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Age of amphibolitic metamorphism in the ophiolitic unit of the Morais allochthon (Portugal): implications for early Hercynian orogenesis in the Iberian Massif

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Abstract: Structurally lower portions of the allochthonous Morais complex are comprised of an ophiolitic unit exposed in two contrasting structural units separated by a ductile thrust fault. The lower unit is dominated by variably foliated amphibolite whereas the upper unit is largely comprised of metaperidotite and metagabbro. Most of the ophiolitic unit has recrystallized synkinematically under amphibolite facies metamorphic conditions (*c.* 500 °C and 5 kbar). Amphiboles formed during this metamorphism are typically magnesio-hornblende. An amphibole concentrate from the lower structural unit records a ^{39}Ar/^{40}Ar plateau age of 397.3 ± 4 Ma. An amphibole concentrate from the upper structural unit displays an internally discordant ^{39}Ar/^{40}Ar age spectrum corresponding to a total gas age of 431.1 ± 27.3 Ma. Gas fractions evolved from each amphibole concentrate at intermediate and high experimental temperatures are characterized by similar apparent K/Ca ratios and yield well-defined ^{36}Ar/^{40}Ar v. ^{39}Ar/^{40}Ar isotope correlations which result in similar ages of 384.2 ± 5.2 and 392.4 ± 7.3 Ma. These are considered to be more reliable than the plateau ages and are interpreted as dating the last cooling through those temperatures required for intracrystalline retention of argon within constituent amphibole grains. The associated tectonothermal event represented a first stage of Hercynian orogenesis in the Iberian massif. It was probably related to oceanic closure and associated obduction of granulitic/eclogitic massifs which at present structurally overlie the ophiolitic unit.

The widespread amphibolite facies metamorphism and associated deformation recorded within allochthonous, mafic–ultramafic complexes in northwestern portions of the Iberian massif have classically been associated with late Palaeozoic (Hercynian) tectonothermal events (Arenas *et al.* 1986 and references therein). Previous attempts to isotopically date this activity yielded K–Ar and Rb–Sr mineral ages ranging between *c.* 370 and 480 Ma (Van Calsteren *et al.* 1979). Within many of the allochthonous structural elements the amphibolite facies metamorphism is retrogressive and overprints generally higher-pressure assemblages (eclogite and granulite facies) which appear to have developed at *c.* 480 Ma (Kuijper *et al.* 1982; Peucat *et al.* 1990). However, within structural units composed of variably metamorphosed, dismembered ophiolitic units (metagabbro and metaperidotite) the amphibolite facies metamorphism represents the initial tectonothermal event (Arenas *et al.* 1986). In an effort to constrain more closely the age of the widespread amphibolite facies event, samples were collected for ^{40}Ar/^{39}Ar dating within allochthonous units exposed in the Morais complex in northern Portugal (Fig. 1). The analytical results are presented herein and allow a more complete understanding of the chronology of tectonothermal evolution within the allochthonous massifs.

Geological setting

The Morais complex is one of a series of crystalline allochthonous complexes exposed in northern Iberia (Fig. 1A). These are characterized by associations of mafic–ultramafic rocks and high-pressure/high-temperature metamorphic units (cf. Arenas *et al.* 1986 for a review of the different units). Imbrication of lithological units appears to have been associated with amphibolite facies metamorphism that has been correlated with initial phases of Hercynian deformation (cf. Arenas *et al.* 1986). However, no geochronological data have been reported for any of the rocks within the Morais complex. Final emplacement of the complex into its present relative structural position occurred during maintenance of relatively low-grade metamorphic conditions during what has been considered a second distinct phase of Hercynian orogenesis (Iglesias *et al.* 1983; Arenas *et al.* 1986).

The Morais complex is comprised by several contrasting structural units. Uppermost structural levels are represented by a structurally imbricated, variably metamorphosed quartzo-feldspathic sequence (Lagoa mylonitic metagranite and tectonically overlying pelitic schists, Fig. 1B). Metamorphism occurred at intermediate pressures and at low to intermediate temperatures (garnet and biotite zones, Anthonioz 1972; Ribeiro 1974). The mylonitic metagranite has been interpreted to represent either a variably deformed Palaeozoic felsic intrusion (Iglesias *et al.* 1983) or part of a Precambrian basement complex (Ribeiro *et al.* 1990). The metasedimentary sequence has been correlated with units of the late Precambrian/Cambrian 'schist and greywacke series' exposed within the Central Iberian Zone (Ribeiro 1983). Fauna within the schist and greywacke series (acritarchs) suggest an uppermost Proterozoic to lower Palaeozoic age (Arenas *et al.* 1986). Intermediate structural levels of the Morais complex are composed of blastomylonitic mafic granulites and metaperidotites. These rocks are not as widely exposed here as within the other Iberian complexes (Fig. 1A, B) where they are commonly

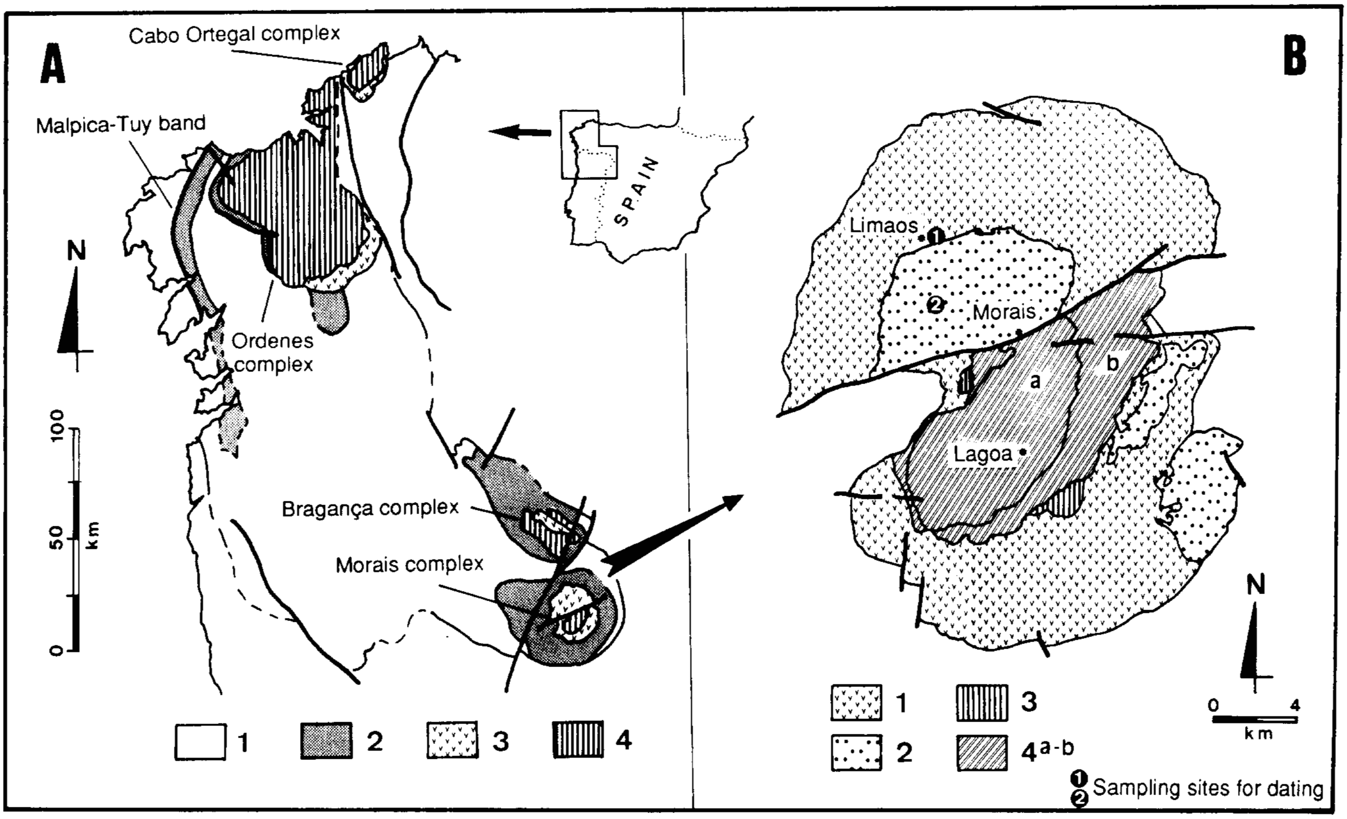

Fig. 1. (**A**) Tectonostratigraphic map of the northwestern Iberian massif (modified from Arenas *et al.* 1986, Ribeiro *et al.* 1990). 1, Central-Iberian Zone and Schistose Domain of Galicia–Tras-os-Montes autocthon to para-autocthon; 2, basal unit with peralkaline rocks and H*P*/L-I*T* metamorphism; 3, ophiolitic complex; 4, upper allochthon with H*P*/H*T* granulites and eclogites. (**B**) simplified geological map of the Morais complex (after Anthonioz 1972; Ribeiro *et al.* 1990). 1, amphibolites; 2, harzburgites, metagabbros, amphibolites; 3, granulites and metaperidotites, 4, Lagoa micaschists (a) and augen-gneisses (b).

associated with high-pressure and high-temperature (B-type) eclogites (cf. Arenas *et al.* 1986). Some units within higher structural levels of the other Iberian complexes appear to have had oceanic protoliths while others could have originated within volcanic-arc environments (e.g. felsic to intermediate granulites), or be metasedimentary in origin (high-pressure migmatic gneisses). Although protolith ages have not been constrained, U-Pb dating of zircon and monazite within the Cabo Ortegal and Ordenes complexes (Kuijper *et al.* 1982; Peucat *et al.* 1990) suggest that the high-pressure metamorphism is likely to have occurred at *c.* 480 Ma.

Most of the Morais complex is represented by the 'ophiolitic unit' which constitutes the lowermost tectonostratigraphic levels (Fig. 1B). This is composed of two contrasting structural units which are in ductile thrust contact (Ribeiro *et al.* 1990). The lower unit is dominated by variably foliated amphibolite, whereas the upper unit is largely comprised by metaperidotite (mostly dunite and harzburgite) and metagabbro. Most of the ophiolitic unit records prograde, amphibolite facies metamorphic assemblages. Locally there are slight but systematic variations in grade which suggest structural inversion (garnet–anthophyllite–staurolite–quartz assemblages in upper horizons, and green hornblende–epidote–albite ± quartz assemblages at the base). Locally, minor retrogression has affected the lower structural unit (Anthonioz 1972; Ribeiro 1974, 1983).

Analytical techniques

Electron microprobe

Minerals were analysed in polished grain mounts and petrographic thin sections at the University of Clermont-Ferrand with a Camebax Microbeam automatic microprobe equipped with three spectrometers. Operating parameters included a 10 s integration time, a *c.* 10 nA beam current and a 15 kV accelerating voltage. Calibration was against BRGM standard minerals and the ZAF correction procedure was used. The presence of ferric iron in the analysed amphiboles was evaluated by charge balance calculations following procedures suggested by Leake (1978).

$^{40}Ar/^{39}Ar$

The mineral concentrates were irradiated for 80 hours in the H-5 position at the Ford Reactor at the University of Michigan. Variations in the flux of neutrons along the length of the irradiation assembly were monitored with several mineral standards, including MMhb-1 (Alexander *et al.* 1978). The samples were incrementally heated until fusion in a double-vacuum, resistance-heated furnace. Temperatures were monitored with a direct-contact thermocouple and are controlled to ±1 °C between increments and are accurate to

±5 °C. Blank-corrected isotopic ratios were adjusted for the effects of mass discrimination and interferring isotopes produced during irradiation using factors reported by Harrison & Fitzgerald (1986) for the Michigan Reactor. Apparent ^{40}Ar/^{39}Ar ages were calculated from corrected isotopic ratios using the decay constants and isotopic abundance ratios listed by Steiger & Jäger (1977) following the methods described in Dallmeyer & Keppie (1987).

Intra-laboratory uncertainties are reported, and have been calculated by statistical propagation of uncertainties associated with measurement of each isotopic ratio (at two standard deviations of the mean) through the age equation. Inter-laboratory uncertainties are *c.* ±1.25–1.5% of the quoted age. Analysis of the MMhb-1 monitor indicates that apparent K/Ca ratios may be calculated as $0.505\ (\pm 0.003) \times (^{39}\mathrm{Ar}/^{37}\mathrm{Ar})_{\mathrm{corrected}}$. The analyses of the amphibole concentrates have been plotted on ^{36}Ar/^{40}Ar v. ^{39}Ar/^{40}Ar isotope correlation diagrams using the regression techniques of York (1969).

Sample description

The two samples studied represent the most common and characteristic metabasic rocks found in upper portions of the ophiolitic unit of the Morais complex. Sample 1, collected *c.* 200 m west of the village of Limaos (Fig. 1B), is a layered, medium- to fine-grained, mineralogically homogeneous amphibolite with a nematoblastic texture. It is composed of green hornblende, plagioclase (oligoclase–andesine), quartz, rutile and apatite. Epidote occurs within pseudomorphic aggregates locally replacing plagioclase. Sample 2, collected 1 km southeast of Mt Pedreiras (Fig. 1B), is a coarse-grained metagabbro with a slightly oriented granoblastic texture. It is composed of green hornblende, plagioclase (oligoclase–andesine), epidote (enclosed in plagioclase) and minor apatite.

The amphiboles separated for ^{40}Ar/^{39}Ar dating (analysed in grain mounts) and those analysed in thin sections have analogous compositions. Most are magnesio-hornblende (classification after Leake 1978), and reflect compositions similar to those of amphiboles analysed from amphibolites elsewhere in the ophiolitic unit (Table 1). On the basis of the chemical composition of the coexisting amphiboles and plagioclases analysed, the temperature for the amphibolitic metamorphism in the ophiolitic unit may be estimated at *c.* 500 °C (using the graphical method of Spear 1980 based on an empirical model for NaSi = CaAl exchange between plagioclase and amphibole). The presence of stable rutile in some samples suggests that temperatures could have been slightly higher (cf. Moody *et al.* 1983). Precise pressure estimates may not be established. The graphical method proposed by Raase (1974) based on statistical analysis of $\mathrm{Al^{VI}/Si}$ ratios in different types of metamorphic amphiboles yields pressure conditions >5 kbar. Other methods, such as $\mathrm{Al^{VI} + Fe^{3+} + Ti + Cr}$ v. $\mathrm{Na^{(M4)}}$, or one independent of $\mathrm{Fe^{3+}}$ estimation, 100 Na/(Na + Ca) v. 100 Al/(Al + Si) proposed by Laird & Albee (1981), suggest a middle-pressure metamorphic regime.

Table 1. *Representative electron microprobe analyses of amphiboles from metabasites of the Ophiolitic Unit of the Morais complex, Portugal*

Sample	PO884	PO872	PO387	PO387*	PO875	PO187	PO187*	PO878
SiO_2	0.56	0.14	0.07	0.19	0.05	0.14	0.22	0.06
TiO_2	11.27	11.49	12.14	11.72	12.74	11.43	11.23	11.58
Al_2O_3	0.24	0.59	0.47	0.47	0.29	0.58	0.67	0.46
FeO^t	17.59	13.89	9.44	9.66	7.88	13.39	17.56	15.45
MnO	0.28	0.42	0.08	0.80	0.49	0.32	0.26	0.27
MgO	0.02	—	0.01	—	0.12	0.05	—	0.08
CaO	1.27	2.16	1.49	2.14	1.10	2.14	2.41	1.92
Na_2O	42.92	44.36	46.87	46.42	51.29	45.18	43.58	45.29
K_2O	14.68	13.21	11.43	13.17	7.90	13.14	13.78	11.79
Cr_2O_3	7.86	10.87	14.44	13.76	16.62	11.48	9.08	10.65
NiO	0.01	0.04	0.09	—	0.02	0.16	0.05	—
TOTAL	97.22	97.17	96.53	98.33	98.50	98.01	98.84	97.55
Cation proportions (ferric iron calculated) (23 oxygens)								
Si	6.406	6.510	6.750	6.591	7.192	6.537	6.379	6.644
Al-iv	1.594	1.490	1.250	1.409	0.808	1.463	1.621	1.356
Al-vi	0.990	0.796	0.691	0.795	0.498	0.778	0.757	0.683
Ti	0.027	0.065	0.051	0.050	0.031	0.063	0.074	0.051
Cr	0.002	—	0.001	—	0.013	0.006	—	0.009
Fe^{3+}	0.316	0.308	0.278	0.323	0.098	0.382	0.465	0.363
Fe^{2+}	1.880	1.397	0.859	0.824	0.826	1.239	1.685	1.532
Mn	0.035	0.052	0.010	0.096	0.058	0.039	0.032	0.034
Mg	1.748	2.377	3.099	2.912	3.473	2.475	1.981	2.328
Ni	0.001	0.005	0.010	—	0.002	0.019	0.006	—
Ca	1.803	1.807	1.879	1.783	1.914	1.772	1.761	1.820
Na-M4	0.197	0.193	0.127	0.217	0.086	0.228	0.239	0.180
Na-A	0.321	0.421	0.290	0.372	0.213	0.372	0.445	0.366
K	0.107	0.026	0.013	0.034	0.009	0.026	0.041	0.011
X_{Mg}	0.482	0.063	0.783	0.779	0.808	0.667	0.540	0.603

PO387* and PO187*: amphiboles in grain mounts of concentrates used for dating; PO387 and PO187: amphiboles from the same samples in thin section. PO872: amphibolite near Limaos; PO875: amphibolite near Morais; PO978: amphibolite near Izeda (N of the complex); PO884: amphibolite near Remondes (S of the complex).

^{40}Ar/^{39}Ar results

An amphibole concentrate from the amphibolitic metabasalt (sample 1) within the lower domain of the ophiolitic unit of the Morais complex displays an internally concordant ^{40}Ar/^{39}Ar age spectrum (Fig. 2, Table 2) in which the 755–870 °C increments (corresponding to more than 94% of the total) yield a plateau age of 397.3 ± 4.3 Ma. The plateau increments are characterized by constant apparent K/Ca ratios. The plateau data yield well-defined ^{36}Ar/^{40}Ar v. ^{39}Ar/^{40}Ar isotope correlation (MSWD = 1.03) corresponding to an age of 384.2 ± 5.2 Ma and an inverse ordinate intercept of 308.5 ± 8.3 (Fig. 3).

An amphibole concentrate from the metagabbro (sample 2) within the upper domain of the ophiolitic unit displays an internally discordant ^{40}Ar/^{39}Ar age spectrum (Fig. 2, Table 2) which defines a total-gas age of 431.1 ± 27.3 Ma. Apparent K/Ca ratios are constant within gas increments evolved between 755 and 845 °C. An ^{36}Ar/^{40}Ar v. ^{39}Ar/^{40}Ar isotope correlation between these five increments is well-defined (MSWD = 1.88) and yields an age of 392.4 ± 7.3 Ma with an inverse ordinate intercept of 371.8 ± 16.9 (Fig. 3).

Interpretation

Gas fractions evolved from each amphibole concentrate at intermediate and high experimental temperatures are characterized by similar apparent K/Ca ratios, indicating that experimental evolution of gas occurred from compositionally uniform amphibole phases. These increments yield well-defined isotope correlations which result in inverse

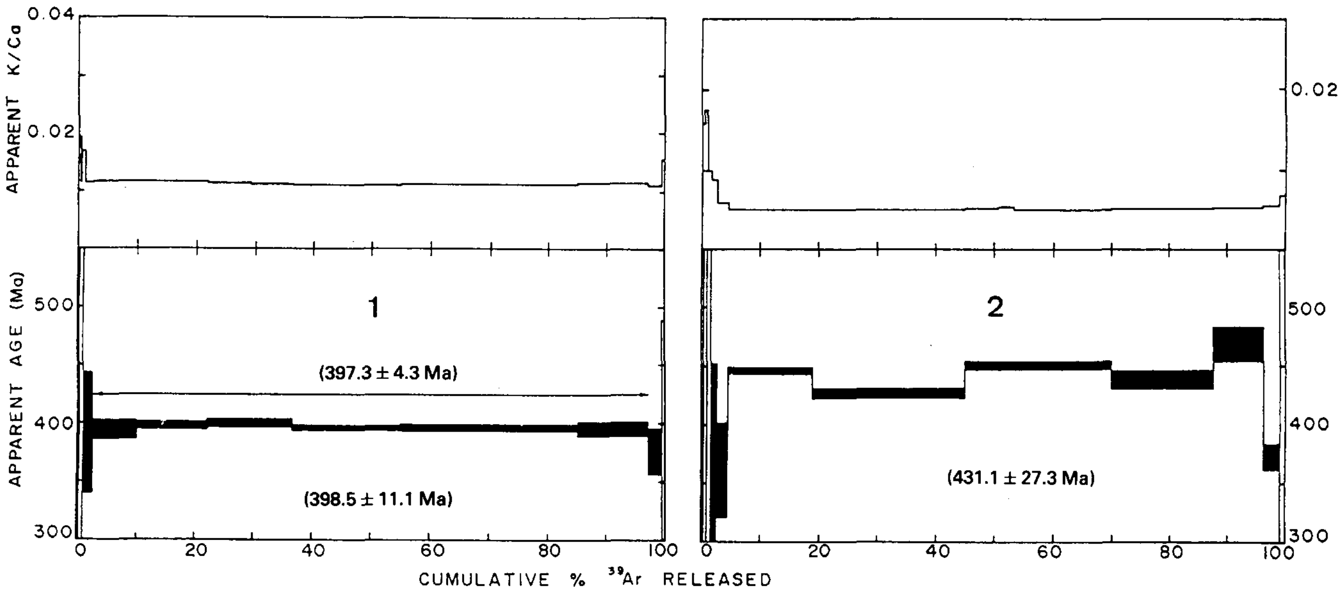

Fig. 2. ^{40}Ar/^{39}Ar apparent age and apparent K/Ca spectra of amphibole concentrates from the ophiolitic unit of the Morais complex (locations shown in Fig. 1B). Analytical uncertainties (two sigma intra-laboratory) are represented by vertical width of bars. Experimental temperatures increase from left to right. Plateau or total-gas ages (parentheses) are listed on each spectrum.

Table 2. *^{40}Ar/^{39}Ar analytical data for incremental heating experiments on amphibole concentrates from the Ophiolitic Unit of the Morais Complex, Portugal*

Release temp (°C)	(^{40}Ar/^{39}Ar)*	(^{36}Ar/^{39}Ar)*	(^{37}Ar/^{39}Ar)^{c}	^{39}Ar % of total	%^{39}Ar non-atmos.†	^{36}Ar$_{Ca}$ %	Apparent Age (Ma)**
Sample 1, J = 0.007071							
600	2033.36	6.59993	25.561	0.31	4.19	0.11	863.8 ± 2144.6
650	423.59	1.18851	42.629	0.27	17.93	1.03	796.1 ± 462.9
700	172.66	0.48875	29.215	0.58	17.76	1.71	361.2 ± 117.2
730	80.94	0.18057	42.921	1.34	38.51	6.80	370.1 ± 55.1
755	41.08	0.03777	42.362	7.46	81.45	32.07	394.4 ± 7.2
780	39.99	0.03250	42.350	12.08	84.84	37.27	399.3 ± 6.9
800	37.70	0.02514	43.950	14.50	90.04	49.99	400.0 ± 4.3
820	35.19	0.01796	44.103	18.45	95.40	70.22	396.0 ± 2.5
845	35.35	0.01835	44.014	30.06	95.08	68.62	396.4 ± 2.8
870	38.71	0.02871	43.373	12.13	87.12	43.20	398.2 ± 6.5
900	46.96	0.07196	44.428	2.25	62.64	17.66	351.6 ± 23.9
Fusion	54.25	0.08920	31.300	0.57	56.22	10.04	359.9 ± 65.8
Total	46.27	0.05421	43.311	100.00	88.14	52.50	398.6 ± 11.1
Total without 600–730 °C, 900 °C and fusion					94.68		397.3 ± 4.3
Sample 2, J = 0.007422							
625	177.22	0.45430	28.175	0.55	25.57	1.77	532.7 ± 133.2
675	161.14	0.49892	48.824	0.63	11.05	2.80	231.8 ± 257.3
705	98.60	0.29848	54.861	0.96	15.21	5.26	198.1 ± 155.8
730	65.01	0.14892	80.336	1.92	42.70	15.43	357.5 ± 3.1
755	43.68	0.05543	92.970	14.33	80.40	47.97	445.5 ± 3.6
780	36.61	0.03741	92.760		91.11	70.91	425.5 ± 5.5
805	41.52	0.04651	91.856	26.03	85.50	56.48	449.5 ± 4.1
825	38.26	0.03915	91.442	17.71	89.96	66.80	436.8 ± 8.9
845	40.58	0.03755	90.687	8.65	91.45	69.07	467.1 ± 15.4
870	44.75	0.07946	86.215	2.81	63.73	31.03	368.0 ± 13.2
900	60.68	0.15935	70.901	0.98	32.21	12.73	257.1 ± 148.3
Total	55.91	0.09971	90.127	100.00	82.09	56.63	431.1 ± 27.3

* measured

^{c} corrected for post-irradiation decay of ^{37}Ar (35.1 day 1/2-life)

† $[^{40}Ar_{tot}-(^{36}Ar_{atmos.})(295.5)]^{40}Ar_{tot}$.

** calculated using correction factors of Dalrymple *et al.* (1981); two sigma, intra-laboratory errors.

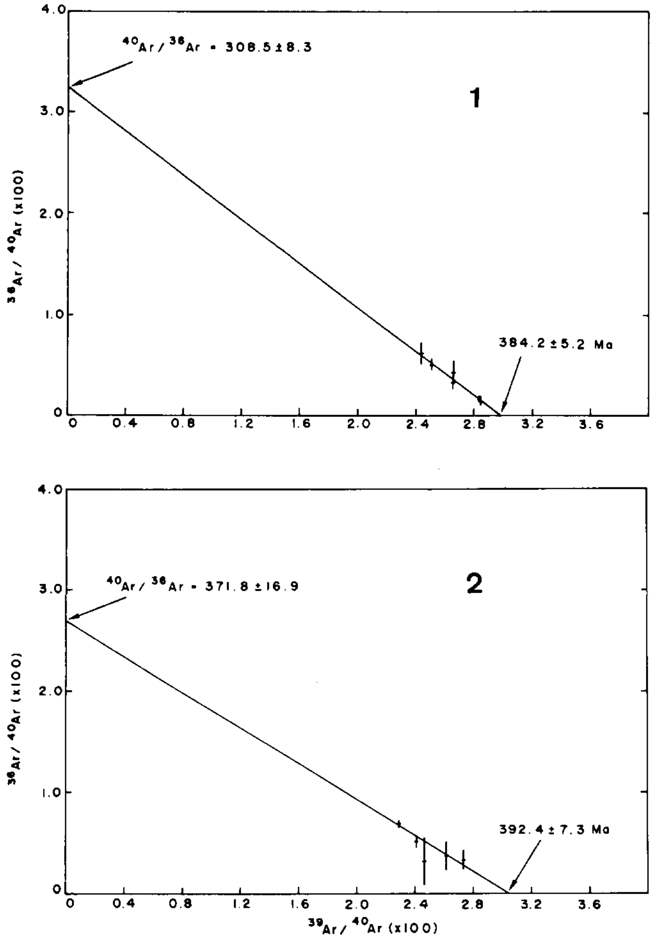

Fig. 3. $^{36}Ar/^{40}Ar$ v. $^{39}Ar/^{40}Ar$ isotope correlations of amphibole concentrates from the ophiolitic unit of the Morais complex (two sigma intra-laboratory analytical uncertainties quoted).

ordinate intercepts consistently larger than the $^{40}Ar/^{36}Ar$ ratio of the present-day atmosphere (295.5). This suggests minor and variable extraneous argon within constituent amphibole grains. Substitution of the inverse intercept values in solution of the age equation for each increment yields ages similar to those calculated directly with the inverse of the abscissa intercept ($^{40}Ar/^{39}Ar$ ratio) in each isotope correlation. These are similar (384.2 ± 5.2 and 392.4 ± 7.3 Ma) and younger than apparent ages calculated with the analytical data. Because they do not depend upon assumption of a modern-day $^{40}Ar/^{36}Ar$ ratio, they are considered more reliable, and the 384–392 Ma ages are interpreted as dating the last cooling through those temperatures required for intracrystalline retention of argon within constituent amphibole grains. Harrison (1981) indicated that closure temperatures for argon systems within igneous hornblende are not significantly affected by compositional variations. He suggested that values of *c.* 500 ± 25 °C are appropriate for the range of cooling rates likely to be encountered in most geologic settings. However, studies of metamorphic amphiboles indicate that closure temperatures may be sensitive to intracrystalline compositional variations (e.g. Harrison & Fitzgerald 1986; Onstott & Peacock 1987).

Geological significance

Development of amphibolitic parageneses in the ophiolitic unit of the Morais complex appears to have accompanied the initial deformational phase. The absence of any previous regional metamorphic event implies that the $^{40}Ar/^{39}Ar$ ages obtained in this study must closely reflect the minimum age for the amphibolite facies tectonothermal event. The present $^{40}Ar/^{39}Ar$ results indicate that the associated compressive events had commenced at least by the Lower Devonian (according to the time-scale of Cowie & Basset 1989) and had reached a metamorphic climax sometime prior to *c.* 384–392 Ma. This tectonothermal activity represents the first stage of the Hercynian orogenesis in this sector of the Iberian massif.

It has been suggested that the protolith oceanic lithosphere of the ophiolitic unit of the Morais complex was generated during a Silurian phase of rifting (Iglesias *et al.* 1983; Ribeiro 1983; Ribeiro *et al.* 1990). The compressive amphibolite-grade event dated in the present study corresponds to a period of compression and tangential tectonics that might correspond to limited subduction (absence of eclogites) of that oceanic crust. Subsequent tectonothermal evolution appears to have been related to obduction process of the ophiolite and its emplacement onto the north Iberian autochthon (the Silurian Centro–Transmontane sequence, Arenas *et al.* 1986, Ribeiro *et al.* 1990). This event appears to have induced local recrystallization of the ophiolitic protoliths with sparse development of greenschist facies associations and local development of a S_2 schistosity along the zones of thrust contact (Anthonoiz 1972; Ribeiro 1974; Ribeiro *et al.* 1990). The present data suggest, however, that the later metamorphic temperatures did not exceed *c.* 500 °C.

Regional interpretation

The different ophiolitic allochthons exposed in northern Iberia may represent erosional fragments of a single, regionally extensive sheet (Fig. 1A, Iglesias *et al.* 1983, Arenas *et al.* 1986). In most places the ophiolitic units record amphibolite-grade metamorphic assemblages. Greenschist facies associations and coronitic metagabbros (aborted eclogitization?) occur only locally. Previous isotopic results bearing on the age of the amphibolite facies metamorphism in these allochthons were reported by Van Calsteren *et al.* (1979). They presented K–Ar ages for only two samples which record a prograde amphibolite facies metamorphism (and eventually later regrograde metamorphic events). These were samples of metagabbro (at S. Julian del Trébol) and of Purrido amphibolite in the Cabo Ortegal complex (Fig. 1A). The metagabbro of S. Julian del Trébol (amphibole age *c.* 436 ± 13 Ma) constitutes a small sheet-like intrusion included in gneisses, and therefore may not be directly compared to the ophiolitic unit of the Morais complex. The Purrido amphibolites constitute a more extensive homogeneous formation that has been correlated with the ophiolitic unit of Morais (cf. Arenas *et al.* 1986). Van Calsteren *et al.* (1979) reported a 483 ± 48 Ma K–Ar age for amphiboles from this unit. However, the concentrate had a very low potassium content (0.08 wt%) precluding a reliable age determination. More recently, $^{40}Ar/^{39}Ar$ results for amphiboles from the Purrido (and Peña Escrita) amphibolites suggest a 380–390 Ma age for amphibolite facies metamorphism, analogous to that obtained for the rocks of the Morais complex (Peucat *et al.* 1990). This suggests that Lower Devonian deformation and metamorphism of oceanic lithosphere was probably more or less synchronous over a distance of several hundred kilometres. The ages obtained by Van Calsteren *et al.* (1979) for retrogressive minerals developed in granulites, metaperidotites and eclogites which structurally overly the ophiolitic unit of the Cabo Ortegal complex, are *c.* 390 ± 28, 388 ± 10, and 413 ± 15 Ma respectively (K–Ar age for 17 amphibole, 1 biotite and 1 phlogopite separates). By the Rb–Sr method, a biotite from the granulites provide an age of 346 Ma and 2 whole-rock–phlogopite pairs yield 380 Ma. Recent ^{40}Ar/^{39}Ar determinations are consistent with this result (*c.* 390 Ma for retrogressive amphiboles within granulites, Peucat *et al.* 1990).

The recent ^{40}Ar/^{39}Ar results support previous workers who have related deformation and metamorphism of the ophiolitic units to the tectonic emplacement of structurally overlying high-grade rocks (Iglesias *et al.* 1983; Arenas *et al.* 1986). Retrogressive amphibolitization in the high-grade units is more extensive in intensely deformed rocks along the intervening, high-temperature (amphibolite facies) shear zones. Hence ages of *c.* 390 Ma of secondary minerals in high-grade rocks are likely to reflect reactivation during thrusting to higher crustal levels.

The synkinematic metamorphism dated in this study is related to thrust tectonics which affected the whole region during Hercynian orogenesis. The event dated may be interpreted as a first stage of the Hercynian compressional activity and corresponds to subduction/obduction processes that preceded eventual Hercynian continental collision. The latter event produced low-pressure/high-temperature metamorphism and effected partial melting within intermediate crustal levels throughout the Orogen (Martínez *et al.* 1988). The ^{40}Ar/^{39}Ar ages obtained clearly indicate that the beginning of the compressive tectonics within this part of the Iberian massif was diachronous: commencing in the Lower Devonian in the west (synkinematic metamorphism of ophiolites of this study, inner parts of the Orogen) and in the Middle Carboniferous in the east (emplacement of nappes within the Cantabrian Zone: external segments of the Orogen, Marcos & Pulgar 1982).

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