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MAFIC GEOSYNCLINAL VOLCANISM IN THE LOWER CARBONIFEROUS OF SOUTH PORTUGAL

L.J.G. SCHERMERHORN[1])

ABSTRACT

Lower Carboniferous mafic volcanism in the Hercynian geosyncline of South Portugal produced spilite flows, often pillow lavas, and albite diabase intrusions. Spilites only occur in a central zone. Felsic volcanism took place at about the same time in this geosyncline: in South Portugal the mafic volcanism followed the felsic eruptions but in Southwest Spain the succession is reversed. The relationships between the mafic and the felsic activity indicate a rough juxtaposition in space and time but no genetical link. The mafic volcanics are considered to derive from the upper mantle and the felsic volcanics are thought to have been generated in local magma chambers by melting in the deep crust.

INTRODUCTION

Initial magmatism is well-developed and widespread in the Upper Paleozoic eugeosynclinal trough of South Portugal, folded during the Hercynian orogeny, as has been argued by several authors (e.g. Mac Gillavry, 1961; Strauss, 1965). This paper discusses the extent, nature and age of the mafic volcanism in the marine Lower Carboniferous of South Portugal and its relationship to the roughly contemporaneous felsic volcanism.

The mafic volcanics are spilites and albite diabases of various types. Some authors have referred to them as "ophiolites" which they are not, as ultramafics are lacking.

An inner zone in which spilites occur together with albite diabases, though at different levels, is surrounded by a much wider area in which albite diabases alone are found.

[1]) Sociedade Mineira Santiago, R. Infante D. Henrique, Prédio B, 3.°-D., Grândola, Portugal.

GEOLOGICAL SETTING

The two major Paleozoic units of South Portugal are (1) a large subsiding basin, bounded to the north by (2) a geanticlinal uplift. They developed by local differentiation, i.c. epeirogenic movements, of the Hercynian geosyncline in the Upper Paleozoic. The strata exposed in the basin are weakly metamorphosed Upper Devonian to Middle Carboniferous geosynclinal sediments and volcanics. On the geanticline appear more strongly metamorphic beds mainly of Lower Paleozoic age, intruded by various types of igneous rocks. This area, the Évora-Beja Massif, here named the Beja Geanticline, is still imperfectly known and need not concern us now. It is in the northern half of the subsiding basin that the volcanics occur which are described here (fig. 1).

The strata in this basin are divided into three conformable lithostratigraphical groups (Schermerhorn and Stanton, 1969; Schermerhorn, in preparation (a)). Lowermost is the *Phyllite-Quartzite Group* of which the base is not exposed; it reaches up to the top of the Devonian. The following *Volcanic-Siliceous Complex,* of Tournaisian to mid-Viséan age, is the bearer of the mafic and felsic volcanics and the associated stratiform pyrite and manganese ore deposits. It is overlain by the *Culm* which represents the flysch phase of this geosyncline, extending up to the middle Westphalian. It is a clastic sequence derived from the rising Beja

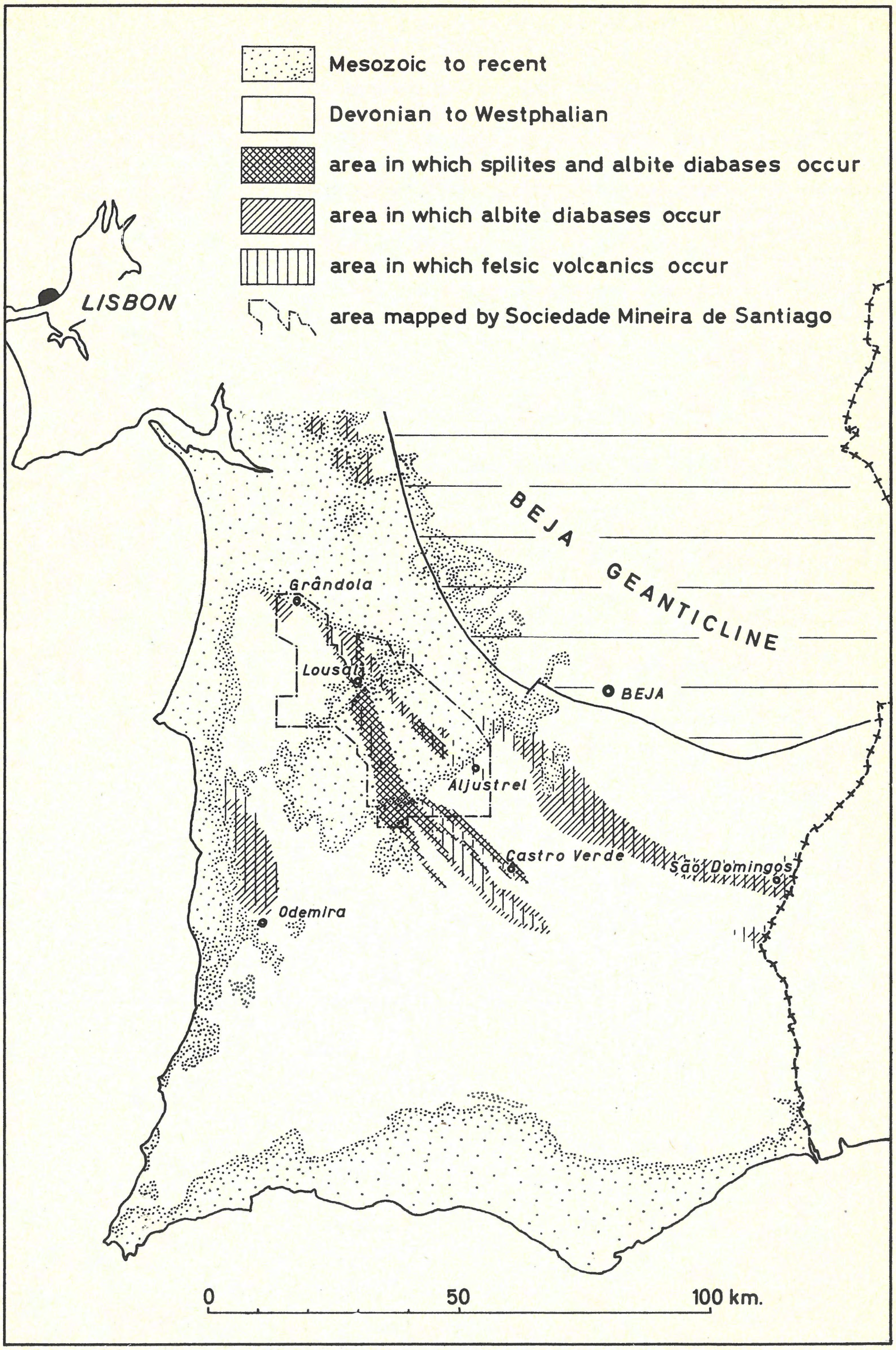

Fig. 1
Distribution of spilites, albite diabases and felsic volcanics in the Hercynian geosyncline of South Portugal.

Geanticline and lacks contemporaneous volcanics.

The volcanics are sharply divided into a leucocratic assemblage of texturally strongly varying but mineralogically simple quartz-keratophyric, more rarely quartz-latitic, rhyolitic or keratophyric, submarine tuffs (S c h e r m e r h o r n, 1970) and a mafic assemblage of spilites and albite diabases, with allied rocks, which locally becomes dominant. All of these volcanics were more or less strongly affected by Hercynian deformation and chlorite-grade regional metamorphism. The effects of shearing and recrystallization are most noticeable in the spilites which often are more or less cleaved or even transformed to greenschists. The coarser diabases generally only show marked deformation along their contacts where they may be rather schistose while still massive and undeformed in the interior of the larger intrusions.

THE BELT OF MAFIC VOLCANISM

As the volcanics are linked to the Volcanic-Siliceous Complex they are only found where this unit outcrops. To the south it disappears below the thick Culm greywackes and slates. In the extreme southwest the top of the Tournaisian and the Viséan reappear in a small area but in a non-volcanic shelf facies. The map showing the extent of the felsic and mafic volcanism (fig. 1) is based for the outlined area in the northwest on mapping done at 1 : 5000 and 1 : 27,500 by Dr. W.I. Stanton and the writer for Sociedade Mineira de Santiago and as regards the Tertiary-covered part of this area, on boreholes and geological interpretation of gravimetric surveys carried out by Serviço de Fomento Mineiro for Sociedade Mineira de Santiago. The mafic volcanics have here been closely studied in the field and in drill cores because several authors (e.g. S t r a u s s, 1965) have postulated that pyrite deposition is genetically linked to mafic vulcanicity, and because the spilite bodies caused high Bouguer anomalies in the Tertiary basin.

The southeast portion of the spilite belt is traced after the Carta Geológica de Portugal (1968 edition), the maps given by C a r v a l h o s a (1961) and Z b y s z e w s k i et al. (1964) and unpublished surveys by Serviço de Fomento Mineiro, supplemented by field observations. Spilite samples from the southeast part of this belt were described in detail, with chemical analyses, by C r u z G a s p a r (1961) and C a r v a l h o s a (1961).

In the areas more to the southwest (K l e y n, 1960) and to the east (W e b b, 1958; v a n d e n B o o g a a r d, 1967; P f e f f e r k o r n, 1968) the felsic volcanism is accompanied by some measure of mafic intrusion but not large spilite complexes occur here. The next zone of spilite eruption is found in Southwest Spain.

Thus, the spilite belt indicated on fig. 1 forms the main occurrence of spilites in South Portugal. Elsewhere spilites are rarely met with, and in small isolated bodies only. The albite diabase aureole around the spilite belt occupies a much larger area.

Within the area surveyed by Sociedade Mineira de Santiago, detailed mapping and many boreholes indicate that the spilites and albite diabases are distinct though closely associated manifestations of the same episode of mafic vulcanicity. The spilites are submarine flows and the diabases are intrusions, mostly sills.

KERATOPHYRE

Some authors (e.g. K l e y n, 1960; v a n d e n B o o g a a r d, 1967) have recorded the presence of keratophyre and albitite, mostly in intrusive bodies, among the mafic volcanics.

The felsic volcanics of the South Portugese basin comprise a minor amount of keratophyres, accompanying the quartz keratophyres. Here the term keratophyre is used according to definition for leucocratic feldspar-phyric eruptive rocks in which the phenocrysts largely or entirely consist of albite; at times the matrix is composed of an aggregate of random or of trachytic-textured feldspar (albite) microlites in which case the rock could be classed as intermediate, but more often there is a microfelsitic groundmass difficult of optical determination but which in many cases seems to be highly siliceous so that the rock composition would be felsic. Such keratophyres differ from the quartz keratophyres only in the absence of quartz phenocrysts. In its entirety, the felsic suite of the South Portuguese geosyncline is highly leucocratic: biotite phenocrysts are scarce and although many of the rocks carry some chlorite it rarely occurs in considerable quantities.

Thus, the keratophyres (in the strict sense) belonging to this suite must be distinguished from the keratophyres of mafic affinities described by Kleyn and van den Boogaard. The latter type, although characteristically showing a high proportion of albite in groundmass and phenocrysts, is quite different from the felsic type in its field relationships, composition (content of mafic minerals) and rather coarser grain size. No transitions exist between the two types.

The distinction thus imposed between keratophyres of felsic and of mafic affinities is rather cumbersome. However, it seems somewhat doubtful whether the latter type of keratophyre is correctly named. It is true that there exists considerable confusion in the literature as to the meaning of the term keratophyre, one author even applying this name to altered phonolite. (In a forthcoming paper (S c h e r m e r h o r n, in preparation (b)) it is proposed to trace the history, use and abuse of the rock name keratophyre.)

Q u i r i n g (1936) who was well acquainted with the keratophyres of the type area, used the terms keratophyre and quartz keratophyre interchangeably for the leucocratic volcanics of the area north of Odemira (so on p. 12: "Der Liegende Keratophyr ist ein Quarzkeratophyr von weisser Farbe.") and recognized their alternation. In his detailed study of part of this region, K l e y n (1960) called these rocks rhyolitic metavolcanics (although albite phenocrysts exceed potash feldspar phenocrysts in amount).

In any case, the mafic-type keratophyres are near-diabases, minor products of the mafic vulcanicity.

Some authors have remarked on the frequent occurrence of spilitic fragments in the Culm greywackes. Yet these greywackes carry an abundance of (felsic-type) keratophyre clasts (with albite-microlite matrix containing some interstitial chlorite: such fragments may well represent in part at least the groundmass of certain quartz keratophyres) but rarely true spilitic clasts.

Lastly, in the area surveyed by Sociedade Mineira de Santiago the true albite diabases of many regions are closely accompanied by rocks of a somewhat different aspect, though of similar composition, which have been designated, for want of an adequate name, as "diabase type II" (they are not keratophyres according to the definition). These are described below.

LITHOLOGY OF THE SPILITES

The spilites are much finer-grained than the diabases in general: their grain size does not exceed 0.5 mm (apart from phenocrysts) and is usually rather less, so that the rocks vary from aphanitic to very fine-grained. They are grey-green to reddish in colour and show a superior resistance to erosion, tending to form rocky ridges.

The rocks are generally amygdaloidal, containing small chloritic amygdules (mostly flattened owing to deformation) and often calcitic ones as well. Under the microscope some albite, epidote, quartz and hematite are seen.

Undeformed or little sheared spilites are made of small laths to microlites of albite in random or subparallel arrangements, occasionally accompanied by microphenocrysts of albite or albite-oligoclase. The albite crystals may touch but more often float in an aggregate of chlorite with finely granular leucoxene or sphene, often accompanied by some calcite and sometimes by epidote and hematite. There is a general absence of pyroxene or olivine.

Strongly deformed spilites consist of a schistose aggregate of chlorite and/or sericite, with leucoxene, calcite and sometimes epidote and hematite. In some of these greenschists albite has postkinetically recrystallized to random fresh undeformed laths.

PILLOW LAVAS

Pillow structures may be seen both in the outcrop and in drill cores (fig. 2). The pillows range up to 2 m. in length and their shape varies from ellipsoidal to highly irregular owing to mutual indentation. They show concentric zoning and chilled margins which may be enriched in epidote or hematite, and may display amygdaloidal cores. In some flows the pillows are highly amygdaloidal, in others barely so. Radial cracks may occur.

Two types of inter-pillow fillings occur: in one the interspaces contain irregular veins mostly of chlorite, with epidote, hematite and calcite (fig. 2b). This type probably formed as a residual product in the interior or the upper parts of flows. In the other type unconsolidated sea floor sediments (now slate, chert and radiolarite) have been taken up in the interstices between the pillows (fig. 2a). This must have occurred at the base or at the periphery of flows when the spilitic magma was spreading on the sea floor.

Where such structures are present, the spilites are pillow lavas and therefore true submarine extrusions. Some spilites form massive flows.

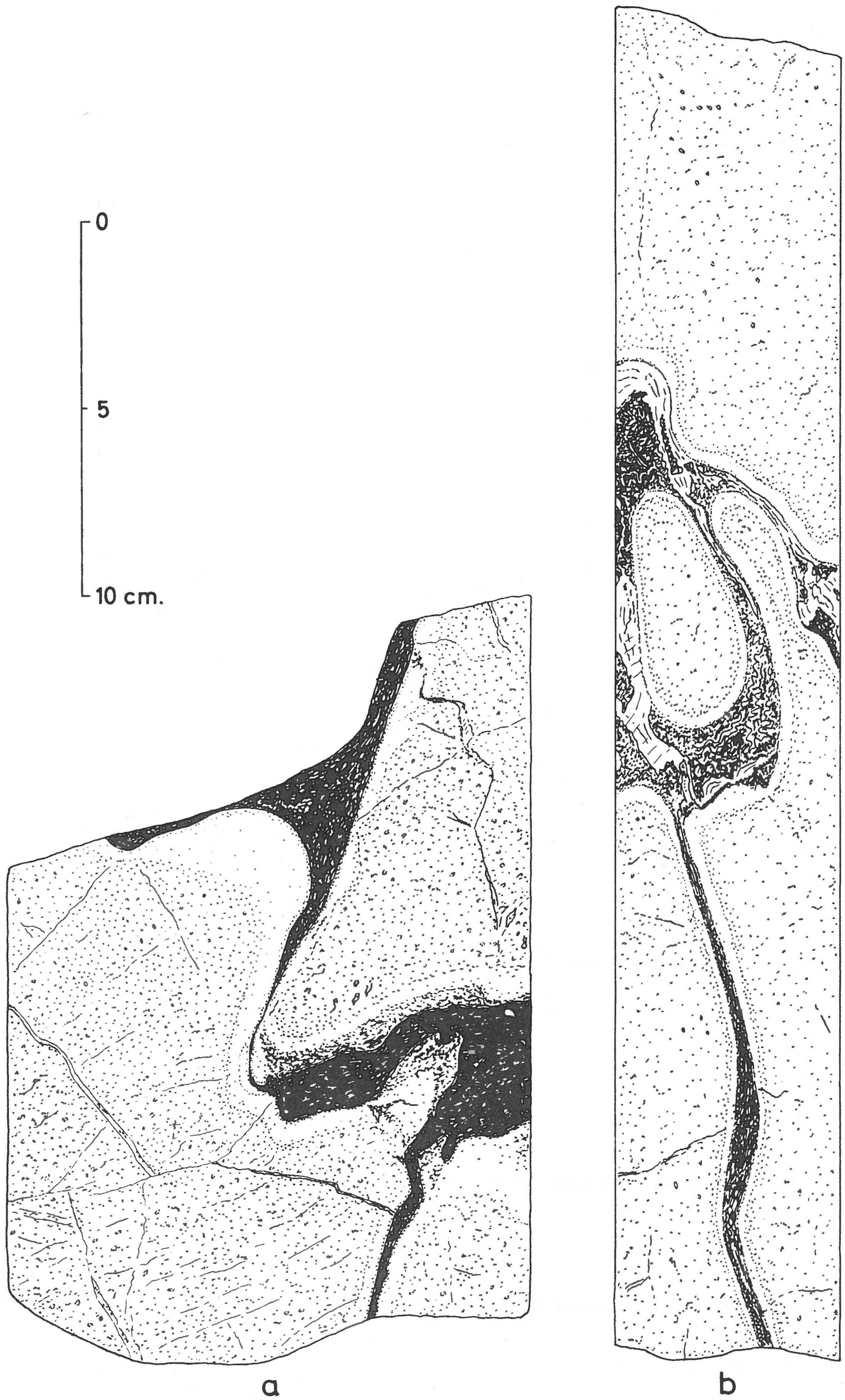

Fig. 2
Drill core sections of spilitic pillow lavas. (a): with radiolarian slate and chert between the pillows; (b): with chlorite, epidote and calcite between the pillows.

FRAGMENTAL SPILITES

In many places the spilite flows are underlain or surrounded by a level of fragmental spilites. These contain angular pieces of amygdaloidal spilite, often fragments of pillows, together with some scattered lumps of other rock types and sometimes hematite pellets, set in a plentiful reddish spilitic or slaty-spilitic matrix.

Such rocks seem to have been called "Schalstein" at Lousal by S t r a u s s (1965) and regarded as mafic tuffs within his ophiolite series.

The origin of these fragmental spilites is uncertain. They could be pyroclastics due to explosive activity of the spilite magma if it were not that the remainder of the spilite and diabase succession displays clear signs of quiet eruption. More likely is an explanation as accumulations of pillow lava debris, produced by shattering of spilite pillows under the sea (chill-breccia) and transported out from the pillow lava piles by sliding and gravity flow.

LITHOLOGY OF THE ALBITE DIABASES

The true albite diabases are coarser than the spilites and are rarely amygdaloidal. In several regions they may become so coarse-grained as to resemble gabbros, with plagioclase laths up to 6 mm long, except for their (sub)ophitic texture. Porphyritic diabases are very rare. Very thin diabase sills and the chilled edges of thicker ones are similar to spilite. The thin sills are sometimes amygdaloidal where they were intruded close below the sea floor.

In contrast to the spilites, the diabases tend to be deeply weathered, producing a dark brown soil, and outcrops are rare. Spheroidal weathering is frequent.

The plagioclase is albite but zonal alteration is sometimes seen (and argues for an originally more calcic composition). The alteration may be saussuritic or chloritic-sericitic. The feldspar builds laths in random orientation. In some rocks there occur grains and patches of pyroxene varying from pigeonite to diopsidic augite, sometimes in ophitic, but mostly in subophitic or intergranular textures. The pyroxene may be accompanied by patches of chlorite (or serpentine) apparently replacing another mafic mineral. In other rocks chlorite only is present. The pyroxene is attacked by green or brown hornblende (or barkevikitic amphibole), tremolite or actinolite, forming small ragged crystals, and alters to chlorite or to chlorite-epidote aggregates. Sphene or leucoxene are generally present. Ilmenite and, less frequently, magnetite, with some apatite and pyrite, occur in accessory amounts. Biotite is infrequent, epidote (clinozoisite) and calcite are of irregular distribution though often present. Pumpellyite is very rare. Several diabases carry a little late-stage quartz and in a few specimens some untwinned potash feldspar is seen replacing albite.

In sheared diabases, along the borders of sills, the pyroxene has been all replaced by chlorite and the plagioclase tends to be sericitized.

Associated with these true albite diabases there are found, as stated, rocks referred to as type II-diabases. They are light greenish grey, of even, fine to medium grain size, and may be rudely sheared. In the field these rocks weather quite differently from the true albite diabases, forming rocky ridges, presenting no spheroidal weathering and producing a light grey-brown soil.

These rocks are composed of albite laths in a more or less random arrangement (albite phenocrysts are very rare), sometimes accompanied by clinopyroxene or hornblende, and contain plentiful chlorite interstitial to or ophitically englobing albite, and occasionally displaying prismatic shapes after original mafic minerals (pyroxene relics may still be included). Calcite normally occurs in abundance (more so than in the albite diabases of type I), as do leucoxene and/or sphene. Epidote, zoisite or clinozoisite are usually present too. At times there occurs some quartz.

Though sometimes forming separate intrusive bodies, this type of rock is more often directly associated with type I-diabase in the same sills, either covering it or underlying it or alternating. The relationship between the two types, evidently closely allied, is not well understood. In the following both are discussed together as albite diabase.

INTRUSIVE RELATIONS

The albite diabases (of both types) form sills and less often larger somewhat irregular intrusive masses (fig. 3) which may have acted as channelways to the magma. Crosscutting dykes have not been seen. In the spilite belt the diabase intrusions occur in thick

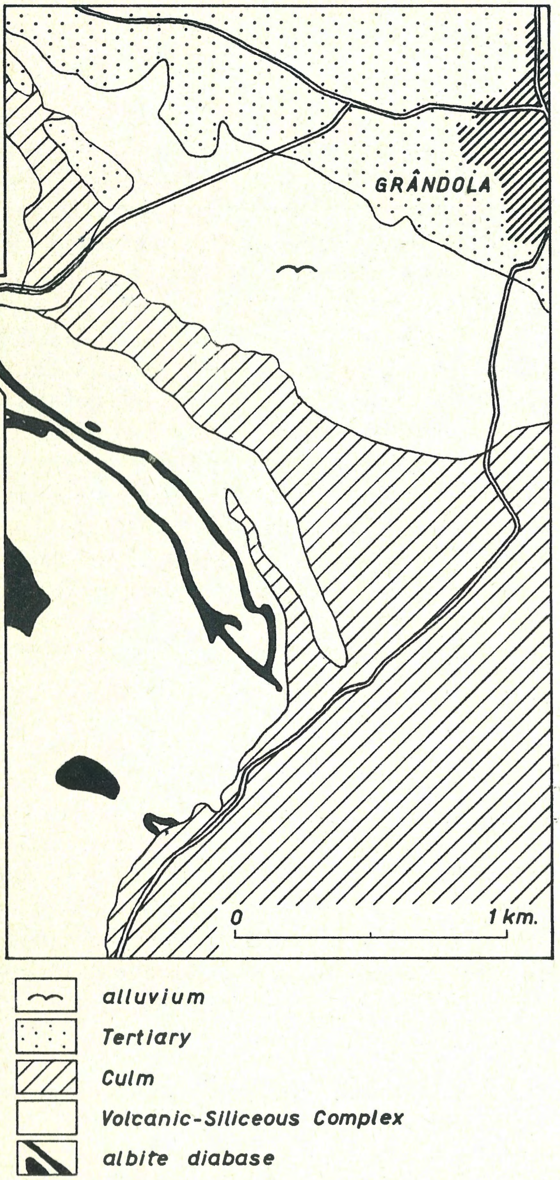

Fig. 3
Albite diabase sills and masses southwest of Grândola, intruded into a slaty lithofacies (slates, siltstones and siliceous slates with cherts) of the Volcanic-Siliceous Complex.

successions, locally up to several hundreds of metres thick, underlying the spilites, but in the outer zone they tend to occur singly though sometimes building very extensive intrusive sheets (fig. 3). Individual sheets are rarely over 25 m thick.

The diabase intrusions are mostly confined to the Volcanic-Siliceous Complex but locally some sills are found at the top of the Phyllite-Quartzite Group. Except where faulted, the diabases are not in contact with the Culm.

The contacts of the diabase sills are generally seen to be roughly concordant, tending to follow bedding planes in the slaty or cherty wall rocks, but overstepping and crosscutting on a minor scale are usually present too. The noses of the sills tend to be blunt. Chilled margins on top and bottom of diabase bodies and contact metamorphism in the wall rocks prove intrusion.

The chilled borders, 10-100 cm thick according to the size of the intrusion, may be somewhat porphyritic, with small pyroxene and plagioclase phenocrysts in a dense, very fine-grained to aphanitic groundmass. The contact metamorphism ranges from slight induration of sedimentary wall rocks around small sills to hornfelses and spotted slates around the larger bodies, in zones up to a few metres in width.

In borehole cores thick successions of sills are seen to contain numerous thin slaty and cherty intercalations, with contacts that sometimes are very irregular, but mostly regular.

It thus appears that the albite diabases are high-level intrusions injected at varying depths, in part into semiconsolidated sediments at no great depth below the sea floor.

AGE RELATIONS OF SPILITES AND ALBITE DIABASES

Both field work and borehole study have established that the normal succession of mafic volcanism in this sector is as follows: the framework of the Volcanic-Siliceous Complex consists of grey-black slates; towards the top of these there appear diabase sills which higher up may coalesce into a distinct level; on top of this there appears a massive succession of spilite flows which are covered by a thin horizon of slates with some jasper, conformably overlain by the Culm. Where felsic volcanism occurs in the spilite area it is below the mafic volcanics.

In some areas the mafic volcanics form the greater part of the Volcanic-Siliceous Complex and few or no felsic rocks are met with. This is the case north of Lousal where diabase sills enclosing thin slaty lenses make up some 500 m thickness, from the base of the Complex up, being covered by a small thickness of spilites and slates.

Outside the spilite belt proper the diabase sills are found within the Volcanic-Siliceous Complex up to near its junction with the overlying Culm.

Since the diabases are intrusive there is no direct evidence as to the period or periods of emplacement within Volcanic-Siliceous Complex times. The spilite levels generally do not contain any diabase sills. Based on the succession from diabase to spilite, it seems that a sequence of albite diabase sills was intruded below the sea floor until such a time as the magma broke through to the surface and extruded spilite lava, towards the end of Volcanic-Siliceous Complex times (i.e. in the lower Viséan). There may have been considerable overlapping in time of the two processes. Elsewhere no spilite effusion took place and all mafic activity was intrusive. The greatest volume of mafic rocks was emplaced in the spilite belt, and the diabase intrusions outside it are sporadic only.

After folding and variable deformation slight metamorphism ensued, not passing beyond the greenschist facies.

LOWER CARBONIFEROUS SPILITES AND ALBITE DIABASES IN SOUTHWEST SPAIN

The Hercynian basin of South Portugal continues into Southwest Spain (Huelva Province) and many authors have here referred to mafic volcanism. Strauss (1965) records pillow lavas from Tharsis. From south of Rio Tinto Williams (1934) mentions a belt of doleritic rocks, generally sills, interdigitating with slates. The map given by Rambaud (1969) only distinguishes mafic lavas and pyroclastics, covering quite extensive tracts.

A detailed description is provided by Soler (1969) who surveyed, in the region north of Rio Tinto, a broad belt of felsic tuffs containing lenses of mafic rocks ranging from spilite to albite diabase.

Observations made in Southwest Spain indicate that mafic flows and intrusions may form an extensive level. In contrast to South Portugal, this mafic level overlies the Phyllite-Quartzite Group, and is followed by the felsic volcanism. Locally, some mafic intrusions are found at higher horizons within the Volcanic-Siliceous Complex.

RELATIONSHIPS BETWEEN THE MAFIC AND THE FELSIC VOLCANISM

The junction between Phyllite-Quartzite Group and Volcanic-Siliceous Complex is a lithostratigraphical boundary marked by the sudden eruption of felsic magma in many different places, leading to the deposition of felsic volcanics and siliceous sediments. (This boundary therefore is not strictly synchronous but not likely either to be markedly diachronous, in view of the large extent of the felsic volcanics and related rocks and of the nature of this type of explosive vulcanicity.) Between the eruptive centres deposition of grey-black slates went on.

The Volcanic-Siliceous Complex was deposited in a period of mild subsidence (up to 750 m of sediments and volcanics during the Tournaisian and Lower Viséan, i.e. some 15 m.y.), hence of some crustal tension. (Strong subsidence set in with the following non-volcanic Culm of which a thickness of some kilometres was laid down in about 30 m.y.)

The mafic eruptions were largely if not entirely of non-explosive nature, yielding outpourings of magma producing what are now spilites and shallow intrusions of what are now mostly albite diabases.

In those areas in South Portugal where both types of vulcanicity operated, the mafic rocks commonly follow the felsic tuffs and there is no intermingling. Under the microscope no gradations are seen and felsic and mafic volcanics are easily distinguishable. Yet in Southwest Spain the converse relationship holds and the felsic eruptions followed the mafic ones.

The felsic-mafic relationships may be summarized as follows:

time – no strict contemporaneity: felsic vulcanicity either earlier (South Portugal) or later (Southwest Spain) than mafic vulcanicity;

space – the mafic activity overlaps the ground of the felsic volcanism but its highest productivity is confined to a central zone; thick mafic successions generally contain little or no felsic material and vice versa;

composition – quite distinct: no transitions, no intermingling or hybridization, no signs of consanguinity;

mode of eruption – explosive felsic eruptions producing tuffs vs. quiet effusion and intrusion of mafic magma.

These points merit some discussion in view of the prevailing opinion that where mafic and felsic volcanism are juxtaposed they must be genetically related.

THE ASSOCIATION OF FELSIC AND MAFIC MAGMA

Many authors have stressed the close relationship between spilites (including albite diabases) and keratophyres (taken to comprise quartz keratophyres), generalized it into the concept of the "spilite-keratophyre-suite" and endeavoured to derive the keratophyres and quartz keratophyres by differentiation from a parent spilite magma.

The mesmerism exerted by this concept has been such that where spilites and felsic volcanics occur in spatial association, a genetical connexion is automatically assumed.

Thus, Rocci and Juteau (1968) claim that mantle-derived mafic lavas become contaminated by the sialic crust through which they rise, resulting in a hybridization towards keratophyre, with all transitions (not quartz keratophyre although one would suppose that assimilation of sialic crust would rapidly produce free quartz). They judge that the spilite-keratophyre series, typical of the Hercynian chains, consists of the differentiated and contaminated products of simatic magma (yet their fig. 2 shows diabases and spilites as being well distinguished from keratophyres in terms of Niggli parameters). To me it appears more probable that little contamination and hybridization of the original magma by sialic crust took place, for spilites and associated albite diabases from various regions always show a similar, quite distinct composition, while keratophyres and quartz keratophyres more often differ widely. Whatever the cause of the special composition of spilites and albite diabases, if it is not a primary feature it must be due to a modification that occurred during ascent; not on contact with sea water, since the albite diabases which did not penetrate into the sea show the same peculiarities as the spilites which did. Spilites and associated albite diabases from all over the world and of all ages display the same characteristics. While their mineral composition has been modified due to secondary alteration after emplacement, whether autometasomatical or not, their average chemical composition is typified by low SiO_2, very low K_2O and high Na_2O. This effectively precludes the possibility of considerable assimilation of sialic basement. While containing less CaO than basalts, many spilites and albite diabases are rather high in CO_2 (others lack it due to the mobility of this component). It is tempting to see here an analogy with other deep-derived carbonate-bearing eruptives such as kimberlite or carbonatite.

Moreover, a differentiation scheme deriving the felsic and mafic magmas from a parent spilitic or basaltic magma runs into difficulties when faced with the fact that in South Portugal the felsic volcanism preceded the mafic eruptions while following them in Southwest Spain.

However, the "spilite-keratophyre suite" and the causal link it implies may be valid for other provinces but in the Lower Carboniferous of South Portugal no direct genetical connexion between mafic and felsic volcanism is evident on closer examination. Only in the wider sense can there be said here to exist an association in time and space of the two volcanisms. The compositions are quite distinct and no signs of mixing of the two magmas have been observed.

Blake et al. (1965) were "impressed by the widespread evidence for the co-existence, side by side, of acid and basic magma". In support they listed composite mafic-felsic flows and intrusions, mixed lavas, tuffo-lavas, tuffs and intrusions (felsic magma containing mafic inclusions incorporated when liquid), net-veined intrusive complexes, and other features due to the intermingling of felsic and mafic magma.

No such hybridization phenomena due to simultaneous eruption are known from the South Portuguese volcanics. In fact, the felsic and mafic eruptive centres appear to have been so well separated that practically no xenoliths of one rock type in the other are known.

Thus, the felsic and mafic vulcanicity evolved in separate episodes and in separate domains, with very little overlapping. It can be said that they are distinctly antipathetic.

SOURCE AND ORIGIN

From the foregoing it is concluded that the felsic and mafic eruptions originated in separate, independent magma chambers and that their loose spatial and temporal relationships are due not to a common origin but to a common tectonic cause of ascent in the crust and eruption, i.e. to crustal evolution during the geosynclinal stage.

It seems hardly likely that the spilites and albite diabases should directly stem from remelting of Precambrian sialic basement underlying the deposits of the Hercynian geosyncline. They must be due to the rise of mafic magma generated in the lower crust or upper mantle, most probably by fractionation of ultramafic mantle material.

The felsic volcanism on the other hand, with its characteristics varying from one eruptive centre to the next, would represent the generation of local magma blisters by melting in deep levels of the crust (and this might well be owing to heat supplied by rising mafic or ultramafic magma).

Envisaging possible mechanisms opening conduits to magmas ascending through the crust, during a period of permissive crustal distension, does not raise difficulties. However, it is hard to explain why all eruptions should have ceased by the time the Culm was being deposited, its accumulation being due to marked vertical movements (subsidence in the flysch basin, uplift of the Beja Geanticline as source area). Later mafic activity in South Portugal is post-orogenic.

To conclude, in orogenic belts where initial felsic volcanism is well developed (ranging from quartz keratophyre and keratophyre to rhyolite; mafic volcanics, including spilites, may accompany the felsic rocks) there is generally also found an extensive syn- to posttectonic phase of granitic plutonism (ranging from quartz diorite and granodiorite to granite s.s.). In orogenic belts such as the Alps where spilites are well in evidence but initial felsic volcanics are rare to absent, granites likewise are poorly developed. This argues for a connexion between initial felsic volcanism and later plutonism and against a direct link between spilites and (quartz)keratophyres.

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