Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 89 (1996)

Heft: 1

Artikel: Inverted Mesozoic rift structures in the Polish western Carpathians (High-Tatric units) : comparison with similar features in the western Alps

Autor: Dumont, Thierry / Wieczorek, Jozef / Bouillin, Jean-Pierre

DOI: https://doi.org/10.5169/seals-167899

Eclogae geol. Helv. 89/1: 181–202 (1996)

0012-9402/96/010181-22 $1.50 + 0.20/0
Birkhäuser Verlag, Basel

Inverted Mesozoic rift structures in the Polish Western Carpathians (High-Tatric units). Comparison with similar features in the Western Alps

THIERRY DUMONT[1], JOZEF WIECZOREK[2] & JEAN-PIERRE BOUILLIN[1]

Keywords: Western Carpathians, Western Alps, rifting, extensional structures, Jurassic, inversion

ABSTRACT

The studied area belonged to the southern (Apulian) margin of a vanished Jurassic branch of the Tethyan ocean postulated by many authors. We propose a restoration of syn-rift extensional structures of Early Liassic to early Middle Jurassic age which are now inverted and involved in the internal zones of the West Carpathians orogen. According to our interpretation, extensional deformation was marked by a predominantly northward-facing normal fault system and by local erosion along associated swells. These structures were draped by post-rift sediments of Bajocian and younger age. A very similar evolution is recorded in the remnants of the north-western (European) paleomargin of the Ligurian Tethys in the French Western Alps, where both continental margin and oceanic series are preserved. In particular, the onset of large-scale extensional deformation is coeval (Early Liassic) in the two compared areas, as it is also in many intermediate localities of Central, Southern and Eastern Alps. During tectonic inversion, which started earlier in the Western Carpathians, the style of deformation was different when Tethyan structures (dip of normal faults) were oriented in the same direction as the thrusting direction (for example in the studied Carpathian area, Apulian margin) or in the opposite direction (for example in a part of the external Western Alps of Dauphiné, European margin).

RESUME

Le secteur étudié se situait d'après la plupart des auteurs sur la marge Sud (apulienne) d'une branche jurassique de la Téthys dont les témoins océaniques ont été entièrement subductés lors de la formation de la chaîne des Carpates occidentales. On y trouve des structures d'extension téthysiennes d'âge Lias-Dogger qui ont été inversées au cours de leur incorporation dans les zones internes de l'orogène. D'après notre interprétation, l'extension syn-rift a été marquée par le développement de failles normales principalement à regard Nord et de (demi)-horsts plus ou moins érodés. Ces structures ont été recouvertes par des sédiments pélagiques bajociens et plus récents, qui représentent probablement les séries post-rift. Cette évolution ressemble à celle qui est enregistrée dans les séries de la paléomarge Nord-occidentale (européenne) et de l'océan Téthysien ligure dans les Alpes occidentales françaises. En particulier, la fracturation en extension et l'effondrement des plates-formes carbonatées sont intervenus au même moment dans les deux secteurs comparés (Lias inférieur), de même que dans beaucoup de secteurs intermédiaires des Alpes centrales, méridionales et orientales. L'inversion tectonique, plus précoce dans les Carpates occidentales, a eu une expression différente suivant que la polarité des structures téthysiennes (pendage des failles bordières délimitant les blocs basculés) d'une part et la direction de transport alpine d'autre part étaient orientés dans le même sens (secteur étudié des Carpates, marge apulienne) ou en sens opposé (par exemple dans une partie du Dauphiné, Alpes occidentales externes, marge européenne).

[1] Laboratoire de Géodynamique des Chaînes Alpines, CNRS, ERS 129, Institut Dolomieu, rue M. Gignoux, F–38031 Grenoble
[2] Polish Academy of Sciences, CPPGSMIE, ul. Wybickiego 7, PL–31261 Kraków

Introduction

The Alpine and Carpathian orogens result from the closure of several oceanic troughs, whose passive margins are now incorporated in these chains. Despite a polyphased deformation during inversion and collision, evidences of syn-rift extensional deformation and of coeval vertical movements are preserved both in external and internal zones. These features are of major importance because they are the last witnesses of the kinematic evolution of the vanished oceanic domains and because they significantly biased the evolution of the chains (Plašienka 1991). Both the chronology of their development and their geometry have been studied in many places.

Some areas of the Alpine foreland (South-East basin of France) and of the internal domains of the Alps (Briançonnais, Piemont, Austro-Alpine and South-Alpine domains) were affected during Middle and Late Triassic by strong subsidence, block faulting and/or intracratonic volcanism. This shows that the post-pangean crustal thinning was already in progress. But it is important to notice that this process was polyphased, and that an important change in the distribution and in the orientation of extension and subsidence took place at the end of Triassic times in many places of the Alpino-Carpathic realm:

- In the French Western Alps of Dauphiné, paleostructures of various size including 10 km-wide fault blocks are known since the early eighties (Lemoine et al. 1981; Lemoine 1984; Lemoine & Trümpy 1987). In this area, the onset of extensional deformation recorded by changes in the sediment distribution, resedimentations and paleobathymetry is Early Liassic in age. This event, which also corresponds to the collapse of the easternmost part of the margin (Piemont domain), is regarded as the onset of the Ligurian rifting itself (Lemoine et al. 1986). A significant increase in tectonic activity occurred during Late Liassic times. This latter event coincides more or less with the uplift of the Briançonnais marginal plateau regarded as a possible rift shoulder effect.
- In the Southern Alps of Italy, large scale block faulting began earlier as the late Middle Triassic sediments in the Dolomites are strongly affected by differential subsidence, resedimentation and volcanism (de Zanche 1990). However, the most important tectonic cycle, giving birth to the Lombardian basin, started during the Early Liassic (Bertotti 1990; Jadoul et al. 1992; Bertotti et al. 1993; Castellarin et al. 1993). It was locally preceeded by important differential subsidence and faulting during the Late Norian-Rhaetian times (Lugano graben).
- In the Austro-Alpine nappes of Graubünden, the thick pile of Triassic sediments is regarded as pre-rift since extensional faulting started during Early Liassic times (Eberli 1988; Froitzheim 1988; Conti et al. 1994). A two-stage, non uniform extensional model was proposed by Froitzheim and Eberli (1990), with a shift in location and geometry of the extensional fault pattern between Early and Late Liassic which resembles the situation in the Southern Alps (Bernoulli et al. 1990).
- In the Tatricum units of the westernmost part of the Western Carpathians (Little Carpathian Mts), the syn-rift extensional tectonic regime which was established since the Early Liassic is recorded first by normal faulting and clastic influx and later (Late Liassic) by the increase of tectonic activity and subsidence (Plasienka et al. 1991).
- In the Fatricum units of the Western Carpathians, the syn-rift sedimentation started

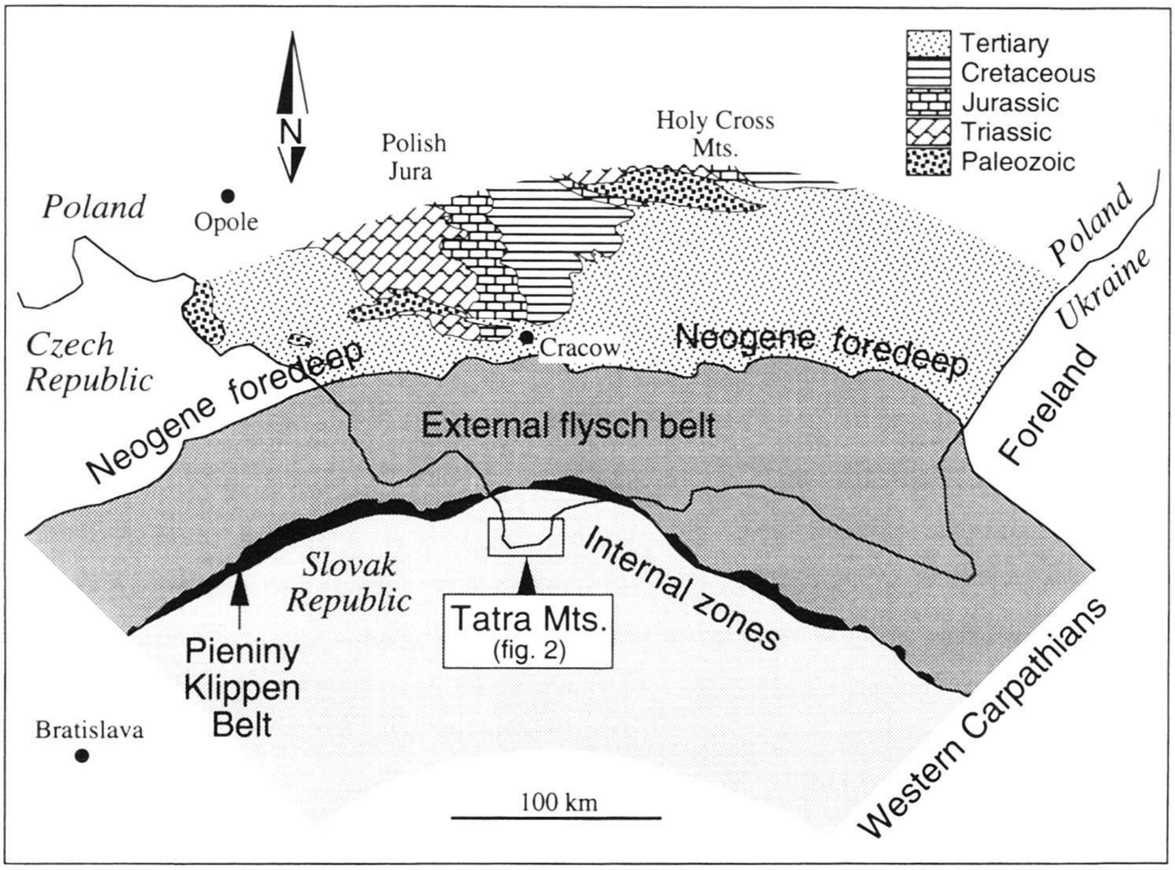


Fig. 1. Location of the Tatra Mts. (Fig. 2) in the Western Carpathians.

with Hettangian shallow marine clastic deposits and got deeper during the Sinemurian (Lefeld et al. 1985; Wieczorek 1989).

An important question arises from these data collected in various places of the Alpino-Carpathic chain: does the rift onset unconformity propagate throughout the Tethyan realm between the opening of eastern Triassic oceans (Vardar, Meliata) and the breakup of the western Jurassic Tethys, or is there an abrupt shift of extensional activity marked by a more or less synchronous turnover in distant places? The aim of this paper is to document this discussion by comparing the paleotectonic history of the internal zones of the Polish Central Western Carpathians with the French Western Alps. According to most authors, these two distant domains were located on opposite margins of the Ligurian (equivalent to the South Penninic or Vahicum) ocean. If a propagation of intracratonic extension had occurred, then it should be possible to observe it between these two very different areas.

Regional setting

The Western Carpathian fold belt (Fig. 1) includes, from north to south: (1) the external zones, predominantly made up of Cretaceous and Paleogene transported flysch series,

(2) the Pieniny Klippen Belt (PKB), a narrow crustal-scale suture which bears some highly tectonised remnants of northern Tethyan marginal series and which should represent the trace of the Tethyan closure (Sandulescu 1975; Birkenmajer 1986; Tomek 1993) and (3) the internal zones, which are made in the Polish transect by the High-Tatric units overlain by the Subtatric cover nappes of more internal origin. Most authors regard the former as an equivalent of the Lower Austroalpine system of the Eastern Alps (e.g. Michalík & Kováč 1982; Mahel' 1983; Rakús et al. 1990; Dercourt et al. 1993). Tollmann (1965, 1990), on the other hand, considers them as an equivalent of the Pennine zone.

The High-Tatric units outcrop in the Polish Tatra National Park (Fig. 1) and provide the highest reliefs of the Western Carpathians. The top of the High-Tatric Hercynian basement is presently dipping towards the North due to a post-nappe anticline structure and its Mesozoic sedimentary cover is locally undetached. It is overlain by several tectonic slices (Fig. 2) whose finding by Lugeon (1903) was the first identification of nappes in the Carpathian belt. These slices were transported over short distances from the South and were folded and locally reversed below the major basal thrust plane of the Subtatric nappes. The latter could have been emplaced upon an erosional surface truncating the deformed Tatric area (Kotański 1961; Bac-Moszaszwili et al. 1981). Thrusting began after the deposition of the lower Turonian beds (Lefeld et al. 1985), and the earliest thrusts are sealed in the Internal Carpathian chain by the Gosau layers of Coniacian age. The post-nappe anticline is Oligo-Miocene in age (Pitrowski 1978). Many detailed studies about structures and microstructures, lithostratigraphy and mapping were carried out in this area: Michalík (1953), Glazek (1959), Rabowski (1959), Wojcik (1959), Kotański (1961, 1963, 1965), Bac (1963), Burchart (1963), Glazek (1963), Grochocka-Recko (1963), Jaroszewski (1963, 1965), Kostiukow (1963), Sieciarz (1963), Szulczewski (1963b), Bac & Grochocka (1965), Piotrowski (1965, 1978), Veizer (1970), Bac-Moszaszwili et al. (1979, 1984), Grodzicki & Kardas (1989), Nemcŏk et al. (1995).

Stratigraphy

The High Tatric series show many similarities to Eastern Alpine series (Häusler et al. 1993). It includes (Fig. 3; data after Kotanski 1956, 1959, 1961; Gorek 1958; Kotański & Radwański 1959; Radwański 1959, 1968; Szulczewski 1963a; Piotrowski 1965; Roniewicz 1966; Gazdzicki 1974; Michalík et al. 1976; Wojcik 1981; Lefeld et al. 1985; and personal data):

a) Lower Triassic (Early Scythian) quartzites, whose fluviatile to marginal marine clastic sediments were transported from the North.
b) Lower Triassic (Late Scythian) red and green shales grading upwards into shallow marine dolomites, limestones and shales (so-called *Myophoria* beds).
c) Middle Triassic (Anisian) open marine limestones with shallow marine dolomitic layers; this massive formation (marker bed I of Fig. 3) is equivalent to the Gutenstein 1st. formation of the Eastern Alps and to the Calcaires de Saint Triphon formation of Western Alps and Prealps (Mégard-Galli & Baud 1977).
d) Middle Triassic (Ladinian) shallow marine calcareous to dolomitic decametric sequences (limestone marker beds II to VI to Fig. 3 are visible in the morphology).
e) Upper Triassic (Carnian to Norian) conglomerates, sandstones and red and green shales (*Carpathian Keuper* facies) grading upwards into yellowish bedded dolomites.

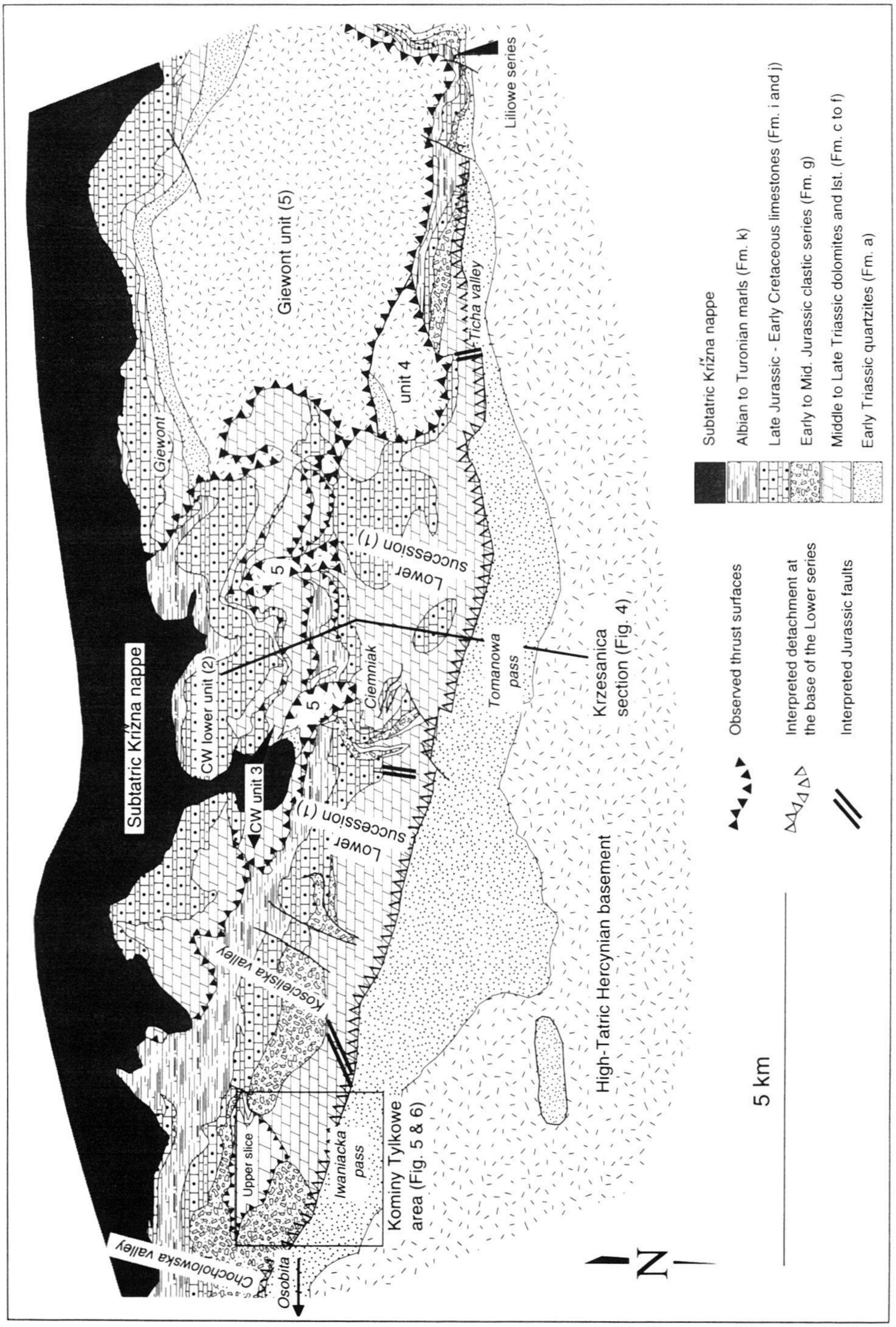


Fig. 2. Detailed map of the studied area, after Bac-Moszaszwili et al. 1979, modified.

f) Uppermost Triassic continental dark shales and sandstones which contain a Rhaetian flora and shallow marine limestones and dolomites. The marine beds (Late Rhaetian or Early Hettangian) overlie the continental deposits in several places and they mark the beginning of the Early Jurassic transgressive cycle.
g) A thick, poorly dated "Liassic" (Lower to Middle Jurassic) series of dark sandstones, sandy crinoidal limestones and spongolites with abundant clasts of Triassic dolomites and rounded quartz pebbles. Most of the clastic material comes from the eroded Triassic series, and the dolomitic pebbles are frequently affected by borings. A Sinemurian brachiopod fauna was found several tenth of meters above the base of the formation, which had been deposited into small basins opened during syn-rift extension.
h) Middle Jurassic hemipelagic condensed sequence: grey, then pinkish crinoidal limestones (Bajocian-Bathonian), red biomicritic highly condensed limestones with deep-water stromatolites (Bathonian) and pelagic grey to red nodular limestones (Callovian).
i) Upper Jurassic massive pelagic limestones (Oxfordian-Tithonian) with a red nodular limestone intercalation (*Rosso ammonitico* facies, Kimmeridgian). Some ash layers and volcanic flows (limburgites) are locally associated with Tithonian limestones.
j) Lower Cretaceous shallowing-upward series of bedded to massive limestones deposited in platform and platform margin settings (*Urgonian* facies).
k) Albian deep-water, highly condensed sequence (erosional unconformity, hardground, phosphatic stromatolites) and Cenomanian to Lower Turonian pelagic marls containing siliciclastic turbidites.

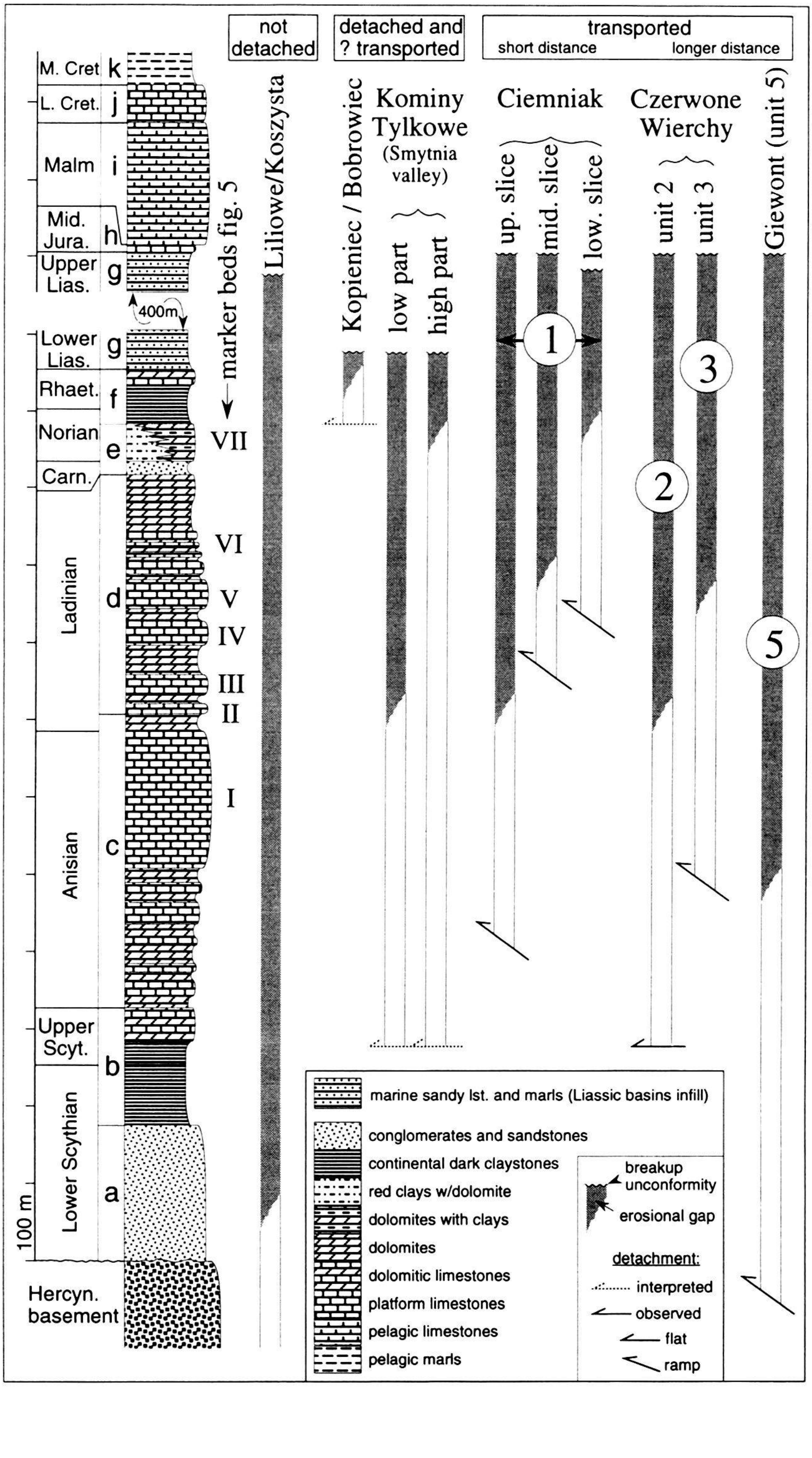
All these formations cannot be found in one single section due to Mesozoic erosional and non-depositional unconformities as well as to Alpine detachments. Formations b and e contain the best potential detachment layers.

Structure of the Tatric zone

In the internal Alpine zones, a correlation between the distribution of syn-rift depocenters or erosional unconformities and the location of Alpine tectonic boundaries is commonly found (Lemoine et al. 1986). This typical result of tectonic inversion is also observed in the studied area, indicating that Alpine thrusts derived from extensional faults. The restoration of the pre-Alpine geometry needs a precise identification of Alpine structures and of their development.

In the eastern part of the studied area (Liliowe, Fig. 2), the Tatric Hercynian basement is overlaid by a very condensed Mesozoic series (*Liliowe succession*, Fig. 3) which is not detached because the two potential detachment layers were removed by Jurassic syn-

Fig. 3. Stratigraphy of the High-Tatric series in the Polish Tatra. *Left*: composite lithostratigraphic succession including all the formations which can be found in the High-Tatric units. These formations are described in the text (small letters to the left of the column). *Right*: depth of Alpine detachment and vertical range of the Jurassic non-depositional and erosional gap (shaded) within each High-Tatric unit in the studied area. Numbers 1, 2, 3 and 5 refer to different High-Tatric units also shown on figures 2, 4 and 7.


not detached
detached and ? transported
transported
short distance
longer distance
M. Cret k
L. Cret. j
Malm i
Mid. Jura. h
Upper Lias. g
400m
Lower Lias. g
Rhaet. f
Norian e
Carn.
Ladinian d
Anisian c
Upper Scyt. b
Lower Scythian a
100 m
Hercyn. basement
marker beds fig. 5
VII
VI
V
IV
III
II
I
Liliowe/Koszysta
Kopieniec / Bobrowiec
Kominy Tylkowe
(Smytnia valley)
low part
high part
Ciemniak
up. slice
mid. slice
low. slice
Czerwone Wierchy
unit 2
unit 3
Giewont (unit 5)
1
2
3
5
marine sandy lst. and marls (Liassic basins infill)
conglomerates and sandstones
continental dark claystones
red clays w/dolomite
dolomites with clays
dolomites
dolomitic limestones
platform limestones
pelagic limestones
pelagic marls
breakup unconformity
erosional gap
detachment:
interpreted
observed
flat
ramp

rift erosion (Kotański 1961). Further west, the basement and its undetached Lower Triassic sandstone cover are overlain by a more or less complete series (fm. b to k) that we name *Lower succession.* It shows some lateral thickness changes which affect the Middle Triassic and Liassic formations, and which are mainly due to syn-rift extensional activity (erosional truncations and differential subsidence). In particular, the thickness of the Liassic clastic formation (fm. g) varies from 400 m (Kotański 1959) to a few meters within a distance of 3 km. According to Kotański (1961, 1965) and Piotrowski (1965), the Lower succession is not detached from the basement, but we believe that this is doubtful for some reasons given below. The Lower succession is overlain by the *Czerwone Wierchy (CW) unit*, a tectonic slice less than 10 km broad which was detached along layer b and which is now split into two superposed elements. The CW unit, the Lower succession and the Liliowe succession are overlain by the *Giewont unit* (Fig. 2), which is detached within the basement and which obliquely cuts the underlying structures. In both the CW unit and the Giewont unit, the whole Liassic formation is missing and the erosional surface at the base of layer h (Bajocian) truncates a more or less important part of the Triassic series.

The emplacement of such a tectonic buildup can be illustrated along the N-S Krzesanica section (Fig. 4, upper part). The ramp-and-flat style of Alpine deformation is documented, for example, by the typical ramp anticline geometry of the northern part of the Giewont unit, or by the occurrence of the detachment layer b at the base of CW units. However, this deformation was combined with northward recumbent folding with a N 120° axis, and a significant part of the Lower succession is upside down. The proposed retrotectonic sketch (Fig. 4, lower part) implies a minimum displacement of 8 km of be highest unit (Giewont) with respect to the Lower succession. This solution is not the only possible, but we think it is the most realistic one to fill the empty space between the reversed limb and the northward-dipping, denuded basement of the southern slope of the Tomanowa pass.

That is why, contrary to the opinion of most of Tatra geologists, we propose that the Lower succession could be detached from its Hercynian basement along layer b. Our arguments are as follows: 1) the reversed limb, that forms a significant part of the outcropping Lower succession, is obviously detached because the basement is not folded; it is unlikely for the southern boundary of the present-day Mesozoic outcrops to coincide exactly with the limit between autochtonous and detached sedimentary series; 2) Tectonic breccias and cellular dolomites are systematically observed along the potential detachment layer b at the base of the Lower succession, whereas in the Giewont unit, which was detached in the basement, the strata of layer b are not deformed (Kotański 1956, 1959); 3) Finally, the Lower succession shows some major differences to both the autochtonous, very condensed Liliowe succession to the east and to other autochtonous series further west (Osobita area). Thus we think that it was cut from its basement and probably also transported, similarly to the CW and Giewont units. Despite the differences between our tectonic sketch and the interpretations of Kotański (1961, 1963, 1965), the restorations of the Jurassic position of the High-Tatric units are similar, except that according to our proposition, the northernmost area before Alpine deformation could be represented only by the High-Tatric basement and the very condensed series of Liliowe.

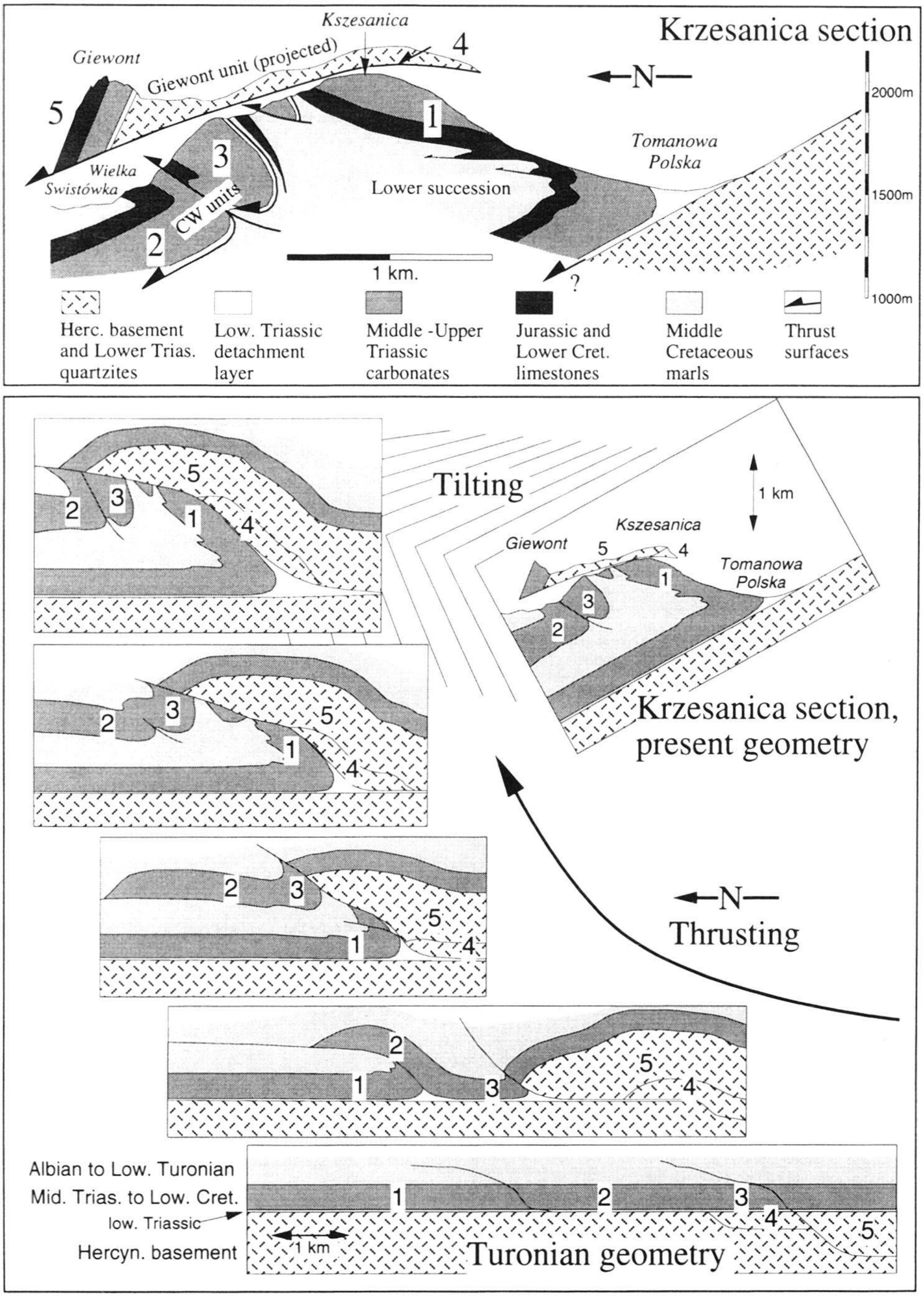


Fig. 4. *Upper part*: N-S section through the Krzesanica peak (location Fig. 2). *Lower part*: proposed restoration of Alpine deformation along the Krzesanica section.

Evidences of extensional activity; from intracratonic extension to passive margin

1. Triassic

According to Kotański (1959, 1961) and Piotrowski (1965), the Tatric Triassic series in the Polish Tatra Mts. recorded an important tectonic activity. This opinion was supported by the occurrence of sedimentary breccias at the base of the Anisian sequence, by an intra-Ladinian unconformity in the Kominy Tylkowe area, by siliciclastic material together with reworked Triassic carbonates in upper Triassic layers (formation e; Carnian ?) and by the abrupt westward truncation of the Middle Triassic series to the west of Kominy Tylkowe (Fig. 2), which is assumed by these authors to have occurred during early Late Triassic. It is noticeable that similar observations were made in many Alpine series, in particular about the Carnian tectonic pulse. However, our data suggest that the importance of Triassic activity in the High-Tatric realm was overestimated with respect to Jurassic features, especially in the Kominy Tylkowe area: we have not observed any Middle Triassic angular unconformity, but only a truncation of Triassic layers by the Lower Liassic deposits (see below). Moreover, the thickness of the Middle Triassic series to the West of the Kominy Tylkowe crest gets from about 700 m to zero in less than 1 km of lateral distance. If this truncation is of Late Triassic age, it should be marked by very strong facies and thickness changes in the coeval deposits, megabreccias and faulted blocks offsetting the basement/Triassic limit. That is not the case, and the Kominy Tylkowe Triassic series is a very "standard" Alpine series as shown by Debelmas (1960) and Kotański (1964). Finally, the Carnian siliciclastic input represents a very small volume of resedimented material and this is a very common feature of many Alpine and outer Alpine Triassic series which should not be regarded as an evidence for important uplift and erosion.

2. Liassic

As shown by Kotański (1961), there are many evidences of tectonic movements during Liassic times. The breakup of the Triassic carbonate platform is documented by:

- The differentiation between thick, mixed siliciclastic-carbonate marine series (about 400 m in the Koscieliska valley) and thin, shallow marine series (a few meters of sandy oolitic limestones in the Ciemniak massif). The periodical supply of bored Triassic pebbles in the thick series indicates the perenniality of littoral eroded areas during the formation of basins, due to uplift and differential subsidence.
- The very high amount of clasts, coming mostly from the eroded Triassic carbonate series, but also from the Carnian and Scythian sandstones and conglomerates.
- The occurrence of an erosion surface with a marked angular unconformity at the base of the Liassic series on both sides of the Kominy Tylkowe crest (see below). In the Smytnia valley to the east of the crest, the erosion surface affects the Norian dolomites whose resedimented blocks are found at the base of Liassic sediments. These features are known for a long time and were interpreted by Radwański (1959) and Kotański (1959) as a littoral cliff formed by a post-Rhaetian and pre-Liassic, possibly compressional tectonic activity (old Cimmerian phase), which had been buried by the Early Liassic marine sedimentation. As shown by these authors, the Triassic rocks are crosscut by a dense pattern of clastic (neptunian) dykes to a depth of 10 m below the

surface. The infill of these dykes is similar to the lower Liassic sediments. Many dolomitic pebbles are affected by borings of *Potamilla* (Radwański 1959), which indicates that they were prepared in a littoral setting. We have observed the same erosional surface to the west of the Kominy Tylkowe crest. Here, the top of the Triassic wedge is eroded and the clastic lower Liassic beds rest unconformably on various layers of the Middle Triassic series. We have observed similar truncations of upper Triassic beds between the Koscieliska valley and the Ciemniak area and also in the Tichá valley in Slovakia (location: Fig. 2; Gorek 1958, and personal observations): in both cases, the erosional surface at the base of the Middle and Upper Jurassic pelagic beds jumps abruptly eastwards from Middle Triassic to Lower Liassic layers. Despite the poor quality of the outcrops, these observations cannot be explained by anything else but Jurassic block faulting and erosion. Syn-rift erosion reached its deepest level in the autochtonous Liliowe succession (Fig. 2) where sandstones of postulated Liassic age (Kotański 1961) are lying in stratigraphic contact onto the lower Triassic sandstones and conglomerates.

3. Middle Jurassic

The syn-rift Liassic formation is crosscut by deep neptunian dykes filled either by crinoid limestones or, more frequently, by reddish pelagic carbonates. A dense network of neptunian dykes is also found at the top of the eroded Triassic platform carbonates where they are overlain by Middle Jurassic pelagic series (near the Ciemniak peak and in the CW and Giewont units). These dykes are connected upward to the condensed sediments of Bajocian to Callovian age (formation h) which are draping the sy-rift structures. This suggests that the contrasted paleogeography, with upthrown, eroded areas and syn-rift grabens, was created not only during the Liassic, but possibly also at the very end of the rifting, during Middle Jurassic times.

The Bajocian to Callovian beds (fm.h) can be regarded as early post-rift sediments, as indicated by:

- the sedimentological break, the erosional/non depositional hiatus and local angular unconformities observed at their base (breakup unconformity),
- their widespread distribution, contrary to Liassic syn-rift deposits,
- their homogeneous and very condensed sedimentological characters, which correspond to a rapid relative sea-level rise compatible with the early post-rift thermal subsidence. These features are not specific for the studied area: Upper Bajocian to Bathonian radiolarian cherts are found in the Branisko Pieniny units (Lefeld et al. 1985) and in the Fatricum units (Krížna nappe; Birkenmajer 1977), which were located to the North and to the South of the Tatric domain respectively. Thus the whole margin was subsiding at that time.

The presumed oceanic domain whose opening was responsible for this subsidence and for the development of the Middle Jurassic breakup unconformity in the High-Tatric domain, is now completely subducted. In our opinion it was located to the north, between the northern margin of the High-Tatric area and the Pieniny Klippen Belt realm. It corresponds to the Vahicum ocean of Mahel' (1981) and to the "X-zone" or Ocean I of Birkenmajer (1988) and it was probably connected to the Ligurian (or South Pennine) ocean to the West.

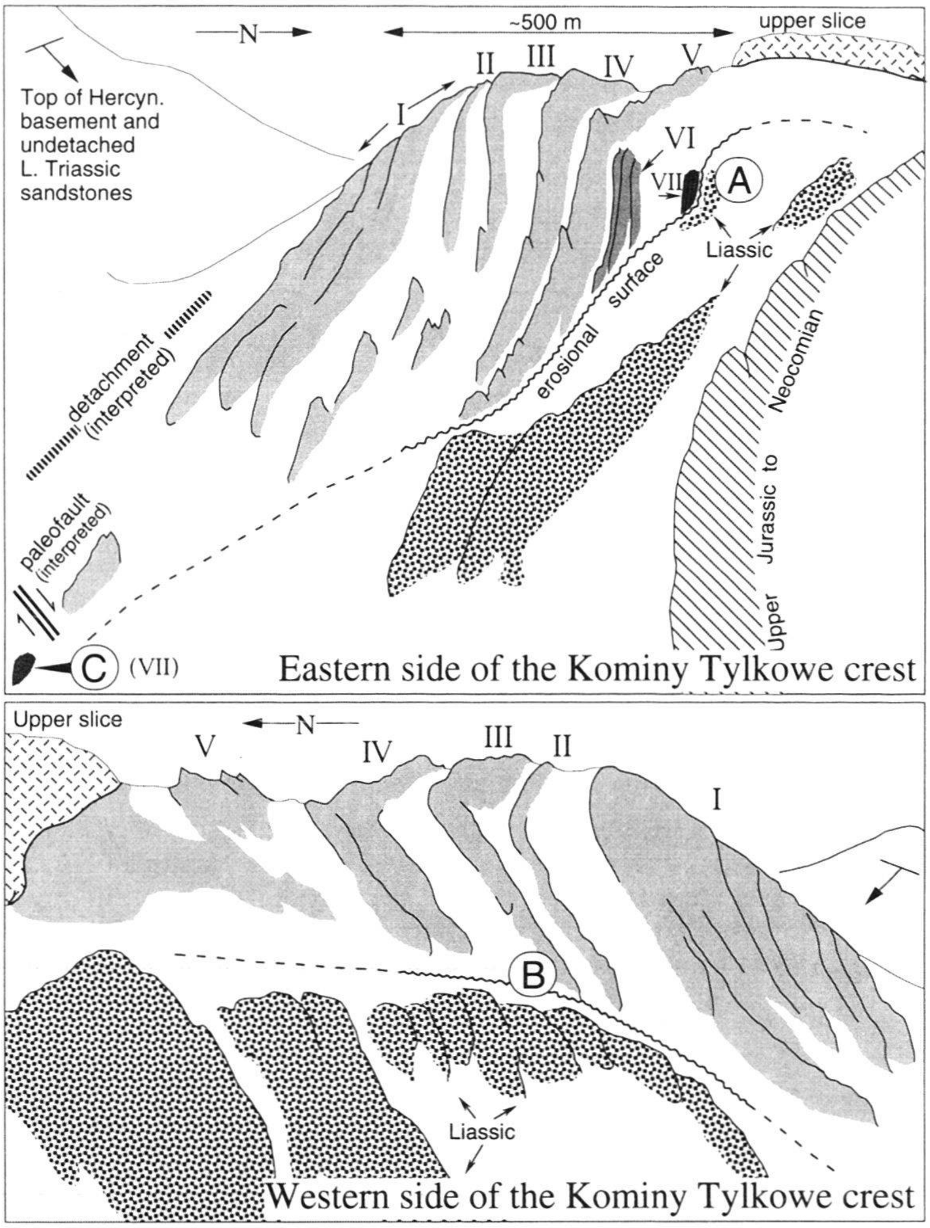


Fig. 5. Interpreted photographs of an inverted Lower Liassic erosional unconformity corresponding to the rift-onset unconformity on both sides of the Kominy Tylkowe crest (location Fig. 2). Roman-type numbers refer to Triassic limestone marker beds (shaded; see Fig. 3) which are truncated by the erosional surface. According to our interpretation, spots A, B and C, also shown on Fig. 6, refer to the upper part of the footwall block, to the lower part of the footwall block, and to the hangingwall block respectively (see Fig. 6, right part).

Restoration of paleostructures

We give here two examples of reconstruction. The first one is obtained by unfolding the angular unconformity and erosion surface of the Kominy Tylkow crest which is involved in the hinge of the major recumbent fold affecting the Lower succession; the second one is a restoration of the tectonic slices to their assumed Jurassic location along the Krzesanica section.

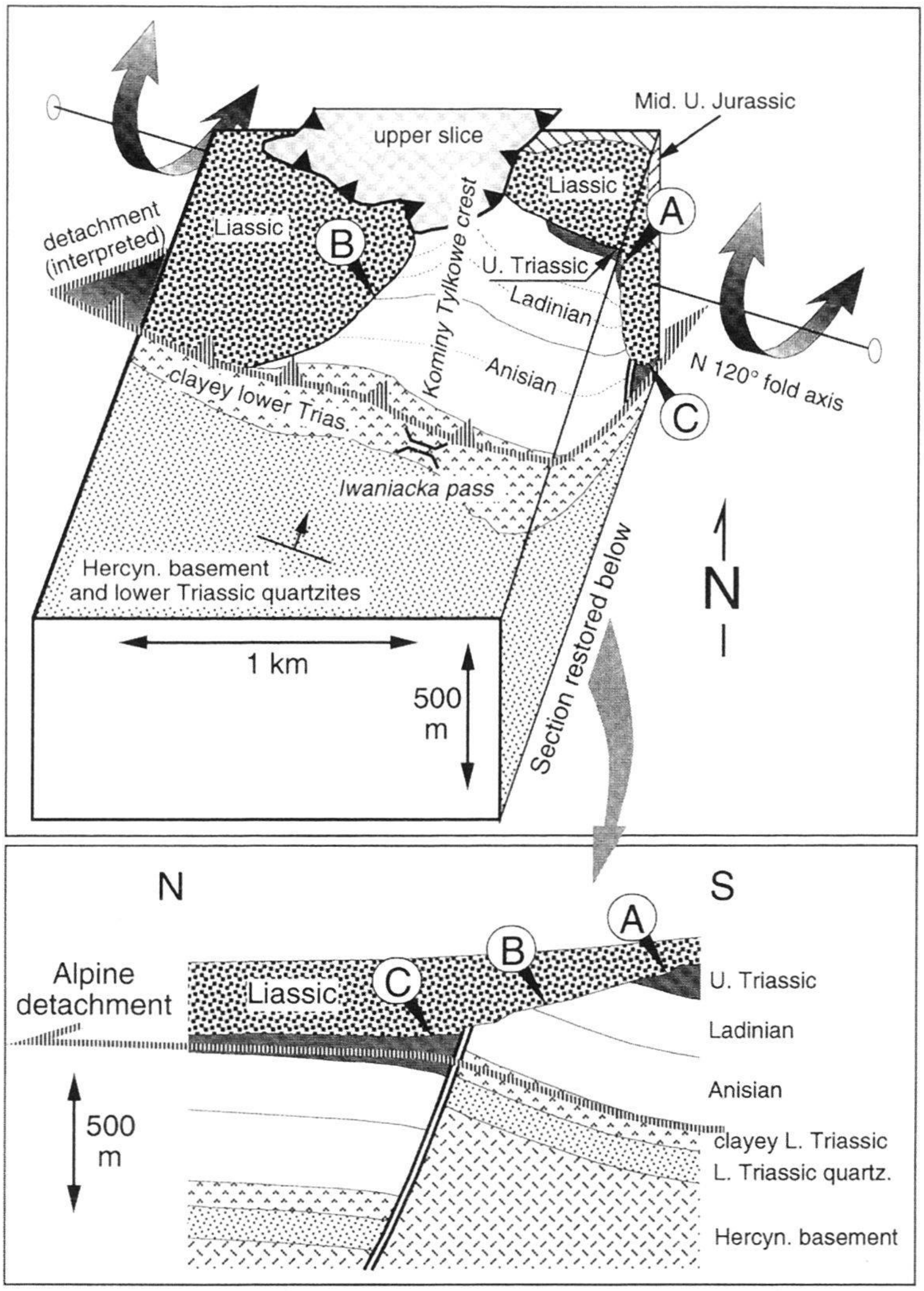


Fig. 6. top: interpretation of the present structure in the Kominy Tylkowe area; bottom: restoration of this structure. We propose that the rapid westward pinching-out of the Middle Triassic series (white) is a combined result of Latest Triassic-Early Liassic erosion and of Alpine detachment. A, B and C indicate outcrops located on Fig. 5.

1. Kominy Tylkowe fault block

As shown on the outcrop views of figure 5 and on the diagram of figure 6, the Early Liassic erosion surface truncates the deepest Triassic layers in the lowest outcroups on both sides of the N-S Kominy Tylkowe crest. Thus, if we unfold the structure: i) the intersection line between Triassic stratification and the erosion surface is running approximately E-W, and ii) the Triassic strata are dipping to the south, and/or the erosion surface is dipping to the north. We present a combination of both solutions.

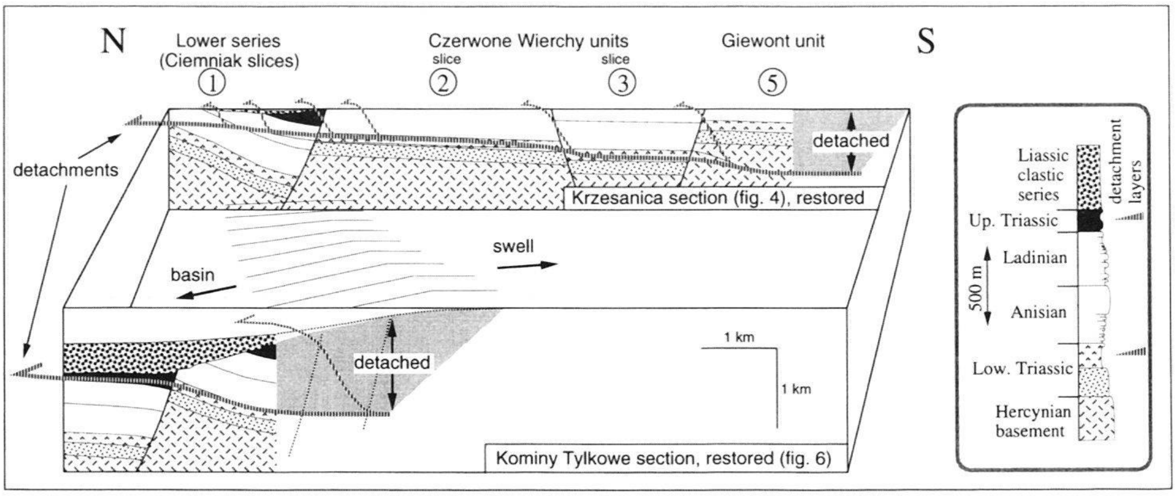


Fig. 7. Proposed restoration of the Krzesanica section (see Fig. 4) and of the Kominy Tylkowe section (see Fig. 6) prior to Alpine deformation. The present structure of the studied High-Tatric area could result from the inversion of an approximatively E-W marginal relief built up during the Tethyan rifting (Early Liassic to early Middle Jurassic).

According to our interpretation, this erosional unconformity and the basin which developed to the North could correspond to the footwall and to the hangingwall of an extensional major fault block respectively. As shown in figure 5, this fault could have been truncated a different depths by the basal detachment of the Lower succession. This interpretation provides an explanation for the abrupt westward pinching out of the Triassic series at point B (Fig. 6), which would result from the interplay between syn-rift extensional faulting and Alpine thrusting. The upper Triassic layers which crop out near the Koscieliska valley (point C, Fig. 5) would belong to the footwall block.

The occurrence of similar Jurassic faults is suspected to the West of the Ciemniak peak and in the Tichá valley (Fig. 2), because the erosional breakup unconformity jumps laterally from Middle Triassic to Liassic beds in a very small distance (less than 100 m).

2. *Krzesanica profile*

We have restored the pile of tectonic slices along this section using the retrotectonic reconstruction of figure 4. Figure 3 shows the depth of syn-rift erosion below the breakup unconformity and the depth of Alpine detachment, which are different in each slice. The result of the restoration is given in figure 7. It shows that the southernmost domain (Giewont unit) was the most uplifted one during the Jurassic and that the basal Alpine detachment was getting shallower northwards, which is consistent with northward thrusting.

3. *Inversion*

The geometries of the two inverted structures given above are different but they both indicate that northward shallowing upwards and emergence of the major Alpine thrust was triggered by northward-oriented Jurassic structures and paleotopography. This suggests

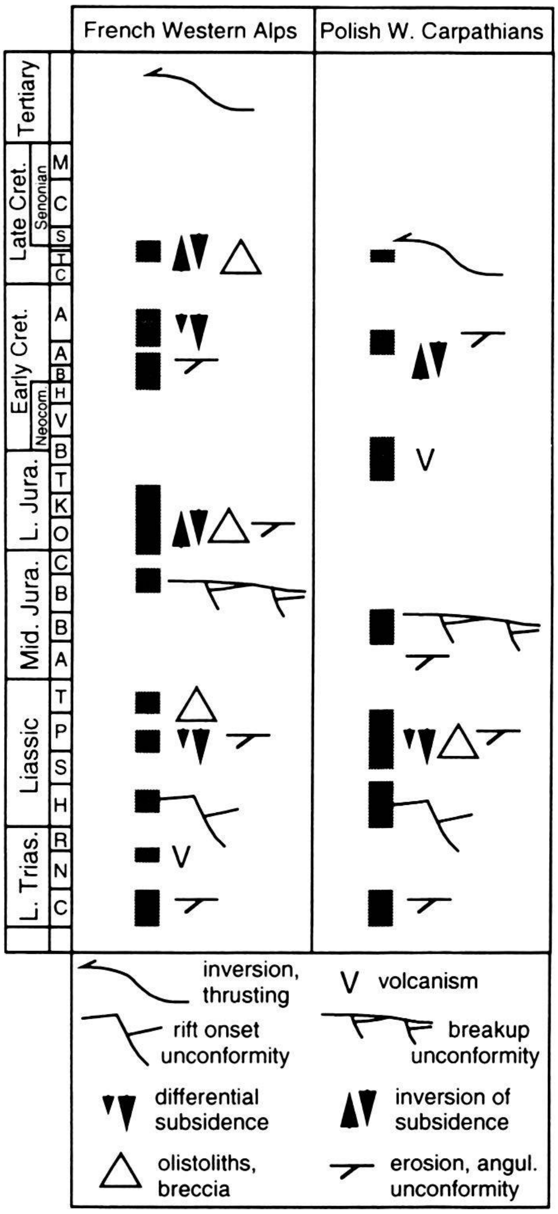


Fig. 8. Comparative evolution from Tethyan extension to Alpine inversion in the Western Alps (external and internal zones) and in the Polish Western Carpathians (High-Tatric zone), compiled after papers cited in the text and also after Bourbon (1980), Dardeau et al. (1988), Faure et Mégard-Galli (1988), de Graciansky et Lemoine (1988), Mégard-Galli & Faure (1988), Tricart et al. (1988). The grey vertical bars indicate the time span in which each event may have occurred. The evolution of the two domains is similar till the end of Liassic times. The breakup unconformity is slightly older in the Carpathians. An important development of tectonic inversion occurred simultaneously in both places during early Late Cretaceous, which is marked by compression (thrusting) in the Carpathians and by inversion of subsidence in the internal Western Alps.

that a regional swell did exist during the Jurassic to the south of the studied area. The observed syn-rift Liassic basin (Lower succession) developed to the north of this swell and was probably pushed out and transported over an other swell represented by the very condensed autochtonous Liliowe-type series.

Similarities and differences with the Western Alps

1. Time of Tethyan extensional deformation

The most striking result of a comparison of the Tethyan history in the Western Alpine units and in the Tatricum-Fatricum units of the Western Carpathians (Fig. 8) is the synchronism of the rift onset. In the French external Western Alps of Dauphiné, significant extensional deformation together with the onset of subsidence began during Late Hettangian (Lemoine et al. 1986; Grand et al. 1987; Dumont 1988; Dumont, in press). It is marked by small-scale block faulting and by the onset of differentiation of environments and bathymetries. During the Sinemurian, the deformation got focused on the boundaries of major tilted blocks of a breadth of more than 10 km. An increase in differential vertical movements is recorded in the sediments of Pliensbachian age (Roux et al. 1988). The breakup unconformity could be slightly younger (Late Bathonian) than in the Tatricum-Fatricum units of the Western Carpathians (which suffered a strong subsidence already during the Bajocian).

2. (Re)sedimentation and erosion

A thick, rythmic hemipelagic series with intercalations of grain flows consisting of shallow bioclastic material was deposited within some half-grabens of the Alpine external zone (Dauphiné). Shoals that developed on the half-horsts are markes by specific, highly condensed marine facies (crinoid limestones) containing bored Triassic pebbles which indicate that some areas were still emergent. However, in comparison with the Carpathian (High-Tatric) coeval series, the bulk of syn-rift clastic sediments is extremely low, probably because emergent areas were more restricted. On the contrary, the internal zones of Western Alps display the witnesses of a large marginal plateau (the Briançonnais plateau) bearing evidence of syn-rift emergence with an erosional gap. Adjacent basins contain abundant resedimented material within the Liassic-Middle Jurassic series. Considering these observations, we can suspect that the studied Carpathian area was located close to a large emergent area comparable to the Briançonnais plateau during the Jurassic. In the Tatric units of the Malé Karpaty Mts., the palinspastic reconstruction of Plasienka et al. (1991) has demonstrated the occurrence of such a feature.

3. Inversion of marginal reliefs and asymmetry of paleostructures

The specific behaviour of marginal highs during inversion is well documented in the Western Alps. At a large scale, the main controlling factor is the relative elevation of marginal structures: the Briançonnais plateau provided the bulk of the stack of nappes presently visible in the internal zones, whereas more proximal marginal basins (Subbriançonnais, internal Dauphiné zone) were largely consumed in major tectonic sutures. Similarly, the high external Pelvoux massif (4000 m) coincides with a Jurassic swell (Rudkiewicz 1988), probably as a result of reactivation of the extensional fault pattern during convergence.

At a small scale, inversion processes are also controlled by the orientation of maximum compression with respect to the direction of inherited structures. For example, in the Dauphiné zone of the Western Alps, where asymmetrical passive margin structures were facing the direction of thrusting, two types of inversion processes are observed:

- when Alpine deformation was weak or moderate (external Dauphiné zone), the major normal faults acted as buttresses and were weakly inverted. The slope of tilted blocks was not suitably oriented to enhance the development of ramps along the basement (cover boundary and shortcuts can affect this boundary (Fig. 9, upper part).

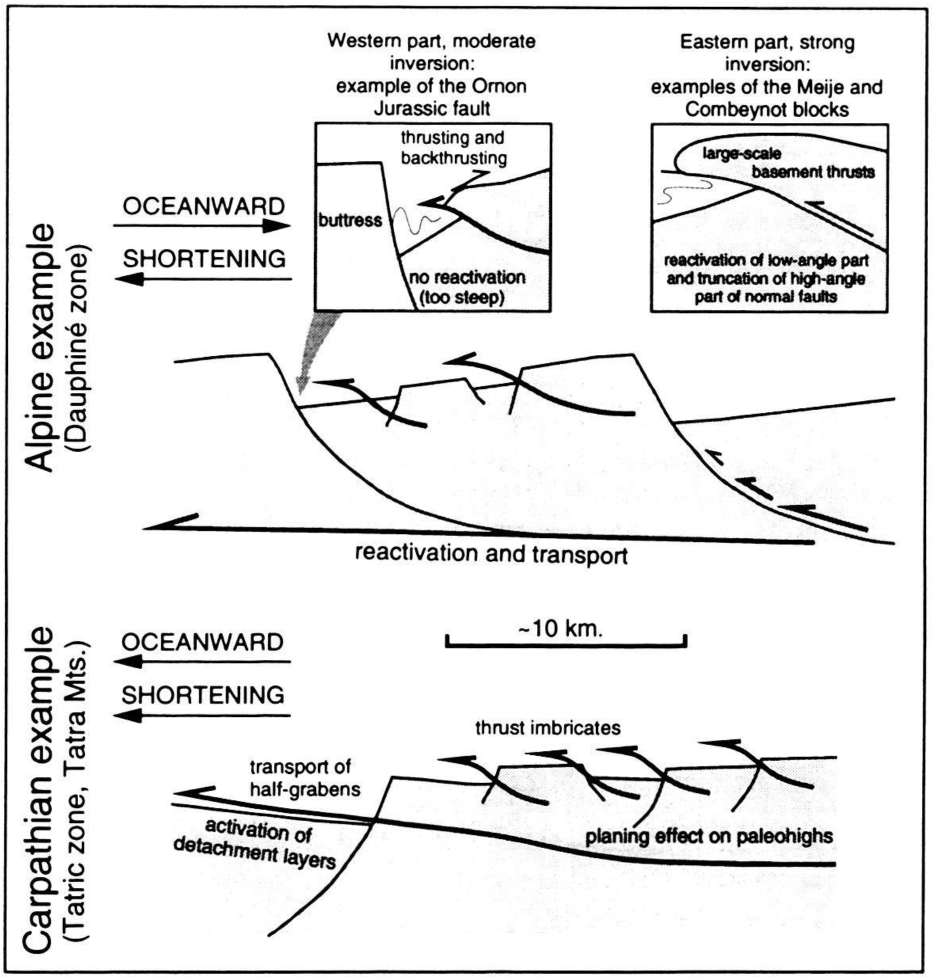


Fig. 9. Differences in style of structural inversion between an example in the French external Western Alps (Dauphiné zone, above) and the High-Tatric zone of Polish Western Carpathians (below). These differences illustrate the key role played during structural inversion by the initial orientation of marginal structures, either opposite or in the same sense than thrusting direction. Hercynian basement is shaded.

- when Alpine deformation was strong (internal Dauphiné zone, near the Pennine frontal thrust), the basement of each block was intensively deformed and partly reversed (Fig. 9, middle part). In that case, the initiation of the frontal basement fold could be explained by the listric geometry of the strongly inverted normal fault, whose low-angle part was more easily reactivated than the high-angle, upper part.

In the studied Carpathian example, in which normal faults were predominantly dipping in the same sense as thrusting, the ramp-and-flat systems can cross the border faults at the bottom of half-grabens and transport sedimentary basins (Fig. 9, lower part).

Conclusion

The structure of the High-Tatric zone of the Polish Western Carpathians results from tectonic inversion of a part of a Tethyan margin which had been strongly marked by synrift extensional deformation. Compared to the data provided by the Western Alpine paleomargin and by the Ligurian fossil ocean, the observed Carpathian features are consistent with crustal thinning and breakup of the postulated Vahicum Jurassic ocean whose remnants are sparsely preserved in the Western Carpathians (Häusler et al. 1993).

The evolution of the studied Carpathian paleomargin was marked by a critical event, which we interpret as the pre-rift/syn-rift limit, around the Triassic-Jurassic boundary (between Late Rhaetian and Early Sinemurian). It occurred simultaneously with the rift onset recorded on the northwestern margin of the Ligurian Tethys as well as on its southeastern margin (Austroalpine and Southalpine realms). This observation does not document any propagation of initial extensional deformation between these distant areas. The early rifting process was more likely controlled by mechanical intraplate stresses than by thermo-mechanical upper mantle activity, which is consistent with the lack of extensive volcanism and of pre-extensional uplift.

Despite the scarcity of paleontological data within the Carpathian High-Tatric syn-rift series, it can be shown that extensional deformation, differential subsidence and subaerial erosion of some uplifted blocks occurred till the early Middle Jurassic. The sedimentological and geometrical features of Bajocian and post-Bajocian strata are typical of a post-rift hemipelagic and pelagic sequence and are very similar to the late Middle Jurassic (post-Middle Bathonian) series of internal Western Alps which are correlated to the earliest supra-ophiolitic sediments of the Ligurian ocean (Lemoine et al. 1986). It would be interesting to compare these data with the precise age of the breakup unconformity in other Alpine or Carpathian units to determine whether the onset of spreading in the Ligurian ocean could have migrated from East to West during the Bajocian-Bathonian interval.

The restored High-Tatric syn-rift paleostructures were asymmetrical and probably linked to northward-dipping listric faults. This is similar to the restoration of Plašienka et al. (1991) in the Tatric units of the Malé Karpaty Mts. close to the connection between Eastern Alps and Carpathians, and this is consistent with the assumed location of the Tatric area on the Southern margin of the Pieniny ocean.

The opposite orientation of Tethyan structures in the two compared examples with respect to the sense of Alpine shortening resulted in significantly different styles of tectonic inversion.

Acknowledgements

Fieldwork was supported by an agreement between CNRS (Mission des Relations Internationales) and Polish Academy of Sciences. The authors are gratefull to Prof. Marcel Lemoine (Paris) and to Dr. Dusan Plašienka (Bratislava) for carefully reviewing and improving the manuscript.

REFERENCES

BAC, M. 1963: The geology of the Stoly massif in the West Tatra. Acta Geol. Polonica 13, 85–91.

BAC, M. & GROCHOKA, K. 1965: La structure du pli de Czerwone Wierchy sur le versant Est de la vallée Koscieliska. Acta Geol. Polonica 15, 350–355.

BAC-MOSZASZWILI, M., BURCHART, J., GLAZEK, J., IWANOW, A., JAROSZEWSKI W., KOTAŃSKI, Z., LEFELD, J., MASTELLA, L., OZIMSKOWSKI, W., RONIEWICZ, P., SKUPIŃSKI, A. & WESTWALEWICZ-MOGILSKA, E. 1979: Geological map of the Polish Tatra Mountains. Wyd. Geol. Warszawa.

BAC-MOSZASZWILI, M., GAMKREDLIDZE, I. P., JAROSZEWSKI, W., SCHROEDER, E., STOJANOV, S. & TZANKOV, T. V. 1981: Thrust zone of the Krizna nappe at Stoly in the Tatra Mts (Poland). Studia Geol. Polonica 68, 61–73.

BAC-MOSZASZWILI, M., JAROSZEWSKI, W. & PASSENDORFER, E. 1984: On the tectonics of Czerwone Wierchy and Giewond areas in the Tatra mts. (Poland). Ann. Soc. Geol. Poloniae 52, 67–88.

BERNOUILLI, D., BERTOTTI, G. & FROITZHEIM, N. 1990: Mesozoic faults and associated sediments in the Austroalpine-South Alpine passive continental margin. Mem. Soc. Geol. It. 45, 25–38.

BERTOTTI, G. 1990: The deep structure of the Monte Generoso basin: an extensional basin in the south-Alpine Mesozoic passive continental margin. Mém. Soc. géol. suisse 1, 303–308.

BERTOTTI, G., PICOTTO, V., BERNOUILLI, D. & CASTELLARIN, A. 1993: From rifting to drifting: tectonic evolution of the South Alpine upper crust from the Triassic to the Early Cretaceous. Sed. Geology 86, 53–76.

BIERKENMAJER, K. 1977: Jurassic and Cretaceous lithostratigraphiec units of the Pieniny Klippen Belt, Carpathians, Poland. Studia Geol. Polonica 45, 1-159.

– 1986: Stages of structural evolution of the Pieniny Klippen Belt, Carpathians. Studia Geol. Polonica 88, 7–32.

– 1988: Exotic Andrusov Ridge: its role in plate-tectonic evolution of the West Carpathian foldbelt. Studia Geol. Polonica 91, 7–37.

BOURBON, M. 1980: Evolution d'un secteur de la marge nord-téthysienne en milieu pélagique: la zone briançonnaise près de Briançon entre de début du Malm et l'Eocène inférieur. Thèse d'Etat, Strasbourg.

BURCHART, J. 1963: Remarks on the directions of the slickensides and fault striae in the cristalline rocks of the Goryczkowa "crystalline island" in the Tatra mountains. Acta Geol. Polonica 13, 41–43.

CASTELLARIN, A., PICCIONI, S., PROSSER, G., SANGUINETT, E., SARTORI, R. & SELLI, L. 1993: Mesozoic continental rifting and Neogene inversion along the south Giudicarie line (northwest Brenta Dolomites). Mem. Soc. Geol. It. 49, 125–144.

CONTI, P., MANATSCHAL, G. & PFISTER, M. 1994: Synrift sedimentation, Jurassic and Alpine tectonics in the central Ortler nappe (Eastern Alps, Italy). Eclogae Geol. Helv. 87, 63–90.

DARDEAU, G., ATROPS, F., FORTWENGLER, D., DE GRACIANSKY, P. C. & MARCHAND, D. 1988: Jeu de blocs et tectonique distensive au Callovien et à l'Oxfordien dans le bassin du Sud-Est de la France. Bull. Soc. géol. France IV, 5, 771–777.

DEBELMAS, J. 1960: Comparaison du Trias haut-tatrique avec celui des Alpes occidentales. Acta Geol. Polonica 10, 107–114.

DERCOURT, J., RICOU, L. E. & VRIELYNCK, (COORD.) 1993: Atlas Tethys Palaeoenvironmental Maps. Gauthier-Villard (Ed.), Paris.

DE ZANCHE, V. 1990: A review of Triassic stratigraphy and paleogeography in the Eastern Southern Alps. Boll. Soc. Geol. It. 109, 59–71.

DUMONT, T. 1988: Late Triassic-Early Jurassic evolution of the Western Alps and of their European foreland; initiation of the Tethyan rifting. Bull. Soc. Géol. France IV, 4, 601–611.

– in press: Sea-level changes and early rifting of a European Tethyan margin in the Western Alps and Southeastern France. In: Sequence stratigraphy of European basins. (Ed. by VAIL, P. R., GRACIANSKY, P. C. DE & JACQUIN, T.) Soc. Econ. Petrol. Min. Spec. Vol., 1995.

EBERLI, G. 1988: The evolution of the Southern continental margin of the Jurassic Tethys Ocean as recorded in the Allgäu Formation of the Austroalpine nappes of Graubünden (Switzerland). Eclogae Geol. Helv. 81, 175–214.

FAURE, J. L. & MÉGARD-GALLI, J. 1988: L'évolution jurassique en Briançonnais: sédimentation continentale et fracturation distensive. Bull. Soc. géol. Fr. IV, 4, 681–692.

FROITZHEIM, N. 1988: Synsedimentary and synorogenic normal faults within a thrust sheet of the Eastern Alps (Ortler zone, Graubünden, Switzerland). Eclogae Geol. Helv. 81, 593–610.

Froitzheim, N. & 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.

Gazdzicki, A. 1974: Rhaetian microfacies, stratigraphy and facial development in the Tatra Mountains. Acta Geol. Polonica 24, 17–96.

Glazek, J. 1959: Geology of the Koszysta Massif (High Tatra Mountains). Acta Geol. Polonica 9, 297–301.

– 1963: Les séries sédimentaires du versant nord de Woloszyn (Hautes Tatra). Acta Geol. Polonica 13, 479–480.

Gorek, A. 1958: Geologicke pomery skupiny Cervenych Vrchov, Tomanovej a Tichej doliny. Geol. Sbornik 9, 203–240.

Graciansky, P. C. de & Lemoine, M. 1988: Early Cretaceous extensional tectonics in the southwestern French Alps: A consequence of North-Atlantic rifting during Tethyan spreading. Bull. Soc. géol. Fr. IV, 5, 733–737.

Grand, T., Dumont, T. & Pinto-Bull, F. 1987: Distensions liées au rifting téthysien et paléochamps de contraintes dans le bassin liasique de Bourg d'Oisans (Alpes occidentales). Bull. Soc. Géol. Fr. 3, 4, 699–704.

Grochocka-Recko, K. 1963: Geology of Wyznia Swistowka (Western Tatra). Acta Geol. Polonica 13, 264–271.

Grodzicki, J. & Kardas, R. M. 1989: Tectonics of the Czerwone Wierchy Massif (Tatra Mountains) in the light of observations in caves. Annales Soc. Geol. Poloniae 59, 275–293.

Häusler, H., Plašienka, D. & Polak, M. 1993: Comparison of Mesozoic successions of the Central Eastern Alps and the Central Western Carpathians. Jb. Geol. B. A. Wien 136, 4, 715–739.

Jadoul, F., Berra, F. & Frisia, S. 1992: Stratigraphic and paleotectonic evolution of a carbonate platform in an extensional tectonic regime: the example of the Dolomia Principale in Lombardy (Italy). Riv. It. Paleont. Strat. 98, 29–44.

Jaroszewski, W. 1963: Tectonics of the high-tatric series in the upper floor of the Koscieliska Valley in the Tatra mountains. Acta Geol. Polonica 13, 58–61.

– 1965: Geology of the upper part of the Koscieliska valley in the Tatra Mts. Acta Geol. Polonica 15, 490–501.

Kostiukow, J. M. 1963: Geological mapping of Wielka Swistowka, and the Mulowy and Litworowy cirques. Acta Geol. Polonica 13, 233–239.

Kotański, Z. 1956: High Tatric Kampilian in the Tatra mountains. Acta Geol. Polonica 6, 1, 65–73.

– 1959: Stratigraphy, sedimentology and paleogeography of the high-tatric Triassic in the Tatra Mts. Acta Geol. Polonica 9, 113–143.

– 1961: Tectogenèse et reconstitution de la paléogéographie de la zone haut-tatrique dans les Tatra. Acta Geol. Polonica 11, 415–476.

– 1963: New elements in the structure of the Czerwone Wierchy massif. Acta Geol. Polonica 13, 181–199.

– 1964: Remarques sur le Trias briançonnais des Alpes occidentales et sa comparaison avec le Trias haut-tatrique des Tatra. Bull. Acad. Pol. Sci. Serv. Sci. Geol. Geogr. 12, 2, 97–104.

– 1965: La coupe géologique du versant Ouest de la vallée Koscieliska dans les Tatra occidentales et son développement historique. Acta Geol. Polonica 15, 254–257.

Kotański, Z. & Radwański, A. 1959: High-Tatric Tithonian in the Osobita region, its fauna with Pygope diphya and products of the volcanoes. Acta Geol. Polonica 9, 532–534.

Lefeld, J., Gazdzicki, A., Iwanow, A., Krajewski, K. & Wojcik, K. 1985: Jurassic and Cretaceous lithostratigraphic units of the Tatra Mountains, Studia Geol. Polonica 84, 7–92.

Lemoine, M. 1984: La marge occidentale de la Téthys ligure et les Alpes occidentales. In: Les marges continentales actuelles et fossiles autour de France. Ed. by Boillot, G. Masson Paris, 155–248.

Lemoine, M., Bas, T., Arnaud-Vanneau, A., Arnaud, H., Dumont, T., Gidon, M., Bourbon, M., Graciansky, P. C. de, Rudckiewicz J. L., Megard-Galli, J. & Tricart, P. 1986: The continental margin of the Mesozoic Tethys in the Western Alps. Marine and Petr. Geol. 3, London, 179–199.

Lemoine, M., Gidon, M. & Barfety, J. C. 1981: Les massifs cristallins externes des Alpes occidentales: d'anciens blocs basculés nés au Lias lors du rifting téthysien. C. R. Acad. Sc. Paris 292, 917–920.

Lemoine, M. & Trümpy, R. 1987: Pre-oceanic rifting in the Alps. Tectonophysics 133, 305–320.

Lugeon, M. 1903: Les nappes de recouvrement de la Tatra et l'origine des klippes des Carpates. Bull. Soc. vaudoise Sc. Nat. 39.

Mahel' M. 1981: Island character of Klippen Belt: Vahicum continuation of Southern Penninicum in West Carpathians. Geol. Zbor.-Geol. Carpathica 32, 293–305.

– 1983: Beziehung Westkarpaten-Ostalpen, Position des Übergangs-Abschnittes – Deviner Karpaten. Geol. Zbor.-Geol. Carpathica 34, 131–149.

MÉGARD-GALLI, J. & BAUD, A. 1977: Le Trias moyen et supérieur des Alpes nord-occidentales et occidentales: données nouvelles et corrélations stratigraphiques. Bull. Bur. Rech. Géol. Min. IV, 3, 233–250.

MÉGARD-GALLI, J. & FAURE, J. L. 1988: Tectonique distensive et sédimentation au Ladinien supérieur-Carnien dans la zone briançonnaise. Bull. Soc. Géol. France 3, 5, 705–716.

MICHALÍK, A. 1953: Budowa Tatr. In: Regionalna Geologia Polski, Karpaty (Ed. by KSIAZKIEWICZ M.) Polskie Towar. Geol., I, 2, 218–245.

MICHALÍK, J. & KOVÁC, M. 1982: On some problems of palinspastic reconstructions and Ceno-Mesozoic paleogeographical development of the Western Carpathians. Geol. Zbor.-Geol. Carpathica 33, 481–507.

MICHALÍK, J., PLANDEROVÁ, E. & SÝKORA, M. 1976: To the stratigraphic position of the Tomanova-formation in the uppermost Triassic of the West Carpathians. Geol. Zbor.-Geol. Carpathica 27, 299–318.

NEMČOK, J., BEZÁK, V., GOREK, A., HALOUZKA, R., JANÁK, M., KAHAN, S., KOTAŃSKI, Z., LEFELD, J., MELLO, J., REICHWALDER, P., RECZKOWSKI, W., RONIEWICZ, P., RYKA, W., WIECZOREK J. & ZELMAN, J. 1995: Geological map of the Tatra Mountains. Geol. Ustav Dion. Štúr. Bratislava.

PIOTROWSKI, J. 1965: Le Trias moyen et la tectonique du massif de Kominy Tylkowe. Acta Geol. Polonica 15, 386–393.

– 1978: Microstructural analysis of the main tectonic units of the Tatra mountains along the Koscieliska Valley. Studia Geol. Polonica 60, 1–90.

PLAŠIENKA, D. 1991: Mesozoic tectonic evolution of the epi-Variscan continental crust of the Central Western Carpathians – A tentative model. Mineralia Slov. 23, 447–457.

PLAŠIENKA, D., MICHALÍK, J., KOVÁČ, M., GROSS, P. & PUTIŠ, M. 1991: Paleotectonic evolution of the Malé Karpaty Mts. – An overview. Geol. Carpathica 42, 195–208.

RABOWSKI, F. 1959: High-Tatric series in the West Tatra Mts. Prace I.G. 27, 1–66.

RADWAŃSKI, A. 1959: Littoral structures (cliff, clastic dykes and veins, and borings of Potamilla) in the High-Tatric Lias. Acta Geol. Polonica 9, 270–281.

– 1968: Petrographical and sedimentological studies of the High-Tatric Rhaetic in the Tatra Mountains. Studia Geol. Polonica 25, 125–145.

RAKÚS M., MIŠÍK, M., MICHALÍK, J., MOCK, R., ĎURKOVIČ, T., KORÁB, T., MARSCHALKO R., MELLO, J., POLÁK, M. & JABLONSKÝ, J. 1990: Paleogeographic development of the West Carpathians: Anisian to Oligocene. In: Evolution of the Northern margin of Tethys; IGCP Project 198 (Ed. by. RAKÚS, M., DERCOURT, J. & NAIRN, A. E. M.). Mem. Soc. géol. Fr. 154 (III), 39–62.

RONIEWICZ, P. 1966: Lower Werfenian (Seisian) clastics in the Tatra mountains. Acta Geol. Polonica 16, 73–91.

ROUX, M., BOURSEAU, J. P., BAS, T., DUMONT, T., GRACIANSKY, P. C. DE, LEMOINE, M. & RUDKIEWICZ, J. L. 1988: Bathymetric evolution of the Tethyan margin in the Western Alps (data from stalked crinoids): a reappraisal of eustatism problems during the Jurassic. Bull. Soc. Géol. Fr. 4, 633–642.

RUDKIEWICZ, J. L. 1988: Quantitative subsidence and thermal structure of the European continental margin of the Tethys during Early and Middle Jurassic times in the Western Alps (Grenoble-Briançon transect). Bull. Soc. géol. Fr. IV, 4, 623–632.

SANDULESCU M. 1975: Essai de synthèse des Carpathes. Bull. Soc. Géol. Fr. 17, 299–358.

SIECIARZ, K. 1963: Geology of the East side of Mt. Kopa Kondracka. Acta Geol. Polonica 13, 289–295.

SZULCZEWSKI, M. 1963a: Stromatolites from the high-tatric Bathonian of the Tatra mountains. Acta Geol. Polonica 13, 142–148.

– 1963b: The geology of Mala Swistówka in Western Tatra. Acta Geol. Polonica 13, 216–223.

TOLLMANN, A. 1965: Gehören die Tatriden zum Unterostroalpin oder Pennin? Geol. Sbornik Slov. akad. vied. 16, 273–279.

– 1990: Paleogeographic maps and profiles in the Eastern Alps and the relationship of the Eastern Alps to neighbouring terrain. In: Evolution of the Northern margin of Tethys; IGCP Project 198, (Ed. by RAKÚS M., DERCOURT, J. & NAIRN, A. E. M.). Mem. Soc. géol. Fr. 154 (II), 23–38.

TOMEK, C. 1993: Deep crustal structure beneath the Central and Inner West Carpathians, Tectonophysics 226, 417–431.

TRICART, P., BOURBON, M., CHENET, P. Y., CROS, P., DELORME, M., DUMONT, T., GRACIANSKY P. C. DE, LEMOINE, M., MEGARD-GALLI, J. & RICHEZ, M. 1988: Tectonique synsédimentaire triasico-jurassique et rifting téthysien dans la nappe briançonnaise de Peyre-Haute (Alpes occidentales). Bull. Soc. géol. Fr. IV, 4. 669–680.

UHLIG, V. 1897: Die Geologie des Tatragebirges. Denkschr. Akad. Wiss. Wien, Math.-Naturw. Cl. 44, Wien.

VEIZER, J. 1970: Contribution to tectogenesis and orogenesis of the Slovak part of the High Tatra mantle series. Geol. Zbor.-Geol. Carpathica 21, 309–326.

WIECZOREK, J. 1989: Main stages of geological development of the Tatra Mts. Carp. Balcan. Geol. Ass. 14th congress, Sofia, 3, 789–792.

WOJCIK, K. 1981: Facies development of the High-Tatric Lias in the vicinity of the Chocholowska valley (Tatra Mts.). Przegl. Geol. 8, Warszawa, 405–410.

WOJCIK, Z. 1959: High-tatric series in the South side of Mt. Bobrowiec (Western Tatra mountains). Acta Geol. Polonica 9, 197–204.

Manuscript received April 20, 1995
Revision accepted August 20, 1995