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Tracing crustal evolution in the NW Iberian Peninsula through the Rb–Sr and U–Pb systematics of Palaeozoic granitoids: a review

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The abundant granitoids in the Palaeozoic basement of the northwestern Iberian Peninsula include 470–440 Ma old suites (Early–Middle Ordovician, now present as orthogneisses) and several Variscan suites. The age data presently available suggest that the latter have been generated in three separate time intervals, ~ 330–320 Ma ago (Late Visean–Early Namurian), ~ 310–300 Ma ago (Westphalian) and ~ 290–280 Ma ago (Late Stephanian–Autunian). Rb–Sr whole-rock and U–Pb zircon systematics, along with field and chemical evidence, testify to the generation of the Early and Late Palaeozoic granitoids from Lower Palaeozoic and Precambrian (maximum age ~ 1.7–1.6 Ga) sedimentary sequences, respectively. The source rocks contained zircons derived from a late Archaean–Early Proterozoic continental crust that probably underlies the whole of western Europe, although for the greater part modified beyond recognition by younger crustal reworking.

1. Granitoid magmatism in the NW Iberian Peninsula

An abundance of granitoid rocks is distributed throughout the axial zone of the broad orogenic belt of Variscan age (the Hesperian Massif) that occupies the western perimeter of the Iberian Peninsula. In western Galicia and northern Portugal, so far the most thoroughly studied parts of the axial zone (e.g., Carte Géologique du Nord Ouest de la Péninsule Ibérique, 1967; Oen, 1970; den Tex and Floor, 1971; den Tex, 1981a, b), the granitoids include an Early Palaeozoic and several Variscan (Late Palaeozoic) suites.

The *Early Palaeozoic granitoids* (470–440 Ma, see next paragraph), now present as orthogneisses owing to metamorphism during the Variscan orogeny, occur both in a number of catazonal, subcircular, partially to wholly fault-bounded complexes in western Galicia (Fig. 1) and NE Portugal (near Bragança and Morais), and in the mesozonal environment of the blastomylonitic graben extending parallel to the Atlantic coast from Malpica to Túy and of the Lalín unit (Fig. 1) (den Tex and Floor, 1971; den Tex, 1981 a, b). In the catazonal complexes they have a calcalkaline granitic to granodioritic composition and are invariably associated with mafic–ultramafic rocks of which the Rb–Sr whole-rock systems suggest an age similar to that of the granitoid precursors of the orthogneisses (van Calsteren et al., 1979). The mesozonal orthogneissses are divided into two series, probably derived from two suites of granites that were spatially separated since no intrusive relationships have been observed. One series is made up by alkaline coarse-grained megacrystal-bearing two-mica granites. The other, which is distinctly concentrated in the southern part of the graben, has

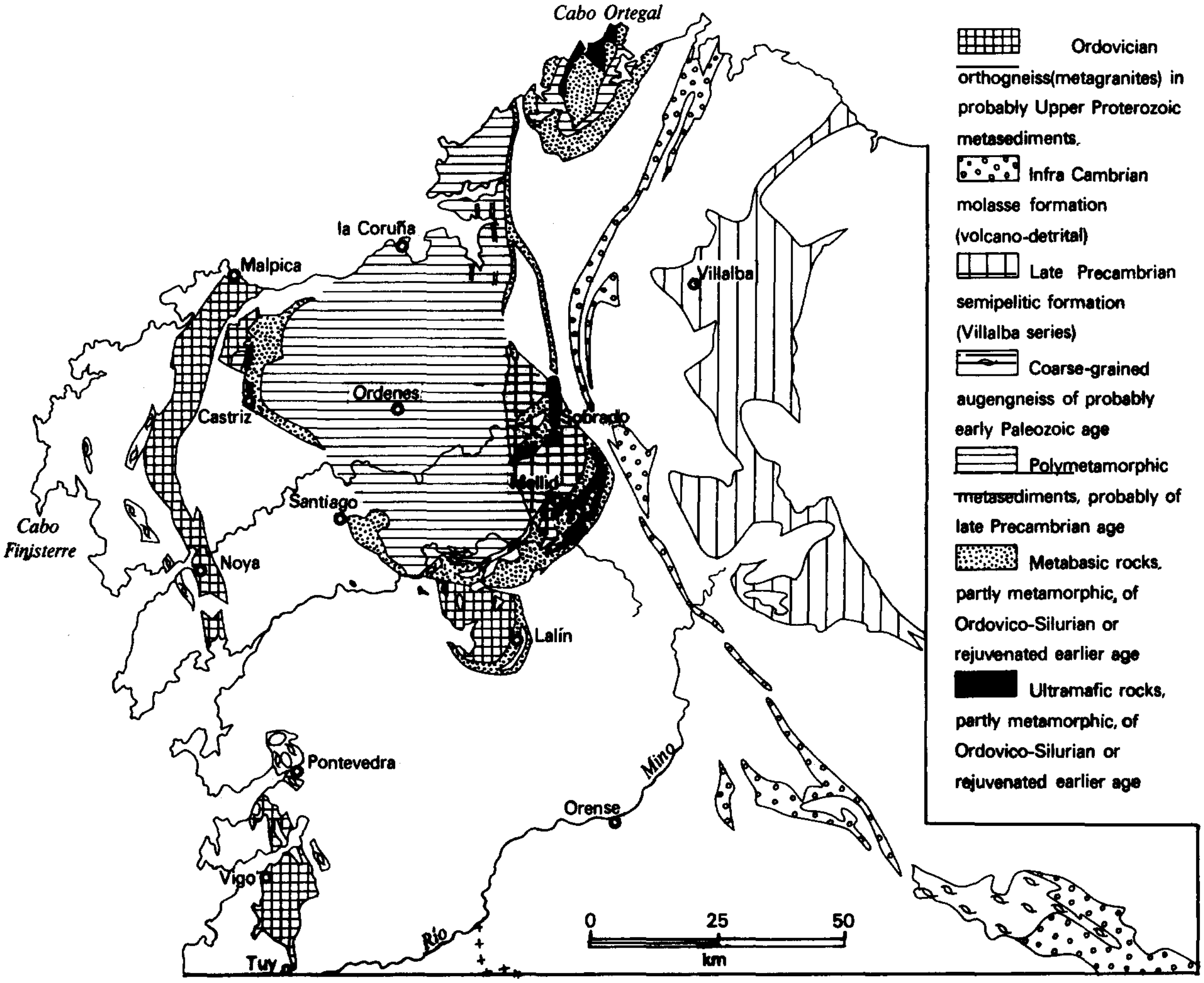

Fig. 1. Map showing the distribution of polymetamorphic basement inliers, of molasse and flyschoid deposits of Upper Precambrian age, and of Ordovician orthogneisses set in probably Upper Precambrian metasediments. After den Tex (1981b).

been divided on the basis of composition and relative age into an older suite of calcalkaline biotite granites and a younger suite of (sub)alkaline hastingsite(-biotite) granites to peralkaline astrophyllite-bearing aegirine–riebeckite granites; a time interval between both suites is suggested by the fact that a basic dike swarm has intruded the former but not the latter suite.

A mantle-plume model has been postulated for the generation of the Early Palaeozoic granitoids (van Calsteren, 1977a, b, 1978; van Calsteren et al., 1979; Kuijper, 1979; den Tex, 1981a, b). It is thought that a mantle plume beneath the continental crust of the NW Hesperian Massif and its ultramafic diapiric off-shoots (for example, the spinel–pargasite lherzolite at Cabo Ortegal) caused granitic anatexis and palingenesis. According to this model, mass movement of hot rock is used to explain both the mechanical features (graben-like structures) and the thermal events (two phases of granulite-facies metamorphism and the generation of bimodal basic and granitoid magmas) that are recorded in the Early Palaeozoic crust of western Galicia.

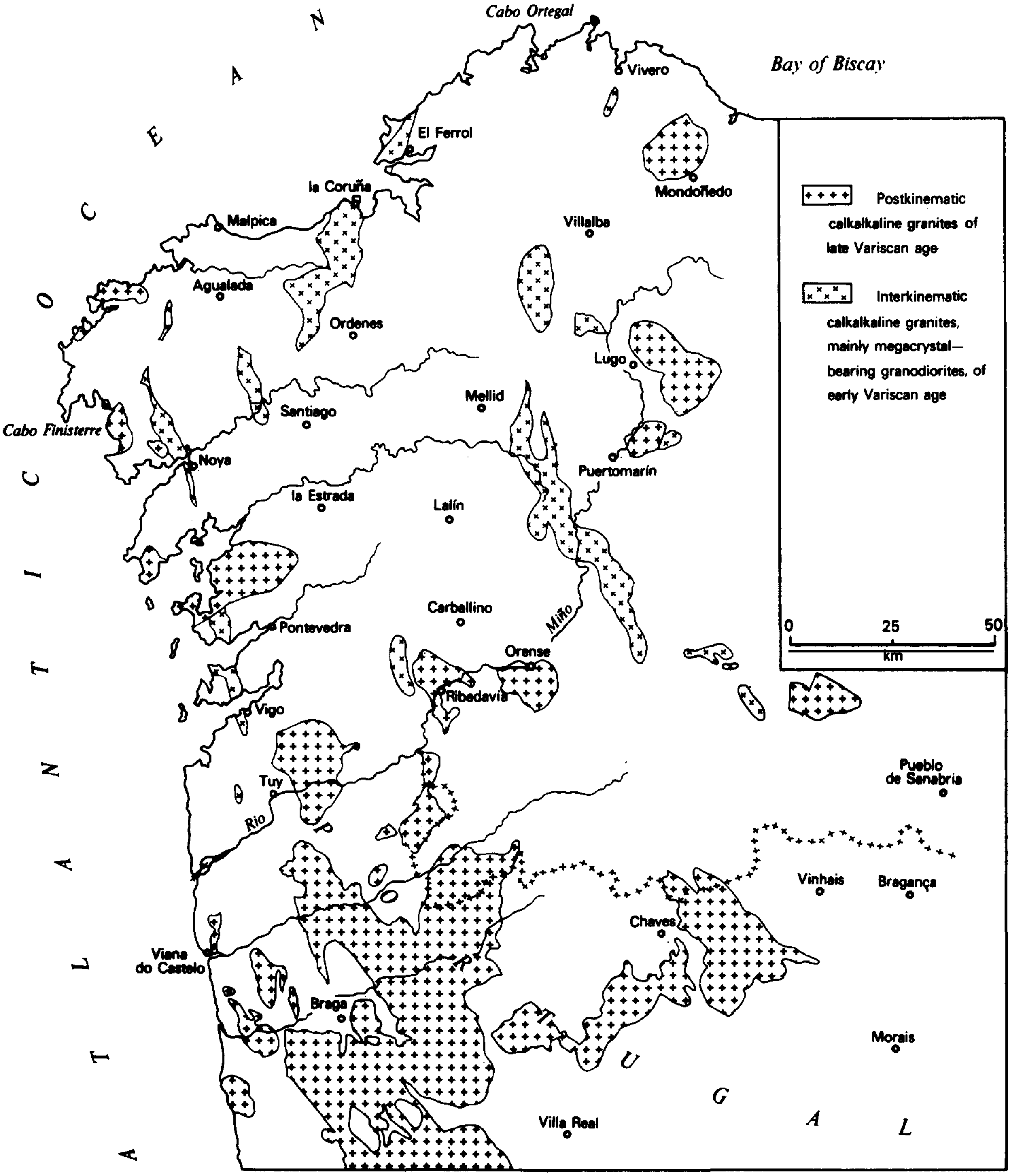

Fig. 2. Distribution map of the calcalkaline biotite granites and granodiorites in the NW Iberian Peninsula. From den Tex (1981b).

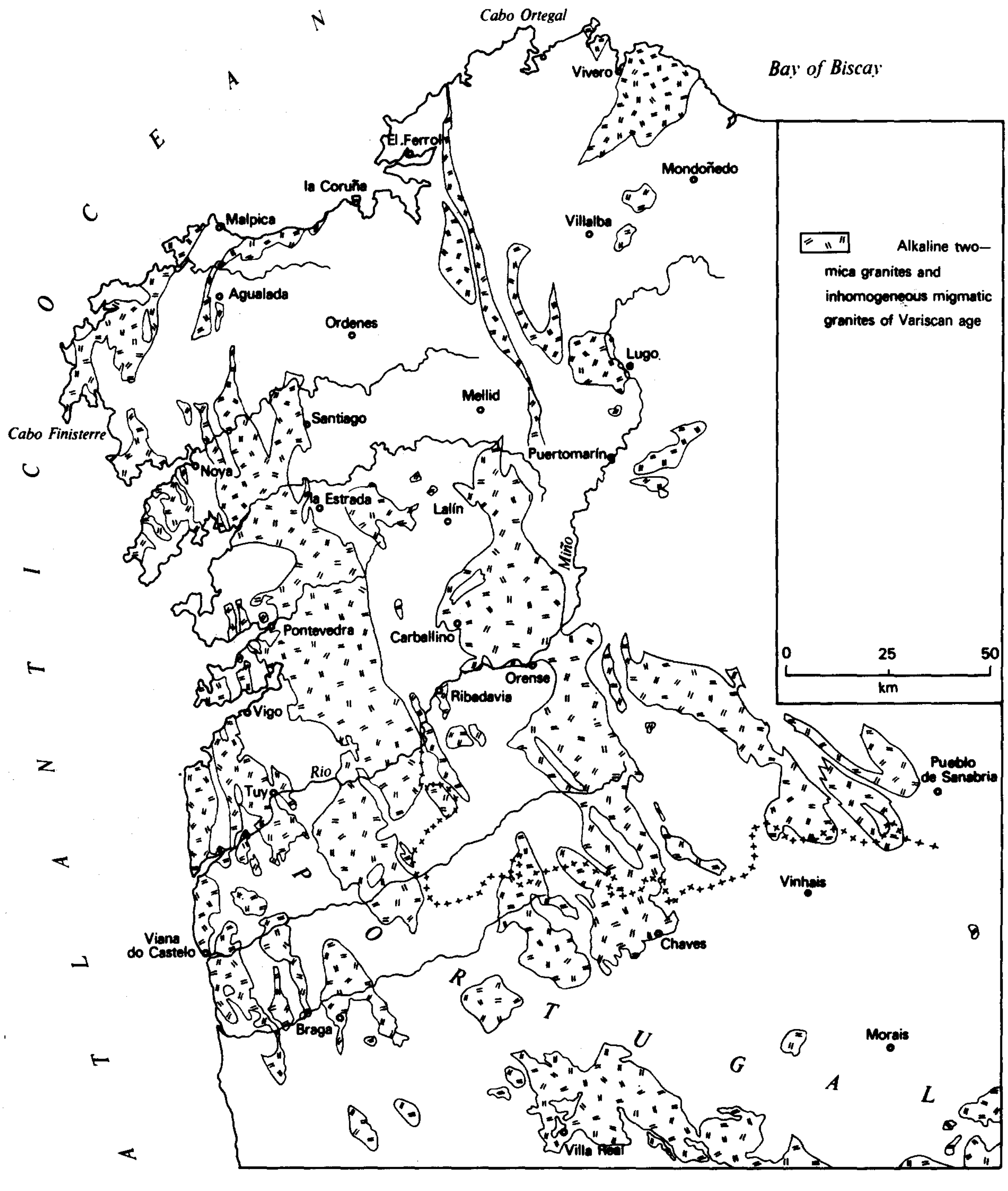

Fig. 3. Distribution map of the alkaline two mica granites in the NW Iberian Peninsula. From den Tex (1981b).

The *Variscan (Late Palaeozoic) granitoids* (330–280 Ma, see next paragraph) occupy huge areas in NW Spain and northern Portugal (Figs. 2 and 3). They vary widely in composition, structure and texture, but on petrographical and chemical grounds two main groups can be distinguished (Floor, 1970; Oen, 1970; Capdevila and Floor, 1970; Capdevila et al., 1973; den Tex, 1981a, b): (a) predominantly calcalkaline granites to granodiorites with a subcalcic plagioclase (An_{10-40}), and (b) predominantly (sub)alkaline two-mica granites carrying albite or albite–oligoclase (An_{0-20}).

For western Galicia it was shown (den Tex, 1981a, b) that among the Variscan granitoids three phases can be distinguished. An early phase of calcalkaline granitoids has been intruded by subalkaline two-mica granites (both phases interkinematic, i.e., emplaced between the two main phases of Variscan deformation), which in turn was followed by the emplacement of a post-kinematic late phase of calcalkaline composition. Both calcalkaline suites are allochthonous intrusions, rarely, if ever, associated with granitic migmatites, pegmatites, quartz veins and ore mineralizations; they are rich in inclusions of intermediate to mafic composition. The two-mica granites, on the other hand, are autochthonous to sub-autochthonous, frequently grading into granitic migmatites, devoid of intermediate to mafic inclusions, and abundantly associated with pegmatites, quartz veins and Sn-, W- and Li mineralizations. It is concluded that the calcalkaline suite originated at a deep crustal level, whereas the two-mica granites were generated at an intermediate level where they remained more or less in situ.

In northern Portugal the Variscan granitoids are customarily divided on the basis of structural and stratigraphic relations into two series, the Older Granites (Late Carboniferous) and the Younger Granites (Late Carboniferous–Autunian) (e.g., Oen, 1970). Both series are allochthonous intrusions, but the former are essentially concordant and the latter essentially discordant with contact-metamorphic aureoles. Each series contains units varying in texture, structure, mineralogy, composition and setting. It has originally been postulated (Oen, 1970; Floor et al., 1970; Capdevila et al., 1973) that the Older Granites would predominantly be an alkaline suite and the Younger Granites predominantly a calcalkaline suite, but this view does not hold any longer (Schermerhorn, 1981): many Older Granites show calcalkaline tendencies and many Younger Granites an alkaline leucogranitic trend. Important mineralizations of Sn, W and Li appear to be confined to the Younger Granites (e.g., Westerveld, 1956; Thadeu, 1977).

2. Isotopic ages

A fair amount of isotopic age data is presently available from western Galicia and northern Portugal, but only those which can be interpreted as signalling the magmatic and pre-magmatic history of the granitoids (Rb–Sr whole-rock isochrons, U–Pb intercepts of suites of zircons and monazites) are considered in this review. All these data were obtained in the ZWO Laboratory of Isotope Geology, Amsterdam (Kuijper, 1979; van Calsteren et al., 1979; Kuijper et al., 1982; ZWO Laboratory, unpublished data) and at the University of Leeds, U.K. (Serrano Pinto, 1979); they are compiled in Table I. The mica ages reported from the orthogneisses and the Variscan granitoids fall in the range from ~ 320 to 270 Ma (Capdevila and Vialette, 1970; Priem et al., 1970; Ries, 1979) and can be related to the Variscan metamorphic and cooling history.

The ages between ~ 470 and 440 Ma yielded by the Rb–Sr whole-rock isochrons and two of the lower U–Pb zircon intercepts of the orthogneisses are interpreted as approaching the time of generation of the granitoid precursors: Early–Middle Ordovician according to Odin and Gale's (1982) time-scale. Both suites of zircons have upper intercepts as high as ~ 2.5–2.3 Ga; they appear to be related to rounded cores in the coarsest fractions and are interpreted as signalling the presence of an inherited late Archaean–Early Proterozoic component along with the Ordovician magmatic zircon (Kuijper et al., 1982). Suites of zircons from three other orthogneisses do not produce geologically meaningful ages, but they also betray the presence of a Precambrian component. These "false discordias" are attributed to isotopic disturbance of

TABLE I

Compilation of isotopic ages signalling the magmatic and pre-magmatic history of the granitoids in the northwestern Iberian Peninsula

(1) Rb–Sr whole-rock ages of Early Palaeozoic granitoids in western Galicia		
	Age (Ma)	initial $^{87}Sr/^{86}Sr$
Orthogneisses near Mellid [1,2,3]	444±40	0.7090±0.0009
Idem, near Curtis, NW of Sobrado [1,3]	450±25	0.7085±0.0009
Idem, near Vigo [1,2,3]	469± 8	0.7100±0.0008
Idem, between Malpica and Noya [2,3,4]	459	0.708
(2) U–Pb intercept ages of suites of zircons from Early Palaeozoic granitoids in western Galicia [3,5]		
	lower intercept age (Ma)	upper intercept age (Ma)
(a) lower intercept corresponding to Rb–Sr whole-rock age [6]		
Orthogneiss near Mellid	459	2267
Idem	482	2548
(b) lower intercept lower than the corresponding Rb–Sr whole-rock age [7]		
Orthogneiss near Noya	170	559
Idem, near Curtis, NW of Sobrado	286	775
Idem, near Vigo	170	551
(3) Rb–Sr whole-rock age of a Variscan granitoid in western Galicia		
	Age (Ma)	initial $^{87}Sr/^{86}Sr$
Two-mica granite of La Guardia, SW of Vigo [1,2]	311±21	0.7143±0.0044
(4) U–Pb intercept ages of suites of zircons and monazites from Variscan granitoids in western Galicia [3,5]		
	lower intercept age (Ma)	upper intercept age (Ma)
Two-mica granite of Espenuca, NNW of Mellid (zircons)	200	940
Idem (monazites)	~0	308
Two-mica granite of Cabo Silleiro, SW of Vigo (zircons)	254	1302
(5) Rb–Sr whole-rock ages of Variscan granitoids in northern Portugal and western Spain [8]		
(a) Older Granites		
	Age (Ma)	initial $^{87}Sr/^{86}Sr$
Barruecopardo tungsten mine, W of Salamanca [1,9]	326± 7	0.7100±0.0022
Canado granite, E of Castro Daire [10,11]	324±11	0.7110±0.0024
Frâgoas granodiorite [10,11]	320±10	0.7069±0.0006
Lamelas hornblende–biotite granodiorite near Castro Daire [10,11]	322±15	0.7063±0.0002
(b) Younger Granites		
Scheelite-bearing aplitic vein in tungsten mine of Barruecopardo, W of Salamanca [1,9,12]	311±26	0.7094±0.0103
Cassiterite-bearing aplitic vein W of Vila Real [1,9]	307± 3	0.7263±0.0061
Castro Daire granite, Castro Daire [10,11]	303±12	0.7078±0.0011
Alva granite, S of Castro Daire [10,11]	304± 7	0.7061±0.0012
Greisenized granite of Panasqueira tin-tungsten mine [1,9]	289± 4	0.7130±0.0003
Lamas granite, S of Castro Daire [10,11]	291±10	0.7075±0.0013
Calde granite, S of Castro Daire [10,11]	282± 5	0.7093±0.0011
Regoufe granite, W of Castro Daire [10,13]	280± 9	0.7222±0.008

[1] Isochron (error limits 95% confidence level).
[2] Van Calsteren et al. (1979).
[3] Kuijper et al. (1982).
[4] No isochron (MWSD = 13).

the two zircon generations posterior to the granitoid emplacement (Kuijper et al., 1982); the intercepts in such cases only represent minimum ages.

A Rb–Sr whole-rock isochron of a (sub)alkaline two-mica granite in western Galicia indicates an age of ~ 311 Ma, although with a fairly large error (probably reflecting incomplete Sr isotopic homogenization in the anatectic magma). A suite of monazites from another two-mica granite yields an upper intercept age of ~ 308 Ma. Following Odin and Gale's (1982) time-scale this points to a Late Namurian–Westphalian age. Suites of zircons from the latter and a third two-mica granite do not produce geologically meaningful ages; this is again interpreted in terms of "false discordias" owing to the presence of an inherited Precambrian component along with the Variscan magmatic zircon, combined with post-magmatic isotopic disturbance (Kuijper et al., 1982).

In northern Portugal, the Rb–Sr whole-rock isochrons presently available allow the provisional distinction of three age groups:

(1) Older Granites ~ 330–320 Ma;

(2) Younger Granites ~ 310–280 Ma,

(2a) ~ 310–300 Ma, and (2b) ~ 290–280 Ma.

No relationship is apparent between the isotopic ages and chemical characteristics of the granitoids. Following Odin and Gale's (1982) time-scale the ages would place the generation of the Older Granites in the Late Visean–Early Namurian, the Younger Granites (2a) about in the Westphalian and the Younger Granites (2b) in the Late Stephanian–Autunian. The generation of the Younger Granites (2a) appears thus to be contemporaneous with that of the (sub)alkaline two-mica granites in western Galicia. A correlation of the Older Granites and the Younger Granites (2b) with the early and late phases of calcalkaline granitoids in western Galicia, respectively, seems obvious, but this has still to be supported by additional age measurements in western Galicia.

More dating work on the granitoids in the northwestern Iberian Peninsula is in progress by the ZWO Laboratory of Isotope Geology, Amsterdam, within the framework of the international Project Ibergranite (Schermerhorn, 1981).

3. The source rocks

The following points are significant with regard to the genesis of the Early and Late Palaeozoic granitoids in the northwestern Iberian Peninsula:

(1) Both the precursors of the orthogneisses and the Variscan granitoids have high initial $^{87}Sr/^{86}Sr$ ratios: ~ 0.709 for the orthogneisses and ranging from 0.706 to 0.722 for the granitoids (even as high as 0.726 in the case of an aplitic dike). This points to the involvement of crustal material with a substantial Rb–Sr history in the generation of the granitoid magmas.

(2) Field relationships demonstrate an origin of Variscan two-mica granites in western Galicia from Lower Palaeozoic sedimentary sequences by processes of anatexis (Kuijper, 1979). This easily explains the presence of inherited Precambrian zircon in the granites.

(3) Younger Granites in northern Portugal display REE patterns that are consistent with a derivation from sedimentary rocks of pelitic to greywackish composition through 30–60% partial

[5] Rather high MWSD values, so no error limits are given.

[6] Interpreted as a mixing line between a small proportion of inherited old zircons and a large proportion of zircons crystallized from the Early Palaeozoic magma (Kuijper et al., 1982).

[7] Interpreted as "false discordias" resulting from a combination of incorporation of inherited old zircons, crystallization of new zircon from the magma and post-magmatic isotopic disturbance (Kuijper et al., 1982).

[8] Most of them outside the map areas of Figs. 2 and 3.

[9] ZWO Laboratory of Isotope Geology, Amsterdam, unpublished data.

[10] Serrano Pinto (1979); isochron (2σ error limits).

[11] For the geology and petrology, see Schermerhorn (1959).

[12] Four points only, leading to fairly large errors at the 95% confidence level (at the 2σ level: 311 ± 10 Ma and 0.7094 ± 0.0050).

[13] For the geology and petrology, see Sluijk (1963).

melting (de Albuquerque, 1978).

(4) The presence of ~ 2.3–2.5 Ga old zircon relicts in the orthogneisses indicates that late Archaean–Early Proterozoic crustal material was an important component of the source rocks of the granitoid precursors of the orthogneisses in western Galicia. Zircon relicts with a minimum age of ~ 1.3 Ga also occur in the Variscan two-mica granites of western Galicia.

(5) It has been argued that parts of the high-grade Precambrian supracrustal sequences in the catazonal complexes of western Galicia (mostly garnet–kyanite–biotite gneisses) have constituted the source rocks for the granitoid precursors of the orthogneisses. This view is supported by (a) a comparison between the major-element composition of the ortho- and paragneisses, which shows that under the conditions of the main phase of Early Palaeozoic metamorphism (~ 800–850 °C and 10 kb) the paragneisses can easily have produced large volumes of melt with compositions comparable to those of the orthogneisses, provided that enough water was available (Kuijper, 1979); (b) trace element studies in a metasedimentary unit of the catazonal Cabo Ortegal Complex, which indicates that these rocks are the residues of deep crustal anatexis (Drury, 1980); (c) the presence in the paragneisses of zircons with an upper-intercept age similar to that of zircons in the orthogneisses, ~ 2.3–2.5 Ga (Kuijper, 1979; Kuijper et al., 1982).

All this evidence leads to the conclusion that the source rocks of the Variscan granitoids are Early Palaeozoic (and possibly older) sedimentary sequences derived from an older, Precambrian continental crust. For the Early Palaeozoic granitoid precursors of the orthogneisses a derivation from Precambrian supracrustal sequences, now present as paragneisses, is apparent.

The Rb–Sr systematics allow to decide whether the late Archaean–Early Proterozoic zircons in the ortho- and paragneisses signal the age of (re)crystallization in the Precambrian supracrustal sequence, for example during an event of volcanism or high-grade metamorphism, or the provenance age of a younger Precambrian sedimentary sequence (Kuijper, 1979; Kuijper et al., 1982). On the basis of the initial $^{87}Sr/^{86}Sr$ ratio of ~ 0.709 for the orthogneisses and assuming (1) a minimum value of ~ 0.704 for the initial $^{87}Sr/^{86}Sr$ ratio of the supracrustal precursors of the paragneisses, and (2) a closed-system Rb–Sr evolution in the supracrustal sequences from which the granitoid magmas were derived between the deposition and the magma generation, it can be calculated that the mean Rb/Sr ratio (by weight) of the sedimentary precursors of the paragneisses would not exceed a value of ~ 0.08 in case of a deposition age of 2.0 Ga or higher. The Rb/Sr ratios observed in suites of paragneisses that did not undergo partial melting are much higher, however, averaging ~ 0.3. If no change in Rb/Sr has taken place during the transformation of the supracrustal rocks into gneisses, this ratio would correspond to a maximum deposition age of ~ 1.6–1.7 Ga. The late Archaean–Early Proterozoic zircon ages should thus be interpreted as the provenance ages of a Precambrian sediment deposited no more than some 1.6–1.7 Ga ago.

4. The late Archaean–Early Proterozoic continental crust

One can only speculate about the nature and extent of the late Archaean–Early Proterozoic continental crust from which the zircons have been derived in the sedimentary piles that acted as source rocks for the Palaeozoic granitoids. Rocks of similar age have been reported from a few places elsewhere in western Europe: relict zircon ages of ~ 2.0 Ga in the Icartian orthogneisses of the Pentevrian basement complex on Guernsey and in Brittany (Calvez and Vidal, 1978; Auvray et al., 1980) and in the Palaeozoic orogen of France (Gebauer and Grünenfelder, 1976; Auvray et al., 1980; Vidal et al., 1980) and elsewhere in western Europe (Gebauer and Grünenfelder, 1977), and Rb–Sr evidence for an age of ~ 2.0 Ga for the Rosslare Complex in SE Ireland (Max, 1975). This suggests that a late Archaean–Early Proterozoic continental crust underlies the whole of western Europe, although the old rocks were for the greater part modified beyond recognition by younger crustal reworking. The Precambrian zircon components in the Palaeozoic granitoids of western Galicia should then represent the southernmost traces known so far of this late Archaean–Early Proterozoic crustal segment.

Acknowledgements

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References

Auvray, B., Charlot, R. and Vidal, Ph., 1980. Données nouvelles sur le protérozoique inférieur du domaine nord-armoricain (France): age et signification. Can. J. Earth Sci., 17: 532–538.

Calvez, J.Y. and Vidal, Ph., 1978. Two billion years old relicts in the Hercynian belt of western Europe. Contrib. Mineral. Petrol., 65: 395–399.

Capdevila, R. and Floor, P., 1970. Les différents types de granites hercyniens et leur distribution dans le nord-ouest de l'Espagne. Bol. Geol. Min., 81: 215–225.

Capdevila, R. and Vialette, Y., 1970. Estimation radiométrique de l'age de la deuxième phase tectonique hercynienne en Galice moyenne (Nord-Ouest de l'Espagne). C.R. Acad. Sci. Paris, 270: 2527–2530.

Capdevila, R., Corretge, G. and Floor, P., 1973. Les granitoides varisques de la Meseta ibérique. Bull. Soc. Géol. Fr., 15: 209–228.

Carte geologique du nord-ouest de la Peninsule Iberique, 1967. Serviços Géologicos de Portugal, Lisbon.

De Albuquerque, C.A.R., 1978. Rare earth elements in "Younger" granites, Northern Portugal. Lithos, 11: 219–229.

Den Tex, E., 1981a. A geological section across the Hesperian Massif in western and central Galicia. Geol. Mijnbouw, 60: 33–40.

Den Tex, E., 1981b. Basement evolution in the northern Hesperian Massif. A preliminary survey of results obtained by the Leiden Research Group. Leidse Geol. Meded., 52: 1–21.

Den Tex, E. and Floor, P., 1971. A synopsis of the geology of western Galicia. In: Histoire structurale du Golfe de Gascogne, Technip, 1: 3/1–3/13.

Drury, S.A., 1980. The geochemistry of high-pressure gneisses from Cabo Ortegal (NW Spain): residues of deep anatexis. Geol. Mijnbouw, 59: 61–64.

Floor, P., 1970. Session de travail consacrée à la subdivision des roches granitiques hercyniennes dans le Nord-Ouest péninsulaire. Bol. Geol. Min., 81: 245–248.

Floor, P., Kisch, H.J. and Oen Ing Soen, 1970. Essai de corrélation de quelques granites hercyniens de la Galice et du Nord de Portugal. Bol. Geol. Min., 81: 242–244.

Gebauer, D. and Gruenenfelder, M., 1976. U–Pb zircon and Rb–Sr whole-rock dating of low-grade metasediments. Example: Montagne Noire (southern France). Contrib. Mineral. Petrol., 59: 13–32.

Gebauer, D. and Gruenenfelder, M., 1977. U–Pb systematics of detrital zircons from some unmetamorphosed to slightly metamorphosed sediments of central Europe. Contrib. Mineral. Petrol., 65: 29–37.

Kuijper, R.P., 1979. U–Pb systematics and the petrogenetic evolution of intracrustal rocks in the Paleozoic basement of western Galicia (NW Spain). Verh. Nr. 5 ZWO Laboratorium voor Isotopen-Geologie, Amsterdam, 1–88.

Kuijper, R.P., Priem, H.N.A. and den Tex, E., 1982. Late Archaean–Early Proterozoic source ages of zircons in rocks from the Paleozoic orogen of western Galicia, N.W. Spain. Precambrian Res., 19: 1–29.

Max, M.D., 1975. Precambrian rocks of south-east Ireland. Geol. Soc. London, Spec. Rep., 6: 97–101.

Odin, G.S. and Gale, N.H., 1982. Géochimie et géochronologie isotopiques - Mise à jour de l'échelle des temps calédoniens et hercyniens. C.R. Acad. Sci. Paris, 294: 453–456.

Oen Ing Soen, 1970. Granite intrusion, folding and metamorphism in central northern Portugal. Bol. Geol. Minero LXXXI-II-III, 271–298.

Priem, H.N.A., Boelrijk, N.A.I.M., Verschure, R.H., Hebeda, E.H. and Verdurme, E.A.Th., 1970. Dating events of acid plutonism through the Paleozoic of the western Iberian Peninsula. Ecl. Geol. Helv., 63: 255–274.

Ries, A.C., 1979. Variscan metamorphism and K–Ar dates in the Variscan fold belt of S. Brittany and N.W. Spain. J. Geol. Soc. London, 136: 89–103.

Schermerhorn, L.J.G., 1959. Igneous, metamorphic and ore geology of the Castro Daire-São Pedro do Sul-Satão region, northern Portugal. Comm. Serv. Geol. Portugal, 37: 1–616.

Schermerhorn, L.J.G., 1981. Project Ibergranite, Newsletter No. 1. Institut für Mineralogie, Freie Universität Berlin, 196 pp.

Serrano Pinto, M.C., 1979. Geochemistry and geochronology of granitic rocks from the Aveiro and Viseu districts (northern Portugal). Ph.D. thesis University of Leeds.

Sluijk, D., 1963. Geology and tin–tungsten deposits of the Regoufe area, northern Portugal. Ph.D. thesis University of Amsterdam, 123 pp.

Thadeu, D., 1977. Hercynian paragenetic units of the Portuguese part of the Hesperic Massif. Bol. Soc. Geol. Portugal, 20: 247–276.

Van Calsteren, P.W.C., 1977a. A mantle-plume model interpretation for the Paleozoic geology of Galicia with emphasis on the Cabo Ortegal area (NW Spain). Proc. Kon. Ned. Akad. Wet., (B) 80: 156–168.

Van Calsteren, P.W.C., 1977b. 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). Leidse Geol. Meded., 51: 57–61.

Van Calsteren, P.W.C., 1978. Geochemistry of the polymetamorphic mafic–ultramafic complex at Cabo Ortegal (NW Spain). Lithos, 11: 61–72.

Van Calsteren, P.W.C., Boelrijk, N.A.I.M., Hebeda, E.H., Priem, H.N.A., den Tex, E., Verdurmen, E.A.Th. and Verschure, R.H., 1979. Isotopic dating of older elements (including the Cabo Ortegal mafic–ultramafic complex) in the Hercynian orogen of NW Spain: manifestations of a presumed early Paleozoic mantle-plume. Chem. Geol., 24: 35–56.

Vidal, Ph., Peucat, J.J. and Lasnier, B., 1980. Dating of granulites involved in the Hercynian Fold Belt of Europe: an example taken from the granulite facies orthogneisses at La Picherais, southern Armorican Massif, France. Contrib. Mineral. Petrol., 72: 283–289.

Westerveld, J., 1956. Roches éruptives, gîtes métallifères et métamorphisme entre Mangualde et le Douro dans le Nord du Portugal. Geol. Mijnbouw, Nwe Ser., 18: 94–105. Also: Bol. Soc. Geol. Portugal, 12: 101–128.