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Towards a Geodynamic Concept of the "Caledonian Event" in Central- and SW-Europe

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With 6 figures

Zentral- und SW-Europa
Alpiner Raum
Ordovizium
Kaledonisches Ereignis
Magmatismus
Geochronologische Daten
Metamorphose
Tektonische Modelle

Summary

The present stage of the discussion on the essence of the Caledonian event in Central- and SW-Europe is reviewed with special reference to the Alpine zone. The authors regard the Ordovician as a time of strong metamorphism and extensive magmatism caused by upwelling mantle material. This magmatism started in the Lower Cambrian and lasted at least until the Silurian. These processes point to a complex geodynamic system which developed by surperposing effects of the collision orogeny at the Atlantic side and spreading processes at the Tethyan side of the European microcontinent assemblage.

Both of the active margins formed a triple junction near the SW corner of Europe. The activity of the asthenosphere in this zone possibly initiated the rise of different sized asthenoliths and mantle plumes. The strongly increased heat flow might have caused strong (amphibolite-granulite facies) metamorphism and extensive magmatism.

The characteristics of this tectonic thermal event in Central- and SW-Europe differ clearly from those processes which are definded as orogeny.

Zusammenfassung

Mit besonderem Augenmerk auf den alpinen Raum wird versucht den Stand der Diskussion um das kaledonische Ereignis in Zentral- und SW-Europa rückblickend darzustellen.

Die Autoren betrachten das Ordovizium als einen Zeitraum ausgeprägter metamorpher und magmatischer Aktivität, hervorgerufen durch aufsteigendes Mantelmaterial. Der Magmatismus begann im unteren Kambrium und dauerte bis ins Silur an. Diese Prozesse sind einem komplexen System zuzuordnen, wobei sich die Auswirkungen der Kollisionsorogenese der atlantischen Seite mit Dilatationspozessen an der Tethysseite des europäischen Mikrokontinents überlagern.

Die beiden aktiven Kontinentalränder bildeten eine triple junction in der SW-Ecke Europas aus. Der Aufstieg verschieden großer Asthenolithen und mantle plumes kann möglicherweise auf die Aktivität der Asthenosphäre in dieser Zone zurückgeführt werden. Der stark ansteigende Wärmefluß bedingt die hochgradige Metamorphose (Amphibolit- und Granulitfazies) und den ausgeprägten Magmatismus.

Der Charakter dieses tektonisch-thermischen Ergeignisses in Znetral- und SW-Europa unterscheidet sich grundlegend von dem einer Orogenese.

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Introduction

Since more than a decade the Caledonian event in the Eastern Alps as well as in Central- and SW-Europe is discussed in literature (SASSI & ZANFERRARI, 1972; SASSI et al., 1974b; BORSI et al., 1975; PURTSCHELLER & SASSI, 1975; VAI, 1975; HEINISCH & SCHMIDT, 1976; SCHMIDT, 1976; SCHÖNLAUB & SCHARBERT, 1978; BORSI et al., 1980) and on symposia (BÖGEL et al., 1979). Although at present an approximate agreement on the essence of the term "Caledonian event" is reached, the question is still under debate, whether the Early Paleozoic magmatism and metamorphism are results of "orogenic" or "anorogenic" processes and whether they have been controlled predominantly by compressional or extensional tectonics (BORSI et a., 1980).

Reflections on the pre-Variscan evolution of the Eastern Alps cannot be restricted to the Alpine zone. We have to include Central- and SW-Europe into our considerations because long lasting and deep reaching mantle processes are involved which cannot be unterstood from a too small regional base. Such an enlargement of the geographical frame is justified by the fact that the Early Paleozoic evolution of these areas followed quite similar lines and offers nearly the same magmatic and tectonic problems (Fig. 1).

What are the termal and magmatic processes we are concerned with?

Special problems are given by the ambiguity of radiometric age determinations. For instance the geochronological data of about 480–420 m. y. are taken as indications for Ordovician magmatism and metamorphism (PURTSCHELLER & SASSI, 1975; SCHMIDT, 1977; SASSI & ZIRPOLI, 1979). On the other side DORNSIEPEN (1979) has called attention to the fact that all data indicating Caledonian metamorphism are obtained from polymetamorphic rocks which have undergone a Variscan low P high T metamorphism. He takes it very possible that the rock systems have been open during the Variscan high temperature event. ZWART & DORNSIEPEN (1980) assume that the supposed Caledonian high grade metamorphism is in fact of Cadomian age.

We consider the Ordovician as a time of thermal and magmatic activity with corresponding metamorphism. Furthermore we believe that the Eastern and Western Alps might have been parts of the Cadomian or of the Pan African domain respectively.

Magmatism

The Ordovician-Silurian plutonism started in Lower Ordovician and reached its maximum in Middle-Upper Ordovician (DORNSIEPEN, 1978). It is known from the Bohemian Massif, the Mid German Crystalline Rise (DORNSIEPEN, 1979), the Armorican Massif (MATTHEWS et al., 1980; VIDAL, 1980), the French Central Massif (BURG & MATTE, 1978), the Iberian Massif (DEN TEX, 1981) and the Alps (SASSI & ZIRPOLI, 1979). According to their chemical composition the igneous rocks vary considerably. Alkaline trend magmatites play an important role in the Iberian and Armorican Massif whereas granites and granodiorites seem to prevail in Central-Europe and in the Alps.

The Cambrian-Silurian magmatites of the Armorican Massif are typical intra-plate rocks or point to crustal distention (BEBIEN & GAGNY, 1980).

The alkaline orthogneisses in the French Central Massif are also supposed to have been emplaced during a period of rifting and thinning of contintental crust (BURG & MATE, 1978). VAN CALSTEREN et al. (1979) assumed mantle plume activity

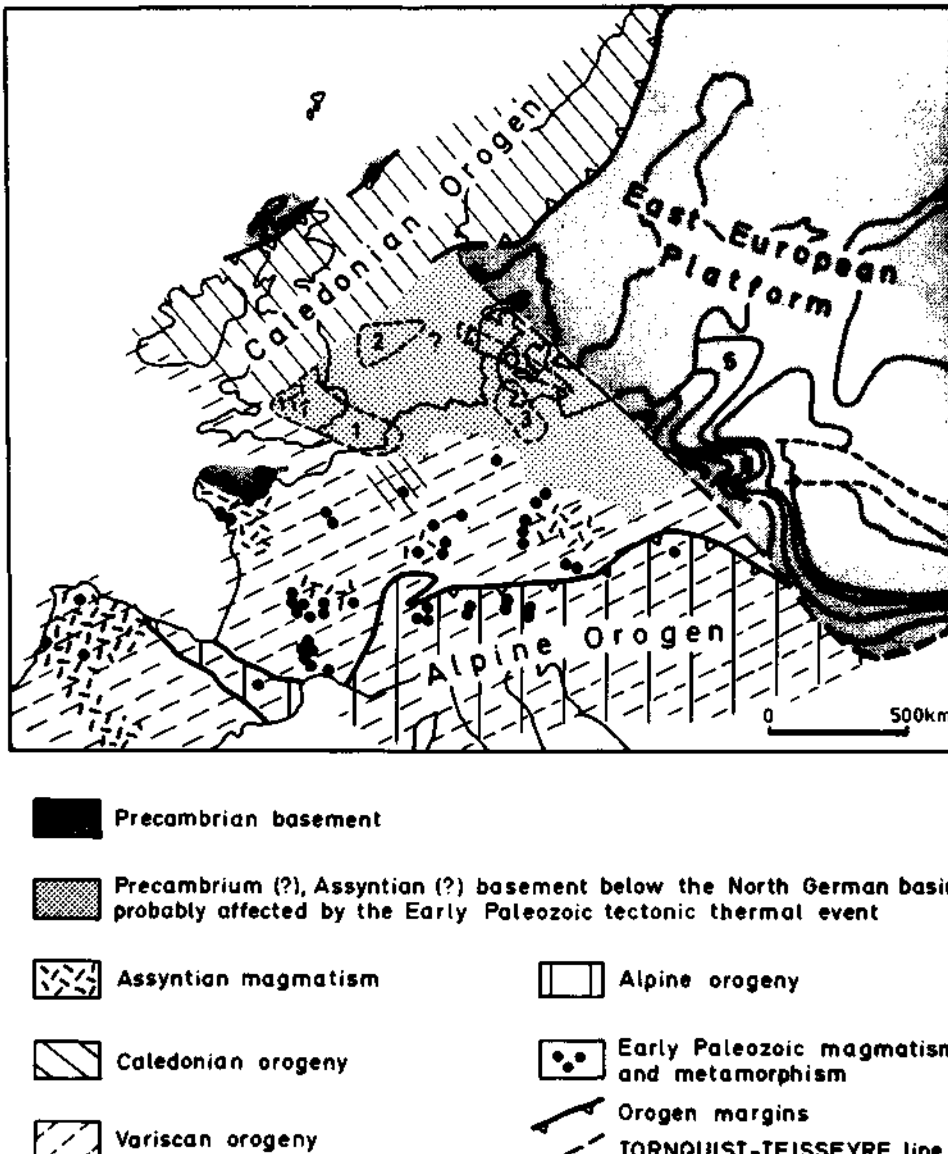

Fig. 1: Tectonic structures of Europe.
1) London-Brabant Massif, 2) Dogger Bank high, 3) East Elbe high, 4) Ringkøbing-Fyn high, 5) Baltic syneclise, 6) Podlasy-Brest syneclise.

in Galicia (NW-Spain) to explain igneous rocks with alkaline affinity. The available age determinations point to a high temperature event in Galicia that started earliest in Lower Ordovician and had passed its climax in the Early Silurian. The corresponding Cabo Ortegal (lherzolite) diapir is thought to have been stuck in the lower crust causing local magmatization and the formation of H-P granulites in the surrounding eclogites. Other ultrabasics in NW-Spain intruded higher crustal levels.

In the Eastern Alps plutonic intrusions between 450–420 m. y. consist of granitic and granodioritic rocks (BELLIENI & SASSI, 1981). They intruded metamorphic rock sequences or are products of in situ anatexis. SÖLLNER recently succeeded in proving an Ordovician anatexis in the Ötztal-Alps by an isochrone (460±30 m. y.) of the Winnebach migmatite (SÖLLNER et al., 1982).

An extensive contemporary and probably comagmatic volcanism is represented by the so called "porphyroides" (rhyolites, alkalirhyolites, rhyodacites, dacites)

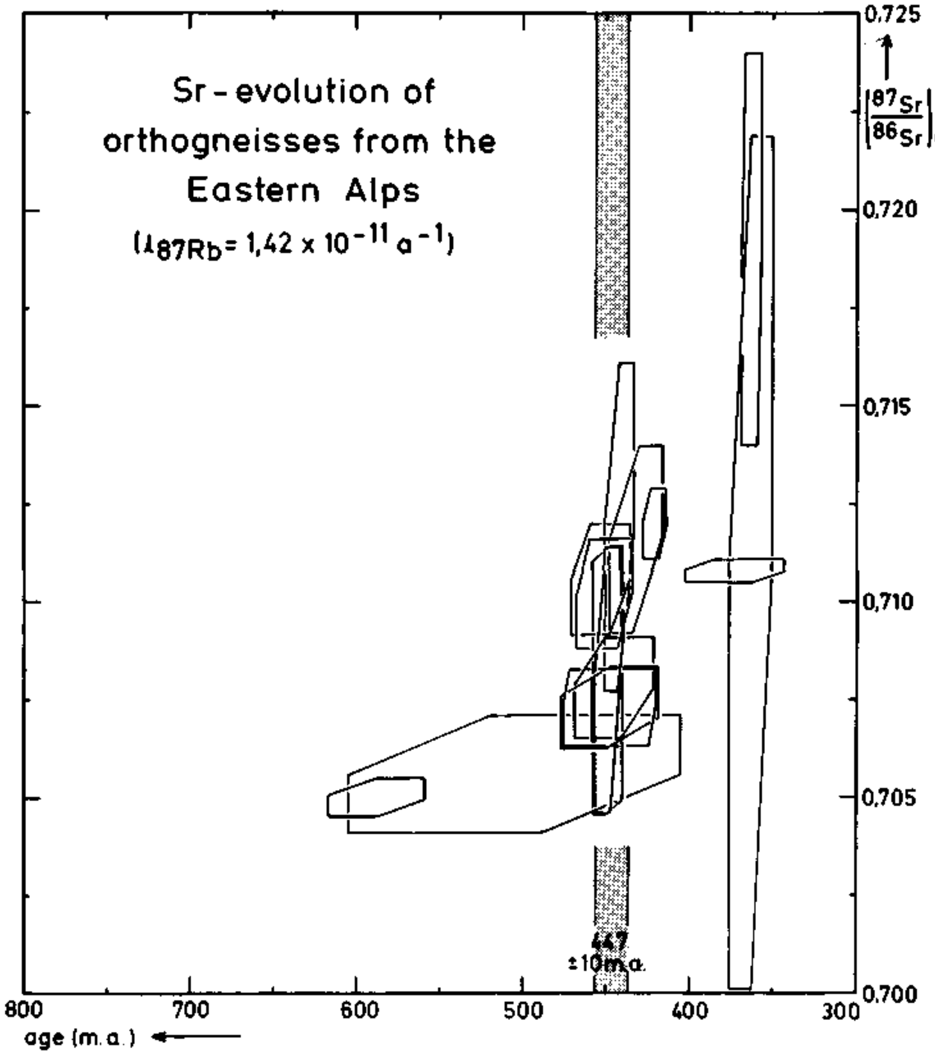

Fig. 2: Sr-evolution of orthogneisses from the Eastern Alps.
The ages are plotted versus $^{87}Sr/^{86}Sr$-initial ratios. The age of 447±10 m. y. indicated the culmination of granitic intrusions.

which are widely distributed and partly extruded as ignimbrites (PECCERILLO et al., 1979; HEINISCH, 1980; 1981). Their equivalents are also very common in Central- and SW-Europe (SCHMIDT, 1976; 1977). Certainly this magmatism started much earlier, at least at the beginning of the Cambrian.

The magmatic evolution can be demonstrated by a $^{87}Sr/^{86}Sr$-age-diagram (Fig. 2).

The Rb-Sr data of each rock unit i. e. age and $^{87}Sr/^{86}Sr$ initial ratio (IR) inclusive errors combined with the average Rb/Sr ratio are plotted into the diagram in form of polygons. The slope of the diagonal edges of each polygon is correlated with the average Rb/Sr ratio.

The diagram (Fig. 2) includes among others older intermediate to granitic orthogneisses of the Ötztal crystalline complex (BORSI et al., 1980; SÖLLNER et al., 1982), of the Silvretta crystalline complex (GRAUERT, 1969) and of the Antholz-Gsies massif (BORSI et al., 1973).

Until now the oldest of the dated intermediate igneous rocks of the Eastern Alps are the monzonitic gneisses of the lake Winnebach area/Ötztal (586±28 m. y.).*) They are followed by quartz diorite gneisses of the Silvretta crystalline (505±100 m. y., estimated error), tonalitic gneisses of the Antholz Gsies massif (449±14 m. y.) and the Acherkogel massif (448±28 m. y.). Ascending IR and growing Rb/Sr ratios with decreasing ages (Fig. 2) might be due to magmatic differentiation. The Sr-evolution trend of the intermediate rocks leads gradually over to the trend of the granitic orthogneisses. Therefore all these rocks can be explained as products of magmatic differentiation during a long lasting petrogenetic cycle (BORSI et al., 1980; GRAUERT, 1969).

There is no significant difference between the intrusion age of the youngest tonalitic orthogneisses (Acherkogel, Antholz-Gsies) and that of the comagmatic granites. Because of their various Rb/Sr ratios different slopes of the diagonal edges were plotted into the same error rectangle. With progressing differentiation to acid melts (Flüela granite gneisses: 442±9 m. y., GRAUERT, 1969; augengneisses of the Schobergruppe: 435±18 m. y., BRACK, 1977; granitic gneisses of the southern Ötztal crystalline complex: 451±17 m. y., SATIR, 1975) the Sr-evolution trend rises steeply. The IR increases more than in preceding phases because of the growing Rb concentration in the residual melt. The maximum of granite intrusions was reached obviously about 447±10 m. y. (average age of 7 rock units).

Layered muscovite-granite gneisses from Vent/Ötztal (425±10 m. y., SÖLLNER et al., in prep.) and light orthogneisses from the Seckauer crystalline complex (432±16 m. y., SCHARBERT, 1981) correspond to a late aplite-pegmatite phase. The muscovite-granite gneisses of the Silvretta crystalline complex (366±13 m. y., 361±25 m. y., 363±10 m. y.) and those of the western Ötztal crystalline complex (363±6 m. y.) have an exceptional position (GRAUERT, 1981). Because of their age, their IR (up to 1.0) and their high Rb/Sr ratio (up to 425) they could be related under reservations to the Early Paleozoic magmatism. It is however not to exclude that they already represent an Early Variscan magmatism. The metasedimentary rocks can be treated in the same manner (Fig. 3). On the assumption that the paragneiss unit of the Antholz-Gsies massif (514±76 m. y., BORSI et al., 1973), of the Silvretta crystalline complex (466±166 m. y., GRAUERT, 1969) and of the lake Winnebach area (460±30 m. y., SÖLLNER et al., 1982) have had a petrological

*) All errors dealed with correspond to the 95% convidence level; ages were calculated with $\lambda_{^{87}Rb} = 1.42 \cdot 10^{-11} a^{-1}$; data from literature were recalulated with this decay constant.

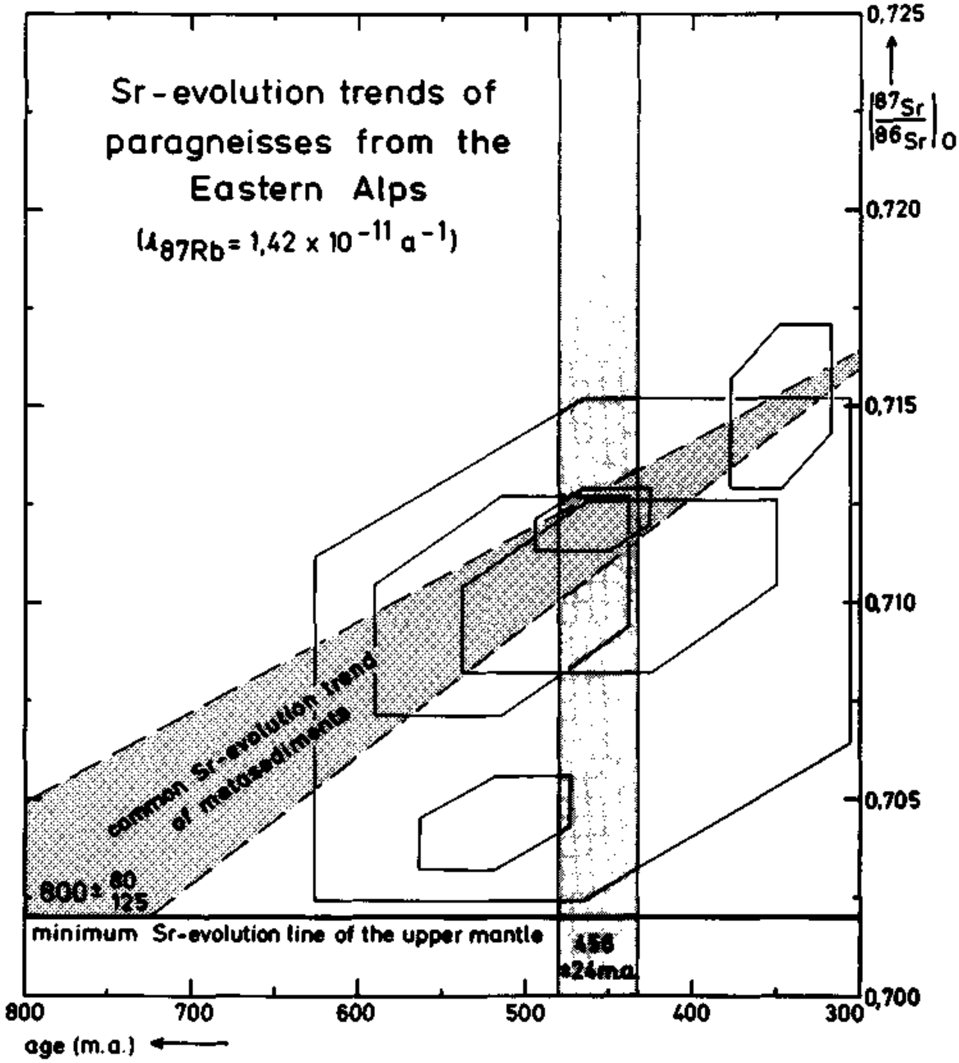

Fig. 3: Sr-evolution trends of paragneisses from the Eastern Alps.
The slope of the diagonal edges is considered to be an initial Sr-evolution trend of each rock unit. The maximum sedimentation age (800±80[125] m. y.) of the metasediments is calculated by the common trend.

comparable history one can pool the Sr-evolution trends to get a more precise estimate for a common trend. The pooled trends (stippled zone in Fig. 3) can be used for a preliminary calculation of the sedimentation age (800+80−125 m. y.). This is in good agreement with the age determined by JÄGER (1977) for metasedimentary rocks of Central-Europe. Extending the common Sr-evolution trend to younger ages one can include also Variscan equilibrated metasediments as the Steinkogelschiefer (347±30 m. y., SATIR & MORTEANI, 1979). The plagioclase gneisses of the Gleinalpe (518±45 m. y., FRANK et al., 1976), which are possibly of volcanogenic provenance have been excluded because of their low IR. Nevertheless the age of about 515 m. y. points to an upper Cambrian anchimetamorphism of the sediments whereas the pooled age of about 456±24 m. y. (average of 3 metasediment units) probably indicate the culmination of the Ordovician HT-metamorphism.

Reviewing both diagrams (Fig. 2, 3) with respect to their low IR the bulk of the Early Paleozoic magmatites cannot be explained only an anatexis of adjacent paragneisses. The low IR (average = 0.7058±0.0008) of the elder intermediate and granitic orthogneisses imply protoliths which are to derive from the lower crust and/or the upper mantle.

As for some other rocks i. e. muscovite-granite gneisses of Vent/Ötztal and orthogneisses of the Seckauer crystalline complex which derivate from the magmatic Sr-evolution trend (lower IR, lower Rb-Sr ratio, Fig. 2), a contamination with sedimentary material can be assumed. This is also supported by the overlap of the common Sr-evolution trend of the magmatites and of the sediments at this time intervall.

Metamorphism

Several authors put emphasis on the difference of the Caledonian and Variscan metamorphism in the Eastern Alps (PURTSCHELLER & SASSI, 1975; BÖGEL et al., 1979; SASSI & ZIRPOLI, 1979; SATIR & MOERTEANI, 1979). A low thermal gradient (20°/km) is attributed to the Caledonian event whereas a high gradient (50°/km) is supposed to be significant for the Variscan orogeny. Consequently the Caledonian metamorphism is thought to be controlled by HP- the Variscan metamorphism however by LP-conditions (PURTSCHELLER & SASSI, 1975).

DORNSIEPEN (1979) has already pointed out that this generalization should be modified because the metamorphic rocks yielding Caledonian ages belong to two different metamorphic facies series: the intermediate P/T type and the LP/T type. Moreover ZWART & DORNSIEPEN (1980) attribute granulites and eclogites in Central- and SW-Europe to the Assyntian orogeny.

BELLIENI & VISONA (1981) described relics of mineral associations from Austroalpine schists and referred them to an Ordovician HP-granulite facies. The authors admit however that this metamorphism might be even older.

The only Ordovician metamorphism we could identify by geochronological means is a high grade one in context with the anatexis of the Winnebach migmatite (SÖLLNER & SCHMIDT, 1981).

HUNZIKER & ZINGG (1980) do not see the necessity of a Cadomian event in the southern Alps but favour a strong (amphibolite to granulite facies) Caledonian metamorphism (478±20 m. y.).

In the Alps granulites have been determined as yet only in the Ivrea zone. For granulite forming processes KÖPPEL (1974) has got 285±10 m. y. by Rb/Sr- and 321±60 m. y. by zirkon data. VAN CALSTEREN et al. (1979) found a granulite age of 354±66 m. y. for slices of mafic granulites from NW-Spain (Cabo Ortegal complex, Galicia) which were partly affected by a younger anatexis. An Early Paleozoic HP- to mediate P-metamorphism (amphibolite-facies to anatexis and/or granulite facies) is known from the Gotthard massif (ARNOLD, 1970).

Granulite-forming processes in Central-Europe however are commonly of Early Paleozoic age: in the Moldanubicum 446±35 m. y. (ARNOLD & SCHARBERT, 1969; 1973), in Saxony 452±25 m. y. (JÄGER & WATZNAUER, 1969) and in the Vosges 527±27 m. y. (BOHNHOMME & FLUCK, 1974).

Eclogites together with basic and ultrabasic metamorphic rocks are however widerspread in the Alps, nevertheless only few of them could be dated as yet by radiometric methods. Zircon data of eclogites in the Helvetian crystalline massifs (Mont Blanc, Aiguilles Rouges etc.) gave ages between 600–400 m. y. (RAUMER, 1979).

Zircon determinations on eclogites in Central-Europe have given Variscan ages (GEBAUER & GRÜNFELDER, 1979; GEBAUER, 1981). The intrusion of the protoliths probably took place in Cambrian-Ordovician times. This is also assumed by VAN CALSTEREN et al. (1979) for lherzolites of the Cabo Ortegal complex (Galicia).

Summing up it may be supposed tentatively that granulites in the Alps are of Early Paleozoic as well as of Variscan age. In Central- and SW-Europe the granulites are of Early Paleozoic, the eclogites predominantly of Variscan age.

It must be stressed however that the geochronological data available are not yet sufficient and their interpretation still too ambiguous to get conclusive results.

Sedimentation and tectonics

The continuation of the North European Caledonian orogen below the Variscan structures of Central-Europe is a long discussed question (KREBS, 1978).

Undisputed seperate deposits of the Caledonian fold belt are the Massif of Brabant and the Ardennes. The Caledonian structures of the last area virtually plunge below the North German Basin and might continue into a zone of Early Paleozoic deformation, nearly 100 km wide, just in front of the East European Platform. This zone is ranging from the Danish-Polish trough in the NW to the Lysa Gora and farther SE to the Dobrudja. Its tectonic style is characterized by faulting, steep dipping complexes of Early Paleozoic rocks, locally by NE vegent folding, cleavage formation and green schist facies metamorphism (KREBS, 1978). During the Ludlow extremely increasing thickness point to accelerated subsidence along the platform margin. POZARYSKI & KONTANSKI (1978) explain these sedimentary and tectonic features by the activity of mantle plumes, which fractures the continental crust and caused the formation of aulacogens cutting across Assyntian blocks and the platform border. The authors assumed one spreading centre in the N near Rügen with two Caledonian aulacogens and another plume in the SE between Wroclaw and Wielun which caused late Baicalian, Caledonian and Variscan aulacogens. This seems to indicate a long lasting tectonic efficiency of these spreading centres. Therefore it seems not to be justified to explain this belt as a branch of the NW European Caledonian collision orogen as FROST et al. (1981) assume. The TEISSEYRE-TORNQUIST-Line served however as compensation zone and absorbed stresses and strains caused by the relative motions of tectonic different units on both sides, the stable East European platform in the E and the mobile Central European microcontinent assemblage in the W. In Central and SW Europe there are wide areas with Early Paleozoic sediments without any Caledonian folding and metamorphism (DORNSIEPEN, 1978, Fig. 2)

The Cambrian main depocentres in Central-Europe are narrow troughs obviously bound to older Precambrian structures. Thick Ordovician sedimentary sequences delinate however larger basin like zones with occasional rapid subsidence (1000 m) and metamorphism in the central parts (HIRSCHMANN et al., 1968; BRAUSE, 1970). The Barrandium and the Saxothuringikum as well as the West Sudetes have been zones of shifting basaltic volcanism from Proterozoic to Carboniferous obviously caused by changing dilatation stresses.

In the Northern Greywacke zone of the Eastern Alps the Wildschönauer Schiefer, more than 1000 m thick and intercalated with metabasalts were deposited in an "eugeosynclinal" trough (MOSTLER, 1970). In the Armorican massif the synclinorium de Saint-Georges-sur-Loire was a zone of pronounced subsidence. Thick sequences of Ordovician schist-greywackes are associated with spilites and keratophyrs (VIDAL, 1980).

Trough- or graben-like zones of Ordovician subsidences are also described from Spain (WALTER, 1965; JULIVERT et al., 1980).

At the same time an important partly bimodal volcanism accompanied deep faulting in same areas (JULIVERT et al., 1980). Marocco was obviously already part of the stable African plate (HOLLARD, 1978).

Following the Cadomian (Assynthian) orogeny an extensive erosion and acidic volcanism due to basement dilatation characterized the Cambrian paleogeography of SW-Europe. The Ordovician in this area was a time of crustal down- and upwarping and eustatic sea level oscillations which have been recorded by local disconformities and widespread conglomerates (BOURROUILH et al., 1980).

In Central-Spain the effects of tectonic movements between the Ordovician and Silurian (Sardian phase) are unimportant or of local importance only. In Sardinia itself these crustal motions resulted only in broad and slight unfolding accompanied by the extrusions of large quantities of acid volcanites before the Caradocian and less quantities of basic (spilitic) rocks roughly between the Caradocian and Ludlovian (CARMIGNANI et al., 1978; FERRARA et al., 1978).

The attempt to typify these tectonic and magmatic processes has aroused a disputation whether they represent orogenic or anorogenic tectonic categories. Under this aspect we appreciate the "contemporary concept of orogeny" recently published by DENNIS (1980). DENNIS (1980) recommended the term "tectonic thermal event" to designate a more fundamental category of geodynamic processes of which orogeny is but one manifestation. The primary cause of such events are most probably ascending mantle plumes or rising bulks of asthenosphere (asthenolith). In this sense one can explain the Caledonian event in the Alps as well as in wide parts of Central- and SE–SW-Europe as result of a tectonic thermal event. The dominating effect of which seem to have been dilatation rather than compression, its prevailing kinematics spreading rather than convergences. The ideas published by AUTRAN & COGNE (1980), VAN DER VOO et al. (1980), ZWART & DORNSIEPEN (1980), BELOW (1981), BELLIENI & SASSI (1981) and HEINISCH & SCHMIDT (1982) pursue the same line.

It is however rather difficult to get a conclusive idea of the overall dilatation pattern and the amount of rifting.

One can suppose an assemblage of limited mantle plumes caused by asthenosphere activity of the triple junction near the SW-corner of Europe. The ascending asthenosphere might have formed triple points of different size, lifetime and efficiency in the upper crust. On the other side one can assume, relying on paleomagnetic results, a ridge-like spreading system (HEINISCH & SCHMIDT, 1982) that cut the Cadomian basement of SW- and South-Central Europe seperating an European continent from a southern continental block including the Iberian peninsula and possibly the Alpine region. This spreading system might have run along the southern rim of the Armorican Massif, across the French Central Massif and along a line in the S of the Bohemian Massif (VAN DER VOO et al., 1980; ZWART & DORNSIEPEN, 1980). If the spreading did not lead to true oceanic sea floor the continental crust must have suffered such considerable attenuation, that subduction zones could evolve later on during the Middle Silurian–Middle Devonian along the southern margin of the Armorican Massif (COGNE, 1977; BURG & MATTE, 1980).

Tectonic models

Using the repertoir of plate tectonics we can discuss some spreading mechanismus which are applicable in combination with subordinate tectonic compression to Central- and SW-Europe.

1. Central- and SW-Europe have been transformed into an active marginal basin in context with the subduction of the Proto-Atlantic along the Caledonian suture in NW-Europe. This case does not exclude episodic compressional deformations in this areas especially during the time of continent-continent collision along the NW-border of the East European platform.
2. Caledonian subduction and collision in NW-Europe have induced intralithospherical processes of the type conceived by BIRD (1978) to explain intra-continental subduction in the Himalayas. This author supposed delaminations of rigid lithosphere below the Moho. The detached lithospherical slabs submerged into the deeper mantel exposing the upper lithosphere to ascending hot asthenosphere. The increase of heat warmed the upper crustal layers sufficently to reduce their strength. Differences in rigidity, vertical dislocations and collision induced shearing resulted in a complex tectonic deformation including intracontinental subfluences (A-subduction). Applying this idea we have to assume that the European plate underthrust the colliding Greenland block as concluded by MYKKELTVEIT et al. (1980) and Central- and SW-Europe might have been subjected to the above mentioned processes.
3. In contrast to the collision along the NW-European margin a spreading system fragmented the basement of SW- and S-Europe seperating the European from the African plate (Fig. 4).

   The supposition of post-Cadomian divergence of Europe and Africa and a corresponding stretching and rifting of crust is supported by geological, petrological and paleomagnetic data as discussed above. The initial rifting might have followed older lineaments in the S of the Armorican Massif cutting the French Central Massif and in the S of the Moldanubicum (Fig. 4).

The position of the Austroalpine in this context is ambiguous. It may be attributed to the European side of the rift or attached to the Gondwana complex in the S (AUTRAN & COGNE, 1980; FLÜGEL, 1981).

This spreading system opened the Paleo-Tethys (BELOW, 1981) and might have developed from a late Cadomian marginal basin on the northern rim of the Gondwana block (COGNE & WRIGHT, 1980).

Keeping in mind the exposed position of the Central- and SE-European microcontinent assemblage near the Atlantic-Tethys triple junction (Fig. 4) it seems rather probalble that Central- and SW-Europe suffered from both the collisional Atlantic and the dilatational Tethys regime.

Therefore the combination of the models mentioned above possibly fits the real conditions much better than the application of only shearing and local compression might have been prevalent in the NW.

Model 3 is sufficient to explain the tectonic-magnetic features of S-Europe. In any case every one of these 3 possibilities comprises a dominating or at least an important dilational compenent. This dilatation fragmented the Cadomian or older basement perhaps under activation of preexisting lineaments.

Above the rising mantle plumes or asthenoliths the more or less attenuated crust broke down forming graben systems, aulacogens and troughlike sedimentary depocentres.

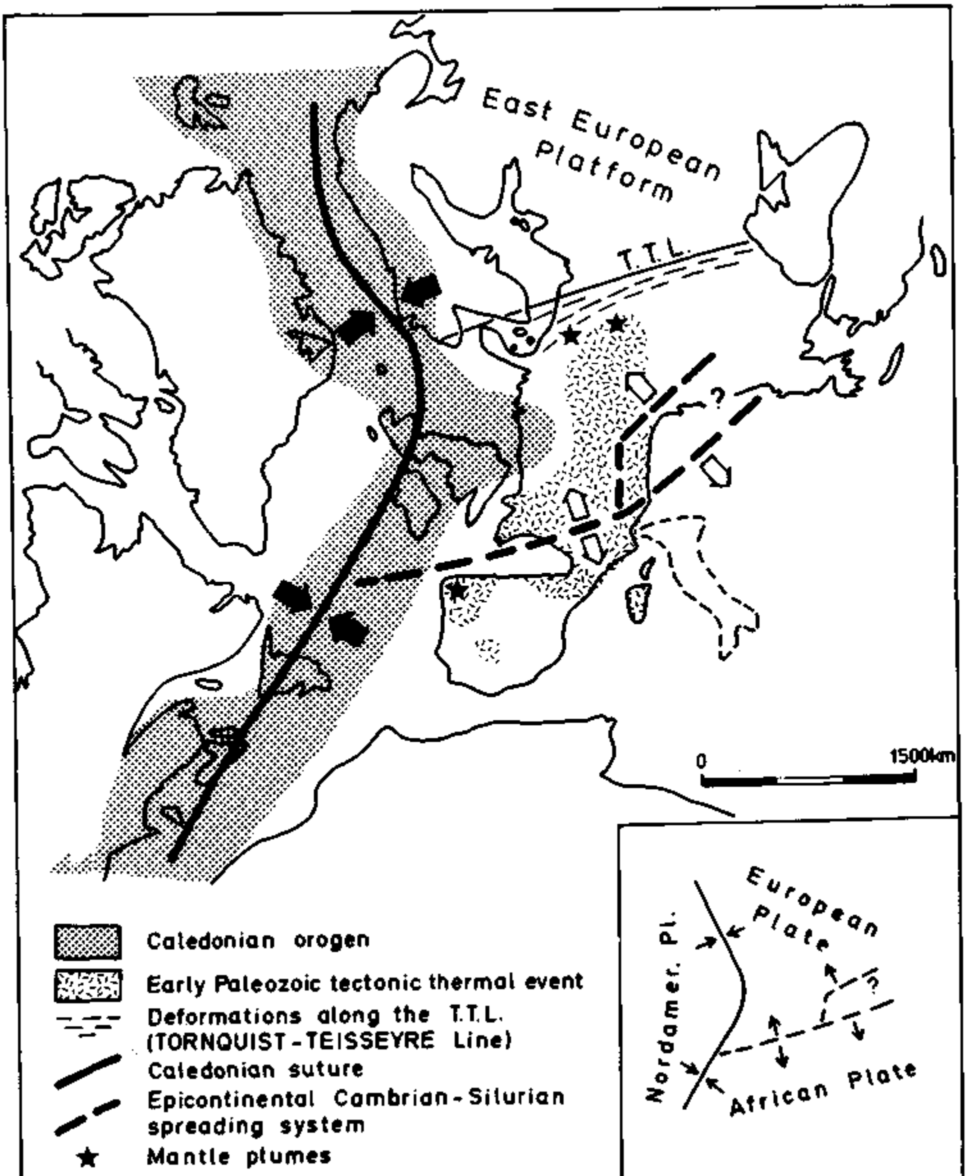

Fig. 4: Tentative scheme of the Early Paleozoic geodynamics of Europe. The Pre-Variscian basement of the Eastern Alps might have been part of the African plate. Both possibilities are shown in the sketch map. Part of the Austroalpine however obviously have an affinity to the European Plate with respect to their magmatism.

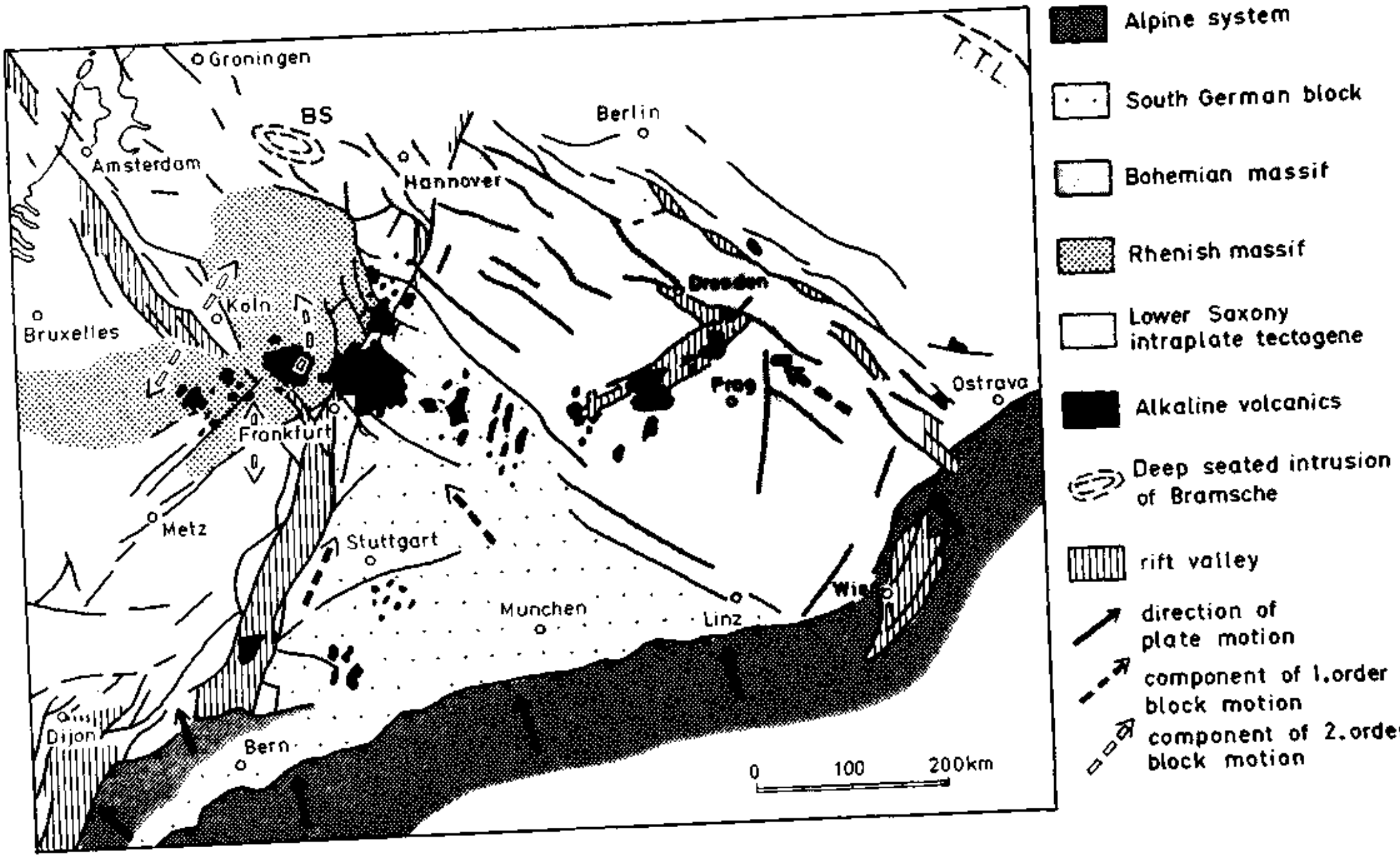

Fig. 5: Tectonic pattern of Central-Europe in the Tertiary according to ILLIES (1978).
Magmatites drawn in by the authors.

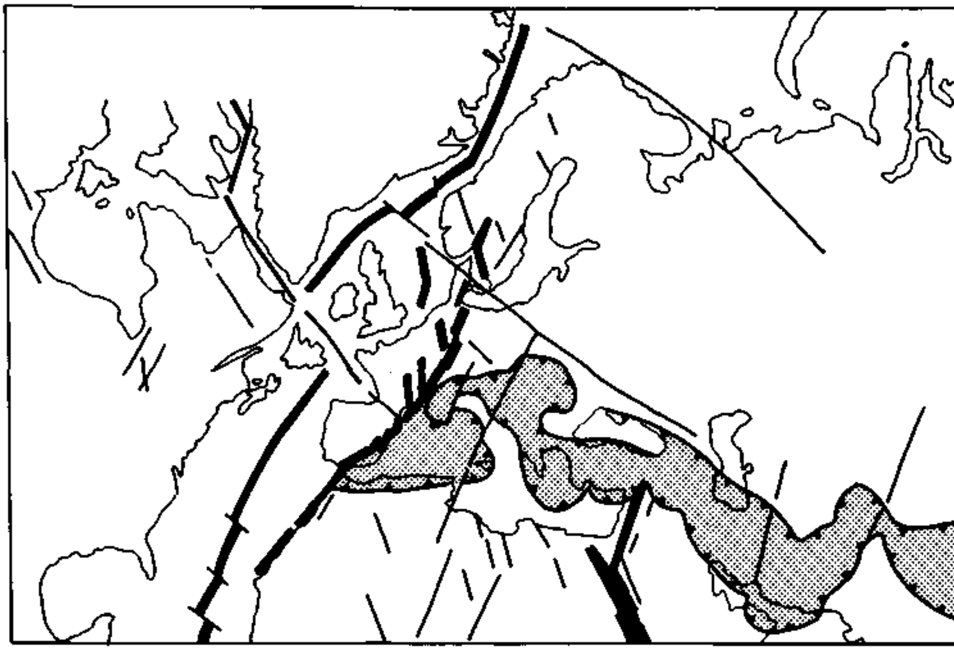

Fig. 6: Tectonic sketch maps of Europe.
Geodynamic systems along the margins of the European Plate in the Tertiary (RICHTER-BERNBURG, 1977). The triple junction of the Atlantic spreading system (black) and the Alpine collision zone (stippled) is located in front of the SW European continental edge. Central-and SW-Europe are covered by superposing dilatational and compressional tectonic regimes.

Besides fault tectonics and block tilting the crustal upwarping lead to local or regional erosion, statigraphic gaps and uncomformities. Quite similar phenomena are described from the Red Sea rift. Furthermore the progressive displacement of spreading axis probalbly coupled with block rotations may have caused local compressional structures, folds and overthrusts as described by ZANNETIN et al. (1980) from the Afro-Arabian rift system.

Mantle uplift and increasing heat flow caused the formation of mantle derived melts, intracrustal anatexis, the intrusion of granitic and granodioritic plutons and a rhyolitic, partly bimodal volcanism.

The variations of the coeval igneous rocks is possibly not only controlled by the rise of asthenosphere but also by the preceding crustal thickening during the Cadomian tectonics.

In the Tertiary the European plate was framed by analogous but sideinverted marginal kinematic systems: spreading along the Atlantic side, subduction and collision along the Mediterrenean side (Fig. 6). Naturally one cannot compare the structural and rheological features of the European lithosphere in Ordovician-Silurian with those of the lithosphere in Tertiary times. It might be however useful for the understanding of the Early Paleozoic events to look for similarities or analogues of the Early Paleozoic and later Mesozoic-Cenozoic history of Central- and S-Europe. In the sketch map published by RICHTER & BERNBURG (1977) both the compressional and the spreading systems affect the whole Central-, SW- and S-

Europe, partly superposing each other. In the preceding Cretaceous time subductions along the Mediterranean margin obviously induced compressional deformations of intracontinental troughs in Central-Europe up to distances of 1000 km from the Alpine suture (VOIGT, 1962; POZARYSKI & BROCHOWICZ-LEWENSKI, 1978).

The tectonic and magmatic results of the Tertiary stress pattern are demonstrated by a tectonic scheme (Fig. 5). In spite of horizontal compression the effects of remarkable doming and dilatation are evident. The resulting structures are caused by graben formation, horizontal block motions, block rotations and strike-slip faulting.

Block elevations up to 1000 m have initiated strong erosions (ILLIES, 1978). The attenuation of the crust in the W European rift system is different. The crystalline crust becomes extremely thin beneath the southern Rhonegraben, where the sediments reach a thickness of about 10 km (PRODEHL, 1981). Large parts of the area are penetrated by basaltic volcanites more or less bound to tectonic lines. Alkaline rocks, particularly olivine basalts from the bulk of the rocks in the Tertiary and Quarternary magmatic provinces of France and Central-Europe (WIMMENAUER, 1974). One of the most important complex, the Vogelsberg, marks the centre of a triple point accentuated by the Y-shaped graben system of the Rhenish shield.

The well known gravity anomaly of the Bram massif is caused by a deep seated basic intrusion which is surrounded by a zone of slight contact-metamorphism (STADLER & TEICHMÜLLER, 1971). Approaching the Atlantic-Tethys triple junction the Mid Atlantic spreading system becomes more than 1500 km wide. If we follow the temptation to use this scheme for a heuristic geometrical operation to illustrate the situation in the Early Paleozoic, we can keep the triple junction in the same position and have to change the marginal kinematic systems of Europe according to the supposed Early Paleozoic geodynamics. Then the Alpine collision zone fits the Caledonian collision belt whereas Central-Europe is occupied as far as to the TEISSEYRE-TORNQUIST-line by a wide spreading pattern which also cuts the northern margin of Africa.

Concluding remarks

In summary and with special reference to the Alpine zone we consider the formation of a S European spreading system as the most important factor in the Early Paleoczoic evolution of the pre-Variscan basement of the Alps. Petrological and geochronological data favour the opinion that the coeval magmatic evolution was initiated at the beginning of the Paleozoic by rising asthenoliths and lasted until the Silurian. In Central Europe spreading and compressional factors obviously superposed each other.

As hypothetical as the discussed proposals may be we hope that data available at present give already the chance to discover the leading principles for the solution of the problems dealt with.

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