GEOLOGICAL SECTIONS THROUGH THE VARISCAN OROGEN IN THE BOHEMIAN MASSIF[1]

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ABSTRACT

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The construction of sections through the Variscan Orogen in the Bohemian Massif is discussed to solve the following problems: the age of the Moldanubicum and the relationship between the Moldanubicum and the Proterozoic of the Barrandian region, the Precambrian/Palaeozoic boundaries, the differentiation of the effects of the Variscan and Cadomian orogenies, the delimitation of the Variscan units in the Bohemian Massif, and the zonal structure of the Variscan orogen in central Europe. The development of the Variscan orogen in time and space is also discussed from the viewpoint of the influence of the supracrustal structure and the secular tendencies of the development of the earth's crust in the central European region.

INTRODUCTION

Kossmat's brilliant concept on the zonal character of the Variscan mountain range in central Europe forms the basis of all modern theories attempting to explain the structure of its parts including that of the Bohemian Massif. This is true in spite of the fact that notably in the Bohemian Massif the interference of the influences of the Variscan and Precambrian orogenies allows various interpretations of its structure and of its position within the orogen deduced from the comparison between the original scheme proposed by Kossmat (Fig. 1) and the concepts of his successors (e.g. DVOŘÁK, 1973, 1975) with the classification of STILLE (1951), and more recent syntheses based on them (e.g. MÁŠKA & ZOUBEK, 1960; ŠKVOR & ZEMAN, 1969; and others).

Whereas the hitherto published sections were generally intended to interpret the deep-seated or block structure of the Bohemian Massif, or to give a geological interpretation of the geophysical data, we have attempted to illustrate in our sections the zonal structure of the Variscan Orogen from the viewpoint of the connection existing between the surface and the intracrustal structures, and the recent revelations on the geologic history of the Variscan Orogen in the Bohemian Massif.

The sections through the Variscan Orogen in the Bohemian Massif are based on those which served within the international geophysical correlation programme (BERÁNEK & DUDEK, 1972; ADAM ET AL., 1976) to illustrate the intracrustal structure and their position in the Variscan structure, as shown in figure 2. The construction of these sections requires a discussion in greater detail of the major geological and geophysical problems involved.

RELATIONSHIP BETWEEN THE UPPER PROTEROZOIC OF THE BOHEMIAN MASSIF AND OF THE MOLDANUBICUM

In the past years, the deliberations of most authors were based on BEDERKE'S (1957) idea that the Palaeozoic rocks do not participate in the structure of the Moldanubicum, but that in the Moldanubicum (Vltava-Dunaj elevation) both Precambrian and Variscan structures occur. Our sections are also based on the following additional observations:

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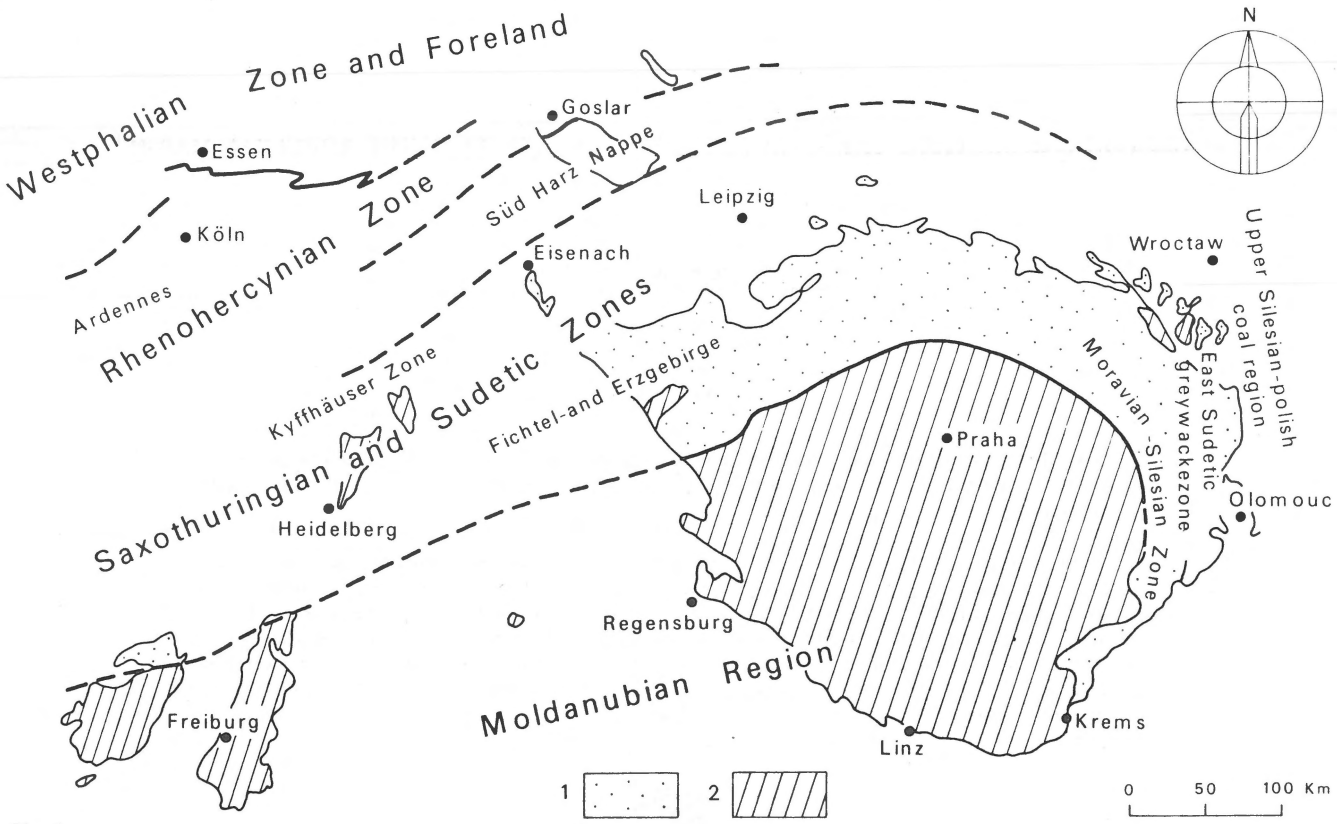

Fig. 1
Zoning of the Variscan orogeny in Middle Europe after Kossmat (1928). 1 = Cadomian basement; 2 = Palaeozoic.

(1) Radiometric dating (GRAUERT ET AL., 1973) excludes an older age of the Moldanubicum than that of the Karelian orogeny (i.e. 1880-2000 Ma), because its products have provided the clastic material forming the primary rocks of the Moldanubicum.

(2) The greater part of the rocks of the Moldanubian stratigraphical sequence constitutes a uniform formation that underwent a uniform geological development. Part of this geosynclinal volcano-sedimentary formation consists of granulites (detailed analysis of the tectonic structure and the borehole in Holubov in southern Bohemia have proved that even large granulite massifs form an integrated part of the stratigraphical sequence and all deliberations on their exotic origin are unsubstantiated). We may consider as exotic elements in the Moldanubicum only part of the eclogites (DUDEK, 1971), some of the ultrabasites (WEISS, 1966) and some of the basites. As evidenced by petrographic data, all other rocks must have undergone, in addition to the Variscan orogeny, an earlier metamorphism and folding which should be earlier than reflected by the data on the primary homogenization of the granulites (i.e. 470 Ma). This was most probably the Cadomian orogeny, as shown by the transitions of the Proterozoic and Moldanubian rocks in the mantle of the Central Bohemian Pluton and in the area of the Domažlice crystalline complex.

(3) No transgression has been found to have occurred in the European Variscides at the boundary between the Upper Proterozoic (Brioverian) and the Moldanubicum. If reported, it has sofar always been proved to consist of metamorphosed Palaeozoic rocks and not of rocks of a late Proterozoic age (e.g. VON ELLER ET AL., 1972, in the Vosges; EMMERMANN & SITTIG, 1977, in the Black Forest; and others). Moreover, in the Bohemian Massif, metamorphic transitions from low-grade metamorphosed late Proterozoic rocks into those of the Moldanubian unit have been proved in the Domažlice region (VEJNAR, 1972), in the Kutná Hora crystalline complex (LOSERT, 1967), and in the Železné hory crystalline complex (LOSERT, 1967).

(4) The argumentation stressing differences in lithology is based on the unsubstantiated comparison of the different lithofacies of the two units. In reality, we are concerned in both cases with a volcano-sedimentary sequence of strata in which in both units a 'varied' development including carbonates, acid and ultrabasic rocks, etc. appears in places of spatial closeness.

Thus, we may consider as an analogy of the Moldanubian granulite formation the Proterozoic of the Jílové zone, where acid metavolcanites, palaeorhyolites (plagiaplites) and granites alternate with basites (amphibolites) and serpentinized ultrabasites.

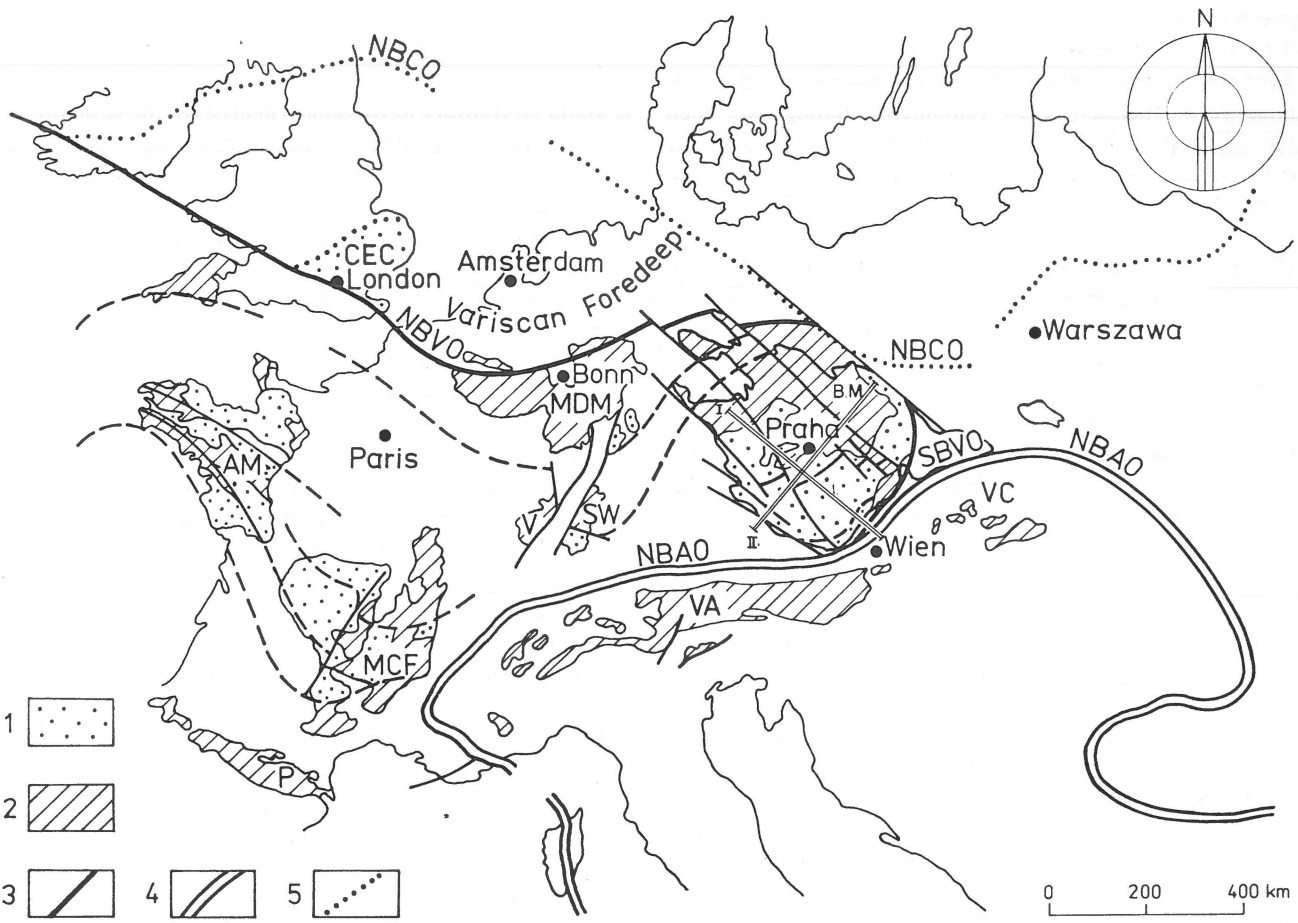

Fig. 2
Cadomian, Variscan and Alpine orogeny in Europe. 1 = Cadomian basement of the European Variscan orogenic belt, (CEC = Central England Cadomian). 2 = Palaeozoic (mainly Lower) in the Variscan orogenic belt. 3 = Boundaries of the Variscan orogeny (NBVO = North boundary of the Variscan Orogen; SBVO = Southeast one). Elevations of the Variscan structures: C = Cornwall; AM = Armorican Massif; MCF = Massif Central Français; V = Vosges; SW = Schwarzwald; MDM = Mitteldeutsches Massif; BM = Bohemian Massif; VC = Variscan in the Carpathian belt; VA = Variscan in the Alpine Belt; P = Pyrenees. 4 = NBAO = North boundary of the Alpine orogeny. 5 = NBCO = North boundary of the Cadomian orogeny.

The lithofacies differences are consequently not conclusive enough to prove a difference in age. Part of the differing qualities recognized in the rocks are also due to the fact that the authors do not consider the differences existing in metamorphic grade. ZOUBEK (1967), for instance, stressed as a distinguishing feature between the Moldanubicum and the Proterozoic of the Barrandian region the presence of significant magnetized strata in the Moldanubicum. The origin of these strata, however, is due to the change of the Fe^2/Fe^3 ratio during metamorphism.

(5) Quite often, the arcuate course of the Proterozoic around the Moldanubian 'nucleus' is quoted as an evidence of the higher age of the Moldanubicum. But LOSERT (1967) and CHALOUPSKÝ (1973) have illustrated that the Proterozoic of the Barrandian (and that of the Železné hory Mts.) continues in the basement under the Cretaceous to the NE, where it is directly connected with the Proterozoic of the West Sudetic System, which corresponds with the general course of the late Proterozoic geosyncline in central Europe. The arcuate course is hence only apparent and is due to a connection believed to exist between the Barrandian sedimentary region and the Železné hory area, which is different also with respect to lithofacies (SVOBODA ET AL., 1966), and to a confusion of the differences caused by metamorphic processes in the stratigraphic sequence (swinging of metamorphic zones near the northern margin of the Moldanubian elevation).

(6) Those data which indicate an older than late Proterozoic (Brioverian) age obtained e.g. in the Armorican Massif (Pentevrian) or in the Bohemian Massif (Brunnides), in the basement of the Carpathian Foredeep (DUDEK & MELKOVÁ, 1975), refer to units whose geological history neither corresponds to the Proterozoic of the Barrandian (Brioverian) nor to the Moldanubicum. In addition to other different features, as geochemical (FRASL ET AL., 1968; DUDEK & ŠMEJKAL, 1968) and

petrographical (ŠTELCL ET AL., 1978) character of magmatism, the lithologic development of the sediments (COGNÉ, 1972) is different. On the contrary, from the Moldanubium metagranites (orthogneisses) even radiometric dating has been recently reported that corresponds to the late orogenic magmatites of the Cadomian orogeny (600-800 Ma; ROZEN, 1976).

(7) The spatial distribution of the cordierite- and andalusite-bearing mineral associations reflects low-pressure conditions in the Moldanubicum and indicates a supracrustal position of granitoid bodies as shown in the geologic sections.

We interpret in those sections the Moldanubicum as a higher-grade metamorphosed equivalent of the Upper Proterozoic with the reservation, that it may also include a significant portion of even older parts of the stratigraphic sequence of the Proterozoic geosyncline.

PRECAMBRIAN-PALAEOZOIC BOUNDARY OF THE BOHEMIAN MASSIF

With respect to the Variscan Orogen, the Precambrian rocks folded and metamorphosed during the Cadomian orogeny form the basement. In the lower-grade parts, a transgression of Cambrian and Ordovician sediments on the folded and metamorphosed Proterozoic has been demonstrated in the Barrandian region (DUDEK & FEDIUK, 1955; MÁŠKA & ZOUBEK, 1960). A similar situation has also been proved to exist in the Black Forest, in the Vosges and in the Armorican Massif.

It is possible to distinguish between the two units also in the higher-grade regions, where a Palaeozoic age of the younger units has in most cases also been proved palaeontologically, because the remains of fossils have been preserved during the Variscan metamorphism into the amphibolite facies (e.g. in the Krkonoše and Jeseníky Mts.: CHLUPÁČ, 1975). In some cases, such a boundary could be defined even geologically (e.g. in the Krkonoše Mts.: CHALOUPSKÝ, 1965); it still remains uncertain, however, in the Saxothuringicum, and generally in those areas where the metamorphic grade has been used as a criterion. Yet, these uncertainties are of minor significance for the interpretation of the sections. Noteworthy is the fact that the metamorphosed Palaeozoic can be appreciably present only in the northern part of the Bohemian Massif and near its eastern boundary, whereas in its southern and southwestern parts (Moldanubicum) the presence of the Palaeozoic is highly improbable. A dominant feature of the Variscan Orogen in central Europe is its interference with the Cadomian Orogen. The Cadomian basement has been affected by the Variscan metamorphism much more than suggested by the degree of denudation of the Palaeozoic and also much more than suggested by the effects of the major orogenies on the basement of the other orogenic belts in Europe: the Caledonian and Alpine ones.

THE UNITS OF THE VARISCAN OROGEN IN THE BOHEMIAN MASSIF

It would be contrary to Kossmat's analysis of the structure of the Variscan Orogen in the Bohemian Massif to draw a distinction between the 'area of intensive Variscan orogeny' in the Krušné hory, Krkonoše and Jeseníky Mts. and the 'intramontaneous block' in the Barrandian and Moldanubian regions (MÁŠKA & ZOUBEK, 1960). The sections show that the principal features of the structure of the Bohemian Massif are dominant tectono-metamorphic systems that were initiated in the Precambrian and enhanced by the Variscan orogeny. Their general character is so prominent that it conceals the classical metamorphic gradient going from the Internides to the Externides. These structural systems form parallel elevations and depressions whose axes trend NE-SW, that were initiated during the Cadomian orogeny (they were already active in the initial Proterozoic sedimentary basin) and decisively influenced the origin of the Palaeozoic sedimentary basin and the course of the Variscan Orogen (e.g. the course of the metamorphic zones). The influence of the Cadomian 'basement' on the Variscan Orogen is also in this respect its outstanding feature in the Bohemian Massif.

The depressional structures (Barrandian, Saxothuringicum) include folded but unmetamorphosed or low-grade Palaeozoic formations on a strongly metamorphosed pre-Variscan basement. In contrast, the high-grade mainly Precambian rocks of the elevation structures (Moldanubicum, Krušné hory Mts.) are penetrated by numerous Variscan plutons and affected by a high-grade Variscan metamorphism that is mainly periplutonic (low-pressure) in character (CHÁB & SUK, 1977). In the depressional structures, the plutons are less numerous, the influence of the Variscan metamorphism is less pronounced and of the Barrovian type. The difference of the tectono-metamorphic structure of the crystalline complex at the NE margin of the Bohemian Massif (the so-called Sudeticum: DVOŘÁK, 1967) is local and rather reflects the specific conditions of this region (NW-SE directions of folding and indications of a higher-pressure metamorphism). As a whole, however, even this area fits very well into the trend of the zones of the Variscides. Its different characteristic and its more complicated structure cannot completely conceal the gradual fading away of metamorphism towards the NW and NE, and near the northern margin of the Bohemian Massif.

The NW-SE section suggests that the Variscan Orogen in the Bohemian Massif has a convergent zoning (including a sequence of elevations and depressions) that corresponds to the Precambrian continent, a miogeosynclinal ridge, a eugeosynclinal ridge, and a eugeosynclinal furrow. This is also in accordance with the abnormal increase in thickness of the Palaeozoic in the Barrandian zone adjacent to the Moldanubian region (HAVLÍČEK, 1971), which already corresponds to the eugeosynclinal furrow.

Like Kossmat, we distinguish in the Bohemian Massif, from the viewpoint of the Variscan orogeny, the Moldanubian zone

and the Barrandian region, together representing the Internides, and the Saxothuringicum zone with the Sudeticum, which together with the Moravicum represent 2 branches of the Externides (THIELE, 1970) of the Variscan Orogen. Another zone is that of the Variscan molasse that extends into the Bohemian Massif as a continuation of the Rhenohercynicum in the northwestern part of the Bohemian Massif and in northeastern Moravia (DVOŘÁK, 1975).

The influence of the Variscan orogeny near the eastern margin of the Bohemian Massif fades out in the Variscan units (e.g. in the Lower Carboniferous of the Nízký Jeseník Mts.: DVOŘÁK, 1973), in the pre-Variscan basement of the Jeseníky Mts., and in the Moravicum (DUDEK & WEISS, 1963; CHÁB & SUK, 1977). The more easterly units, e.g. the crystalline basement of the Carpathian Foredeep, have a different geological history (e.g. sedimentation of the Silurian and Devonian that remained unmetamorphosed: SVOBODA ET AL., 1966) and cannot, therefore, be referred to the Variscides, whose Carboniferous molasse transgresses over them.

The main information yielded by the NE-SW section is the fact that denudation has exposed in the Bohemian Massif increasingly deeper and deeper zones ranging from those in the NE which have a significant proportion of Palaeozoic rocks to those in the SW corresponding to the ultrametamorphic level (DUDEK & SUK, 1965). This differential uplift occurred towards the end of the Variscan orogeny (it is, for instance, not recognizable in the sedimentary development of the Barrandian Palaeozoic) and has nothing in common with the Variscan Orogen itself; its causes should be sought in the deeper structure.

The Precambrian eugeosynclinal basin continues from the Bohemian Massif to the W to include the Proterozoic of the Black Forest and in the French Central Massif, the Brioverian of the Armorican Massif and the Proterozoic of the Central English Precambrian craton (Fig. 2), and as suggested by fairly scarce geological data, also to the E, e.g. into the Góry Sowie (OBERC, 1972), and into the mantle of the Ukrainian Shield (NEČAEV, 1968; POUBA, 1970). As published by ROTH (1977) it partly forms also the underlying 'basement' of the northern margin of the Carpathians. This is confirmed also by the trend of the zones of the Cadomian Orogen in central Europe (SUK, 1969). The trend of the zones of the Variscan Orogen is far more complicated. In the major part of the basin this trend is in agreement with the influence of the structure of the basement. Even the direction of the metamorphic zones of the two orogens may be partly or entirely similar. This interference has made some authors such as ŠKVOR & ZEMAN (1969) reject the zonal structure of the Variscan Orogen in the Bohemian Massif. However, identical zones of the Variscan Orogen appear both in the NW of the Bohemian Massif and at its eastern border. Of exceptional significance is therefore their relationship in the Sudeticum at the northeastern margin of the Bohemian Massif near the Odra lineament. This lineament either cuts these zones (DVOŘÁK, 1975), or they turn from a SW-NE direction to the S into Moravia. In any case, the structure of the Variscan Orogen is convergent. Noteworthy is also the direction of the continuation of these zones at the southeastern margin of the Bohemian Massif. The analysis of the metamorphic zoning of the Austrian part of the Moravicum (HÖCK, 1976) indicates that the Variscan metamorphic zones turn near the southern margin of the Bohemian Massif to a southwestern direction. The same delimitation of the Variscan Orogen in this area is also evident from the extent and palaeogeography of the Carboniferous sedimentary basins ('Variscan Foredeep') in Moravia. Important in this respect is also the analogy observed in the structure of the Moravian Palaeozoic and that of the Montagne Noire, which corresponds to the marginal zones of the Variscan Orogen S of the Massif Central.

The character of the Variscan metamorphism is variable in different parts of the Bohemian Massif. Most frequently one deals with a low-pressure facies series (periplutonic). At the northeastern border (Sudeticum), medium-pressure facies with transitions to high-pressure rocks (CHÁB & SUK, 1978) occur. Similar differences may be observed also in other parts of the Variscan zone in Western Europe, where near the northern margin of the units rocks showing features of an intermediate-pressure metamorphism also occur frequently (Thüringer Wald, Spessart). This would substantiate the assumption of the occurrence of a paired metamorphic belt in the Variscan part of the Bohemian Massif, as proposed by Miyashiro; however, the duality of the two zones is indistinct, and the fault zone of the 'median line' type and the corresponding volcanism are completely missing. Hence, as also shown in the profiles (Encl. I), no Palaeozoic subduction zone can be expected to have existed in this region.

CHRONOLOGY OF THE VARISCAN OROGENY IN THE BOHEMIAN MASSIF

The application of the theory of plate tectonics to the Bohemian Massif could explain an uninterrupted tectonometamorphic development from the end of the Proterozoic until the Permian. In accordance with this, ŠKVOR & ZEMAN (1969) and ŠKVOR (1970) have proposed that the Palaeozoic metamorphic history of the Bohemian Massif is a uniform long-term process, being uniform to such a degree that the Variscan orogeny, according to these authors, cannot be considered as a separate cycle. This possibility is, as pointed out by FISCHER & TROLL (1973), also supported by the considerably scattered radiometric datings from the Palaeozoic era.

The geological data, however, rather suggest two separate cycles (Fig. 3):

(1) the Cadomian orogen which can be followed to the E and to the W. It has its own geosynclinal, orogenic and late-orogenic stages with a complete cycle of magmatism ranging from geosynclinal to subsequent magmatism. Its last manifestation in the superficial part of the crust is represented by the Cadomian molasse, a remnant of which occurs as the Cam-

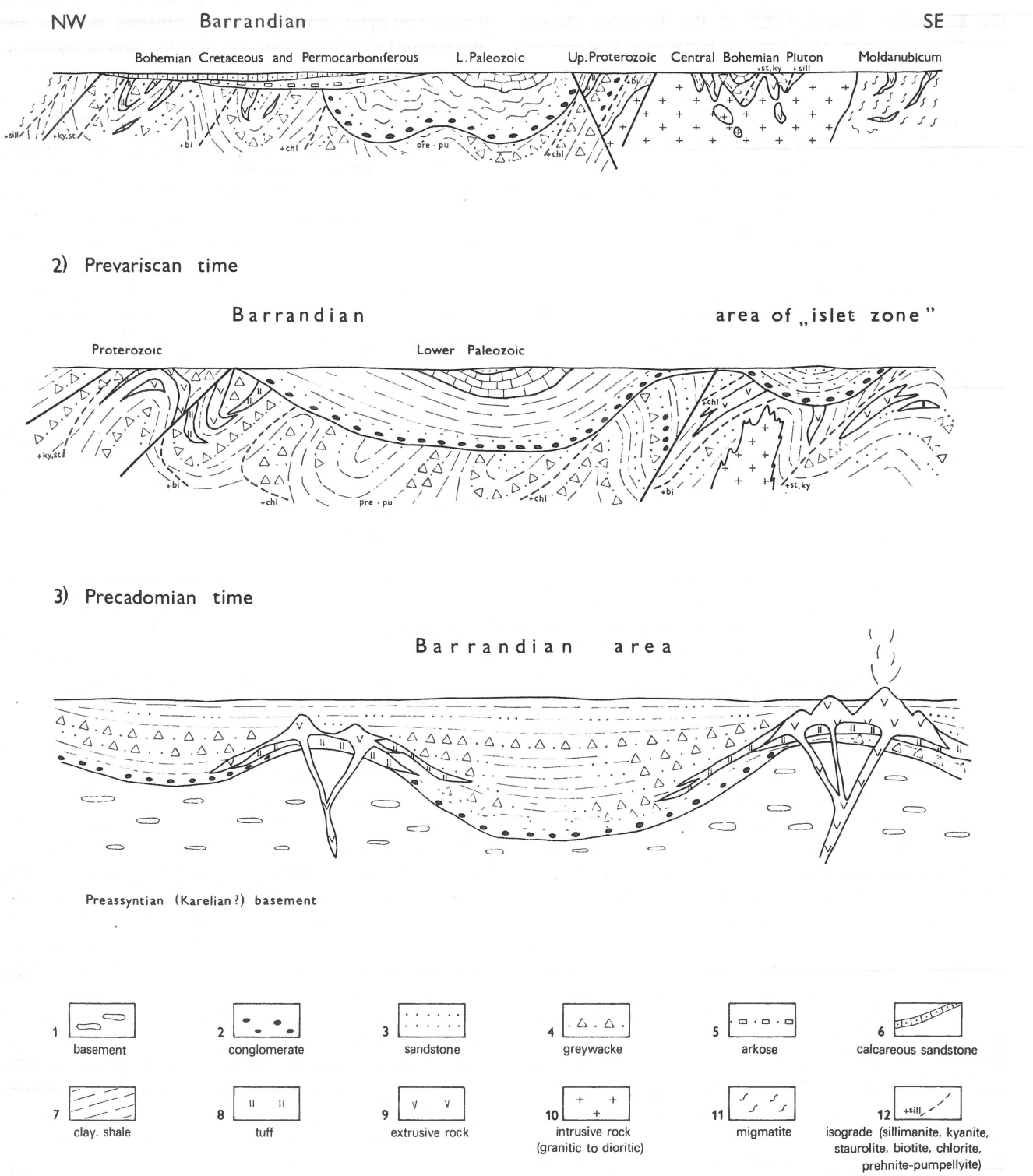

Fig. 3
Synoptic palaeogeological sections through the Barrandian area (Bohemian Massif). 1 = basement; 2 = conglomerate; 3 = sandstone; 4 = greywacke; 5 = arkose; 6 = calcareous sandstone; 7 = shale; 8 = tuff; 9 = extrusive rock; 10 = intrusive rocks (granitic to dioritic); 11 = migmatite; 12 = isograde (sillimanite, kyanite, staurolite, biotite, chlorite, prehnite-pumpellyite).

brian of central Bohemia (HAVLÍČEK, 1971) and as the subsequent volcanism of Cambro-Ordovician age (470 Ma: VIDAL ET AL., 1975). From the tectonic point of view this final stage is represented by the so-called Bohemian (i.e. Sardinian) emersion phase,

(2) the Variscan Orogen, which ends in the eastern part of the Bohemian Massif, has its specific geosynclinal stage with initial volcanism, an orogenic stage comprising late-orogenic granite magmatism, molasse and subsequent volcanism in the Carboniferous and Permian.

The independence of the Ordovician-Devonian sedimentation from the late Proterozoic stage is beyond doubt and it has also been sufficiently demonstrated (RÖHLICH, 1966), that the Palaeozoic volcanism in the Bohemian Massif has the character of a geosynclinal magmatism as early as in the Ordovician. This agrees with the present-day opinions on the duration of the tectonomorphic development of the Variscan orogeny. KODYM (1946), ŠKVOR (1965) and WATZNAUER (1968) have provided convincing evidence on the beginning of the rise of isotherms in the uplifted structures of the Bohemian Massif as early as during the Ordovician, which has also been confirmed by radiometric datings (JÄGER, 1971). The data on unconformities within the Ordovician-Devonian sedimentary sequence (e.g. in the Ještěd region: CHALOUPSKÝ, 1966) indicate the beginning of the intensive folding as Devonian, with a climax around the Devonian/Early Carboniferous boundary. Consequently, the Bretonian phase is the main and concluding phase of Variscan metamorphism and folding in the major part of the Bohemian Massif. In the late Visean the rocks in this area (ŠTELCL, 1960) were already exposed and subject to denudation. In the Saxothuringicum and Sudeticum these processes occurred somewhat later; they culminated – according to presently available data – after the Visean (the Krušné hory and Sudetic phases), which agrees well with the classical concept of the polarity of the orogenic development of geosynclines. This has also been confirmed by the reconstruction of the palaeoheatflow in the Bohemian Massif at the Carboniferous/Permian boundary (DVOŘÁK & SKOČEK, 1975).

STILLE (1949), for instance, considered the effects of the late Caledonian movements as a fragment of the Caledonian orogenic belt (the so-called Norgidic branch). However, the Caledonian orogeny in the Bohemian Massif cannot be considered as an independent cycle because it neither has a magmatism of its own, nor its own flysch and molasse formation. Any manifestations of metamorphism are also missing and the Caledonian deformations are associated with dynamometamorphic processes only and lack the character of an orogen (OBERC, 1977).

We have therefore every reason to presume that in the Bohemian Massif the Variscan orogeny lasted for a very long period, from the Ordovician until the Permian, i.e. more than 100 Ma ((CHÁB & SUK, 1978).

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