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GEOCHRONOLOGICAL, GEOCHEMICAL AND GEOPHYSICAL INVESTIGATIONS IN THE HIGH-GRADE MAFIC-ULTRAMAFIC COMPLEX AT CABO ORTEGAL AND OTHER PRE-EXISTING ELEMENTS IN THE HERCYNIAN BASEMENT OF GALICIA (NW SPAIN)

BY

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SUMMARY

Mafic and ultramafic rocks from a high-grade complex at Cabo Ortegal in NW Spain were investigated in the field and in the laboratory by means of petrological, isotope-geochronological and geochemical methods. Isotope-geochronological methods were applied to orthogneisses from a high-grade complex near Mellid and from the blastomylonitic graben between Malpica and Tuy, a mica-bearing eclogite lens from the same graben, and to a two-mica granite from the area near La Guardia. A gravity survey was carried out in part of the belt of sub-circular complexes surrounding the Ordenes basin.

The geochronological investigations revealed ages of about 500 Ma to 320 Ma for older elements in the Hercynian basement of Galicia. Geochemical investigations in the Cabo Ortegal complex showed that the granulites and eclogites form a group that was part of an older, pre-existing continental crust. The ultramafic rocks of the Cabo Ortegal complex may have been derived in two melting episodes from a proposed mantle-plume. It is possible that the metagabbros in the complex originated in the second melting episode. The gravity survey showed the existence of three positive anomalies, situated below high-grade complexes near Santiago de Compostela, near Mellid and near Sobrado, that can be interpreted as ultramafic diapirs.

A model involving continental rifting, mantle-plume diapirism, rejuvenation of the lower crust and initial seafloor-spreading is proposed for the evolution of the Early Palaeozoic continental lithosphere of the northwestern Iberian Peninsula.

SAMENVATTING

Mafische en ultramafische gesteenten uit het hooggradige complex van Cabo Ortegal in NW Spanje zijn onderzocht in het veld en in het laboratorium met behulp van petrologische, isotopen-geochronologische en geochemische methoden. Isotopen-geochronologische methoden werden toegepast op orthogneizen uit het Mellid complex en uit de blastomylonitische slenk tussen Malpica en Tuy, op een glimmerhoudende eklogietlens uit deze slenk en op een twee-glimmer graniet uit het gebied rond La Guardia. Een gravimetrisch onderzoek werd uitgevoerd in een gedeelte van de gordel van sub-circulaire complexen rond het Ordenes bekken.

Het geochronologische onderzoek heeft ouderdommen opgeleverd van ongeveer 500 Ma tot 320 Ma voor oude elementen in het Hercynische grondgebergte van Galicië. Het geochemische onderzoek aan gesteenten uit het Cabo Ortegal complex heeft aangetoond dat de voorkomende granulieten en eklogieten een groep vormen die deel uitgemaakt heeft van een oude continentale korst. De ultramafische gesteenten uit het Cabo Ortegal complex kunnen in twee smeltepisodes zijn ontstaan uit een gepostuleerde mantelpluim. Mogelijk zijn de in het complex voorkomende metagabbros tijdens de tweede smeltepisode ontstaan. Het gravimetrische onderzoek heeft het bestaan aangetoond van drie zwaartekrachtsanomalieën in de ondergrond rond hooggradige complexen bij Santiago de Compostela, bij Mellid en bij Sobrado die geïnterpreteerd kunnen worden als ultramafische diapieren.

Er wordt een model voorgesteld van continentale slenkvorming, mantelpluim diapirisme, rejuvenatie van de onderste korst en initiële zeebodem-vorming voor de ontwikkeling van de vroeg-Paleozoische continentale lithosfeer in het noordwestelijke deel van het Iberisch Schiereiland.

GEOLOGICAL SETTING

For the geological setting of the complexes under discussion the reader is referred to Vogel (1967) and Engels (1972) for the Cabo Ortegal complex, to Hubregtse (1973) for the Mellid complex, to Den Tex & Floor (1967), Floor (1966) and van der Wegen (1977) for the blastomylonitic graben, and to Buiskool Toxopeus et al. (1977) for the La Guardia area. Several related aspects to Galician geology are given by Koning (1967), Den Tex & Floor (1971) and Den Tex (1977).

GEOCHEMISTRY OF THE CABO ORTEGAL COMPLEX (van Calsteren, 1977a)

The geochemical data of the mafic and ultramafic rocks in the Cabo Ortegal complex are interpreted in terms of the origin and evolution of the rocks. The mafic rocks in granulite and eclogite facies appear to belong to one geochemically homogeneous group of quartz-normative tholeiites, enriched in lithophile elements, and with mean La/Sm and K/Rb ratios of 3.25 and 284, respectively. This group has great similarities to continental tholeiites such as the Columbia River Plateau basalts and the Deccan Traps (Schmitt et al., 1964). Metagabbros and amphibolites occurring in the western extremity of the complex appear to form another geochemically homogeneous group of olivine-normative tholeiites. This group of rocks is impoverished in lithophile elements and has mean La/Sm and K/Rb ratios of about unity and 319, respectively. They are comparable to oceanic island tholeiites such as occur on Iceland (Schilling, 1973) and Hawaii (Schilling & Winchester, 1969). Pyroxenite layers in the ultramafic rocks have characteristics similar to the enclosing peridotitic rocks, although with somewhat higher incompatible element contents, and lower La/Sm and K/Rb ratios. This shows that the pyroxenite layers originated from peridotitic rocks by processes of local partial melting. The ultramafic rocks are depleted in incompatible elements, showing that they were the residual phase in a melting episode during which the melt fraction left the system (Raleigh melting); a similar behaviour is inferred, for example, for the high-temperature peridotites of the Lizard and Tinaquillo by Frey (1969) and Frey & Green (1974). However, the high mean K/Rb and La/Sm ratios of 747 and around 9, respectively, indicate that the peridotitic rocks themselves represent the melt fraction in another melting event.

These geochemical characteristics may be explained invoking two successive episodes of partial melting, with ultramafic rocks forming the melt phase in the first, and the residual phase in the second episode.

ISOTOPE GEOCHRONOLOGY OF THE CABO ORTEGAL COMPLEX (van Calsteren et al., 1977)

The isotopic age data are interpreted in terms of the ages of geological events. For the ultramafic rocks a Rb-Sr isochron is obtained of 487 ± 122 Ma, which is interpreted as representing the intrusion age of these rocks. Phlogopites separated from the ultramafic rocks have a Rb-Sr age of 394 ± 10 Ma, while the K-Ar ages of different minerals from various mafic and ultramafic rocks also cluster around 390 Ma; this age is interpreted as approximating the time at which the granulite facies metamorphism terminated. The Rb-Sr whole-rock biotite age of 354 ± 17 Ma measured on granulites, and the Rb-Sr mineral age of 344 ± 10 Ma of edenites from the ultramafic rocks, are interpreted as reflecting the end of the conditions of the hornblende granulite facies metamorphism.

ISOTOPE GEOCHRONOLOGY OF OTHER PRE-EXISTING ELEMENTS IN W GALICIA (van Calsteren et al., 1977)

Isotopic dating of orthogneisses in the Hercynian basement of W Galicia yielded ages of the same order as the ages obtained from rocks in the Cabo Ortegal complex (see above). A metamorphosed and tectonized calcalkaline granite gneiss suite from an area near Mellid revealed a Rb-Sr whole-rock isochron age of 409 ± 24 Ma. Similar orthogneisses from the southern part of the blastomylonitic graben yielded a Rb-Sr whole-rock isochron age of 466 ± 29 Ma, while an orthogneiss from the northern part of the same graben gave a Rb-Sr whole-rock age of 462 Ma. The ages of the orthogneisses are interpreted as reflecting an episode of granitic magmatism between 465 and 400 Ma ago, apparently contemporaneous with the intrusion of the ultramafic rocks from the Cabo Ortegal complex. A genetic relationship between these two types of magmatism seems obvious.

Phengites from an eclogite lens near the township of La Pioza in the northern part of the blastomylonitic graben have Rb-Sr ages averaging 374 Ma while their mean K-Ar age is 331 Ma; paragonites from the same lens have K-Ar ages averaging 352 Ma. The mineral ages between about 370 and 330 Ma of these paragonites and phengites correspond to the age deduced for the end of the hornblende granulite facies metamorphism in the Cabo Ortegal complex. This suggests that the conditions of high-grade metamorphism came to an end at about the same time in both high-grade complexes.

In the area around La Guardia in SW Galicia, alkaline two-mica granites occur that originated before the second Hercynian deformation phase, and are genetically related to a regional migmatization episode in W Galicia (Buiskool Toxopeus et al., 1977). The Rb-Sr whole-rock isochron age of these granites is 318 ± 21 Ma. The time interval between the end of the high-grade metamorphism in the high-grade complexes and the emplacement of these granites is thus comparatively short, so a genetic relationship between the two episodes cannot be excluded.

GRAVITY SURVEY (Keasberry et al., 1976)

A gravity survey was carried out in part of a basin with mainly sedimentary rocks around Ordenes, and in a girdle of high-grade complexes surrounding this basin. This revealed the existence of three separate gravity anomalies. An asymmetrical positive anomaly with an amplitude of 25 mGal, compared with the regional gravity, located around Santiago de Compostela, is accompanied by two symmetrical positive anomalies with amplitudes of 10 mGal and 15 mGal around Sobrado and Mellid, respectively. This points to the presence of three deeprooted structures of dense material, which can be interpreted as ultramafic diapirs. Van Overmeeren (1975) uses the same interpretation as one of the possible explanations for the gravity distribution pattern in and around the Cabo Ortegal complex.

MANTLE-PLUME MODEL (van Calsteren, 1977b)

The data summarized above, together with numerous data collected by the research group 'Galicia' from the Petrology Department of the State University at Leiden and many other research teams working in the western and northern part of the Iberian Peninsula, are incorporated in a hypothesis for the Palaeozoic evolution of W Galicia.

The starting point of this model is a normal continental crust consisting of igneous mafic and sedimentary rocks, with a metamorphic grade up into the eclogite facies. It is assumed that in the Early Palaeozoic a mantle-plume developed under the crust. A short explanation of the phenomenon 'mantle-plume' seems appropriate here.

At some level in the mantle, perhaps at a depth of several hundreds of kilometers, a comparatively thin layer originates with a density lower than the density of the overlying mantle material. Such a density inversion can be caused by an anomalous composition of the mantle (mantle heterogeneity) or by a rising heat current from the lower mantle. At certain places on the interface between low and high density material, the lighter material will tend to rise (Raleigh-Taylor instability). The viscosity ratio between the rising material and the wall-rock determines the style of the diapirism. If the wall-rock is more viscous, rim-synclines will develop and the diapir becomes mushroom-shaped. If the material of the diapir is more viscous, there will be no rim-synclines, and the diameter of the diapir at its top is less than at its base. A first order diapir can have a diameter of about 100 to 200 km depending on the thickness of the low density source layer (see: Whitehead & Luther, 1975).

In the proposed model, a first order diapir, for the sake of convenience called 'mantle-plume', was situated in the mantle below Galicia. In this mantle-plume the diapir production process was duplicated on a smaller scale. Second order diapirs of lherzolitic composition developed, which intruded the lower crust. Within the crust the density inversion ceased to exist and the diapir lost its buoyancy. Some lateral extension might have accompanied the process.

The lherzolite of the Cabo Ortegal complex is regarded as representing one of the second order diapirs, and its proposed evolution will be discussed. The lherzolites were the melt fraction of the mantle-plume at great depth as indicated by the high La/Sm and K/Rb ratios. During the diapiric rise the lherzolite solidified. At a depth of about 100 km, in the astenosphere, partial melting started again, leading to a liquid of tholeiitic composition (cf. Green & Ringwood, 1963) that was able to leave the diapir, and intruded the lower crust. The group of metagabbros and amphibolites in the Cabo Ortegal complex may be regarded as representing this magma. A very small part of the melt-fraction was not able to leave the diapir, and crystallized in situ as pyroxenite layers and veins in the lherzolite. The very last melt-fraction in the lherzolite crystallized at a temperature of about 1100 °C as veins and lenses consisting mainly of phlogopite and pargasite or edenite (cf. Green, 1973). Heat given off by the lherzolite diapir induced granulite facies metamorphism in the already medium to high-grade metamorphic crust. The group of rocks with quartz-normative tholeiitic composition may be regarded as part of this older crust.

The regional temperature increase caused by the mantle-plume induced anatexis in the deeper parts of the crust, leading to the generation of calcalkaline granitic magmas. These magmas intruded higher parts of the crust, mainly along deep reaching faults, sometimes causing contact metamorphic aureoles. The oldest representatives of these granite suites are now orthogneisses. Some of the calcalkaline magmas were enriched in juvenile material, derived from the mantle-plume or its diapirs, and differentiated to peralkaline granite magmas (Bailey, 1974) that also intruded higher crustal levels. Heat from the mantle-plume also caused migmatization in higher levels of the crust, and the generation of alkaline two-mica granite suites. The relatively low-grade metamorphism of penecontemporaneous sediments in the upper crust shows a rough spatial relationship with the younger granites.

The mantle-plume caused strong deformation of the crust. The regional updoming induced deepreaching faults along which mainly vertical movements took place, causing horst and graben tectonics as exemplified by the blastomylonitic graben between Malpica and Tuy. The blastomylonitic zones, varying in thickness from a few centimeters to 200 meters, are concentrated near the borders of the high-grade complexes. These zones were formed during the mainly vertical movements that brought the complexes to their present position, mostly surrounded by low-grade, weakly deformed Palaeozoic sediments. The horizontal schistosity planes occurring in rocks from originally deep parts of the crust might be caused by the upward pressure of the diapirs, or the lateral spreading of the diapiric hats.

CONCLUDING REMARKS

The model sketched above offers an explanation for the Early Palaeozoic evolution of Galicia that is visible in the high-grade complexes. Alternative models appear to be inadequate considering the now available data. The hypothesis that the high-grade complexes are relics of a Precambrian (Grenville) orogen (Parga-Pondal, 1956; Vogel & Abdel Monem, 1971) must be rejected, based on the geochronological data. However, Precambrian crustal elements might have been preserved elsewhere in the Hercynian orogen of the northwestern Iberian Peninsula. The gravity data make the hypothesis that the high-grade complexes are remnants of a nappe (Ries & Shackleton, 1971) very improbable. A formation of the complexes during the Caledonian orogeny is unlikely, since the eastern margin of the known Caledonian mobile belt was situated some 300 to 400 km west (following a pre-Continental Drift reconstruction). Whether the mantle-plume might also be held responsible for the Hercynian orogeny in Galicia is a matter of speculation; the available data are inconclusive to this respect.

One might speculate that the thermal events recorded around 450 Ma ago in several other Hercynian terrains in Europe are also caused by processes comparable to the proposed Galician mantle-plume.

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