Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 68 (1988)

Heft: 3: Geodynamik des eurpäoschen Variszikums : Kaledonisch-Variszische Strukturen in den Alpen

Artikel: Ordovician-Silurian geodynamic evolution of the Alps : the orogeny back-arc basin model

Autor: Neubauer, Franz / Frisch, Wolfgang

DOI: https://doi.org/10.5169/seals-52073

SCHWEIZ. MINERAL. PETROGR. MITT. 68, 351–357, 1988

Ordovician-Silurian geodynamic evolution of the Alps – the orogeny back-arc basin model

by *Franz Neubauer*[1] and *Wolfgang Frisch*[2]

Abstract

The Ordovician-Silurian geodynamic evolution of the Eastern Alps, which is referred to as the "Caledonian event", is interpreted in terms of a multistage model and compared with the evolution of more recent (mainly Tertiary) structures in the Alpine-Carpathian belt. Crystalline complexes were formed in different zones of the Austroalpine basement during two metamorphic stages in the Early Paleozoic. The consolidated crystalline complexes suffered post-orogenic uplift and rifting along with the creation of a back-arc basin in the Late Ordovician to Early Silurian. Sedimentation in this basin was accompanied by calc-alkaline volcanism in the Late Ordovician, and by alkaline volcanism in the Silurian.

Keywords: Caledonian event, crystalline basement, rifting, back-arc basin, Eastern Alps.

Introduction

The Austroalpine basement, which is incorporated into the Alpine structural edifice of the Eastern Alps, is subdivided by means of pre-Alpine sedimentation and metamorphism. Fossiliferous sedimentary sequences range continuously from the Late Ordovician to the Carboniferous (ca. 450–320 Ma before present). In contrast, most geochronologic data from pre-Carboniferous crystalline rocks range from 460 to 430 Ma and hence show evidence for Ordovician thermal activity (metamorphism and magmatism). This is referred to as the "Caledonian event" in the Eastern Alps. The relationship between Early Paleozoic sedimentary sequences and basement, i.e. whether the units affected by the "Caledonian thermal event" were the basement to the fossiliferous sequences or not, is a much discussed topic (e.g., SASSI et al., 1974; HEINISCH and SCHMIDT, 1976; HEINISCH et al., 1984; SCHÖNLAUB and SCHARBERT, 1978).

Based on different sets of data the Early Paleozoic geodynamic evolution was interpreted in different ways: The existence of an Early Paleozoic orogeny is advocated by PURTSCHELLER and SASSI (1975); subduction models were proposed by LOESCHKE (1977) and HÖLL (1979), and multistage subduction-collision-rifting models by FRISCH et al. (1984) and LOESCHKE (in press).

This paper undertakes the attempt to combine published and new data, some of which are apparently conflicting. An advanced model is presented and compared with a more recent but similar situation in the Alpine orogen. The exact calibration of the biostratigraphic framework with geochronologic data has essential significance for the correct interpretation of the Early Paleozoic geodynamic evolution of the Eastern Alps. Unfortunately the time-scale cal-

[1] Institut für Geologie und Paläontologie der Universität, Heinrichstrasse 26, A-8010 Graz.
[2] Institut für Geologie und Paläontologie der Universität, Sigwartstrasse 10, D-7400 Tübingen.

ibration in the Ordovician and Silurian is still a matter of discussion (e.g., HARLAND et al., 1982; ODIN, 1982; PALMER, 1983). Some of the uncertainties were recently eliminated (ODIN, 1986; RUNDLE, 1986).

Relevant data concerning the "Caledonian event"

The evolution and age relationships of the fossiliferous sequences preserved in the Upper Austroalpine unit (UA; Fig. 1) and of the crystalline core complexes in the Middle Austroalpine unit are regarded separately because of their different metamorphic state.

In the *Upper Austroalpine unit*, the oldest fossils from several localities reveal a late Ordovician (Caradocian) age (Tab. 1; RIEHL-HERWIRSCH, 1970; FLAJS and SCHÖNLAUB, 1976; NEUBAUER, 1980; NEUBAUER and PISTOTNIK, 1984). The fossils derive from layers of marine carbonates intercalated in sandstones, pelites, and mafic tuffs. Three stages of volcanic activity are recognizable (Tab. 1): In the western Gurktal thrust system (Fig. 1), GIESE (1987) found Ordovician calc-alkaline volcanism which contrasts with Silurian (HÖLL, 1970; NEUBAUER and PISTOTNIK, 1984) mafic, alkaline volcanism. Alkaline basalts and basalts transitional between alkaline and tholeiitic were found in the Paleozoic of Graz (Fig. 1; FRITZ and NEUBAUER, this. vol.). A rhyolitic to rhyodacitic sequence with subaerially deposited tuffs (HEINISCH, 1981) is the dominant volcanic episode in other areas. It separates two episodes with basaltic volcanics in the Greywacke Zone (Tab. 1).

A point of discussion is the nature of the basement to these sedimentary sequences. DAURER and SCHÖNLAUB (1978) described gneiss-pebble bearing paraconglomerates ("Kalwang Gneiskonglomerat formation") near the base of the Ordovician sequence. NEUBAUER (1985) found a conglomerate of similar composition in primary contact with a pre-existing basement consisting of amphibolites and paragneisses in another locality. The lower intercept of a U/Pb zircon discordia from a gneiss layer of this basement yielded a model age of approximately 510 Ma (NEUBAUER, FRISCH and HANSEN, 1987). This age is interpreted as dating a metamorphic event which affected a probably late Archean protolith as is indicated by the upper intercept model age. The conglomerate contains both amphibolite pebbles comparable to the amphibolites of the pre-existing basement, and also ultramafic rocks and trondhjemite gneisses which crystallized 500 Ma before present (NEUBAUER et al.,

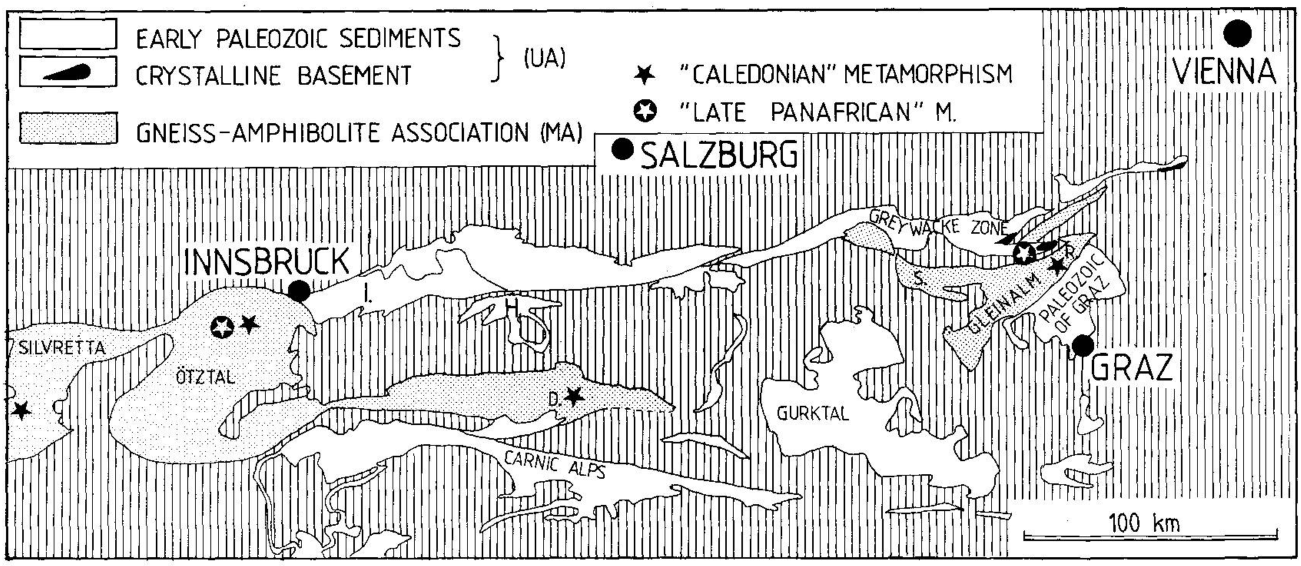

Fig. 1 Basement rocks of the Eastern Alps affected by late Proterozoic to Silurian events. Amphibolite facies metamorphic rocks similar in lithology to fossiliferous, weakly metamorphosed formations are omitted because of clarity. MA – Middle Austroalpine unit: D. – Defereggar Alps; R. – Rennfeld; S. – Seckauer Tauern; UA – Upper Austroalpine unit and comparable weakly metamorphosed early Paleozoic sediments of the Penninic domain (H. – Habach formation) and the Lower Austroalpine domain (I. – Innsbruck quartzphyllite).

1987). The basement rocks as well as the crystalline pebbles were deformed under amphibolite facies conditions prior to the sedimentation of the conglomerate. These facts strongly support the existence of an Early Paleozoic orogenic episode in the basement of the Upper Austroalpine zone. The sedimentation following this event is suggested to be related to rifting, as is indicated by geochemical data of tuffs (SCHÄFFER and TARKIAN, 1986). These tuffs are intercalated in a series of siltstone, arkosic sandstone, and paraconglomerate (see also LOESCHKE, in press).

In the Upper Austroalpine zone, Late Ordovician to Silurian sedimentation is characterized by the following: (1) continental-derived quartz-rich sandstones, (2) heavy mineral spectra with minerals predominantly of metamorphic origin like garnet (STATTEGGER, 1980, 1982), and (3) metamorphic rock components in sporadic conglomerate layers and agglomerates (MOSTLER, 1970). It should be stressed, however, that fossil data confirming the Ordovician or Silurian age are rather scarce and that long-distance correlation of fossiliferous strata is necessary. The exact onset of sedimentation is also not known.

The *Middle Austroalpine unit* passed through an evolution of magmatism and metamorphism in the Late Proterozoic and Early Paleozoic. The existence of an Ordovician "Caledonian" event in the Middle Austroalpine crystalline mass was proposed by GRAUERT (1966), GRAUERT and ARNOLD (1968), and HARRE et al. (1968) based on radiometric work. SÖLLNER and HANSEN (1987) found evidence for a Late Proterozoic "Pan-African" thermal event followed by the crystallization of mafic and intermediate magmatic rocks around the Cambrian/Ordovician boundary in the Ötztal mountains (Fig. 1). They argue in favour of an Early Paleozoic multistage metamorphic evolution: Eclogite metamorphism, dated 497 Ma old (SÖLLNER and GEBAUER, pers. comm.), was followed by migmatite formation around 460 Ma ago; the last step was widespread crystallization of the augengneiss protoliths in the range of 445–425 Ma (BORSI et al., 1980; HAMMERSCHMIDT, 1981; SATIR, 1976; SÖLLNER and HANSEN, 1987; BRACK in TROLL et al., 1976). Similar data were found in the region south of the Tauern Window (CLIFF, 1980), where a deformation event produced a foliation between the crystallization of two granitoids of slightly different ages. 450–425 Ma ages were also found east of the Tauern Window in the Seckauer Tauern (SCHARBERT, 1981) and the Rennfeld area (NEUBAUER, FRISCH and HANSEN, 1987) (Fig. 1). FRANK et al., (1976) dated orthogenic plagioclase gneisses in the Gleinalm (Fig. 1) at 518 ± 50 Ma, which is evidence for Early Paleozoic formation of acid melts.

All these areas in the Middle Austroalpine unit were later overprinted by Variscan metamorphism, which reached amphibolite facies conditions (FRANK et al., 1987b). It is not known whether all these areas were uplifted after the Ordovician metamorphic event or not. The metasedimentary sequence of the Schneeberger Zug in the Ötztal mountains, which can be compared to the fossiliferous Silurian-Devonian shelf sequences, is most probably the

Tab. 1 Data concerning the age of metamorphism in early Paleozoic basement rocks, the age of sedimentation and the nature of volcanism in subsequent sedimentary basins.

	Carnic Alps	Gurktal thrust system	Eastern Greywacke zone (Noric nappe)	Paleozoic of Graz
Stages of volcanism	Felsic tuffs (late Ordovician)	Alkaline volcanics (Silurian) Felsic tuffs (late Ord.) Calcalkaline volcanics (late Ordovician)	Mafic volcanism (Silurian) Felsic tuffs Mafic volcanism (in part tholeiitic)	Alkaline volcanism (Silurian)
Oldest Fossils	Caradocian	Caradocian	Caradocian	Llanodovery/Wenlock
Basement	Unknown	Unknown	"Kaintaleck slices" (Ritting and Frauenberg complexes) Frauenberg complex with U/Pb zircon ages (lower intercept) around 510 Ma	

sedimentary cover of the Early Paleozoic basement (FRANK et al., 1987a).

Discussion: The intra-orogenic back-arc basin model

It is important to note that, concerning their Early Paleozoic history, two different areas are preserved in the Austroalpine region (Fig. 2):

1. The Upper Austroalpine zone shows a metamorphic peak around 500 Ma and forms a basement which is covered by sediments no later than 440 Ma before present. The sedimentary sequence includes calc-alkaline mafic volcanism near its base, followed by felsic, and then alkaline mafic volcanism.

2. The Middle Austroalpine (e.g. Ötztal/Silvretta) zone shows two metamorphic events (SÖLLNER and HANSEN, 1987), from which the earlier (eclogite formation around 500 Ma) may be related to the contemporary metamorphism in the Upper Austroalpine zone. The later metamorphic event (ca. 460–440 Ma) has high-temperature character (SÖLLNER et al., 1982) and is followed by granite intrusions (445–425 Ma).

A significant question is whether a spatial relationship between the later Upper and Middle Austroalpine regions exists during the Early Paleozoic. Some arguments speak in favour of such a relationship:

a) The metamorphic ages around 500 Ma are common to both regions.

b) The late Ordovician acid magmatism is also a characteristic for both regions. HEINISCH and SCHMIDT (1982) compared major element data of Upper Austroalpine volcanic rocks and the Middle Austroalpine plutonic rocks of this period and found that the data are comparable. After a calculation of SMITH (1979), nine tenths of acid composition magmas crystallize within the crust as plutonic rocks. This suggests that the late Ordovician acid tuffs require great volumes of plutonic rocks at depth. The only known granitoids of Late Ordovician age in the Eastern Alps are those of the Middle Austroalpine domain.

A geodynamic model for the Early Paleozoic in the Eastern Alps must explain the following features:

- Sedimentation in a subsiding basin formed immediately after metamorphism and consolidation of its basement.
- Calc-alklaine volcanism postdating the collisional event.
- Volcanic evolution from calc-alkaline mafic to felsic, and then alkaline.

The proposed back-arc basin model incorporates all the data related to the "Caledonian event" displayed above. A parallel is drawn to basins within the Mediterranean Alpine orogenic range, e.g. the Pannonian and the Egean basins (for a review, see ROYDEN et al., 1983). The basement of these Tertiary basins was formed during two stages of metamorphism which accompanied the stacking of nappes in the orogenic wedge. In the Eastern Alps (the basement to the Pannonian basin) the two stages are the eo-Alpine and the late Alpine metamorphic events. The newly formed basement is exposed at the margins of the subsiding basin and in horsts within it, e.g. the Rechnitz Window in the Pannonian basin. The reason for the two-step metamorphic evolution is progradation of subduction from internal to external zones (FRISCH, 1979). Uplift and cooling of the thickened crust is related to buoyancy and orogen-parallel extension. This extension is due to continental escape in the Eastern Alps in response to continued compression (BALLA, 1986; NEUBAUER, 1988). Calc-alkaline volcanism in the newly formed sedimentary basin is caused by the progradation of the subduction zone (BALLA, 1986).

Similar plate tectonic processes as described for the Pannonian basin may have been active in the Austroalpine domain in the Early Paleozoic since both regions have fundamental features of geodynamic significance in common (Fig. 2). High-pressure metamorphism in the Middle Austroalpine Ötztal mountains (appr. 500 Ma) followed by high-temperature metamorphism (appr. 460 Ma) requires decompression and uplift within a short time interval. The Upper Austroalpine zone was uplifted immediately after the 500 Ma metamorphic episode, possibly facilitated by low-angle normal faulting. A sedimentary basin or several basins formed by lithospheric stretching of the newly consolidated crust. Consequently, metamorphic complexes and sedimentary basins were facing each other in the same region. The rise of a plume of lithospheric mantle as a late expression of subduction activity in a back-arc environment and calc-alkaline volcanism connected herewith caused both a rise in temperature within the newly formed continental crust,

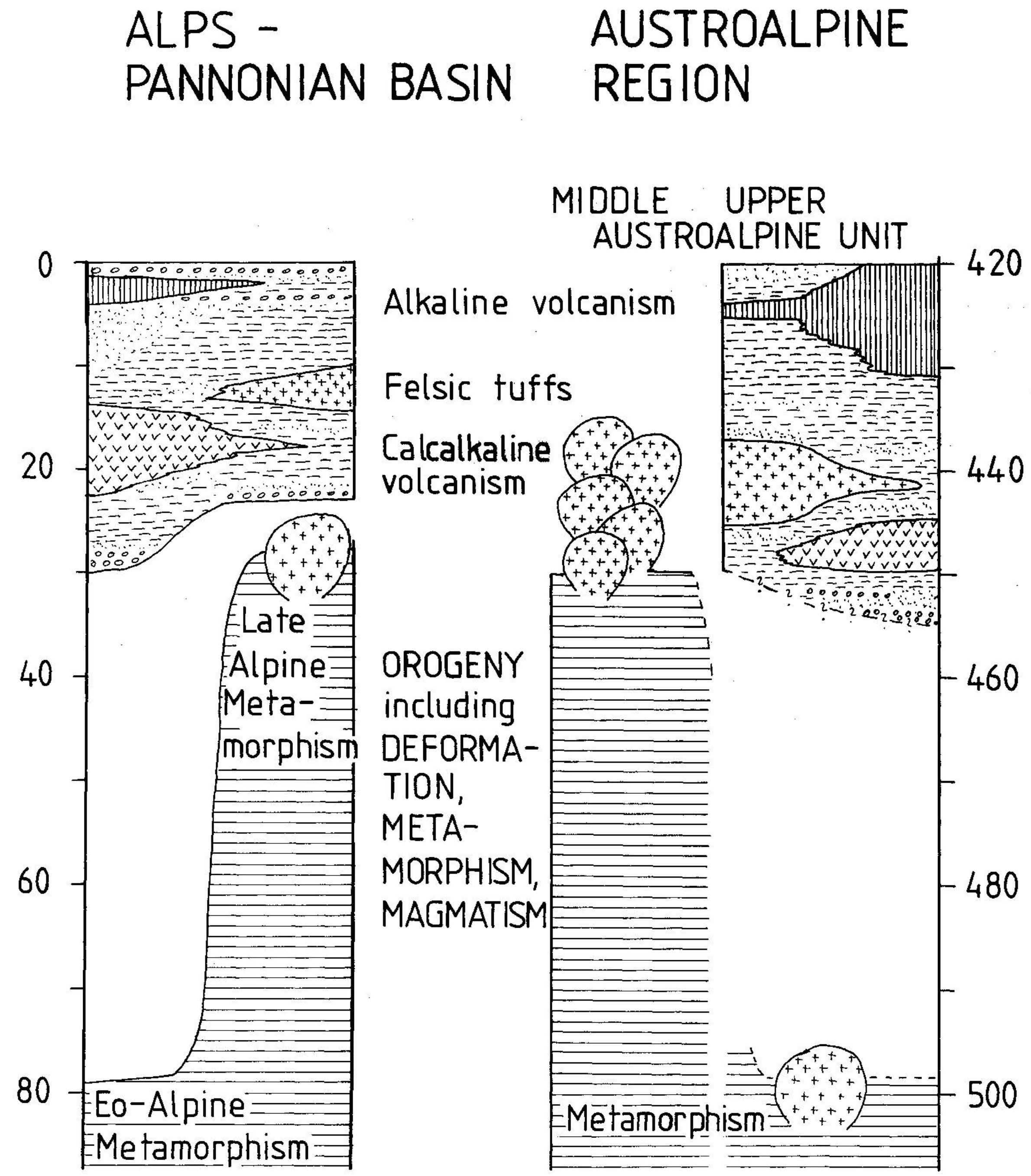

Fig. 2 Diagram concerning early Paleozoic geodynamic evolution in comparison to the intra-Alpine, Neogene Pannonian basin. Same scale for time.

and crustal melting. The melt products are the late Ordovician acid plutonic and volcanic rocks. Convective removal of thermal energy led to a decrease in thermal and gravitational instability and of subsidence, which is recorded in the Silurian sedimentary sequences. The alkaline volcanics dominating in the Silurian can be seen as a late effect of the mantle plume, or as the magmatic expression of rifting with which the Variscan cycle was initiated.

Acknowledgements

The authors are grateful for constructive comments and discussions concerning the topic of this paper to H. W. Flügel and H. Fritz (Graz), W. Frank (Vienna), H. Heinisch (Munich) and J. Loeschke (Tübingen).

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Manuscript received May 31, 1988; accepted October 1, 1988.