The Pre-Variscan History of the Eastern Alps

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Content: Summary — Introduction — Acknowledgments — Geological observations — Pre-Variscan evolution — Discussion — References

Summary

In the light of present-day multidisciplinary geological research methods a set of pre-Variscan geodynamic processes has been recognized which allow to reconstruct the evolution of basement rocks in the Eastern Alps. In chronological order, the pre- Variscan history starts with (1) obscure Archeozoic events implying Precambrian rock formation of which, however, no trace is now recognizable; followed by (2) semipelitic sedimentation which terminated in local basic magmatism (Late Cambrian ?). This probably long lasting period was succeeded by (3) regional metamorphism in the late Cambrian or early Ordovician; (4) acid plutonism and (5) volcanism represents the next event in the Upper Ordovician (Berounian). Finally, there is proof of a (6) widespread basic volcanism of Llandoverian and early Wenlockian age. (7) Stratigraphic gaps near the Ordovician/Silurian boundary, (8) splitting of the sedimentary facies in the basal Silurian, and (9) the logical implication of a supply-area for the Upper Ordovician-Devonian greenschist rocks (and also higher grade Variscan metamorphics) support the concept of a primarily intra-Ordovician orogenic cycle in the Eastern Alps.

Introduction

For many years, the metamorphic basement of the Eastern Alps has been designated by the comprehensive name „Altkristallin" (Old Crystalline). On one hand this emphasized the position of these rocks as the basal element of the stratigraphic sequences, and on the other covered the many gaps in our knowledge by stressing the "undifferentiated" and complex character of this old basement. The lack of objective data was such that some authors assigned the history of these rocks to very remote, Precambrian times (e. g., STUR, 1854; SCHWINNER, 1927, 1951; DAL PIAZ, 1939; KRAUS, 1951; FLÜGEL, 1963), while others maintained that Caledonian and Variscan events were the principal causes of their metamorphism (e. g., STILLE, 1951; ERNST, 1973; FLÜGEL, 1975). In recent years, however, systematic research has provided important results, which have allowed to recognize a definite—even though not very detailed—sequence of geological events in the "Altkristallin". This progress is mainly due to four developments:

(1) Micropaleontological studies based mainly on conodonts have provided many new biostratigraphic data in low-grade metamorphics (phyllites; see papers of H. P. SCHÖNLAUB and other authors; lit. cit.);

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(2) recently the feasibility of carrying out geobarometric analysis of the phyllites has been demonstrated (SASSI, 1972, SASSI & SCOLARI, 1974; Fig. 3). In many areas thus it has enabled to detect a sharp contrast between the low-pressure character of the Variscan phyllites and the intermediate- to high-pressure character of the underlying kyanite-bearing basement (SASSI & ZANFERRARI, 1972; PURTSCHELLER & SASSI, 1975);

(3) recognition in some areas of the original depositional contacts of these phyllites over their original substratum (METZ, 1953; HOMANN, 1955; SASSI et al., 1974c);

(4) and progress of radiometric geochronology (MILLER et al., 1967; SCHMIDT et al., 1967; HARRE et al., 1968; GRAUERT, 1969; BORSI et al., 1973; BRACK et al., 1975; SATIR, 1975a, b; FRANK et al., in prep.).

From these four developments, not only very important Variscan effects but also a pre-Variscan history have been reconstructed with temporal constraints which are reasonably well defined on chronostratigraphic and radiometric bases.

This series of pre-Variscan geological events is the subject of our report. In short, we deal with geological phenomena recognizable in the Eastern Alps prior to the onset of the pre-orogenic Variscan sedimentary phase which represents—without major unconformities—a sediment column from the Middle Silurian to Upper Carboniferous. Hence, Variscan effects will be considered here only insofar as they serve to show evidence of the older ones.

It should also be noted that we refer mainly to the "Altkristallin" and low-grade metamorphics of the Austrides (= East Alpine sheet) and the Southern Alps, and to a lesser degree to the Pennides which, owing to a strong polyphase metamorphic overprint of Alpine age, no longer allow detailed analysis of older geological processes.

In the terms of modern global tectonics our paper deals with the pre-Variscan history of the "Carnic Plate" of DEWEY et al., 1973, which collided with a northern one (or continent) during the Cretaceous ("pre-Gosavian phase") and overthrust it during Tertiary to produce the Alpine orogen.

The statements and conclusions presented in this report are derived from cited literature or they are the result of a cooperative study of the three authors. Yet, no full agreement has been reached in some points (for example, time of emplacement of basic magmatites; age of metamorphism as reflected from the isochron of BORSI et al., 1973; or general application of the pressure character to distinguish different metamorphic events). These remarks are marked in the text by the initials of the author who holds the responsibility for that statement.

With regard to our Fig. 1 it should be noted that the map has been compiled by H. P. SCHÖNLAUB by use of present literature and unpublished data of the author (SCHÖNLAUB, H. P. & SCHARBERT, S. in prep.).

This paper has been carried out in 1975.

Acknowledgments

One of us (H. P. SCH.) greatly appreciates critical comments from the staff of the Geological Survey of Austria. He is also indebted to the same institution for providing technical help and support of field-work, and to students of the Department of Geology of the University of Vienna for cooperation in the study of low-grade metamorphics.

The Italian authors (F. P. S.; A. Z.) appreciate financial support of "Consiglio Nazionale delle Ricerche (Centro di Studio di Padova)."

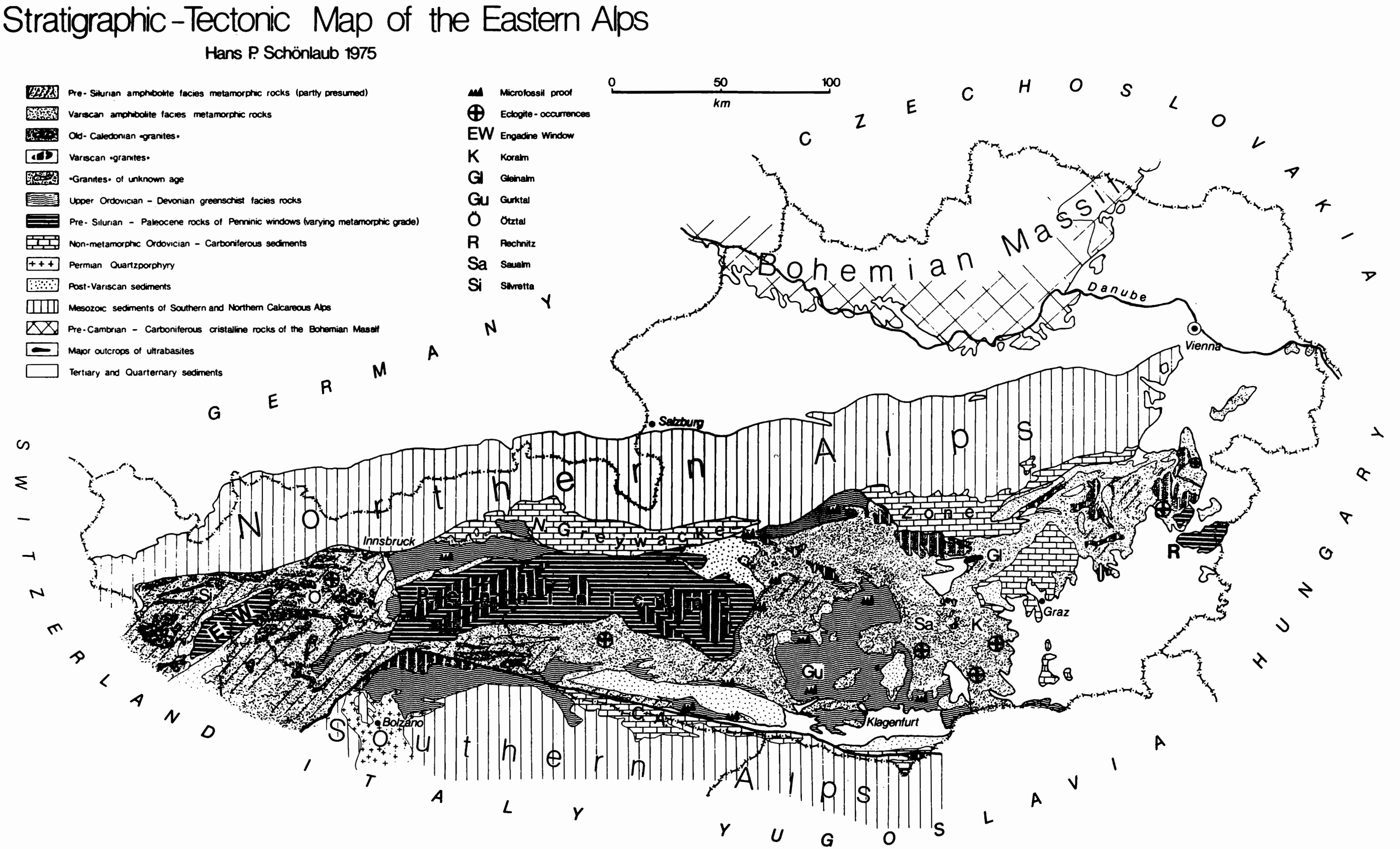

Fig. 1: Stratigraphic-tectonic map of the Eastern Alps.

Finally, all three authors wish to express their sincere thanks for many linguistic improvements of the manuscript suggested by W. C. SWEET, Columbus, Ohio, and Ch. V. GUIDOTTI, Madison, Wisconsin.

Geological Observations

Below are presented the data available for the reconstruction of the pre-Variscan history of the Eastern Alps:

1. PRECAMBRIAN

Neither Precambrian magmatic rocks nor rocks whose metamorphism is Precambrian are known in the Eastern Alps.

The only evidence of Archeozoic events is represented by the U-Pb radiometric ages of detrital zircons contained in metasediments. Most of these data give age values between 2300—2000 m. y. and other less frequently found age values range between 1500 and 700 m. y. (GRAUERT et al., 1973; NUNES & STEIGER, 1974). These data indicate an old Precambrian terrain, of which no trace is recognizable today (see also JÄGER, 1969; HÄNNY et al., 1975).

2. OLD BASIC MAGMATISM

Indications exist for a basic to ultrabasic magmatism developed near the Cambro/Ordovician boundary.

Interesting from the point of view treated here, are the pre-Alpine metabasites and meta-ultrabasites, whose occurrences in the Eastern Alps are relatively widespread (Fig. 1). These rocks have been studied recently (MILLER, 1970; 1974; BRENNEIS, 1971, ROST, 1971; HERITSCH, 1973; RICHTER, 1973). They are eclogites (more or less intensely changed into amphibolites), metagabbros and peridotites ("olivinites": ANDREATTA, 1935). The magmatic origin of most of these rocks is beyond doubt. In particular, the composition of the eclogites corresponds substantially to that of alkali-olivine basalts and olivine-tholeites, with a tendency towards high-alumina basalts in some cases (Fig. 2).

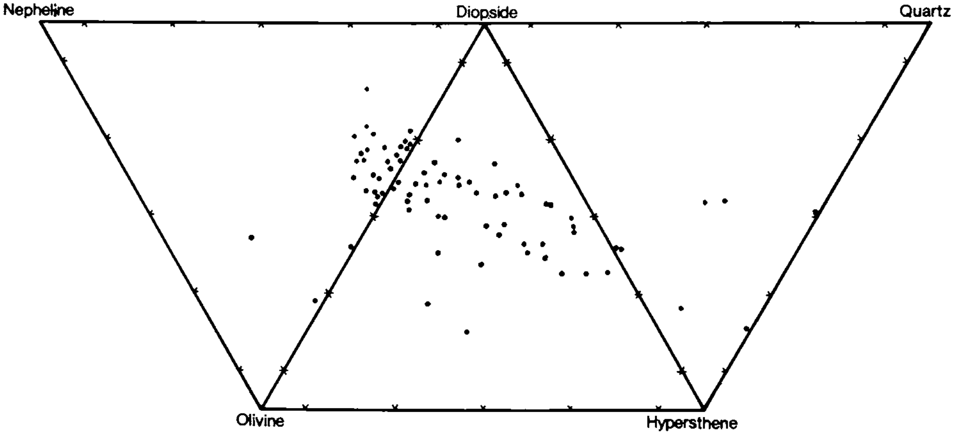

Fig. 2: Normative mineral composition of eclogites from the Eastern Alps (chemical data according to RICHTER, 1973).

The composition of the minerals present in the eclogites indicates that these rocks were metamorphosed at HP conditions (mostly 8—10 Kbs). But such conditions (as far as we know today) did not occur during the Variscan orogenic cycle in the Eastern Alps (F. P. S.; A. Z.) and in Europe generally (ZWART, 1969). However, they are plausible for the pre-Variscan event which we will discuss. Consequently, the original emplacement of these magmatitites pre-dated the pre-Variscan metamorphic event (F. P. S.; A. Z.).

This conclusion is supported by the first results of heavy mineral analysis of Upper Ordovician-Lower Silurian clastic rocks of the Carnic Alps, which imply the existence of a hinterland with ultrabasic rocks already at the Ordovician/Silurian boundary (SCHNABEL, in print).

Several authors have maintained that eclogites in the Saualpe and Koralpe are in a Variscan sequence, but definite age determinations are lacking. We (F. P. S.; A. Z.) tentatively include also these rocks in the pre-Variscan cycle (PURTSCHELLER & SASSI, 1975), because they too formed under high-pressure conditions (lit. cit.).

Further indications of a basic volcanism at that time (?) occur in the unfossiliferous Habach Series of the Hohe Tauern (FRASL, 1958) and, according to MOSTLER, 1970, in the Tyrolean part of the Northern Greywacke Zone. His assumption, however, is not in accordance with biostratigraphic data in the Styrian Greywacke Zone, where basic magmatism clearly has a Silurian age (SCHÖNLAUB, in prep.).

Finally, FRANK et al., 1976 have obtained a Rb/Sr whole rock isochrone of 500 m. y. from a metabasic-bearing volcanogenic sequence in the Gleinalpe of Styria.

3. REGIONAL METAMORPHISM

Evidence exists for a regional metamorphism of intermediate-to high-pressure metamorphism in Late Cambrian or Early Ordovician.

In fact, as has been long known, the high-grade "Altkristallin" is locally covered by pre-Alpine phyllitic sequences. The low-pressure character of the latter (Fig. 3) contrasts distinctly with the intermediate- to high-pressure character of the kyanite-bearing "Altkristallin", in which moreover eclogites formed under very high pressure occur (SASSI & ZANFERRARI, 1972; SASSI et al., 1974c; PURTSCHELLER & SASSI, 1975). In conclusion, two quite distinct pre-Alpine metamorphic events exist in the Eastern Alps: The older one developed prior to deposition of the rocks now converted to phyllites and after emplacement of the basic rocks from which eclogites formed; the younger one, on the other hand, is Variscan in age. Micropaleontological findings clearly demonstrate that at least parts of the phyllites have Upper Ordovician to Devonian ages (NEUGEBAUER & KLEINSCHMIDT, 1971; EXNER & SCHÖNLAUB, 1973; SCHÖNLAUB, 1974, 1975; SCHÖNLAUB & ZEZULA, 1975; PRIEWALDER, in print). Consequently, the pre-Variscan metamorphism cannot be younger than Upper Ordovician.

The same conclusion is reached by taking into consideration the situation existing in the "Norische Decke" of the Styrian Greywacke Zone (METZ, 1937, 1953; HAUSER, 1938; CORNELIUS, 1941, 1952; HOMANN, 1955): There, a low-grade metapelitic series in which Caradocian porphyroids occur, is stratigraphically linked to its original substratum, made up of high-grade metamorphics, which in Variscan times were altered to retrograde rocks (see also SCHMIDEGG, 1959, for the Tyrolean

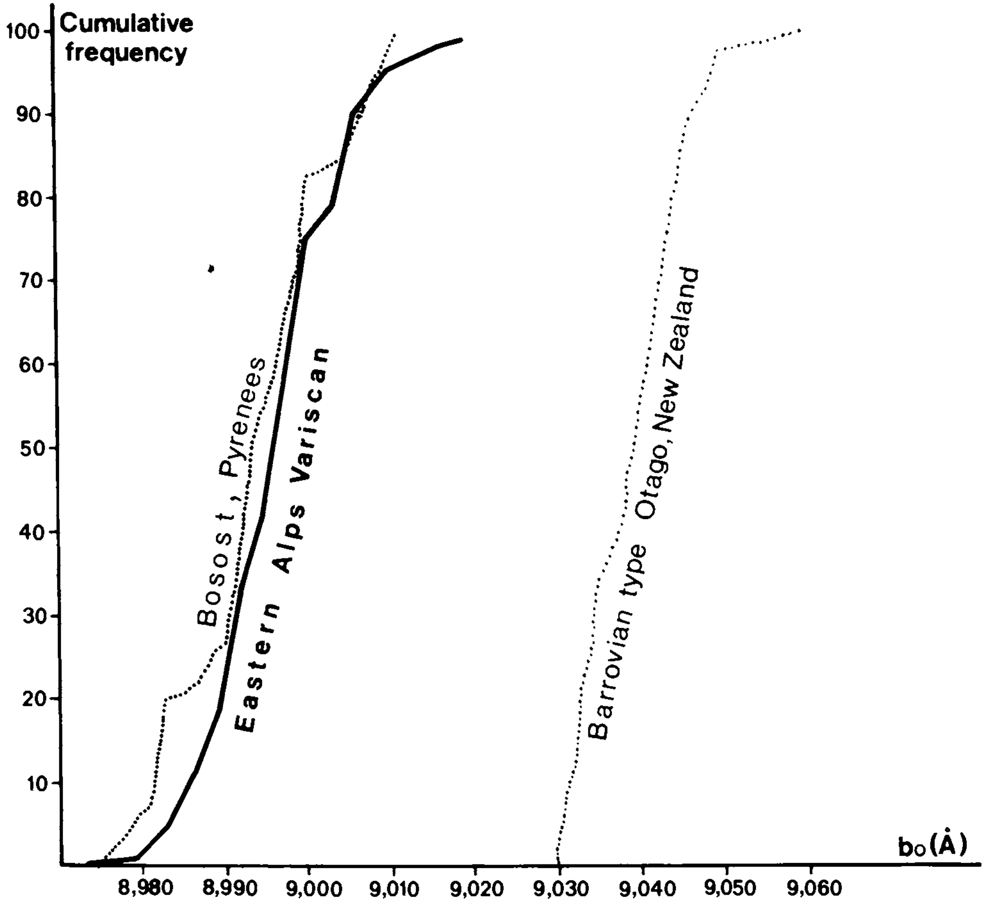

Fig. 3: Cumulative frequency curve of the b_0 values of Variscan K-white micas from the Eastern Alps showing the low-pressure character of the phyllite metamorphism; for comparison purpose the curve of the Bosost and Otago metamorphism are shown. The Variscan micas (320 samples; $\bar{x} = 8,996$; $s = 0,008$) are partly derived from the Southern Alps (161 samples from Recoaro, Bressanone, Val Badia, Plan Corones, Pusteria, Sesto, Comelico) and from the Eastalpine units (159 samples from the Gail valley, Turntal, Steinach, Padauner Kogel, Innsbruck phyllites). Data taken from SASSI, 1972, SASSI & Scolari, 1974, SASSI et al., 1974b, VISONÀ, 1975.

Greywacke Zone). Hence, this high-grade metamorphism is certainly pre-Caradocian in age!

Other independent evidence for a high-grade pre-Caradocian (pre-Berounian) metamorphic event is provided by the fact that fossil-bearing beds older than Caradocian (Berounian) are lacking in the Eastern Alps.

BORSI et al., 1973 assigned to this metamorphism an age of 497 ± 38 m. y., on the basis of a Rb/Sr whole rock isochron obtained from metasediments which crop out south of the western Tauern Window. This age value is in good agreement (F. P. S.; A. Z.) with the above quoted chronological constraints (see SATIR, 1975a, comments).

In areas in which the Variscan event was of low temperature, the older high-grade rocks show clearly a retrograde overprint. In the areas in which the Variscan metamorphism reached high temperature, typical low-pressure minerals appear (cordierite, andalusite), and the older mineral assemblages are either distinguishable with great difficulty or not at all (GREGNANIN & PICCIRILLO, 1972; SASSI & ZANFERRARI, 1972; BORSI et al., 1973; SASSI et al., 1974c; PURTSCHELLER & SASSI, 1975). In the latter cases, the identification of the Ordovician-Devonian rocks (which elsewhere occur as microfossil-bearing phyllites) can be attempted only as a speculation, because of their high metamorphic grade. Then, criteria for an identification are, for example, abundance, thickness and variety of marbles; appearance of black schists; or occurence of acid and basic metavolcanics (METZ, 1952; CLAR et al., 1963; NEUGEBAUER & KLEINSCHMIDT, 1971).

These summary remarks raise the question of the general introduction and application of our paradigm on various other parts of the Eastern Alps where as yet no radiometric data are available. In fact, according to published geological information old pre-Silurian high-grade metamorphics might be represented and well documented in some areas, for example (Fig. 1, according to H. P. SCH.):

- the "Gailtal-Augengneise" and other types of gneisses in the Gailtal-Crystalline (HERITSCH & PAULITSCH, 1958);
- the "Liesergneis" of SCHWINNER, 1927;
- gneisses of the "Krems-Metnitz-Anticline" of SCHWINNER, 1927, e.g., "Priedröf Gneis"; "Einnach-gneis" (HERITSCH, 1924) or gneisses in the "Einheit von Stadl" (THURNER, 1958);
- the "Wechselgneis" of MOHR, 1913 and WIESENEDER (cf. 1971); or
- the "Strallegger Gneis" of SCHWINNER, 1932.

As a result of these considerations, the map and the model presented here are slightly modified from the one proposed by PURTSCHELLER & SASSI, 1975.

F. P. S. and A. Z. do not agree with H. P. S. as regards the representation of the Austridic high-grade rocks in Fig. 1. In particular, the following points are stressed by F. P. S. & A. Z.:

i) in general, when a demonstration that two metamorphic events of different ages were developed under equal pressure conditions is lacking, then it must be reasonably assumed that the pressure conditions were different. Consequently, from the representation in Fig. 1 a different petrologic situation is to be expected in the Eastern (Variscan metamorphism according to H. P. S.) and Western (pre-Silurian metamorphism according to H. P. S.) sectors. In reality, no significant differences exist: in both sectors (e.g., "S" and "O") two metamorphic events can be distinguished, the younger (Hercynian) being of lower pressure than the older. These two metamorphisms often— but not everywhere—overlap, so that in both sectors monometamorphic, Hercynian sequences in amphibolite facies (low-pressure) can occur.

ii) the area north of Turntaler phyllites is not "Variscan amphibolite facies" but "pre-Silurian amphibolite facies" of intermediate-high pressure.

iii) a relatively large part of the Oetztal is in the Variscan amphibolite facies of low pressure.

iv) in the areas shown as "pre-Silurian amphibolite facies", the occurence of Silurian-Devonian sequences in low-pressure amphibolite facies is possible, and probable in some places (e.g., marbles in central Oetztal: see Fig. 3 and relative text in PURTSCHELLER & SASSI, 1975).

Reply by H. P. S.:

The author—well aware of the complex metamorphic history of East Alpine rocks— has intended to make an approach towards the sedimentary age of various metamorphic rocks in Fig. 1. Thus, "pre-Silurian amphibolite facies rocks" means that time of deposition has been in the pre-Silurian; and according to the metamorphic map of the Alps (NIGGLI et al., 1973) these rocks may occur in the presently outcropping levels as "amphibolite facies rocks".

4. Acid Plutonism

A pre-Variscan acid plutonism took place 440—410 m. y. ago.

In the Eastern Alps, many metagranitoids outcrop, surrounded by old high-grade metamorphics of the sort which we have just described (Fig. 1). The basic information available on these metagranitoids is as follows. (a) All the radiometric age determinations carried out so far have supplied recurring values around 440—410 m. y. (Miller et al., 1967; Schmidt et al., 1967; Harre et al., 1968; Grauert, 1969; Borsi et al., 1973; Satir, 1975 a); (b) in those cases in which the analysis of the relationships with the country-rocks has been carried out, it is indicated that we always deal with old "massifs circonscrits" (F. P. S.; A. Z.) which were intruded into already metamorphic and foliated rocks (Gregnanin & Sassi, 1969; Borsi et al., 1973; Sassi et al., 1974 c; Purtscheller & Sassi, 1975), or, in some cases, they are old products of anatexis in situ (Grauert, 1969). Hence, the existence of a regional metamorphism older than the emplacement of the injected granitoids has to be considered; (c) the radiometric ages of their minerals indicate that these old granitoids were metamorphosed during the Variscan orogeny (Harre et al., 1968; Grauert, 1969; Borsi et al., 1973).

5. Acid Volcanism

Proof exists of a widespread pre-Variscan acid volcanism of Upper Ordovician (Caradocian) age.

These volcanites, described as "Porphyroide" (i. e. acid metavolcanics), reach a thickness of as much as 600 m. Locally they are associated with fossiliferous sequences for which a Caradocian age has been proved by means of conodonts (Flajs & Schönlaub, in print).

The distribution (Sassi et al., 1974 b) and features of the numerous outcrops of these rocks suggests that they originally were parts of an extensive ignimbrite plateau (d'Amico, 1964; Sassi & Zirpoli, 1965, 1968; Mostler, 1968, 1970; Bauer et al., 1969), the extent of which, estimated on the basis of an over-simplified calculation, was several thousands km^2 in the Austrides and the Southern Alps. In the high temperature Variscan areas these volcanites may have been altered to "Augengneise" or similar rocks, as for example has been shown recently by Heritsch & Teich, 1975.

As assumed by Loeschke & Rolser, 1971, and Loeschke, 1974, the acid and intermediate volcanic rocks within the Northern Karawanken Alps may also be referred to the same volcanic cycle. A similar correlation could be attempted for the metakeratophyres in the Saualpe (associated with metabasites) which have been referred to the Ordovician-Silurian by Neugebauer & Kleinschmidt, 1971.

This volcanism took place in the same time interval in which the granitoids considered in paragraph 4 were emplaced. Hence, a possible petrogenetic correlation between volcanism and plutonism of Upper Ordovician age is stressed here (cf. Mostler, 1970; Sassi et al., 1974 b).

6. Silurian Basic Volcanism

This event is certainly Landoverian and basal Wenlockian in age and has been demonstrated in several areas, for example, the Northern Greywacke Zone (Flajs & Schönlaub, in print; Schönlaub, in prep.; Mostler, 1968); Middle Carinthia (Clar et al., 1963); Graz (FLÜGEL & SCHÖNLAUB, 1972); and Southern Styria (EBNER, 1975; BUGGISCH et al., 1975). The products of this volcanism occur as nonmetamorphosed to epimetamorphic diabases, tuffs or tuffites. Detailed analysis, however, are as yet not available and petrological data thus insufficient.

Lack of biostratigraphic data in the Eisenkappel area of the Karawanken Alps makes it thus far questionable as to whether the spilitic volcanism studied in great detail by LOESCHKE, 1970; 1973 and LOESCHKE & WEBER, 1973 can also be correlated with this event.

7. STRATIGRAPHIC GAPS

A certain amount of lower Paleozoic sediments, comprising one or more graptolite or conodont zones, is lacking in the Carnic Alps and in the Northern Greywacke Zone, in particular at the Ordovician/Silurian boundary.

These hiatuses in sedimentation at the level of the Ordovician/Silurian boundary were assumed by HERITSCH and GAERTNER in the early 1930's, and have been well established in the last decade by use of microfossils (FLAJS, 1967; MOSTLER, 1968; SCHÖNLAUB, 1970, 1971). The last author has clearly demonstrated that omission can last from the Ashgillian to the Upper Silurian, whereas JAEGER et al., 1975 have shown that probably only in very few places is sedimentation continuous across the Ordovician/Silurian boundary.

In any case, no angular unconformity has thus far been detected in Lower Paleozoic sequences of the Eastern or Southern Alps.

8. SPLITTING OF SEDIMENTARY FACIES IN THE BASAL SILURIAN

Carbonate petrology, microfacies analysis and fossil data suggest that several isochronous lithofacies developed during Silurian and Lower Devonian.

The causes of these varying facies must include the world-wide transgressive character of the Silurian sea, so that both endogenic and exogenic factors controlled the Silurian bathymetry and the nature of sedimentation in it. In order to explain this situation in the Northern Greywacke Zone, MOSTLER, 1970 supposed a break-up of the porphyroid-plateau in the lowermost Silurian. This event led to basins of different bathymetry. MOSTLER's model, however, seems inappropriate for the Southern Alps, where a mutual relationship between basement mobility, high-energy environments and isolated, oxygen-starved black-shale basins lasted through the whole Silurian and Lower Devonian. In the part, however, sea-bottom movements also began as early as earliest Silurian.

9. HINTERLAND

Biostratigraphic results obtained in the phyllitic series imply the existence of a source area for the tremendous quantity of sediments from which the phyllites originated.

The Lower Paleozoic age (Upper Ordovician-Devonian) of different levels has been demonstrated by many fossil proves (Fig. 1; HÖLL, 1970; NEUGEBAUER & KLEINSCHMIDT, 1971; EXNER & SCHÖNLAUB, 1973; SCHÖNLAUB, 1974; 1975; SCHÖNLAUB & ZEZULA, 1975; PRIEWALDER, in print; SCHÖNLAUB, in print). However, the real thickness and the beginning of sedimentation of these complexes are not yet known.

Nevertheless, a rough sedimentological-stratigraphic characterization can be outlined very briefly:

(a) Ordovician limestones and dolomites very probably are lacking;
(b) dated Silurian beds are very similar to the well studied shelf deposits of the Carnic Alps and the Northern Greywacke Zone although there are indications of an increase in thickness. Most common occur dark bituminous shales and a few limestones, but C-slates and C-quartzites are also very common;
(c) indications exist for a Devonian age of parts of the Innsbruck-, Radstadt- and Gailtal quartzphyllites, in which carbonate horizons could be studied by means of conodonts.

These remarks based on biostratigraphy, lithology and new fossil data in almost all East Alpine phyllitic areas raise the question of a supply area for the sediments now exposed in section several hundreds of meters thick. Thus, we include the need of a source area in our consideration of pre-Variscan events.

The existence of such a hypothetical hinterland cannot be denied, but strongly supports the idea of an old crystalline high land over which the predecessors of the phyllitic sequences transgressed. In effect, the contacts between the phyllites and their original basement have been described in some areas, e. g. in the Thurntaler area, in the Gailtal or in the "Norische Decke" of Styria (METZ, 1937; 1953; HAUSER, 1938; CORNELIUS, 1941; 1952; HOMANN, 1955; SASSI & ZANFERRARI, 1972; SASSI et al., 1974c; ANGENHEISTER et al., 1975: comments).

Pre-Variscan Evolution

An evaluation of the data presented in the foregoing nine points permits recognition and characterization of four important pre-Variscan events in the Eastern Alps:

I. The oldest—which in reality may have been more than one—is the time of crystallization of magmatites of unknown composition in which zircons were formed. Age: Approx. 2300—2000 m. y. (see also JÄGER, 1969).

II. The next event (certainly pre-Ordovician) is a sedimentary phase during which the old magmatites mentioned under Point I were eroded, and consequently their zircons were incorporated into pelitic and semipelitic sediments as detritic grains: In this way the parent materials of most of the present high-grade metasediments formed. The problem arises as to what extent Cambrian sediments occur in this sequence, but an answer can only be speculative and influenced by lithological comparisons with other European regions where Cambrian sections are well known (Bohemia, Frankenwald, Black Forest, Montagne Noire, Sardinia, Yugoslavia). In short, it is quite possible that a similar sedimentation regime is reflected in some metamorphic series of the Eastern Alps (e. g., Kreuzeck Crystalline of Carinthia); however, biostratigraphic data thus far are lacking.

III. Of great significance is an extensive basic to ultrabasic magmatism which probably took place in a very late phase of the pelitic sedimentation considered in Point II. Peridotites and basalts were emplaced at this time.

IV. The next event corresponds to a complex geological event of mainly Ordovician age. It seems to have all the characteristics typical of an orogeny. The following effects have been recognized:

(a) Volcanism quoted under Point III, which is assumed as "initial" in the classic sense (BORSI et al., 1973; PURTSCHELLER & SASSI, 1975);

(b) polyphase, Barrovian-type, eclogite producing (F. P. S.; A. Z.), regional metamorphism which, in the presently outcropping levels, took place at temperatures of the amphibolite facies (SASSI & ZANFERRARI, 1972; BORSI et al., 1973; PURTSCHELLER & SASSI, 1975). The pressure was 6—9 Kbs, and perhaps even higher if we also consider data from the periodotites (BRENNEIS, 1971; ROST, 1971). This event took place in the Lower Ordovician (H. P. SCH.) or in an interval between Upper Cambrian and Early Ordovician according to F. P. S. & A. Z.;

(c) Dynamic activity, at least on micro- and mesoscopic scales; regional metamorphic foliation formed and microfolds and snowball textures developed; moreover, mesoscopic folds are preserved in some xenoliths occuring in the metagranitoids of 440—410 m. y. (SASSI et al., 1974a; PURTSCHELLER & SASSI, 1975);

(d) uplifting and erosion of at least 10—15 km of rocks of the cover. This event is older than or partly contemporaneous with the sedimentation of the precursors of the phyllites (SASSI & ZANFERRARI, 1972; BORSI et al., 1973; SASSI et al., 1974a);

(e) acid magmatism of both plutonic (present metagranitoids) and volcanic (present porphyroids) type in the Upper Ordovician (440—410 m. y.; according to the geochronologic time scale the last value represents a Silurian event).

(f) early Silurian basic volcanism and splitting of the sedimentary facies as well as hiatuses in sedimentation are considered to reflect the final effects of the Ordovician orogenesis.

The remarks (b), (c) and (d) are to be considered as subcontemporaneous events, but they are younger than (a) and older than (e).

The sediments and volcanics (including various transgressive Silurian to Carboniferous limestones) which were deposited after the early Silurian basic magmatism belong to the Variscan cycle. This orogeny can be characterized very briefly as:

— Thermal apex 330—320 m. y.;
— dynamic paroxysm in late Carboniferous time; and
— very abundant acid magmatism with intrusives and ignimbrites in the Lower Permian.

Discussion

Above we have presented the features of the pre-Variscan history as it is recognizable in the Eastern Alps. The problem now arises as to whether the geological processes treated under Point IV represent phenomena of a true orogenic event. The chronological relationships and the nature of the different effects mentioned, which imply important dynamic and thermal disturbances, evidently provide a clear answer. This conclusion is also supported by the definition given in the "Glossary of Geology" (GARY, MCAFEE & WOLF, eds., 1972, p. 500), in which the term "orogeny" is the process producing structures within the mountains, which include "thrusting, folding, and faulting in the outer and higher layers, and plastic folding, metamorphism, and plutonism in the deeper and inner layers".

Is there any indication of similar orogenetic processes in other European regions outside the Caledonides s. s.?

From geochronological data the sequential picture of the pre-Variscan events obtained for the Eastern Alps corresponds well to the one obtained in the Western

Alps. In fact, an important metamorphic-migmatitic cycle with production of granitoids, about 500—430 m. y. old, has been ascertained in the most westerly south-Alpine basement and in the Helvetic massifs (NUNES & STEIGER, 1974; BORIANI et al., 1974). However, the pre-Variscan history of the Western Alps is much less detailed due to the lack of sedimentary or low-grade metamorphic cover of Lower Paleozoic age and to the very strong Alpine overprints.

Numerous data which are in good accordance with ours have been reported also from Central Europe: Movements contemporaneous with Caledonian orogenic phases are well known in Central Europe (HORNY, 1962; SDZUY, 1971; SCHÖNLAUB, 1971; JAEGER, HAVLICEK & SCHÖNLAUB, 1975); furthermore, a radiometric picture substantially identical to that of the Eastern Alps has been obtained in recent years (ROQUES et al., 1971; HOFMANN & KÖHLER, 1973; GEBAUER & GRÜNENFELDER, 1974; GRAUERT et al., 1974); and finally, the paleogeographic-biostratigraphic relationship deduced from fossils, climate and rocks in the lower Paleozoic of Central Europe is in good agreement with the data from Paleozoic sequences in the Eastern Alps (BERRY & BOUCOT, 1967; 1973; SPJELDNAES, 1967; JAEGER, 1968; BOUCOT et al., 1969; HAVLICEK, 1974).

As regards Sardinia, we can note granitoid plutonism of approx. 430 m. y. (DI SIMPLICIO et al., 1974), an extensive acid volcanism (porphyroids) whose chronostratigraphic position is strikingly similar to that of the Eastern Alps (COCOZZA et al., 1974), and there is a local occurrence of relics of eclogites (MILLER & SASSI, unpubl.).

From all the considerations made above the need arises to compare and reconsider critically the distribution and the character of all Ordovician orogenic processes in Europe. Moreover, in the attempt to understand the relationship in time and significance with the Caledonian orogeny s. s., the contemporaneous dynamo-thermic processes well documented in large parts of the African block have to be considered too ("Pan-African Tectonic Episode": CLIFFORD, 1963; 1967; KENNEDY, 1964; FURON, 1968; CHOUBERT & FAURE-MURET, 1969; 1971).

It is this regional distribution over a wide area that still suggests—at least provisionally—the application of the term "Caledonian" (cf. POLL, 1973) for these processes which can be recognized outside the Caledonides s. s. (as defined by KAY, 1970 or McKERROW & ZIEGLER, 1972), but subcontemporaneously to Caledonian movements ("Taconic orogeny" s. RODGERS, 1971). The introduction of new local names could not only produce confusion but also is an obstacle to attempts at correlation. In any case, it is not so much the problem of finding the most suitable name for an event, but it is that of understanding its significance in a geodynamic context which may have had some similarities but evidently also some differences in comparison with the so-called "Alpino-type" tectogenesis.

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