and Mostler, H., 1973. Mikrofaunistische Untersuchungen der Triasschollen im Raume Csóvár, Ungarn. Verh. Geol. Bundesanst. (Austria) 1973(2): 291–325.
- Laubscher, H.P., 1971. Das Alpen–Dinariden-Problem und die Palinspastic der südlichen Tethys. *Geol. Rundsch.*, 60: 813–833.
- Laubscher, H.P., 1988. Material balance in Alpine orogeny. *Geol. Soc. Am. Bull.*, 100: 1313–1328.
- Laubscher, H.P. and Bernoulli, D., 1977. Mediterranean and Tethys. In: A.E.M. Nairn, W.H. Kanes, F.G. and Stehli, (Editors), *The Ocean Basins and Margins*. Plenum, New York, Vol. 4A, pp. 1–28.
- Lein, R., 1985. Das Mesozoikum der Nördlichen Kalkalpen als Beispiel eines gerichteten Sedimentationsverlaufs infolge fortschreitender Krustenausdünnung. *Arch. Lagerstättenforsch., Geol. Bundesanst. (Austria)*, 6: 117–128.
- Lein, R., 1987. Evolution of the Northern Calcareous Alps during Triassic times. In: W. Flügel and P. Faupl (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 85–102.
- Lemoine, M., 1980. Serpentinities, Gabbros and Ophicalcites in the Piemonte–Ligurian domain of the Western Alps: possible indicators of oceanic fracture zones and of associated serpentinit protrusions in the Jurassic–Cretaceous Tethys. *Arch. Sci.*, 33: 2–3.

- Mager, D., 1985. Geologische und petrographische Untersuchungen am Südrand des Rieserferner-Plutons (Südtirol) unter Berücksichtigung des Intrusionsmechanismus. Diss., Naturw. Fak. Univ. Erlangen-Nürnberg, Erlangen, 182 pp.
- Majoros, Gy., 1980. Problems of Permian sedimentation in the Transdanubian Central Range. A palaeogeographic model and some consequences. *Földt. Közl.*, 110: 323–341 (in Hungarian with English abstr.).
- Majoros, Gy., 1983. Lithostratigraphy of the Permian formations of the Transdanubian Central Mountains. *Acta Geol. Hung.*, 26: 7–20.
- Mariotti, A., 1972. Précisions sur la stratigraphie des Lienzer Dolomiten. Hypothèse sur les relations paléogéographiques entre les Alpes méridionales: conséquences structurales. *Geol. Alp.*, 48: 121–129.
- Mauritsch, H.J. and Becke, M., 1987. Palcomagnetic investigations in the Eastern Alps and the Southern Border Zone. In: H.W. Flügel and P. Faupl (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 282–308.
- Montadert, L., De Charpal, O., Roberts, D.G., Guennoc, P. and Sibuet, J.C., 1979. Northeast Atlantic passive margins: rifting and subsidence processes. In: M. Talwani, W.W. Hay and W.B.F. Ryan, (Editors), *Deep-Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironments*. (Maurice Ewing Ser., 3) Am. Geophys. Union, Washington, D.C., pp. 154–186.
- Neubauer, F., 1987. The Gurktal thrust system within the Austroalpine region—some structural and geometrical aspects. In: H.W. Flügel and P. Faupl (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 226–236.
- Niedermayr, G., Seemann, R. and Scheriau-Niedermayr, E., 1978. Die Perm-Trias Grenze im westl. Drauzug, Kärnten-Osttirol. *Ann. Naturhist. Mus. Wien*, 81: 1–17.
- Oberhauser, R. (Editor), 1980. *Der geologische Aufbau Österreichs*. Springer, Vienna, 701 pp.
- Prey, S., 1978. Rekonstruktionsversuch der alpidischen Entwicklung der Ostalpen. *Mitt. Österr. Geol. Ges.*, 69 (1976): 1–25.
- Prey, S., 1980. Das Frühälpidikum (Die geologische Entwicklung zwischen der variszischen und der alpidischen Hauptorogenese vom Oberkarbon und Perm durch das frühe Mesozoikum bis ins Neokom). In: R. Oberhauser (Editor), *Der geologische Aufbau Österreichs*. Springer, Vienna, pp. 21–34.
- Ramovš, A., 1974. Die Trias in Jugoslawien. In: H. Zapfe, *Die Stratigraphie der alpin-mediterranen Trias*. Schriftenr. Erdwiss. Kommiss., Österr. Akad. Wiss., 2, pp. 161–165.
- Ratschbacher, L., 1986. Kinematics of Austro-Alpine cover nappes: changing translation patch due to transpression. *Tectonophysics*, 125: 335–356.
- Ratschbacher, L., 1987. Strain, rotation, and translation of Austroalpine nappes. In: H.W. Flügel, and P. Faupl (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 237–243.
- Ratschbacher, L. and Neubauer, F., 1989. West-directed décollement of Austro-Alpine cover nappes in the Eastern Alps: geometrical and rheological considerations. In: M.P. Coward, D. Dietrich and R.G. Park (Editors), *Alpine Tectonics*. Geol. Soc. London, Spec. Publ., 45: 243–262.
- Ratschbacher, L., Frisch, W., Neubauer, F., Schmid, S.M. and Neugebauer, J., 1989. Extension in compressional orogenic belts: the Eastern Alps. *Geology*, 17: 404–407.
- Ratschbacher, L., Behrmann, J.H. and Pahr, A., 1990. Penninic windows at the eastern end of the Alps and their relation to the intra-Carpathian basins. *Tectonophysics*, 172: 91–105.
- Reading, H.G., 1980. Characteristics and recognition of strike-slip fault systems. In: P.F. Ballance and H.G. Reading (Editors), *Sedimentation in Oblique-slip Mobile Zones*. Int. Assoc. Sedimentol., Spec. Publ., 4: 6–24.
- Reti, Z., 1985. Triassic ophiolite fragments in an evaporitic melange, northern Hungary. *Ofioliti*, 10: 411–422.
- Ricou, L. E., Dercourt, J., Geysant, J., Grandjaquet, C., Lepvrier, C. and Biju-Duval, B., 1986. Geological constraints on the Alpine evolution of the Mediterranean Tethys. *Tectonophysics*, 123: 83–122.
- Royden, L.H., Horváth, F. and Burchfiel, B.C., 1982. Transform faulting, extension, and subduction in the Carpathian Pannonian region. *Geol. Soc. Am. Bull.*, 93: 717–725.
- Savostin, L.A., Sibuet, J.C., Zonenshain, L.P., Le Pichon, X. and Roulet, M.J., 1986. Kinematic evolution of the Tethys belt from the Atlantic to the Pamirs since the Triassic. *Tectonophysics*, 123: 1–35.
- Schmid, S.M., Aebli, H.R., Heller, F. and Zingg, A., 1989. The role of the Periadriatic Line in the tectonic evolution of the Alps. In: M.P. Coward, D. Dietrich and R.G. Park (Editors), *Alpine Tectonics*. Geol. Soc. London, Spec. Publ., 45: 153–171.
- Schröder, M., 1985. *Zur Stratigraphie, Tektonik und Fazies der nördlichen Karawanken (Kärnten, Österreich)*. Thesis, Giessen, 140 pp. (unpublished).
- Schröder, M., 1988. *Stratigraphische und fazielle Untersuchungen der Obertrias bis Unterkreide am Nordrand der Karawanken zwischen St. Margareten im Rosental und Abtei (Kärnten)*. *Jahrb. Geol. Bundesanst. (Austria)*, 131(1): 133–151.
- Sengör, A. M. C., 1979. Mid-Mesozoic closure of Permo-Triassic Tethys and its implications. *Nature*, 279(5714): 590–593.
- Spieler, A., 1990. *Beckenentwicklung im Unter- und Mitteljura nordwestlich des Achensees (Tirol) und ihre Beziehung zur "Achentaler Schubmasse"*. Ph.D. Thesis, Univ. Innsbruck, Innsbruck, 185 pp.
- Tollmann, A., 1963. *Ostalpensynthese*. Deuticke, Vienna, 256 pp.
- Tollmann, A., 1969. *Die tektonische Gliederung des Alpen-Karpaten-Bogens*. *Geologie*, 18: 1131–1155.
- Tollmann, A., 1976a. *Analyse des klassischen nordalpinen Mesozoikums*. Monographie der Nördlichen Kalkalpen, Bd. 2. Deuticke, Vienna, 580 pp.
- Tollmann, A., 1976b. *Der Bau der Nördlichen Kalkalpen*.

- Monographie der Nördlichen Kalkalpen, Bd. 3. Deuticke, Vienna, 449 pp.
- Tollmann, A., 1977. Geologie von Österreich, Bd. 1. Deuticke, Vienna, 766 pp.
- Tollmann, A., 1978. Die Seitenverschiebung an der periadriatischen Naht auf Grund des Vergleiches der Triasfazies. *Schriftenr. Erdwiss. Kommiss. Österr. Akad. Wiss.*, 4: 179–192.
- Tollmann, A., 1980. Grosstektonische Ergebnisse aus den Ostalpen im Sinne der Plattentektonik. *Mitt. Österr. Geol. Ges.*, 71–72 (1978–1979): 37–44.
- Tollmann, A., 1984. Entstehung und früherer Werdegang der Tethys mit besonderer Berücksichtigung des mediterranen Raumes. *Mitt. Österr. Geol. Ges.*, 77: 93–113.
- Tollmann, A., 1985. Geologie von Österreich, Bd. 2, Ausserzentral-alpiner Anteil. Deuticke, Vienna, 710 pp.
- Tollmann, A., 1986. Geologie von Österreich, Bd. 3, Gesamtübersicht. Deuticke, Vienna, 718 pp.
- Tollmann, A., 1987a. Neue Wege in der Ostalpengeologie und die Beziehungen zum Ostmediterrän. *Mitt. Österr. Geol. Ges.*, 80: 47–113.
- Tollmann, A., 1987b. Late Jurassic/Neocomian gravitational tectonics in the Northern Calcareous Alps in Austria. In: H.W. Flügel and P. Faupl, (Editors), *Geodynamics of the Eastern Alps*. Deuticke, Vienna, pp. 112–125.
- Tricart, P. and Lemoine, M., 1986. From faulted blocks to megamullions and megaboudins: Tethyan heritage in the structure of the Western Alps. *Tectonics*, 5(1): 95–118.
- Trümpy, R., 1980. *Geology of Switzerland, a guidebook*. Wepf, Basel, 334 pp.
- Trümpy, R., 1983. Alpine paleogeography: a reappraisal. In: K.J. Hsü (Editor), *Mountain Building Processes*. Academic Press, London, pp. 149–156.
- Trümpy, R., 1988. A possible Jurassic–Cretaceous transform system in the Alps and the Carpathians. *Geol. Soc. Am., Spec. Pap.*, 218: 93–109.
- Von Gosen, W., 1989. Gefügeentwicklungen, Metamorphosen und Bewegungen der ostalpinen Baueinheiten zwischen Nockgebiet und Karawanken (Österreich). *Geotekt. Forsch.*, 72: 1–247.
- Wächter, J., 1987. Jurassische Massflow- und Internbreccien und ihr sedimentär-tektonisches Umfeld im mittleren Abschnitt der Nördlichen Kalkalpen. *Bochumer Geol. Geotech. Arb.*, 27, 239 pp.
- Weissert, H.J. and Bernoulli, D., 1985. A transform margin in the Mesozoic Tethys: evidence from the Swiss Alps. *Geol. Rundsch.*, 74(3): 665–679.
- Westphal, M., Bazhenov, M.L., Lauer, J.P., Pechersky, D.M. and Sibuet, J.-C., 1986. Paleomagnetic implications of the evolution of the Tethys belt from the Atlantic Ocean to the Pamirs since the Triassic. *Tectonophysics*, 123: 37–82.
- Wiedenmayer, F., 1963. Obere Trias bis mittlerer Lias zwischen Saltrio und Tremona (Lombardische Alpen). Die Wechselbeziehungen zwischen Stratigraphie, Sedimentologie und syngenetischer Tektonik. *Ecolog. Geol. Helv.*, 56(2): 529–640.
- Winterer, E.L. and Bosellini, A., 1981. Subsidence and Sedimentation on the Jurassic Passive Continental Margin, Southern Alps, Italy. *Am. Assoc. Pet. Geol. Bull.*, 65(3): 394–421.
- Ziegler, P.A., 1988. Evolution of the Arctic–North Atlantic and the Western Tethys. *Am. Assoc. Pet. Geol., Mem.*, 43: 198 pp.