

VARISCAN VOLCANISM OF CENTRAL AND WESTERN EUROPE¹



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ABSTRACT

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The type of volcanism in Central and Western Europe clearly reflects the tectonic conditions of the time of its manifestation. Two main types of Variscan volcanism can be distinguished: (1) spilito-keratophyre (pre-orogenic); and (2) postorogenic calc-alkaline.

The spilito-keratophyre associations are widespread in space and time and form belts related to regional faults, intraplate rifts and grabens. This reflects a tectonic regime of tension. Spilito-keratophyre sequences are connected with the initial stages of the individualisation of new basins (Devonian, Carboniferous). They can appear several times in one region. It seems possible that the spilitic belts mark the boundaries of small plates or blocks. The source of magma was the upper mantle. The tectonic conditions during the time of eruption of postorogenic volcanics is quite different. They are characterised by folding, vertical movements, compression and anatexis melting in the sialic crust. Two associations can be distinguished: (1) a late-orogenic one of monotonous acid (rhyolites, dacite) composition, forming magmatic structures of the central type related to cauldron subsidence; and (2) a postorogenic or final one of bimodal composition on (trachybasalts-rhyolites) marking the beginning of a new period of tension related to the uplift of the region.

INTRODUCTION

Different aspects of the Variscan volcanism of Europe, such as its distribution in space and time, age, composition, relation to tectonic structures and orogenic movements have been investigated by many authors. Nevertheless, at the present time some important questions about the geology of these volcanics remain unsolved.

This paper is an attempt to approach these questions in a different way. I shall not discuss the well-known problems, but rather emphasize the relationships between different types of volcanic sequences and various types of tectonic movements along their geological and tectonic setting. Maps of Europe showing the distribution of volcanics (Encl. I and II) as well as some more detailed maps (Figs. 1-7) are presented to illustrate these relationships.

The Palaeozoic volcanics of Western and Central Europe can be separated into two types:

- (1) a submarine spilito-keratophyre sequence;
- (2) a subaerial suite including volcanics of acid, inter-

mediate and partly basic composition. The first one is pre-orogenic, the second one post-orogenic.

Volcanic rocks of the above-mentioned types can appear in one and the same or in different geological zones. Often spilito-keratophyre volcanism took place several times in the same region during a long period. These facts are of great importance in understanding the regularity of occurrence of the Palaeozoic volcanism. It is also important to determine the relationships of Variscan volcanism to the early Palaeozoic volcanism because it occurs sometimes in the same regions and without interruption (from Cambrian to Early Devonian).

An understanding of these relationships may be useful in solving the question as to the existence of a Caledonian magmatic cycle, one of the intriguing problems confronting European geologists today (KREBS, 1978; KREBS & WACHENDORF, 1973; SCHMIDT, 1976, 1977).

THE SPILITO-KERATOPHYRE ASSOCIATIONS

Early Palaeozoic spilito-keratophyre volcanism

This association is widespread in Europe and appears repeat-

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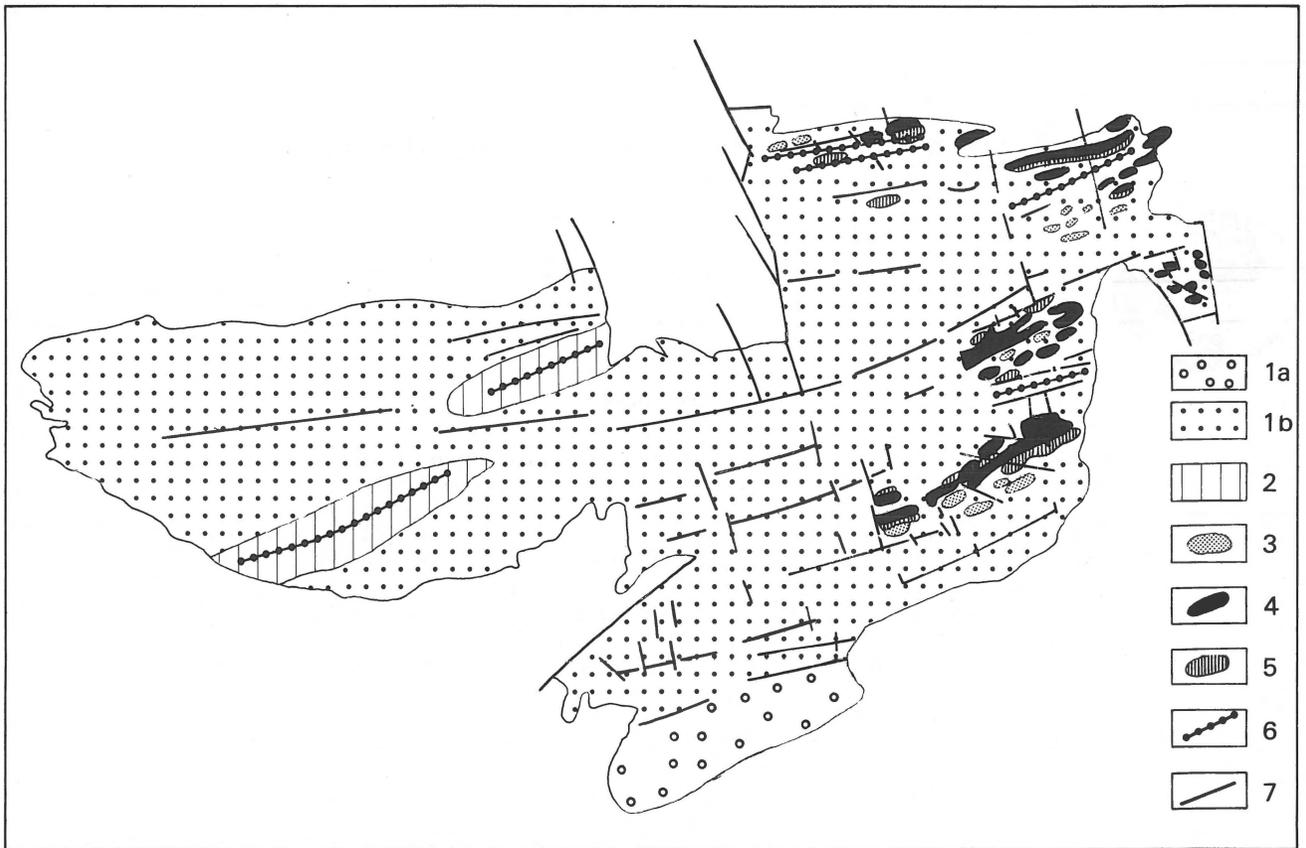


Fig. 1

Palaeozoic volcanics of the Rheinische Schiefergebirge.

1^a = Sediments of Permian age; 1^b = Sediments of Early and Late Devonian; 2 = Sediments of Ordovician and Silurian; 3 = Diabases of Early Carboniferous age; 4 = Spilites of Middle Devonian; 5 = keratophyres of Early and Middle Devonian; 6 = Axes of geoanticlines; 7 = major faults.

edly during the whole Palaeozoic (BANKWITZ, 1977; BRAUSE, 1973, 1978). Considering the volcanism of the Early Palaeozoic it is clear that in the Cambrian one is mainly dealing with subaerial activity of predominantly acid composition, marking the end of the Cadomian orogeny. Examples are: The Armorican Massif, French Central Massif and the Barrandian in Czechoslovakia (FIALA, 1978; VIDAL ET AL., 1975; WALDHAUSOVA, 1971; ZOUBEK, 1965).

In contrast, in eastern Europe (Western Sudetes, Görlitzer Synclinorium a.o.) and southwestern Europe (Spain, Portugal) submarine spilito-keratophyre sequences occur which are related to a new period of geological development (Encl. I and II, Figs. 6 and 7). Their manifestations are connected with subsidence and formation of new sedimentary basins. The ascent of magma took place at different times in different areas: Middle Cambrian, Late Cambrian or Cambro-Ordovician. The volcanic suites mainly consist of spilites, pillow-basalts, diabases (as subvolcanic intrusions), tuffs and keratophyres which appear to be clearly subordinate to the basic rocks. Ultramafic differentiates (picrites) are known.

The rocks are concordantly interbedded in a marine sedimentary sequence. In some zones (Barrandian, Boberkatzbach-

gebirge, Görlitzer Synclinorium a.o.) the volcanism continues after a short interruption in the Ordovician. The Ordovician volcanics are also present in graben-like basins associated with deep-seated faults, such as at Erquy, Crozon (Armorican Massif) and in SE Spain. The composition of Ordovician volcanic rocks is more variable, sometimes the explosions began with keratophyres (Bergaer Sattel, Boberkatzbachgebirge), in other cases keratophyres are almost absent or form subvolcanic dykes (Barrandian, Crozon, Ossa-Morena). In some regions acid tuffs are present.

The volcanics of this age are found also in Limousin, Rouergue, Albigeois, Cevennes (French Central Massif) and the south of Armorican Massif. It is very probable that the Ordovician-Silurian volcanics of the synclinorium of 'St. George sur Loire' (Armorican Massif) form a belt that continues into Limousin where they were earlier regarded as Precambrian (AUTRAN & GUILLOT, 1977).

Most of the rocks are spilites, pillow-lavas, basic and acid tuffs. Different authors have tried to define the composition of the primary magma of the Early Palaeozoic volcanics. According to FIALA (1974, 1978) the spilites of Barrandian Basin

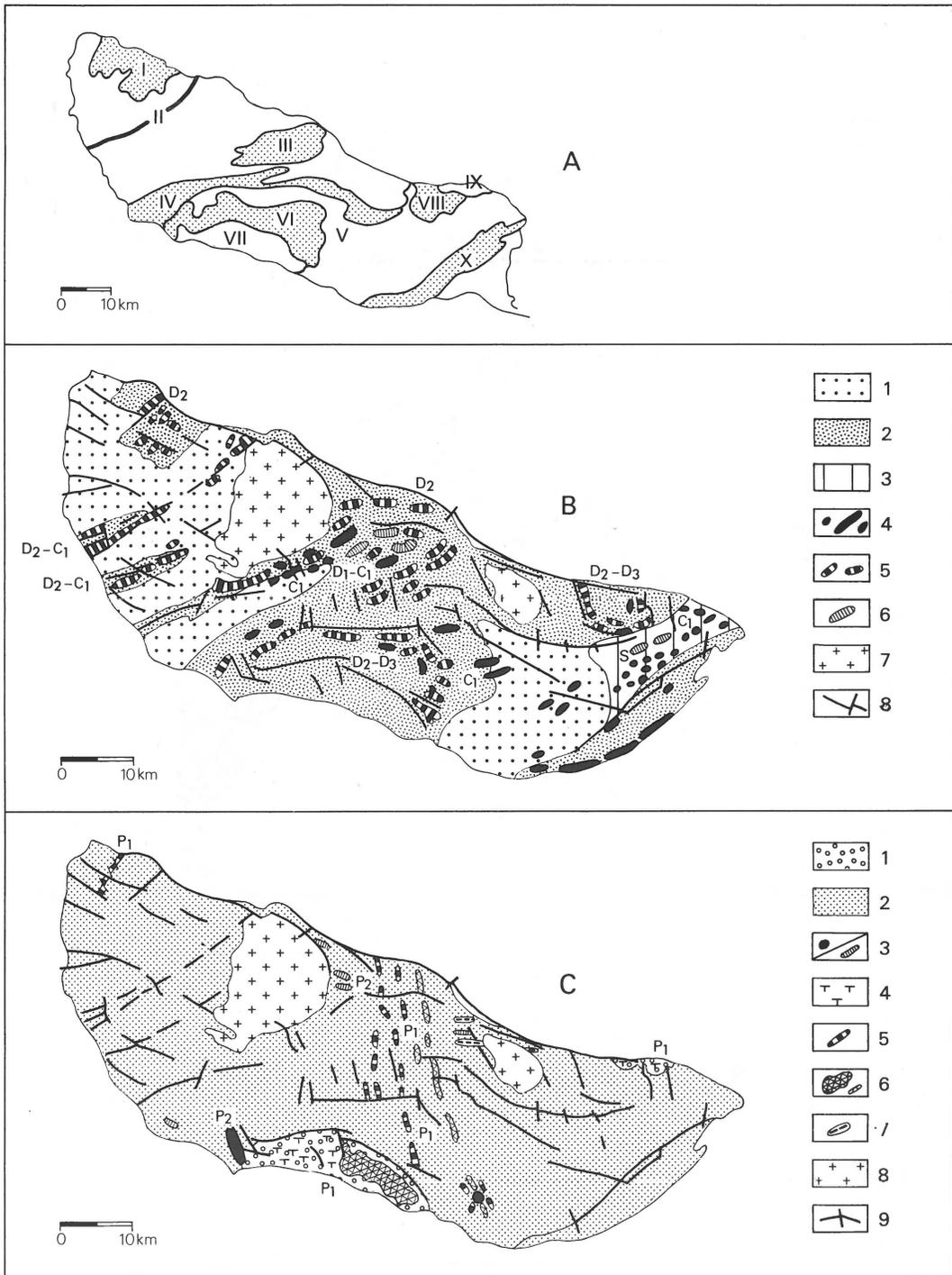


Fig. 2

The Harz

A: Some structural zones. I = Oberharz Devonsattel; II = Oberharz Diabaszug; III = Elbingeröde Komplex; IV = Tanner Zug; V = Harzgeröder zone; VI = Südharzer Mulde; VII = Ilfelder Becken; VIII = Selke Mulde; IX = Meißdörfen Becken; X = Wippraer zone (Lutzens & Schwab, 1972).

B: Spilito-keratophyre volcanics. Sedimentary rocks: 1 = Lower Carboniferous; 2 = Devonian; 3 = Silurian. Volcanics: 4 = Diabases and tuffs of the Lower Carboniferous; 5 = spilites, diabases, partly keratophyres and tuffs of the Lower Devonian - Lower Carboniferous; 6 = keratophyres and tuffs (Silurian, Devonian); 7 = granites; 8 = faults.

C: Postorogenic volcanics. Sedimentary rocks: 1 = Permian; 2 = Devonian-Carboniferous. Volcanics: 3 = rhyolites of Early Permian age (a = lavas, subvolcanic bodies; b = dykes); 4 = tuffs of Late Permian age; 5 = dykes of kersantite and quartz-porphyrines of Early (?) Permian age; 6 = bronzit-porphyrines, basalts of Early Permian age; 7 = dykes of kersantites of Westphalian age; 8 = granites; 9 = faults.

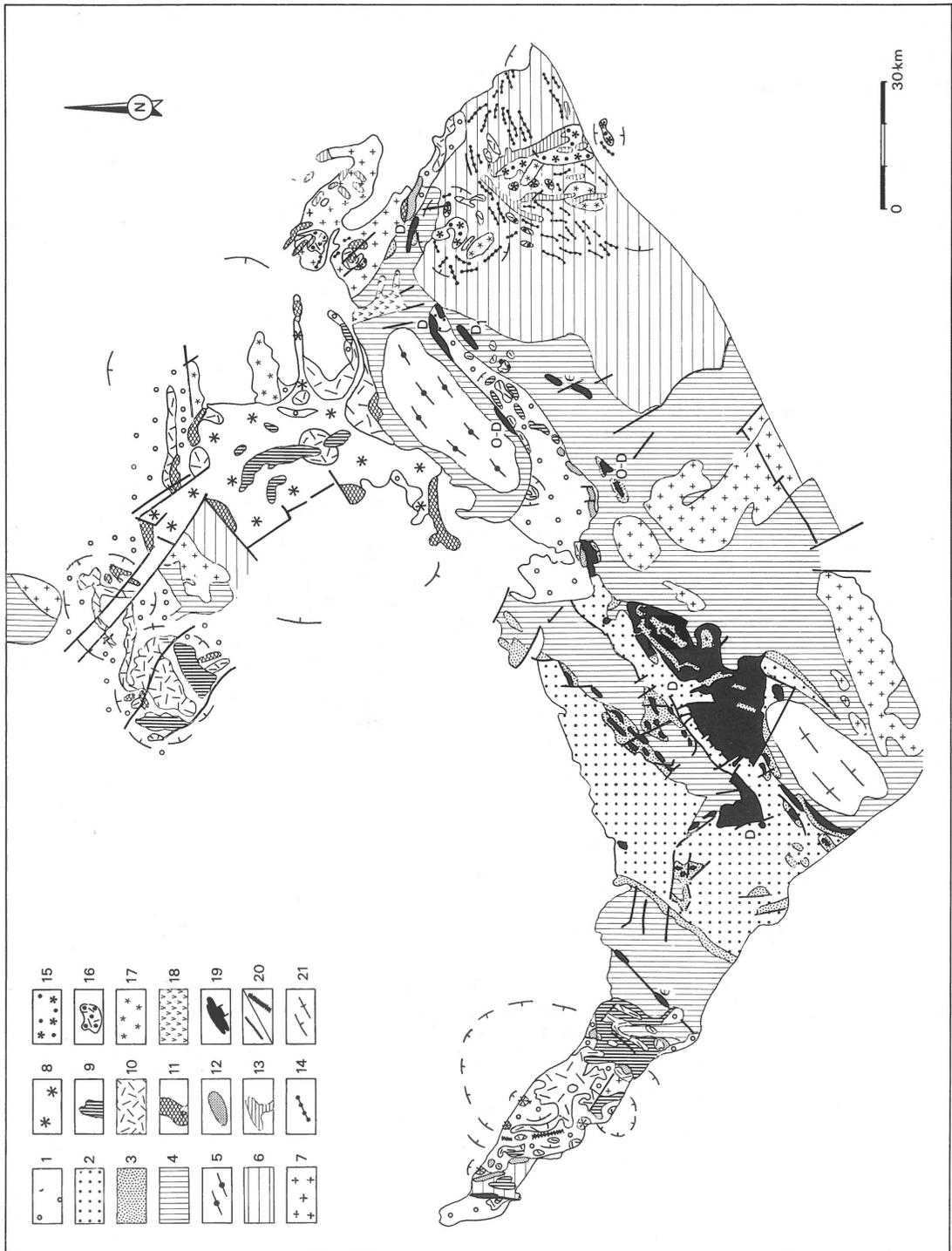


Fig. 3
Volcanic rocks of the eastern part of the Saxothuringian zone and German crystalline rise.

Sediments: 1 = Permian; 2 = Carboniferous; 3 = Devonian; 4 = Early Palaeozoic (Cambrian, Ordovician, Silurian); 5 = Granulitgebirge; 6 = Precambrium; 7 = Variscan granites. Volcanics: 8 = ignimbrites of Early-Late Permian age; 9 = granite porphyries, quartz porphyries (subvolcanic bodies) of Early-Late Permian age; 10 = rhyolites of Early-Late Permian age; 11 = porphyrites of Early Permian age; 12 = trachybasalts, basalts (melaphyres) of Early Permian age; 13 = granite porphyries (subvolcanic bodies) of Late Carboniferous age; 14 = dykes of rhyolites of Late Carboniferous age; 15 = ignimbrites of Late Carboniferous age; 16 = rhyolites of Late Carboniferous age; 17 = subvolcanic granites of Namurian age; 18 = diabases of Early Carboniferous age; 19 = spilites and keratophyres of Middle Devonian age (partly of Cambrian and Ordovician); 20 = (a) faults; (b) ring faults; 21 = inferred contours of volcanic and volcano-tectonic structures.

(Bohemian Massif) as well as those of the Ossa-Morena Zone (Portugal) are olivine-bearing alkali-basalts; for the same rocks BARD (1967, 1972) suggested a tholeiitic composition.

The Ordovician spilite-keratophyres form belts: e.g. Armorican - French Central Massif, Barrandian Basin - West Sudetes. The later tectonic movements have displaced these belts along faults.

Spilites of Silurian age are less widespread. They have been described in the West Sudetes, Barrandian Basin, Armorican Massif, Galicia and Ossa-Morena. In some cases a more mafic composition was noted as well as the presence of a few ultramafic rocks.

At sites where the Early Palaeozoic volcanism ended in the Early Devonian with basic effusions (Barrandian Basin) they have a higher amount of alkalis than all rocks from previous periods.

Summary – The facts mentioned above indicate that the most important characteristics of the Early Palaeozoic spilite-keratophyre volcanism are: (1) the repeated ascent of basaltic magma often in the same areas; (2) the predominance of spilites over keratophyres; (3) the presence of ultrabasic differentiates; (4) a clear association of volcanism with faults and fissures with a NW direction; (5) their occurrence in belts; (6) the presence in some areas of acid tuffs of Ordovician age. Therefore the Cambrian-Early Devonian is a period of predominance of tensional tectonics; the presence at the end of this time of acid volcanics and granites can indicate a change of tectonic regime (vertical movements and a short period of compression).

It may be noted that numerous spilite-keratophyre sequences are frequently separated by phases of rather weak tectonic movements. It is possible that the spilite-keratophyre belts indicate the boundary of microplates that could have existed during this period; but the evidence for subduction zones and an oceanic crust are lacking.

Variscan spilite-keratophyre volcanism

The Variscan orogenic period began in Europe in the Devonian and there is ample evidence of tensional tectonics at that time with the formation of new sedimentary basins and effusions of spilite-keratophyre volcanics. It concerns shallow-water basins, formed on a continental crust.

European geologists distinguish two types of basins: external ones like the Rhenic Trough, East Sudetes, South Portugal and internal basins such as the Thuringian Trough, Vogtland. A third type must be added: graben-like basins formed directly on the (Precambrian?) crystalline basement (e.g. Morvan and Brevenne in the French Central Massif).

The subsidence of the two first groups of basins was related to consolidation and uplift of the adjoining areas: Ossa-Morena for the South-Portugal Trough, the Caledonian belt for the Rhenic Trough etc. The newly formed faults and basins now mostly have a NE direction, like the spilite-keratophyre

belts which are connected with the initial stage of development of sedimentary basins.

The Rheno-Hercynian Trough – The subsidence of the Rheno-Hercynian Trough (Fig. 1) (DVORJAK, 1977) began in the Early Devonian, and a clastic sequence of great thickness (Siegerland, Sauerland) is sometimes accumulated.

The first volcanics of keratophyric composition appear in the Early Devonian. The climax of volcanism and graben-formation is reached in Givetian time. The predominance of spilites is evident, but keratophyres are more abundant than in the early Palaeozoic sequences and in some places they appear as the first effusions (mainly tuffs). Mafic volcanics are spilites, pillow-lavas, tuffs and subvolcanic diabases. The degree of spilitisation is quite different at various places. The 'spilite-keratophyre volcanism terminated in the late Devonian and the 'Deckdiabase' of early Carboniferous age have no connection with the spilites.

The chemical composition of the volcanics of the Rheno-Hercynian zone has been investigated by many authors and in particular by JUTEAU & ROCCI (1974, 1978). They were able to show the existence of two types of spilites: calcic and siliceous ones. In the Lahn-Dill area the chemistry of the volcanics is variable. Attempts have also been made (JUTEAU & ROCCI, 1974; HERRMANN & WEDEPOHL, 1970) to determine the composition of the primary magma. According to Juteau and Rocci they are continental alkali basalts; Herrmann and Wedepohl proposed continental (intraplate) tholeiites. The differences in opinion are due to metasomatic processes that may have disturbed the original chemistry of the rocks.

JUTEAU (1965, 1968, 1974) proposed to divide the Devonian spilites in two main groups: 'spilites de fosse' (Lahn-Dill) and 'spilites de ride' (Vosges); the latter containing more keratophyres.

The volcanic belt of the Rheno-Hercynian Trough extends eastwards to the Harz (Fig. 2). There basaltic magmas rose to the surface along longliving faults during the Devonian and Carboniferous.

The Harz – The composition of the volcanics of the Harz is comparable with those of the Rheno-Hercynian Trough but the amount of keratophyres is still greater (e.g. Elbingeröde zone). According to several authors (BURCH, 1977; MÜCKE, 1973; SCHWAB, 1977; SCHWAB & LUTZENS, 1972), the evolution of Devonian volcanism of the Harz began in the Eifelian with eruptions of spilites, mafic tuffs and rare microsyenites. The main volcanic activity during the Givetian produced keratophyres followed by mafic tuffs, spilites and pillow-basalts. This activity gets a more keratophyric character towards the end. 'Deckdiabase' of Dinantian age occur also in the Harz. According to MÜCKE (1973) and SCHWAB (1977) the primary magma was an alkali-tholeiitic basalt, whereas the keratophyres have a trachytic trend.

The difference of volcanism between the Rheno-Hercynian Trough and the Harz lies in the absence of postorogenic

volcanics in the first and their presence in the last mentioned area.

The South-Portugal Basin – Another Devonian basin of the same type in South Portugal (Encl. I) is separated from adjoining areas by deep-reaching faults; it has now a NW trend changing towards the NE. The basement of the basin is unknown, but the seismic data show its sialic composition. The geological structure and the volcanism have been described in detail by BARD (1971, 1973), BOOGAARD (1967), SCHERMERHORN (1970, 1975), SOLER (1973) and RAMBAUD (1978).

The subsidence began in the Early Devonian and was accompanied by effusions of volcanic rocks. Schermerhorn has shown that the volcanic activity during the Middle and Upper Devonian was predominantly of acid character: dacitokeratophyric tuffs. Spilites and keratophyres are associated with Tournaisian and early Viséan greywackes. The keratophyres are more abundant in the northern part of the basin, spilites more in the central and southern part. The whole complex is of typical submarine nature. Volcanics of intermediate composition are also present. The keratophyres and associated pyroclastics have a rhyolitic composition.

There are different opinions concerning the chemistry of the volcanic suite. According to SCHERMERHORN (1970, 1975), it is a basalt-mugearite-andesitic suite; SOLER (1973) in contrast thinks of it as a tholeiitic magma. In the opinion of most investigators the volcanics have a tholeiitic character.

The Eastern Sudetes – An important example of another Devonian basin lies in the Eastern Sudetes (Niski Jésenik) (Fig. 6); it shall be considered very briefly. This is a trough with a NE direction filled with a volcano-sedimentary sequence (DVORJAK, 1977) of Devonian and Carboniferous age. The submarine spilito-keratophyre rocks erupted mainly during the middle Givetian. 'Deckdiabase' are of Early Carboniferous age. All sequences are covered by greywackes of Early Carboniferous age.

There is a difference in age of volcanics in the basins mentioned above – Early to Middle Devonian in the Rheno-Hercynian Trough and Middle to Late Devonian and Early Carboniferous in the South Portugal Trough

The Thuringian Trough (Fig. 3) – The volcanics of Devonian age are of spilito-keratophyric nature and show a climax in the Upper Devonian. The basins and its volcanic belts have a NE-SW trend. The chemistry of the volcanic series is not very different from that of the Lahn-Dill region where the rocks contain a higher amount of alkalis. The primary magma corresponds to that of tholeiites of continent rifts.

The Vogtland Trough – The adjoining trough of Vogtland (Fig. 3) contains also shallow-marine sediments of Devonian and Early Carboniferous age. Spilitic volcanism started in the Middle Devonian with a maximum in the Late Devonian. Again the most abundant rocks are spilites, pillow-lavas,

tuffs and keratophyres. Rare picrites are differentiates of a basaltic magma. Shortly before the folding phase the quantity of keratophyres increased. The volcanic belts have the same NE direction as the other Variscan belts and extend to the Elbe lineament. The volcanics correspond in their chemistry to continental (SCHROEDER, 1973) or oceanic tholeiites (BEBIEN, 1971, 1977).

Devonian spilito-keratophyric volcanism is also known from the Fichtelgebirge anticlinorium, the Delitz synclinorium, Doberlug and other areas (see Encl. I).

Summary – The data about the spilito-keratophyre associations of the two groups of Devonian basins reveal that both in the external and the internal basins volcanism is associated with the beginning of subsidence and the deposition of a shallow-marine sedimentary facies. The chemistry of the volcanics of all basins under discussion is variable in detail but similar, perhaps indicating the same source of magma and mode of formation. Difference in opinions about the chemistry (tholeiites, alkali-basalts) is related in most cases to the difference in the degree of metasomatic alteration.

The volcanics form linear belts following regional deep-seated faults and have a similar geological and tectonic setting. Therefore early Variscan tectonics was of tensional nature.

Devonian troughs formed directly on the crystalline basement

Devonian troughs formed directly on a strongly metamorphosed (Precambrian?) crystalline basement are small narrow troughs or grabens flanked by E-W or NE-SW trending faults.

The Vosges – An interesting example is formed by the Vosges (Fig. 4), investigated by many authors (BLANAT, 1973; VON ELLER & FLUCK, 1977; FOURQUIN, 1973; HAMEURT, 1976; JUTEAU & ROCCI, 1965, 1974; RUHLAND, 1970; a.o.). The central part of the Vosges consists of crystalline basement separated from the Devonian area in the north by deep faults. The Devonian trough started forming probably at the beginning of Devonian. The first sediments are greywackes of Early Devonian age. Basic volcanism appears at the same time, but its maximum development is of Givetian age. The volcanics form here also an ENE trending linear belt consisting locally of more or less isometric volcanic structures (e.g. Moyemontier). The palaeovolcanic reconstruction is difficult, but the non-linear character of some volcanic structures seems to be clear. The greatest structure of this kind (Schirmeck at the eastern part of the trough) has been described by Juteau and Rocci. The submarine spilito-keratophyric suite is characterized by a predominance of keratophyres and quartz-keratophyres. The volcanics alternate with sediments of Givetian age. Three groups of rocks have been distinguished: (1) keratophyres; (2) spilitic lavas and subvolcanic diabases; and (3) pyroclastics of basic and acid composition. The geological

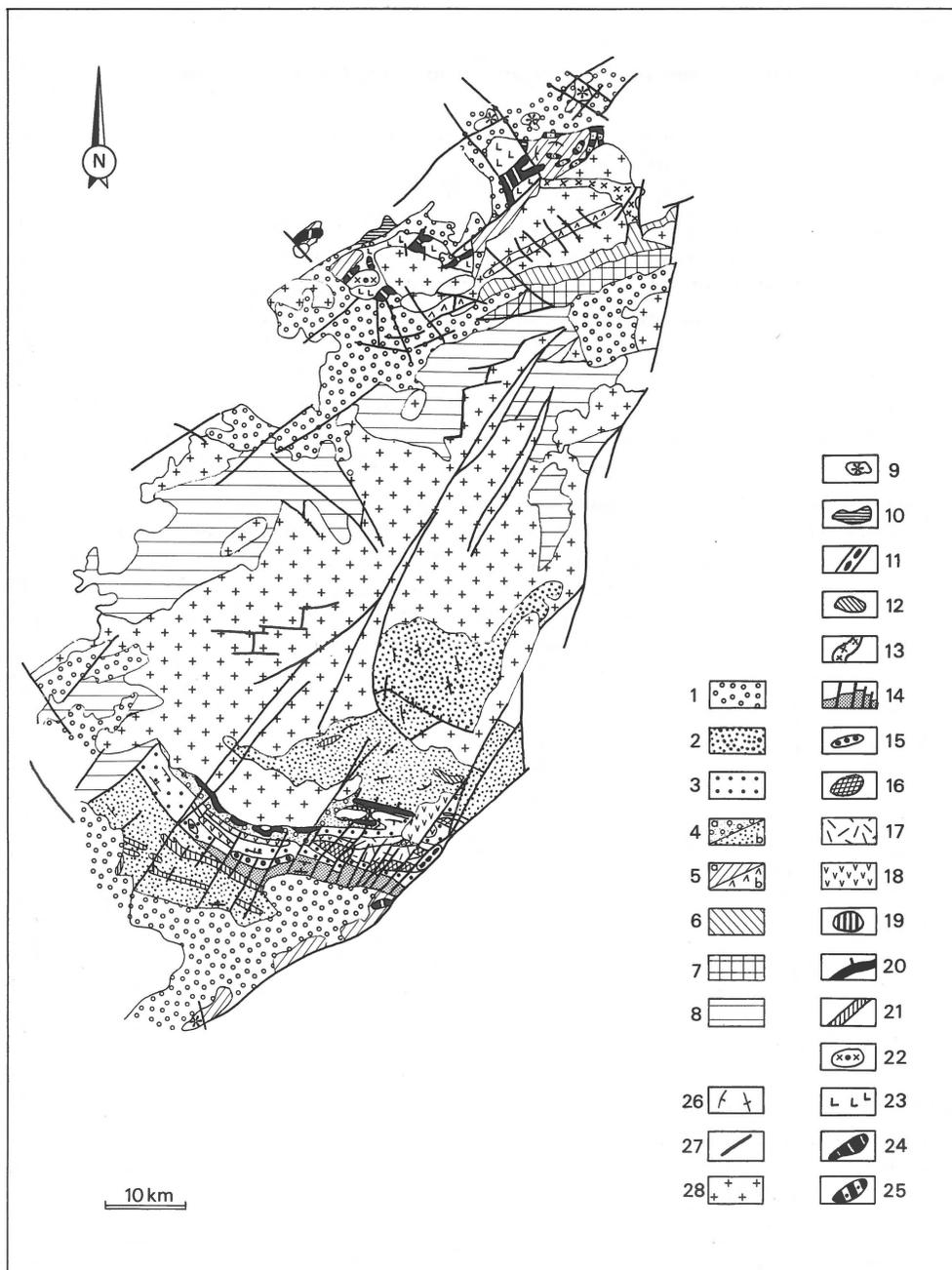


Fig. 4

Volcanic rocks of the Vosges.

Sediments: 1 = Permian; 2 = serie Markstein of Westphalian age; 3 = Early Carboniferous (Visean); 4 = (a) serie Malvaux, (b) serie Oderen, Plancher Bas (early Carboniferous-Visean); 5 = Devonian: (a) sediments, (b) sediments and volcanics; 6 = Ordovician-Silurian; 7 = Precambrian (?); 8 = Precambrian. Volcanics: 9 = rhyolites, ignimbrites of Late Permian age; 10 = trachybasalts, basalts of Early Permian age; 11 = dykes of lamprophyres of Westphalian age; 12 = rhyolites comagmatic to granites of Westphalian age; 13 = subvolcanic variscan granites; 14 = ignimbrites (serie Giromagny) of early Carboniferous (Visean) age; 15 = trachytes, trachyandesites (serie Giromagny); 16 = ignimbrites (serie Thann) of early Carboniferous (Visean) age; rhyolites (serie Thann); 18 = labradorites (serie Thann); 19 = breccia (serie Malvaux) of Early Carboniferous age; 20 = keratophyres and spilites of the serie Malvaux; 21 = spilites, diabases (series Plancher Bas, Oderen) of early Carboniferous-early Visean age; 22 = subvolcanic granites and rhyolites of Devonian age; 23 = keratophyres and tuffs of Late Devonian age; 24 = spilites and keratophyres of Late Devonian-Early Carboniferous age; 25 = basalts, diabases, spilites of Late Devonian age; 26 = dip of rocks; 27 = faults; 28 = granitoids of different age.

structure of the Schirmeck-complex is not yet well known due to its bad exposure. There is, however, no doubt that the magma rose to the surface along faults, some of semicircular form.

The structure of the eastern part of the volcanic belt of the northern Vosges is that of the Bruche valley; in this area bodies and layers of spilites and keratophyres surround an isometric syncline formed by volcano-sedimentary rocks of Visean age. This type of structure is quite different from those mentioned above and the volcanics are of Early Carboniferous age. It is clear that the internal structure of this volcanic belt is complex and differs from other Variscan spilite belts. This fact is due to the position of these volcanic complexes directly on a rigid block of basement.

JUTEAU & ROCCI (1965, 1974) especially have drawn attention to the chemistry of these volcanic complexes and concluded that the great quantity of acid rocks is due to the influence of the crystalline basement (assimilation, interaction etc.), they designate these complexes as 'série de ride'.

Also in the southern Vosges Devonian spilites exist, but they are rather scarce. A submarine spilite-keratophyre suite of early Visean age is largely developed within an early Carboniferous trough formed on the crystalline basement. Today it is a syncline with a NE-SW direction, bounded by faults. The outer parts are built up by early Visean sequences, the centre by the rocks of late Visean age. The sequences are separated by tectonic movements.

The subsidence of the trough began probably in the Late Devonian or Early Carboniferous and clastic sedimentation was followed by eruption of typical submarine spilites and keratophyres with pillow-lavas, basic and acid tuffs and bodies of diabbases. The spilites alternate with keratophyres, but the last eruption produced keratophyres.

The Black Forest – The spilites of the Northern Black Forest occur in continuation of the volcanic zone of northern Vosges (FLUCK & OTTO, 1978). The early Visean volcanics of the Southern Black Forest are of porphyritic composition and extruded in a graben-like basin.

The Armorican Massif – Troughs of Devonian and Early Carboniferous age are known in the Armorican Massif (basin d'Ancenis, Châteaulin, Menez-Bel-Air, Laval a.o.) (Fig. 5) (BABIN & REGNAULT, 1978; CONQUÉRÉ, 1966; DEUNFF ET AL., 1973; LARDEUX ET AL., 1977; SAGON, 1967). Today they seem to form one structure trending E-W across the whole massif along a zone of weakness. Their geological history, however, was different and during the Dinantian they became isolated basins (COGNÉ, 1976).

The time of the first subsidence of the Châteaulin basin is supposed to be Middle Devonian. The sedimentation was accompanied by local manifestations of spilitic volcanism, but the climax came later (Middle-Late Devonian). Volcanism was absent during the Late Devonian. Volcanic rocks of Dinantian age are more widespread and of a greater thickness;

this is also a spilite-keratophyre sequence with pillow-lavas and hyaloclastics. Thus the same volcanic associations reappear in the Châteaulin basin.

The Central French Massif – The Devonian troughs of the Central French Massif (CHENEVOY, 1974; CHENEVOY & RAVIER, 1977; DIDIER & LAMEYRE, 1977) are typical grabens; they are known only in the eastern part of the Massif - 'zone de Brevenne', 'Synclinorium de Loire', 'Synclinorium de Morvan', 'Bourbonnais', 'Forez' etc.

All these zones are of small size compared with the Rhenohercynian or South Portugal Troughs. The 'zone de Brevenne' is built up by a volcano-sedimentary sequence of Devonian-Dinantian age (PETERLONGO, 1960): arkoses, shales, keratophyres and an alternation of spilites and keratophyres. The chemistry of the basic rocks is tholeiitic (FONTEILLES, 1968).

The Synclinorium of Morvan (BEBIEN, 1971; BEBIEN ET AL., 1977; BOYER, 1976; BERTAUX ET AL., 1978) also trends NE-SW and is bordered by faults. The spilite-keratophyre volcanism is of Devonian-Dinantian age. The sediments are clastic shallow-marine deposits.

The spilite-keratophyre sequences of Bourbonnais and Forez have nearly the same characteristics, but in addition andesites are present. In Roannes (BERTAUX ET AL., 1978) and Macón the age of this suite is Late Devonian-early Visean.

Summary – We can state that the Variscan spilite-keratophyre association is widespread. It appears in great Devonian basins (Rhenic Trough, South Portugal and others) in the beginning of the initial stage of their subsidence and the climax of the volcanic activity is reached in the Middle and Late Devonian. The ascent of basic magma can take place uninterrupted during the Devonian and Early Carboniferous. In basins formed directly on the crystalline basement (The Vosges, Basin Châteaulin a.o.) spilites recurred in the Devonian and after an interruption in the Early Carboniferous. In comparison with the Lower Palaeozoic the Late Palaeozoic suites contain more keratophyres. As to the chemistry of basic rocks they are continental tholeiites or alkali-basalts. The Variscan spilite-keratophyre associations are arranged in narrow belts along faults and rifts, striking NE-SW.

The tectonic movements of Variscan time during the emplacement of spilitic suites were of a tensional nature. It is difficult to relate the volcanic activity to a subduction zone which has been proposed in the south of the Armorican Massif and any relation between them is absent. It seems that the existence of two major (the northern and the southern) spilitic belts is the more realistic hypothesis. There is a lack of evidence for assigning them to one belt (see ELLENBERGER & TAMAIN, 1980). The position of the belts was disturbed many times by tectonic movements.

The Variscan spilite-keratophyre associations are related to intracontinental rift-zones and probably marked the border of microplates.

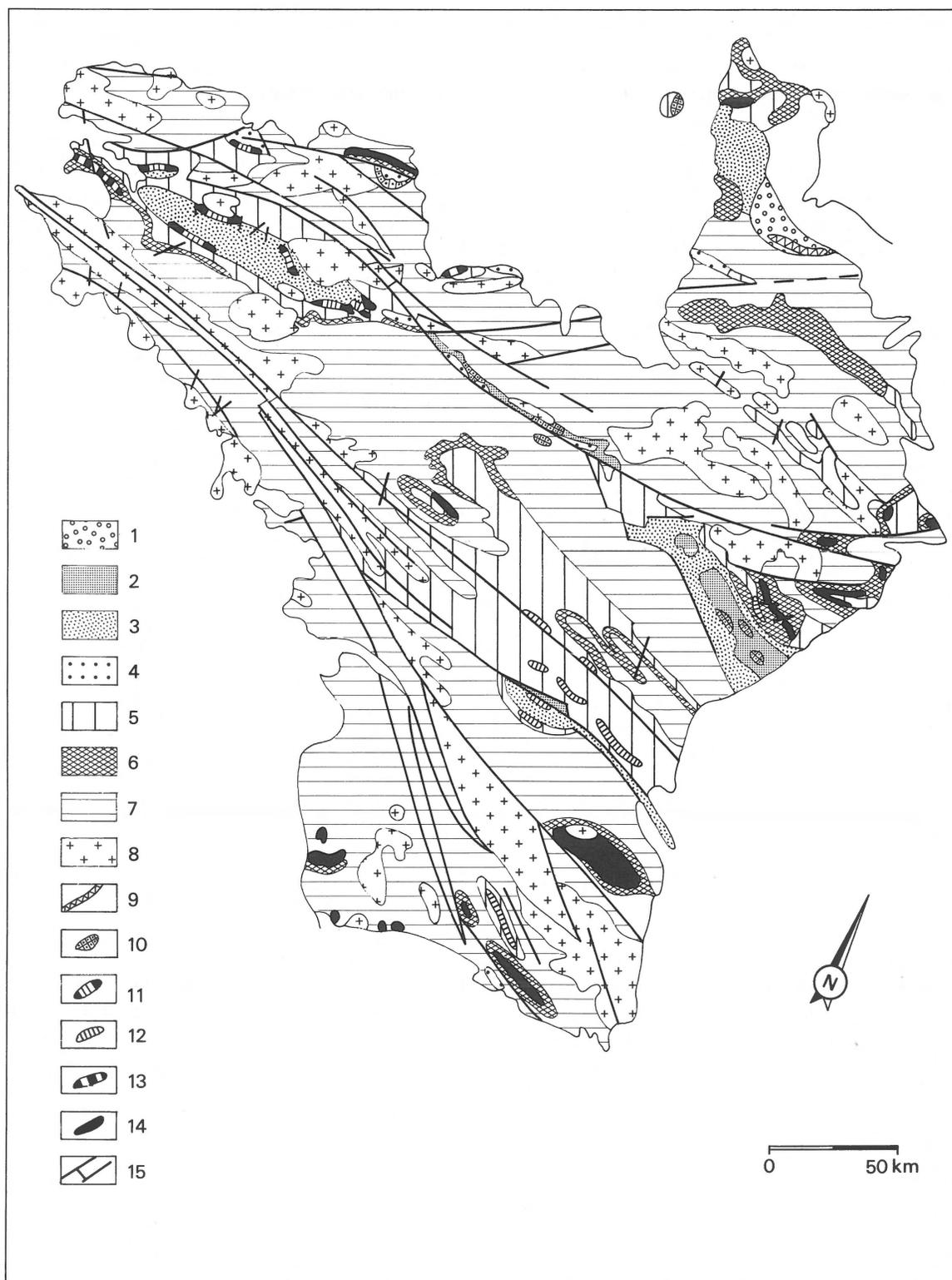


Fig. 5

Volcanic rocks of the Armorican Massif.

Sediments: 1 = Permian; 2 = Carboniferous; 3 = Devono-Dinantian; 4 = Devonian; 5 = Silurian; 6 = Cambrian; 7 = Precambrian; 8 = granites of different age. Volcanics: 9 = basalts of Permian age; 10 = rhyolites and ignimbrites of Late Carboniferous age; 11 = spilites and keratophyres of Early Carboniferous age; 12 = spilites and keratophyres of Silurian age; 13 = spilites, tuffs and diabases of Ordovician (to Devonian?) age; 14 = metarhyolites and metaignimbrites of Cambrian age; 15 = faults.

POSTOROGENIC CALC-ALKALINE VOLCANISM

The Variscan postorogenic volcanism succeeds the major tectonic phase during the Late Carboniferous. This volcanic activity followed the folding either immediately or after a certain interval. In these two cases the composition of the rocks and the shape of magmatic structures are quite different. The volcanism that took place immediately after the tectonic movements (late Visean-Westphalian, sometimes to Early Permian) can be defined as a late-orogenic volcanism. The other one, that appears after a certain time (in Stephanian-Early Permian, or Early-Middle Permian) is termed the post-orogenic or final volcanism. Of course, transitional types exist.

Late-orogenic volcanism

The late-orogenic volcanism appears on consolidated blocks, anticlines, Precambrian (?) crystalline basement (such as the Armorican Massif, French Central Massif, Erzgebirge) or at the borders of the grabens formed directly on the crystalline basement (such as Morvan, Brevennes a.o.) (Encl. II; Figs. 3, 4 and 5). It is absent in the great Devonian troughs.

Magmatic rocks of this group are of rather monotonous acid granitic composition (rhyolites, ignimbrites); the volcanics of the Southern Vosges are an exception. In some areas (Erzgebirge, North Portugal a.o.) they are cogenetic with the Variscan granites and form volcano-plutonic structures. Basic rocks are virtually absent. Very typical is a close association of magmatic rocks of different facies (volcanic, subvolcanic, hypabyssal). Swarms of subvolcanic dykes of linear or circular form are widespread. Magmatic structures of this type (volcano-plutonic) have been described in many places, e.g. in the Eastern Erzgebirge (BENEK ET AL., 1973; EIGENFELD, 1972; EIGENFELD & SCHWAB, 1974) and in the Black Forest (Encl. II; Fig. 3).

In the Eastern Erzgebirge we can mention two structures: Altenburg and the Tharander Wald. The Altenburg structure is very complex; it has an elliptical shape; the central part is built up by ignimbrites cut by dykes of granite-porphry. Another dyke of the same composition has a semicircular form and cuts through an intrusive Variscan granite. The structure is surrounded by a semicircular dyke swarm of rhyolites and porphyries. The whole represents a volcano-plutonic structure of the central type related to vertical movements, perhaps to a cauldron subsidence filled by ignimbrites. The complexes of the Tharander Wald and Teplice are of the same type.

Saar-Saale Trough – A similar type of structure with a greater role of volcanic rocks of intermediate and basic composition and of Late Carboniferous-Early Permian age is known in the Saar-Saale Trough (on the German crystalline rise). This type can be regarded as a transitional one, as mentioned above. The volcanic complexes here were investigated in detail by many geologists (BENEK ET AL., 1973; SCHWAB, 1970;

EIGENFELD & SCHWAB, 1974; and others). Three important volcanic structures of the central type are known - the Halle, Thüringer Forest and the Northern Saxonian (Fig. 3). They will be described briefly.

The development of the Halle structure started in the Westphalian A/B with deposits of red-beds lying directly on the crystalline basement. The magmatism appears in the Stephanian as subvolcanic intrusions of trachyandesites; this type of magmatism continues in the beginning of the Early Permian, but the composition and the facies of igneous rocks change strongly. Later lavas, tuffs and ignimbrites of rhyolitic composition are the dominant rocks. The volcanic Permian sequence of Halle is quite complex. The Lower Halle porphyries (subvolcanic partly) have a thickness of 1000 m. Porphyrites are also known in this sequence. The structure of the Halle complex is characterised by the presence of a volcano-tectonic depression with volcanic rocks in the centre surrounded by circular subvolcanic intrusions of acid composition. The mechanism of formation of those structures is due to vertical movements, synvolcanic and cauldron subsidence.

The Northern Saxonian complex (Encl. II; Fig. 3) occupies an area of about 2000 m². Three volcanic sequences were established: (1) porphyrites, ignimbrites, acid tuffs and lavas; (2) rhyolites and ignimbrites; (3) subvolcanic intrusions of acid composition. The great amount of ignimbrites supports the opinion that calderas have been present. The structure is of volcanic-subvolcanic central type. Palaeo-volcanic reconstructions are still not available, but it is very probable that this complex is of the same type as the structures of Halle and the Thuringer Forest and also of the volcanic belts, surrounding the Variscides of Europe in the North and East.

The Vosges – The volcanism of the Southern Vosges is of a particular character. In the centre of a Visean syncline the submarine volcano-sedimentary sequence containing spilites is unconformably overlain by a complex of late Visean age (COULON ET AL, 1975, 1978; MARCHAND, 1973; STUSSI, 1967). Within this complex four episodes of volcanism succeeded one another; the first gives small linear bodies of labradorites; their composition is that of tholeiitic basalt; the second episode is represented by layers of trachyandesites, trachylabradorites and pyroclastics; the third one gives dacites, rhyolites and tuffs. Masses of acid tuffs and ignimbrites were produced during the fourth episode. The thickness of the whole sequence is about 400 m. The specific composition of volcanics (potash-rich basalts and andesites) as well as their restriction to a single area, are probably the result of their origin from an isolated magma chamber and reaction of basaltic melts with the rocks of the sialic basement.

In graben-like depressions in the East of the French Central Massif the rhyolites and ignimbrites of late Visean age ('tuffs anthracifères') occur in form of flows and layers (in Morvan) (BERTAUX ET AL., 1978). A special type of volcanism was established in small coal basins of Stephanian age local-

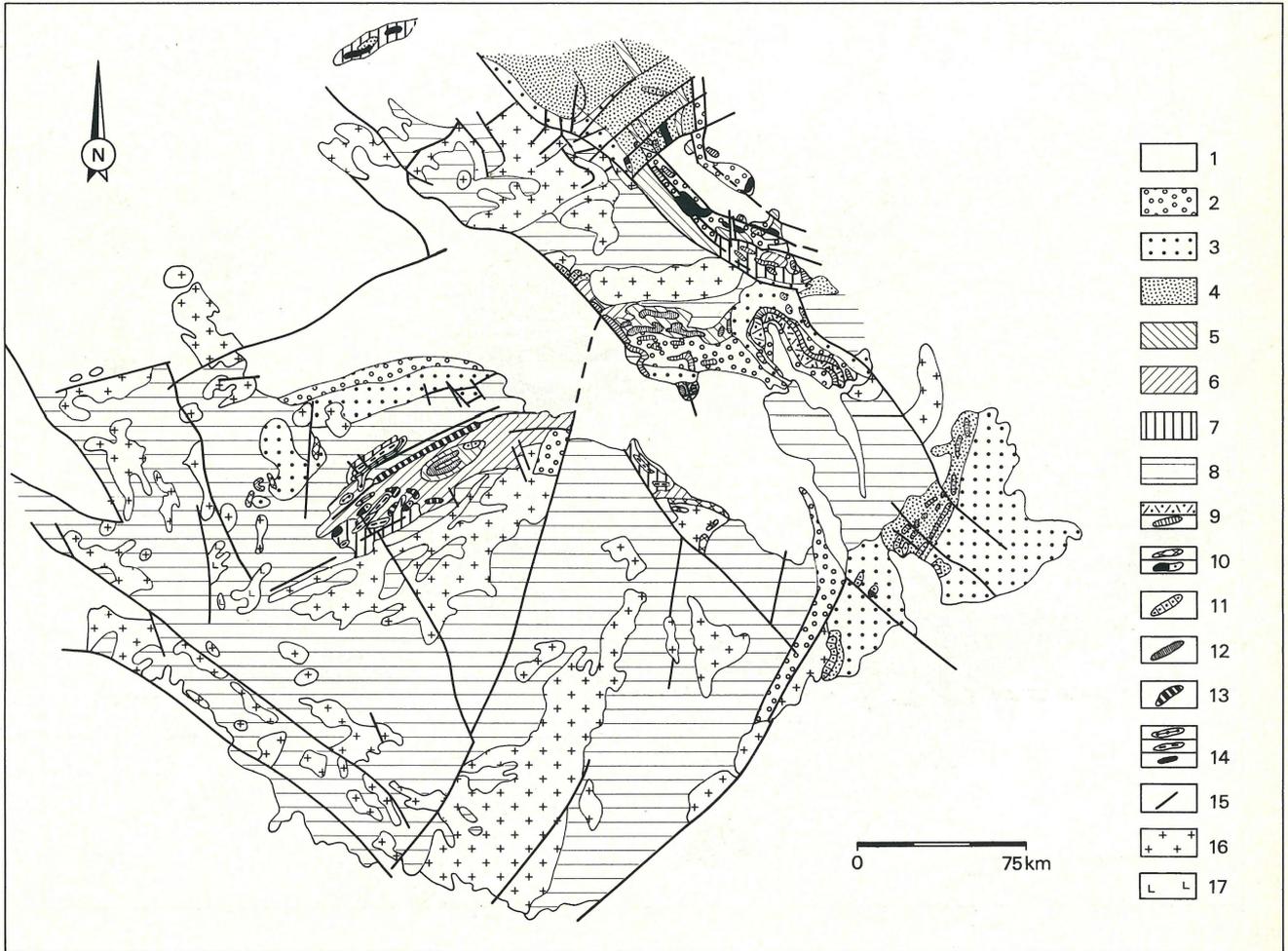


Fig. 6
Volcanics of the Bohemian massif and Sudetes.

Sediments: 1 = covering formations; 2 = Permian molasse; 3 = Carboniferous; 4 = Devonian; 5 = Silurian; 6 = Ordovician; 7 = Cambrian; 8 = Precambrian. Volcanics: 9a = rhyolites of Late (?) Permian age; 9b = trachybasalts and melaphyres of Early Permian age; 10a = subvolcanic granite porphyries of Carboniferous age; 10b = 'Deckdiabase' of Carboniferous age; 11 = spilites and diabases; 12 = picrites of Silurian age; 13 = spilites and diabases of Ordovician age; 14a = metarhyolites of Cambrian age; 14b = porphyrites of Cambrian age; 14c = spilites and diabases of Cambrian age; 15 = faults; 16 = granites; 17 = basic intrusions.

ised along regional faults (e.g. the French Central Massif along the 'Sillon Houiller'). They are filled with detrital sediments of molasse type with layers of rhyolitic lavas and tuffs. This volcanism indicates the end of a regional development of the anatectic melting.

In the whole the late-orogenic volcanism is a product of a regional anatectic melting in the crystalline basement and is related to blocks of basement or regions where the basement occupies a high position. The predominant type of tectonic movement was vertical movements of blocks along linear and circular faults.

Post-orogenic or final volcanism

The last type of volcanism treated here is a bimodal one and

occurs in Permian grabens of different size filled with molasse. The volcanics are exclusively trachybasalts (or basalts), rhyolites and tuffs (without rocks of intermediate composition). This type is known in different parts of Europe: 'Nahe Mulde' (South of the Hunsrück), Zwickau (Erzgebirge), Schonaer Graben (Boberkatzbachgebirge), 'Ilfelder Becken' (Harz), 'Tratenauer Tafel Mulde' (Sudetes), Intra Sudetic syncline and many others (Encl. II; Figs. 2a, 3, 6 and 7).

Lavas and tuffs alternate with sediments; the acid rocks sometimes form subvolcanic bodies, necks. Dykes of basic and acid composition occur also (for example the dykeswarm of the Harz). Usually basic and acid volcanics are found in one and the same basin (or graben), but in some cases only basalts (Tratenauer Mulde) or only acid rocks (Meisdorfer Becken, Harz) are present. Most geologists consi-

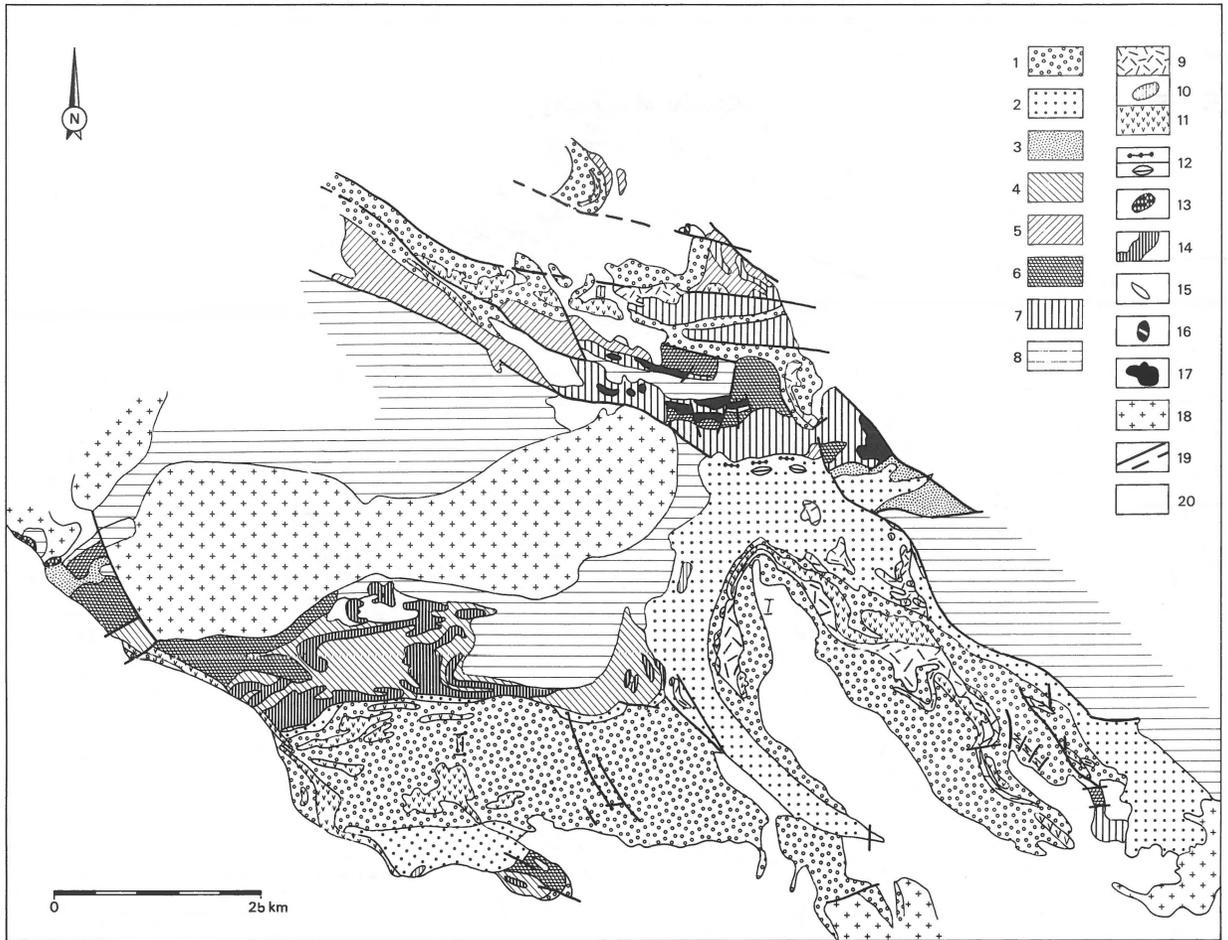


Fig. 7

Volcanics of the central part of Western Sudetes.

Sediments: 1 = Permian molasse; 2 = Carboniferous; 3 = Devonian; 4 = Silurian; 5 = Ordovician-Silurian; 6 = Ordovician; 7 = Cambrian; 8 = Precambrian. Volcanics: 9 = rhyolites and ignimbrites of Middle-Late (?) Permian age; 10 = porphyrites of Early Permian age; 11 = basalts and trachybasalts of Early Permian age; 12a = rhyolites of Late Carboniferous age; 12b = palaeobasalts of Late Carboniferous age; 13 = spilites and diabases of Devonian age; 14 = spilites, keratophyres and diabases of Silurian age; 16 = diabases of Ordovician age; 17 = spilites and diabases of Cambrian age; 18 = granitoïdes. 19 = faults; 20 = covering strata: (I) Central Sudetic syncline, (II) Tratenauer syncline, (III) Schonauer graben.

der the basic rocks as volcanics of Early Permian age and the acid lavas as Late Permian; however, both can be of Early or Middle Permian age.

The Intrasudetic Syncline (Fig. 7) – This is one of the most important Permian structures. It is built up by Late Carboniferous clastic sediments and Permian molasse. According to NOWAKOVSKI (1968) and NOWAKOVSKI & TEISSEYRE (1971), scarce basalts and acid tuffs erupted already in the Late Carboniferous, but the climax of volcanic activity was reached in the Middle Permian. The eruptions start with rhyolitic lavas and ignimbrites, followed by trachybasalts; rhyolites reappear after a short interruption.

In other Permian troughs the basic volcanics are clearly related to faults and form linear bodies; the chemical composition of Permian volcanics is in general much the same in

different parts of Europe: basalts with an alkalic trend and calc-alkalic rhyolites. The source of magma lies probably in the upper mantle for basalts and the acid magma is a product of partial melting caused by the heat of the basic magma.

Volcanic belts

Large regions of the European Variscides are covered by Mesozoic and Cenozoic sedimentary deposits, but in the last few years data from drillholes and seismicity have shown that volcanics of late Palaeozoic age surround the exposed Variscides in the North, North-East and East (Encl. II). The data obtained have permitted to suggest some ideas about the structure of the basement of this region and about the nature and geological setting of the volcanism (ERKHARDT, 1968; DVORJAK & PAPROTH, 1969; BUSCH & KIRUSCHIN, 1972; KAT-

ZUNG ET AL, 1977; and others). It seems that the basement is heterogeneous and consists of Precambrian and Early Palaeozoic rocks. A volcanic zone exists along the northern boundary of the Variscides and can be followed further to the East and Southeast along the Tornquist line and the NW-trending aulacogen at the SE border of the Russian Platform. The structure and the composition of this belt is not yet sufficiently known and probably more complex than is thought now.

The E-W trending Weser-Ems zone with basalts, diabases and andesites lies unconformably on rocks of Westphalian and Stephanian age. According to EIGENFELD & SCHWAB (1974) this zone belongs to the Externides; in our opinion this can be an area of terminal volcanism at the border of a sub-platform area.

The second zone (Fehmarn-Usedom) has a complicated structure and consists of Carboniferous and Permian rhyolites, rhyodacites and tuffs. The basic volcanics of the adjacent Rügen Island belong now to the platform.

The third zone trends along the boundary of the North German-Poland lowland (zone Wustrow) and can be followed according to Katzung as far as Berlin. The thickness of volcanics is about 1.300 m; the major rocks are tuffs of Early Permian age. It seems possible that this zone is connected with the Ostrow-Welikopolski zone.

All zones mentioned form a complex volcanic belt (or belts?) and their relationships are in most cases unclear. Nevertheless it is evident that the volcanics are quite similar to those of the exposed Variscides. These types of volcanic belts have been described by Russian geologists in such areas as Kazakstan, Central Asia, Far East etc. They separate usually structures (or regions) of different age and time of consolidation. The comparison of these types of belts with those of Variscides seems justified (BUSCH & KIRUSCHIN, 1972). The forming of volcanic belts surrounding the Variscides can be related with the remobilisation of the Precambrian (?) basement during the major phase of deformation (Carboniferous).

CONCLUSIONS

Our present knowledge of the Variscan volcanism of Europe permits us to make some conclusions concerning its history and relations with the tectonic development.

The widespread distribution in space and time as well as the reappearance throughout the whole Palaeozoic of the spilito-keratophyre associations show clearly that the main tectonic regime was one of tension. The source of this magma was the upper mantle. Spilito-keratophyre sequences of Variscan time are connected with the initial stage of the individualisation of new basins and form linear belts. They can reappear later, but before the major folding phase. It is noteworthy that the source of basaltic magma remains in many areas nearly at the same place during a long period. It seems possible that the spilitic belts marked the boundaries

of plates which were partly displaced during the Palaeozoic. There is no evidence of a relation of these belts to any subduction zone. Neither is there good evidence for the existence of an oceanic crust. The regime of tension can be the result of movements of large global plates in the North-Atlantic (ZIEGLER, 1978; ZWART & DORNSIEPEN, 1978).

The postorogenic Variscan volcanism had a completely different tectonic and thermal history. The tectonic regime was one of folding, compression and vertical movements. Source of the magma was regional anatexis melting in the sialic crust. The volcanic structures were of central type.

The gradual consolidation of the melting front with time leads to the formation of isolated magma chambers and a decrease in the amount of volcanics as well as the change of their composition. The ascent of basaltic magmas, which caused a partial melting in the crust, became possible.

The bimodal volcanism is the result of these processes and tectonics now related to the uplift of the whole area. The volcanic structures are predominantly of linear shape. As to the Caledonian 'event' the evolution of the magmatism of this time corresponds to a particular but complete 'cycle': a long period of tension with numerous spilitic sequences and a short period of vertical movements with acid volcanism and granites.

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