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THE MESOZOIC OPHIOLITES IN THE EASTERN ALPS - A REVIEW

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Abstract

Mesozoic ophiolites in the Eastern Alps are confined only to three tectonic windows of the Penninic zone: the Lower Engadin window, the Tauern window and the Rechnitz window group. They display an almost complete sequence with serpentinites, mafic and ultramafic cumulates, volcanics and a sedimentary cover of radiolarites and calcschists but lack a sheeted dyke complex. During the alpine orogeny they recorded a two stage metamorphic evolution with a high pressure facies event followed by a greenschist to amphibolite facies event. Non-ophiolitic volcanism is widespread.

The geochemical data of the metabasalts are consistent with a MOR - environment of a complex slow spreading ocean. Geological and petrological investigations indicate a polyphase evolution of the Penninic ocean. A rifting phase involving deposition of clastic sediments intruded by an early basaltic magmatism is probably followed by a phase of uplift and erosion of newly formed oceanic crust along fracture zones. A further episode generated the widespread basalts on top of the serpentinites and gabbros. At the same time off axis volcanism was active in the Tauern window. The duration of magmatic activity is not known but ceased with the onset of the subduction process during the Cretaceous.

Introduction

The ophiolites of the alps and especially those of the Eastern Alps provide a nice example that at least these ophiolite bodies in contrast to many other Tethyan or Cordillieran ophiolites (Moores 1982, Coleman 1984) formed in small extending ocean basins similar to the Red Sea or the gulf of California and are not related to any subduction processes.

Geological setting and lithology

Major occurrences of ophiolites and related rocks (except for the Reckner complex, which is part of the Lower Austroalpine nappe) in the Eastern Alps are virtually restricted to the Penninic windows, submerging below the Austroalpine units (Fig. 1). These are, from west to east: The Lower Engadin window, the Tauern window and the Rechnitz window group.

The age of the ophiolites within the Eastern Alps is not well documented because the intense alpine metamorphism and deformation destroyed all fossils and primary magmatic minerals. A contemporaneous origin with the Jurassic ophiolites of the Western Alps (Abbate et al., 1984) is very probable in view of their overall similarities and their comparable geological position.

In the following sections the ophiolites of each window will be treated separately. Tab.1 provides a synopsis of all for ophiolite complexes comparing lithological, geochemical, metamorphic and miscellaneous features.

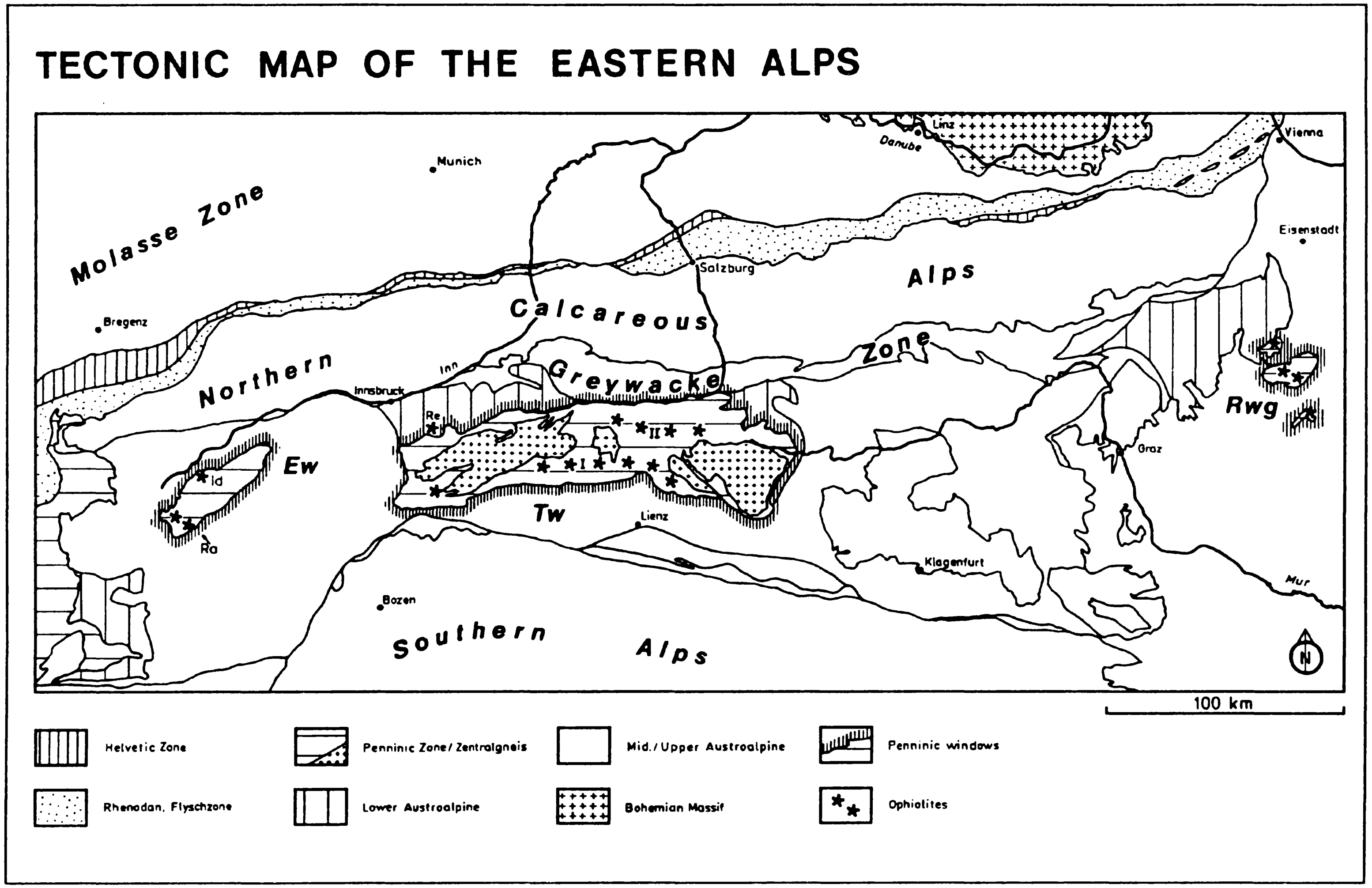

Fig.1: Geological-tectonic sketch map of the Eastern Alps showing the major occurrences of Mesozoic ophiolites

Ew	*Lower Engadin window, Id for Idalp and Ra for Ramosch ophiolite*
Tw	*Tauern window, I, II for ophiolite unit I and II*
Rgw	*Rechnitz window group*
Re	*Reckner complex, Lower Austroalpine nappe*

The Lower Engadin window

It is situated at the Swiss-Austrian border and consists of several tectonic units: The lower part, including the Ramosch ophiolite, is assigned to the north Penninic area; the Tasna nappe is middle Penninic and the highest structural unit, the Arosa zone, with the Idalp ophiolite (Daurer, 1980; Höck & Koller, 1987, 1989) is believed to be of south Penninic origin (Trümpy, 1972; Tollmann, 1977; Oberhauser, 1980; Frisch, 1984).

The Ramosch ophiolite is dominated by a serpentinized peridotite, which originated from a lherzolitic mantle (Vuichard, 1984a, b). The ultramafics are highly serpentinized and associated with ophicarbonates and serpentinite breccias. Basaltic and gabbroic partly rodingitized dikes crosscut the serpentinites. Metagabbros form lenticular bodies within the serpentinites. The volcanic complex (pillow basalts and minor sills) is tectonically emplaced upon the serpentinites. The presumed continuation of the Ramosch ophiolite towards the east is problematical. Only tuffs and some pillow lavas and pillow breccias are preserved. They show a geochemical composition which indicates some intense alterations especially in respect to the alkaline elements. Geochemical patterns of the immobile trace elements as well as from REEs indicate a generation either as T-type MORBs or as withinplate basalts.

The internal pseudostratigraphic pile of the Idalp ophiolite in the Arosa zone contrasts somewhat with the Ramosch ophiolite section (Höck & Koller, 1987, 1989). The sequence (Fig. 2; column A) starts with approximately 60 - 80 m thick serpentinites. They rest tectonically on the sediments of the Arosa zone. The overlying gabbros are in tectonic contact with the serpentinites and are intruded by rare diabase dikes. The volcanic section is in tectonic contact with the gabbros and starts with pillow lavas alternating with massive lava flows and hyaloclastites. The abundance of the hyaloclastites increases towards the upper levels. At the stratigraphic top tuffs with radiolarian schists were deposited. The volcanic pile (including the sediments) has a thickness of 250 to 300 meters.

Tauern window

In contrast to the other windows, the south Penninic Tauern window is characterized by a pervasive regional metamorphism in greenschist to amphibolite facies overprinting the older high pressure mineral assemblages. The original mineralogy, magmatic textures and possible remnants of an oceanic metamorphism are widely obliterated and only occasionally preserved.

Two coherent units (I and II) have been distinguished so far in the middle part of the Hohe Tauern (Höck, 1980, 1983; Höck & Miller, 1980, 1987) which comprise metamorphosed ophiolites including serpentinites, gabbros and basalts (unit I and II). Units I and II are situated in the central part of the Tauern window at its southern and northern margin respectively (Fig. 1). They rest tectonically on calcschists which grade into the more clastic metasediments (quartzites, breccias, black phyllites) of the Brennkogel facies, a deeper structural unit (Frasl & Frank, 1966; Frank, 1969). The latter is believed to have formed at the northern margin of the south Penninic ocean and comprises, in addition to the metasediments, some non-ophiolitic greenschists too. Other metamorphic volcanic rocks (former basalts, basaltic tuffs and thin banded tuffites) generated probably in an off-axis regime (Höck, 1983; Höck & Miller, 1987) are originally embedded in calcschists which overlie the ophiolites in the northeastern part of the Tauern window (unit III by Höck, 1983; Höck & Miller, 1980, 1987). They are, in turn, tectonically overlain by clastic sediments and coarse grained gabbroic rocks of the Fusch facies (Frasl & Frank, 1966; Frank, 1969), which has probably developed along the southern margin of the south Penninic ocean.

The ophiolitic sequence (Fig. 2; column B) starts with serpentinites at the base (maximum 100 m thick) which occur partly as foliated slivers, partly in stratigraphic contact with the overlying cumulate to gabbro sequence. The latter includes tremolite-chlorite-antigorite schists which are believed to be metamorphic remnants of ultramafic cumulates and ferrogabbros, forming small lenses in serpentinites, as well as leucogabbros. The 200 - 600meters thick extrusive series consists of metamorphosed basalts rarely showing features of pillows lavas, hyaloclastites and breccias. The ophiolite profile is completed with an up to 400 meters thick sedimentary cover of calc-mica schists and black phyllites sometimes interlayered with the volcanics at their base. Only occasionally a small quartzite horizon (metachert?) has formed on top of the extrusives.

	Lower Engadin Window (Arosa zone, Idalp)	Tauern Window	Rechnitz Window group	Reckner complex
Ophiolite type	high-Ti	high-Ti	high-Ti	high-Ti
Environment	MOR	MOR	MOR	
mantle composition	depleted	depleted, slightly variable	depleted, slightly variable	sligthly enriched
degree of melting	~ 10%	~ 10-15%	~ 10-15%	
MORB-type	N	N	N	
spreading rate	small	small	small	
Stratigraphy				
radiolarites	+	not clear	+	very common
tuffs/tuffites	+	+	+	?
hyaloclastites	+	+	+?	---
breccias	---	?	---	---
pillow lavas	+ (common)	+?	?	---
massive lavas flows	+	+?	+?	---
dikes within the gabbros	+	?	?	---
plagiogranites	---	---	+	---
ferrogabbros	very rare	rare	very common	---
cpx-plag-gabbros	+	+	+	very rare
ultramafic cumulates	?	+	+	+
rodingites	+	+	+	---
ophicarbonates	---	rare	+	very common
ultramafics	harzburgite	harzburgite	harzburgite	dominant lherzolite
Further Information				
transform-faults	?	?	+	+
non-ophiolitic volcanic activity	---	wide spread	+	---
oceanic metamorphism	poorly	overprinted by regional metamorphism	strong influence	strong influence
sedimentation rate	high	high	high	?
size of the oceanic basin	narrow	narrow	narrow	?
Alpidic metamorphism				
a) high pressure event	pumpellyite-actinolite-facies	eclogite/blueschist-facies	pumpellyite-actinolite-facies	blueschist-facies
b) young Alpine metamorphism	low T greenschist-facies	greenschist-/amphibolite-facies	greenschist-facies	greenschist-facies

Tab.1: Comparison of the more important features between the ophiolites of the Eastern Alps, compilation after Höck, (1983); Koller, (1985); Höck & Miller, (1987); Koller & Höck, (1987, 1990); Höck & Koller, (1987, 1989), Dingeldey, (1990).

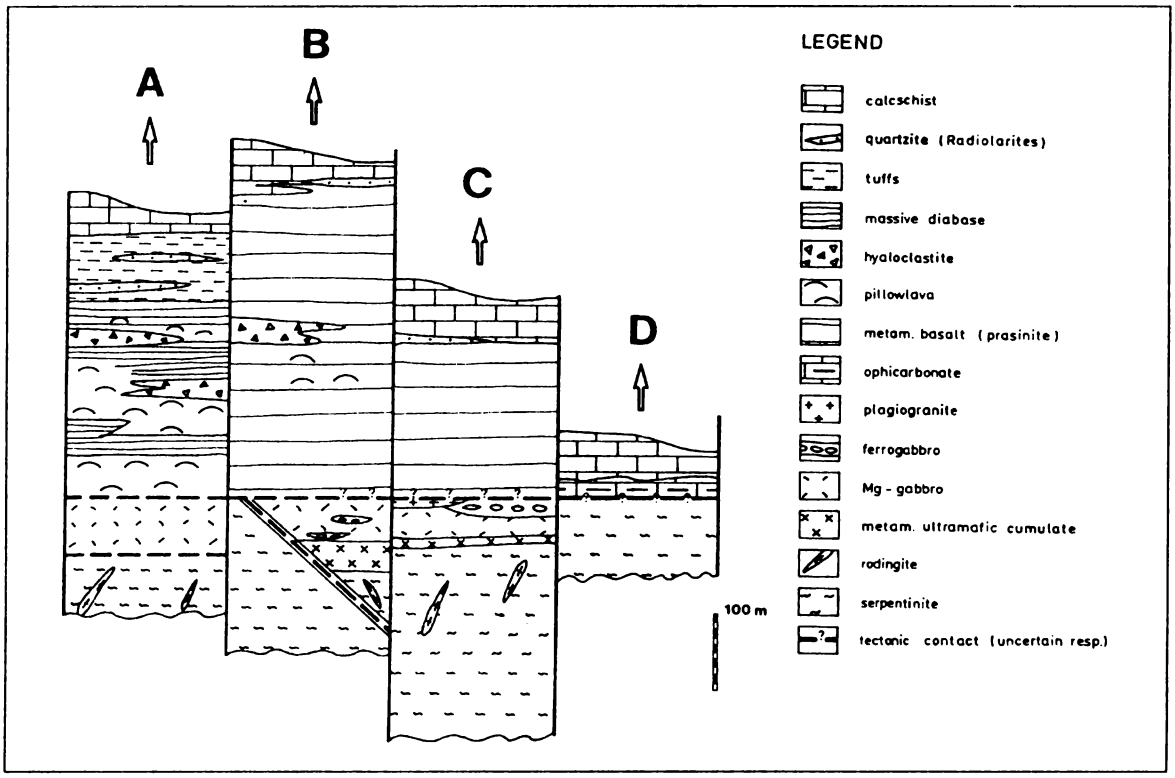

Fig.2: Generalized columnar sections through the ophiolites in the different windows:
AIdalp ophiolite (Lower Engadin window)
BTauern window
C Rechnitz window group
D Profile near Glashütten in the Rechnitz window and in the Reckner complex (Lower Austroalpine nappe). This is the only section with ophicarbonates on top of the serpentinites.

The Reckner complex

The Reckner ophiolite (Dingeldey, 1990; Dingeldey & Koller 1990) is situated in the upper parts of the Tarntal mountains near to the NW corner of the Tauern window. Tectonically it belongs to the higher parts of the Lower Australpine nappe (Fig.1). Besides a intensive oceanic metamorphism, a low temperature high pressure metamorphism overprinted by a regional themal event in greenschist facies is reported by Dingeldey (1990).

The ophiolitic sequence starts with ultramafic rocks mainly serpentinized lherzolites including small bodies of gabbros and ultramafic cumulates such as probable ilmenite-rich clinopyroxenites. The cover of these ultramafic rocks is formed by thin ophicarbonates, radiolarites and some questionable basaltic derivates which can not be used as geochemical markers. The thickness of this cover does not exceed more than 10 meters compared with more than 150 metres for the serpentinites. Dingeldey (1990) interpreted the metabasalts as transitional MORBs formed in the vicinity of a transform fault or in an incipient rifting zone. It is interesting to note, that the Reckner complex shows some striking similarities with the Ramosch ophiolite in the Lower Engadin window.

The Rechnitz window group

The Mesozoic Penninic rocks at the eastern end of the Alps forming several small windows are termed "Rechnitz Series". They comprise metasedimentary rocks together with several ophiolites (Koller, 1985; Koller & Höck, 1990; Höck & Koller, 1989). The following columnar sections can be established (Fig. 2; column C): serpentinites with a maximum thickness of 270 meters form the base. They are overlain by rare ultramafic cumulates, metaleuco- and ferrogabbros associated sometimes with metamorphosed plagiogranites and ferrodiorites. The maximum thickness of the plutonic sequence does not exceed 60 - 70 meters. Metamorphosed basalts including Fe-Ti-rich varieties and tuffs (up to 200 meters) form the extrusive section. Radiolarites (up to 10 meters) and calcareous sedimentary rocks terminate the whole sequence. Basic intercalations in the sediments are interpreted as tuffites.

It should be noted here that in contrast to the Tauern ophiolites and the Idalp ophiolite, but in accordance with the Ramosch ophiolite, ophicarbonates resting directly on the ultramafics play an important role in some ophiolitic profiles (Fig. 2; column D).

Geochemistry

The geochemistry will be treated here only briefly, a more detailed description is given elsewhere (Bickle & Pearce, 1975; Höck, 1983; Höck & Koller, 1987, 1989; Höck & Miller, 1987; Koller, 1985; Koller & Höck, 1990).

The generally serpentinized ultramafics in the Lower Engadin window are still recognisable as harzburgites from a petrographic point of view. The geochemistry with low $Al2O3$ contents, low $TiO2$, Cr ranging from 2200 - 2700 ppm and Ni 1000 - 2700 ppm is consistent with the petrographic evidence. The serpentinites in the other windows show similar concentrations of major and trace elements. Only some metamorphosed ultramafic cumulates (antigorite - tremolite schists, diopside - chrysotile - chlorite and talc-tremolite schists) have lower MgO and high CaO and $Al2O3$ values than the normal serpentinites. The leucogabbros show higher MgO and Cr, low $TiO2$, P, Nb, Zr, and Y concentrations. By contrast the ferrogabbros are depleted in Cr and enriched in Fe, Ti, V, Zr, Y, and P.

The chemical composition of all ophiolitic basalts is tholeiitic with a strong affinity to N-type MORB (Höck, 1983; Höck & Koller, 1987; Höck & Miller, 1987; Koller, 1985; Koller & Höck, 1987). The major elements as well as the trace elements including the REE (Koller, 1985) are in the typical MORB - range. According to the scheme of Beccaluva et al. (1983) they can be classified as high Ti - ophiolites. The effects of alteration are generally small.

In contrast to the uniform MORB characteristics of the ophiolitic basalts, the off-axis basalts and tuffs from the Tauern Window and some within plate metabasalts from the Rechnitz window group show a wider field of compositions. They range from tholeiites to mildly alkaline basalts with a significant enrichment in some trace elements such as Nb, Zr and the light REE, thus resembling T-type to E-type MORB (Höck & Miller, 1987; Koller, 1985).

As Höck & Koller (1989) have shown the variable Zr/Y ratios observed in the metabasalts from all Penninic windows cannot be explained by fractionation/accumulation mechanisms only. Other possibilities such as variation in source composition and different degrees of partial melting have to be considered. The petrogenetic evolution of the fractionated magmas will be dicussed briefly by means of the Zr/Y vs Zr diagram (according to Pearce & Norry, 1979). The non-cumulate magmas form two arrays in this diagram (Fig. 3) called field I and II, the latter having higher Zr/Y ratios at given Zr level. The distribution of lavas in these fields can be attributed to two factors: a variable mantle source and different degrees of partial melting. A somewhat depleted mantle, compared to a C3 composition (Pearce & Norry, 1979), partially melted to 10q5% (estimated degrees of partial melting are taken from Höck & Koller, 1989) gives rise to magmas which upon closed system fractionation of plag + ol + cpx (Fig. 3) can produce the basalts of field I. The tapping of a slightly more enriched mantle combined with a higher degree of partial melting (around 15%) and a similar fractionation history would account for the lavas of field II.

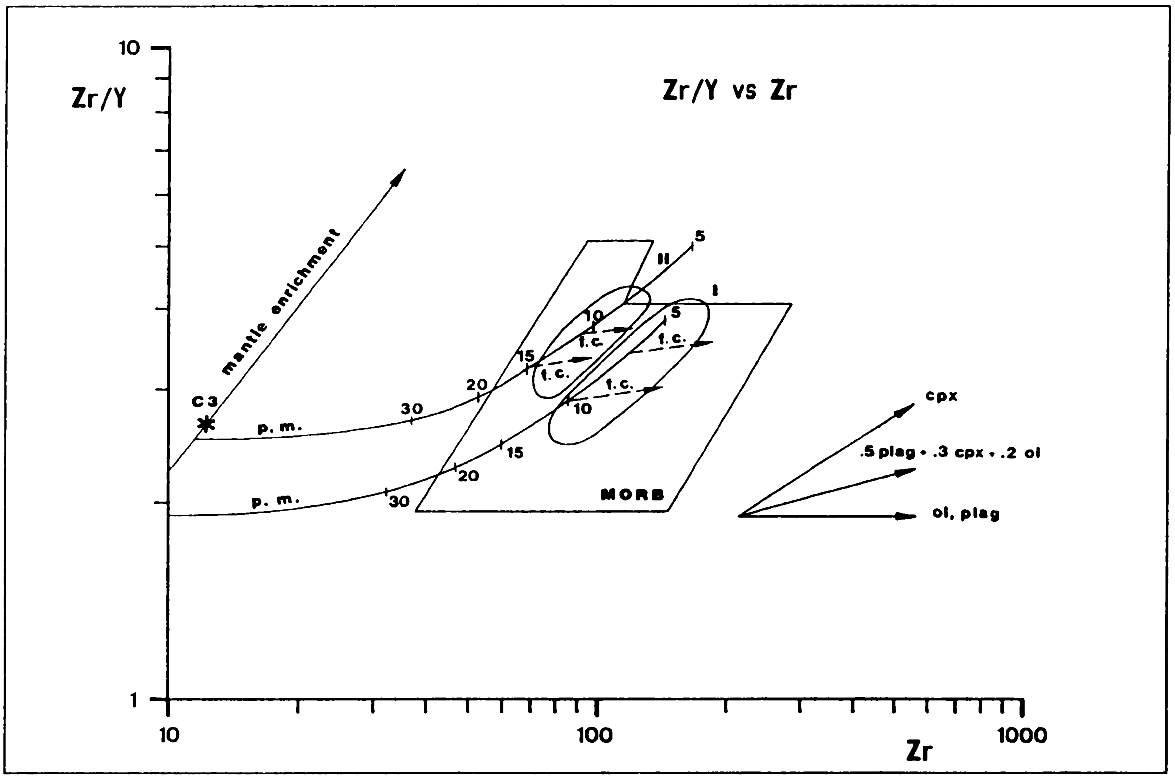

Fig.3: Zr/Y vs Zr diagram showing possible petrogenetic pathways for the two arrays I and II. The mantle enrichment and depletion trends starting from a C3 composition, partial melting curves (p.m.) and fractional crystallisation vectors (f.c.) are modelled according to Pearce & Norry (1979). Lavas from field I could have been formed by low partial melting (5 - 10%) of a depleted mantle with subsequent fractional crystallisation of plag + ol + cpx. Lavas of field II can be derived by 10 - 15 % partial melting of a less depleted mantle accompanied by 20-30 % fractional crystallisation of plag+cpx+ol. Fractionation trends for ol,pl,cpx for theoretical basaltic assemblage with ca. 50% crystallisation are inserted.

Höck (1983) and Höck & Miller (1987) have also shown utilizing several discrimination diagrams such as Zr-Ti/100-3*Y or Zr/Y vs Zr and MORB normalized multielement plots that the generation of the off-axis basalts and tuffs (unit III), of the coarse grained Fusch metabasics and of some eclogitic protoliths require a considerable variation (enrichment) in the mantle source to explain the high concentrations of some HFS elements and their ratios.

Geodynamic evolution

The internal structure of the ophiolites and their general geological situation is not only comparable within the Eastern Alps, common characteristics can be found over the whole range of the Alps from Eastern Liguria to the Austro/Hungarian border (Abbate et al.,1984; Höck & Koller 1989). The Mesozoic ophiolites in Austria compare quite well with the "Piedmont ophiolite composite nappe" as descibered by Monviso (1979); Abbate et al. (1984). Thus a similar geodynamic evolution can be expected for the entire Penninic realm. Nevertheless differences may occur.

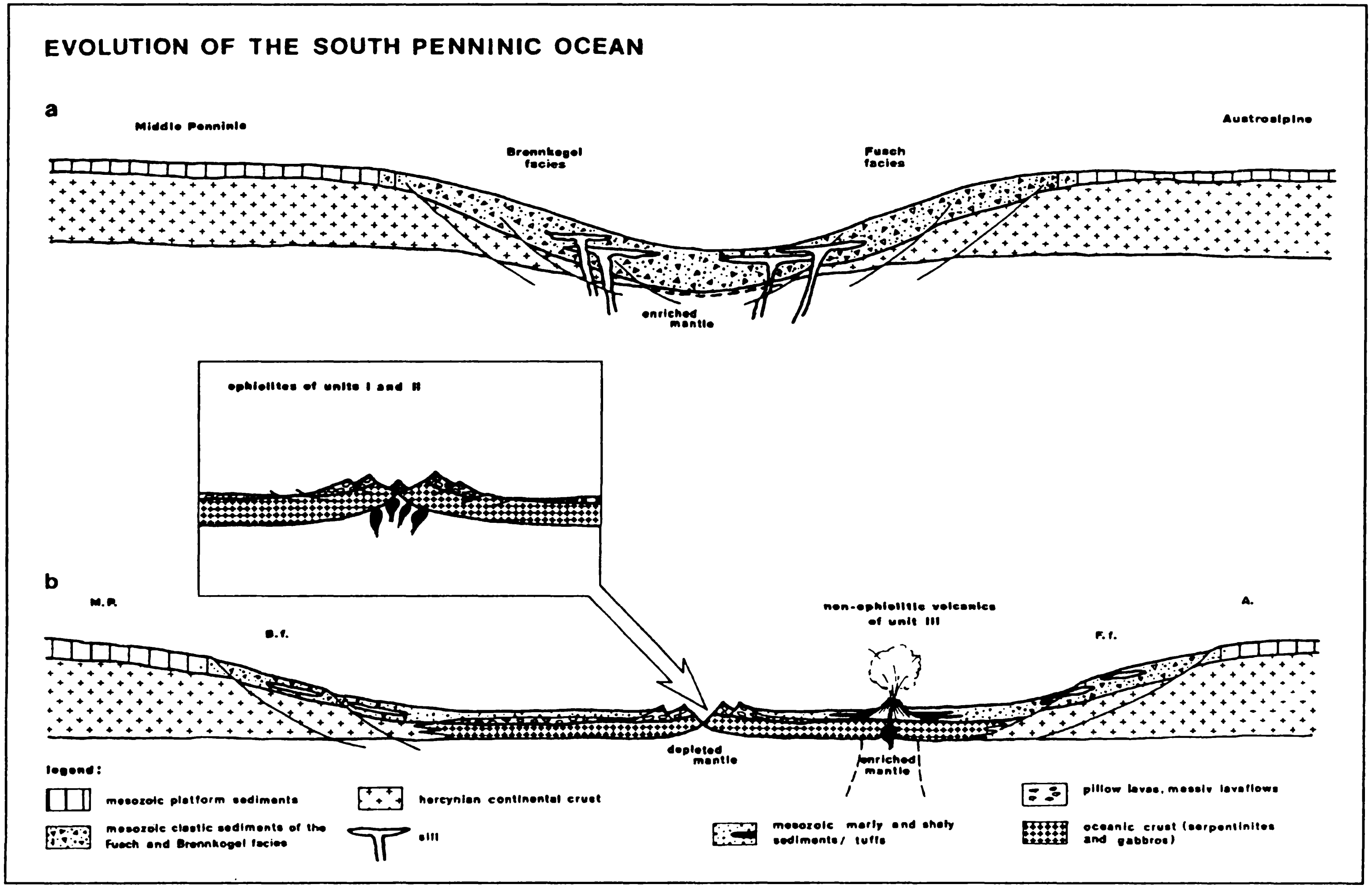

Fig.4: Tentative cross-sections showing the possible evolution of the South-Penninic ocean (The profiles are not in scale and not orientated.) 4a) depicts the early stage of rifting with the deposition of clastic sediments and the intrusion of sills. 4b) shows an oceanic stage with thinned crust near fracture zones and off-axis volcanism.

The following scenario for the evolution of the South-Penninic ocean (Fig. 4) is proposed. It should be noted however, that our model is based on information gleaned from the Tauern window, which provided the most complete sections.

The initiation of the Penninic ocean probably took place in the Early to Middle Jurassic with the rifting of the Hercynian continental crust and its post-Hercynian sedimentary cover forming a continental margin (Fig. 4a). The continental crust became thinner along normal (listric) faults and was covered with clastic sediments, shales, sandstones and breccias forming along fault scarps. During the last stages of thinning or the early stages of opening of the ocean basin, basaltic magmas derived from a relative enriched mantle were generated and injected into the clastic (still wet?) sediments of the Fusch and Brennkogel facies where they formed thick coarse-grained sills.

Subsequently a basin formed (Fig. 4b), floored by oceanic crust, probably segmented by closely spaced fracture zones (Abbate et al., 1984; Boccaletti et al., 1984; Lemoine, 1983; Weissert & Bernoulli, 1985). In the vicinity of the fracture zones the oceanic crust of the ridge area was stretched and eroded so that the gabbros and the ultramafics reached the ocean floor forming a rugged morphology (see insert in Fig. 4b). Such a scenario would be consistent with the tectonic models developed by Fox & Gallo (1984) for slow spreading ridge - transform - ridge plate boundaries or with the situation in the vicinity of the Kane fracture zone (Karson & Dick, 1984). An alternative model presented by Lemoine et al. (1987) postulating a Penninic ocean completely floored by ultramafics with small pods of gabbros and little extrusives seems not to fit the situation in the Eastern Alps, where coherent extrusive bodies are prevailing. The stage of stretching and erosion was accompanied by a slight hydrothermal oceanic metamorphism recorded mainly in the gabbros with the formation of pargasite and magnesio-hornblende. Further magmatic episodes generated the basalts on top of the gabbros and serpentinites. Their petrographical and geochemical variability reflects a depleted but slightly variable mantle composition and a slow spreading rate. The latter is postulated for the sinistral movement between Europe and Africa in the Jurassic by Savostin et al. (1986), Dercourt et al. (1986) and Ricou et al. (1986). A large influx of sediments sealed the basalts and prevented seawater from percolating through the lavas resulting in their minor hydrothermal alteration.

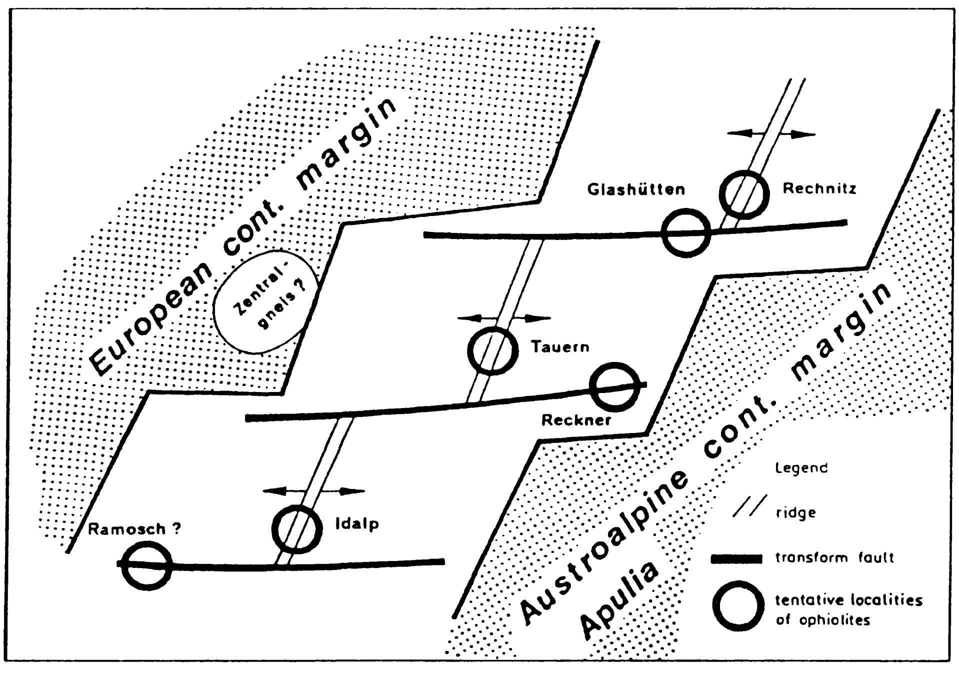

Fig.5: Tentative paleogeographic sketch map of the Penninic ocean in the Eastern Alps. The ophiolites from the Idalp, the Tauern Window and the Rechnitz Window Group are generated on ridge segments close to a ridge transform intersections. The ophiolites of Glashütten (Rechnitz Window) and Ramosch (Lower Engadin Window) as well as the Reckner complex (Lower Austroalpine unit) have possibly formed in a fracture zone environment.

Summarizing, the ophiolites in the Tauern window, in the Arosa zone (Lower Engadin window) and certain bodies in the Rechnitz window group were probably generated near a ridge-transform intersection in a slow-spreading ocean (Fig. 5). On the other hand, the ophiolites from Eastern Liguria, the Cottian Alps and the Arosa zone W of the Lower Engadin window (Abbate et al., 1980, 1984; Lemoine, 1980; Tricart & Lemoine, 1983; Weissert & Bernoulli, 1985), the Ramosch ophiolite (Vuichard, 1984a, b), smaller parts from the Rechnitz ophiolites (Koller, 1985) and also the Reckner complex in the Lower Austroalpine unit (Dingeldey, 1990; Dingeldey & Koller, 1991) are more likely to have formed in a fracture zone environment (Fig. 5).

Approximately coeval with the ophiolites were volcanic eruptions off the ridge axis (Fig. 4b). Several sequences consisting mainly of very fine grained and thin banded tuffs and lava flows were interbedded with the sediments. These different off-axis magmas have originated from relatively enriched mantle sources reflecting an inhomogeneous mantle beneath the south Penninic ocean.

The period and duration of the volcanic activity - ophiolitic or non-ophiolitic - is not well known. The evolution of the oceanic crust in the Penninic realm, however, had finished when subduction started to close the ocean sometime in the Cretaceous giving rise to the high pressure metamorphic assemblages in the ophiolites. Northward directed nappe movement accompanied by a greenschist to amphibolite facies metamorphism caused by the overthrusting of the Austro-alpine nappes (Frank et al., 1987), uplifting brought the ophiolites and associated rocks into their present position.

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