

Granites as indicators in paleogeodynamics

JEAN-PIERRE PUPIN

Laboratoire de Pétrologie-Minéralogie, Faculté des Sciences, Parc Valrose, 06034 Nice Cedex (France)

ABSTRACT. — The study of the spatial distribution of granitic rocks in different orogenic belts lead to define magmatic polarities from zircon typology data. A more or less complete magmatic zoning with the succession of tonalites and 4a calc-alkaline granites, anatectic granites 1-2-3, calc-alkaline and K-calc-alkaline granites 4b-c, K subalkaline granites 5 can be observed. Abundance of anatectic rocks, $\bar{T}$ values of calc-alkaline, subalkaline rocks are depending upon the relative importance and duration of mantle-crust interactions during subduction-collision processes.

Key words: Magmatic zoning, orogenic granites, tonalites, zircon typology.

LES GRANITES, MARQUEURS EN PALEOGEODYNAMIQUE

RÉSUMÉ. — L'étude de la répartition spatiale des roches granitiques de différents domaines orogéniques conduit à définir des polarités magmatiques basées sur les données typologiques des populations de zircons. Une zonalité magmatique plus ou moins complète de tonalites et granites calco-alcalins 4a, granites anatectiques 1-2-3, granites calco-alcalins et calcoalcalins potassiques 4 b-c, granites subalcalins potassiques 5 peut ainsi être observée. L'abondance des roches anatectiques, les indices $\bar{T}$ des roches calco-alcalines et subalcalines dépendent largement de l'importance relative et de la durée des interactions manteau-croûte pendant les processus de subduction et de collision.

Mots clés: zonalité magmatique, granites orogéniques, tonalites, typologie du zircon.

I. Introduction

Magmatic zoning is known for a long time (KUNO, 1959; JAKES and WHITE, 1972;

McKENZIE and CHAPPELL, 1972; GILL and GORTON, 1973; LEFEVRE, 1979) from the characteristics of volcanites in (relatively) recent orogenic domains. The spatial distribution of the magmatism often yields a clear polarity with increasing contents of K, Rb, Ba, Ti, Th, U and light R.E.E. when going away from the trench zone in convergent margin environments (continental margins and island arcs).

In ancient orogenic zones of subduction-collision, most of the volcanites disappeared, but in contrast granitoids are more or less well represented. Such deep produced orogenic plutonites, especially granites, linked to deep structures of the orogens, are able to give fundamental criteria to discuss the plate tectonics. Some results had been obtained from the geochemical data on calc-alkaline granites (BATEMAN and DODGE, 1970; DODGE, 1972; BAIRD et al., 1974; KIKUCHI in MIYASHIRO, 1975), the use of isotopes (SINHA and ZIETZ, 1982), iron oxydes (ISHIHARA, 1977, 1980) or zircon typology (PUPIN, 1981, 1985; WERNICK et al., 1987).

But this implies the availability of a good genetic classification for granites. Recent and important progresses have been registered in this domain (BOWDEN et al., 1984; CHAPPELL and WHITE, 1974; DIDIER et al., 1982; ISHIHARA, 1977; LAMEYRE, 1980; LAMEYRE and BOWDEN, 1982; ORSINI, 1976, 1980; PEARCE et al., 1987; PITCHER, 1979; PUPIN, 1980, 1981, 1985).

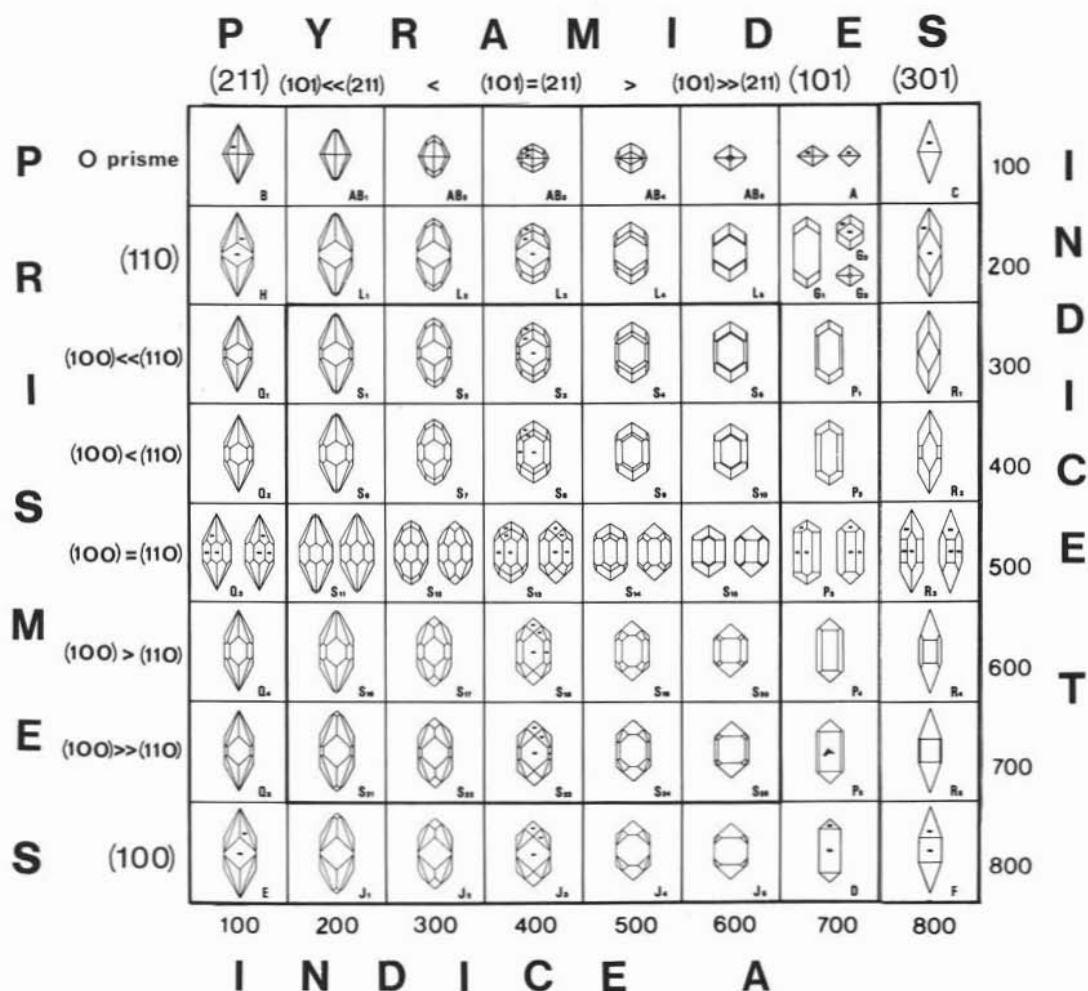


Fig. 1. — Main types and subtypes of the typologic classification.

II. The typology method

Zircon typology is a cheap and easy method (PUPIN and TURCO, 1972a; PUPIN, 1976). Zircon is generally well distributed in granites and the zircon population of one sample is generally enough to characterize an homogeneous granitic body (PUPIN, 1985). Zircon gives information on the primary crystallization of the host rock and is generally not affected by deuteric phenomena (hydrothermal alteration, weathering, tectonic and metamorphic events,...) (PUPIN, 1976).

An arrangement of given prismatic and pyramidal crystal faces constitutes a

population type. Main types and subtypes are related on a square board with two variables (Fig. 1), depending upon the relative development of the crystalline faces.

For each sample, in the 0.050-0.160 mm fraction, the typologic distribution has been determined on the basis of the examination of 100 unbroken zircon crystals whenever possible, and the coordinates ($\bar{A}$, $\bar{T}$) and the T.E.T. have been calculated (Fig. 2) [$\bar{A}$, $\bar{T}$] represent the mean point of the population:

$$I.A = \frac{\sum I.A \times n_{I.A}}{I.A = 100}$$

$$I.T = \frac{\sum I.T \times n_{I.T}}{I.T = 100}$$

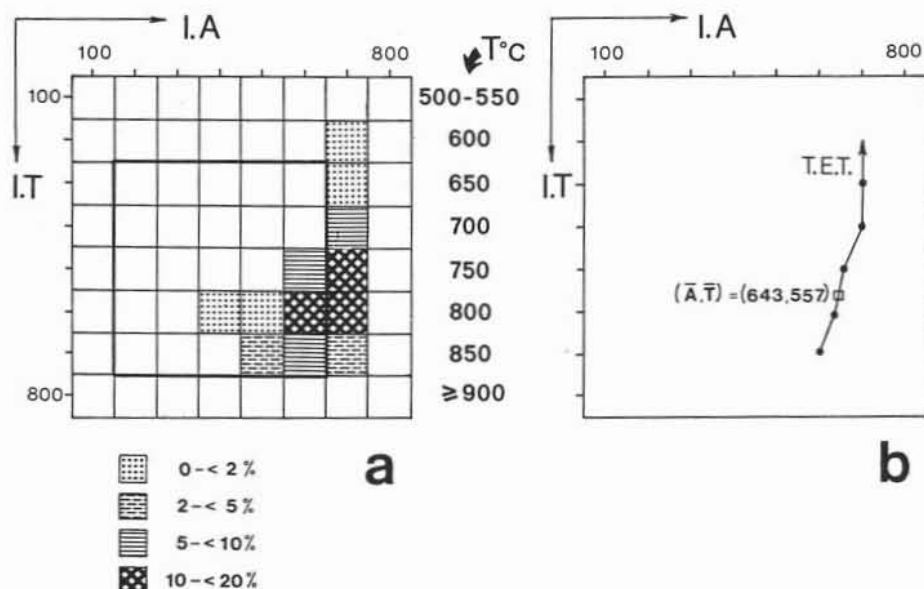


Fig. 2. — Representation of a zircon population: a) typologic frequency distribution; b) mean point $(\bar{A}, \bar{T})$ and typological evolutionary trend (T.E.T.).

where $n_{I.A.}$ and $n_{I.T.}$ are the respective frequencies for each value of I.A. or I.T. ($\sum n_{I.A.} = \sum n_{I.T.} = 1$).

The T.E.T. (Typological Evolutionary Trend) is drawn through the different $\bar{A}$ points calculated for each value of I.T. (PUPIN, 1976, p. 62)].

The T.E.T. represents the chronology of crystallization of the different types and subtypes during the magmatic stage. It can be deduced from the observation of crystal zoning along sections parallel or perpendicular to the c axis: under transmitted light for ancient crystals (PUPIN and TURCO, 1970; PUPIN, 1976) or with fission tracks techniques to reveal Uranium distribution and crystal growth for recent crystals (CARPENA et al., 1987; GAGNOL, 1987).

The typologic data give direct information on the crystallization medium:

- T index is directly and positively correlated with the temperature of zircon crystallization; a geothermometric scale was thus proposed (PUPIN and TURCO, 1972b).
- A index is correlated with the chemistry, a peraluminous medium favouring the development of {211}, an alkaline or

peralkaline medium favouring the development of {101} (PUPIN 1976, 1980; PUPIN and TURCO, 1975).

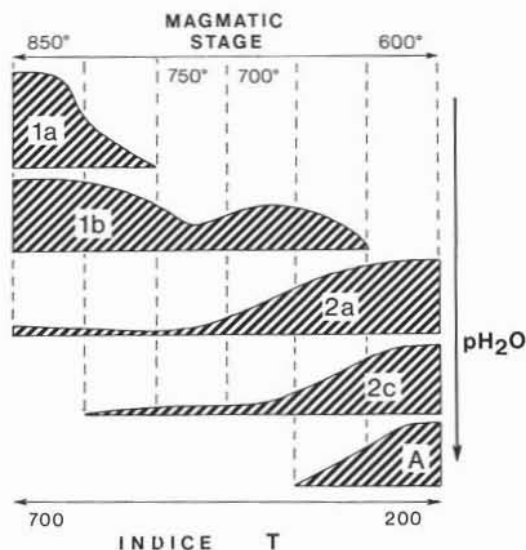


Fig. 3. — Zircon crystallization period with corresponding temperatures related to the T values in the K-subalkaline granitic rocks of Ploumanach, Brittany [granites of Traouïéros (1a), La Clarté (1b), Kerleo-Canton (2a), Saint-Samson (2c) and aplite of Tregastel (A)].

Another factor corresponds to the water pressure which modifies the period of zircon crystallization. An illustration (Fig. 3) can be given by the K-subalkaline granite series (PUPIN, 1981) of Ploumanach (BARRIÈRE, 1977) with an early crystallization of zircon (now limpid crystals) in the coarse grained pink granites (Traouieros, La Clarté) crystallized from dry magmas to the late crystallization of zircon in the fine grained granites (Kerleo-Canton, Saint-Samson) and aplites where crystals are richer in U and now metamict.

A genetic classification for granitic rocks based on zircon typology had been proposed (PUPIN, 1980). At this time, other studies permit to define more precisely (from about 600 samples) the domains corresponding to the mean points distribution of the different genetic types (Fig. 4). This classification shows some advantages related notably to the possibility of a good separation between granites of crustal or mainly crustal origin and mantle derived or hybrid mantle + crust granites, especially hololeucocratic differentiates from the calc-alkaline, K-

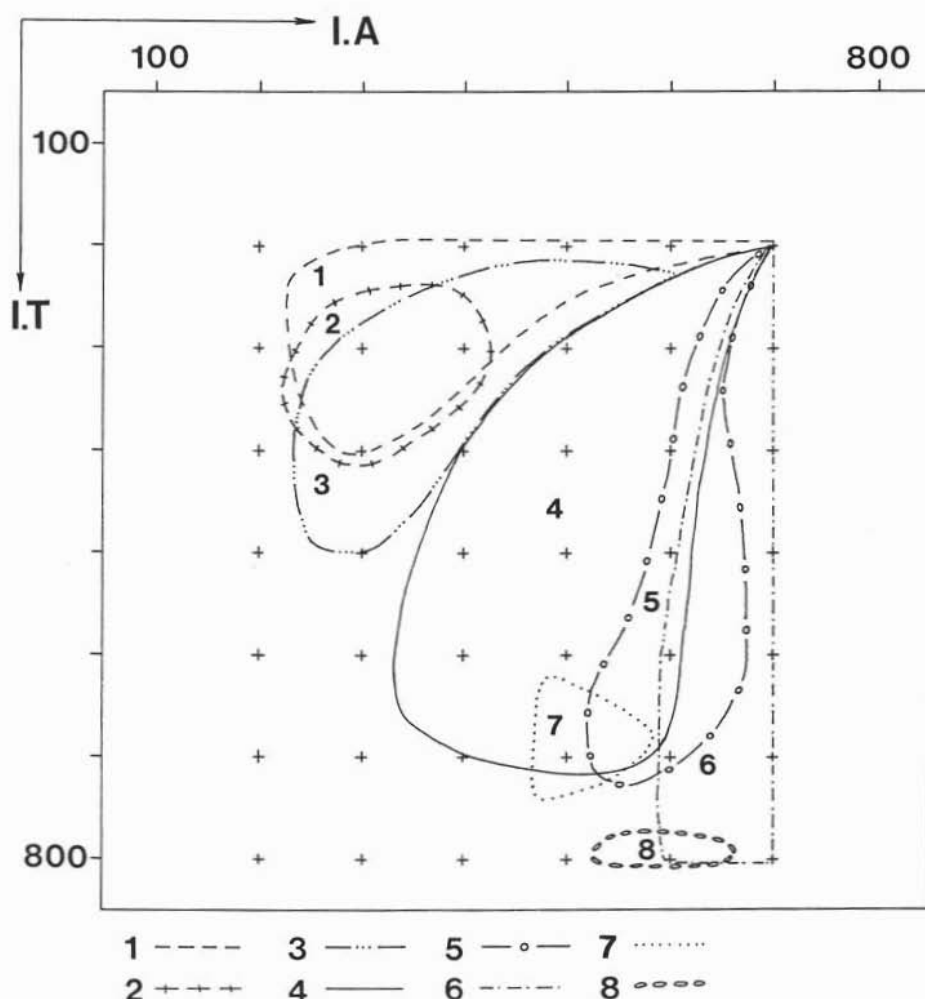


Fig. 4. — Distribution of granitic rocks in the typologic diagram (PUPIN, 1980, 1985 slightly modified): aluminous leucogranites (1), (sub)autochthonous monzogranites-granodiorites (2), intrusive aluminous monzogranites-granodiorites (3), calc-alkaline and K-calc-alkaline series granites (4), subalkaline series granites (5), alkaline series granites (6), continental tholeiitic granites (7), oceanic tholeiitic series granites (8).

calcalkaline, subalkaline or alkaline series.

The calc-alkaline granites belong to the low K («tonalitic») and normal K («granodioritic») series (LAMEYRE and BOWDEN, 1982). The monzonitic association or high K series (ORSINI, 1976; PAGEL and LETERRIER, 1980; DEBON and LEFORT, 1983) corresponds to the K-calcalkaline series (sometimes qualified as

magnesiopotassic relatively to the composition of biotite: i.e. Balagne, Corsica and Ballons, Vosges, France; ORSINI, 1976, 1980; PAGEL and LETERRIER, 1980) and the subalkaline series (ferropotassic: i.e. Ploumanach; BARRIÈRE, 1977; BARRIÈRE and CHAURIS, 1971; DUPUIS, 1972).

For each population, the position of the

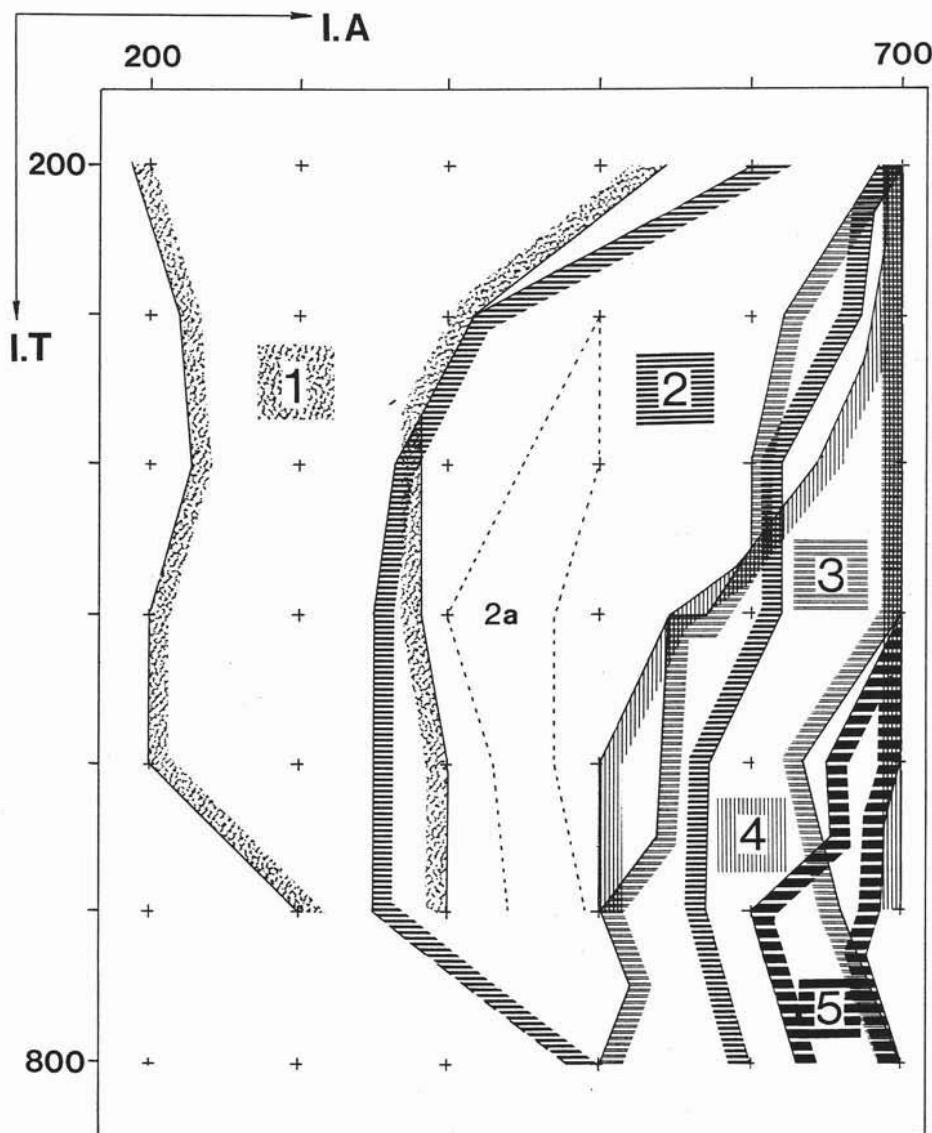


Fig. 5. — Distribution of T.E.T. for granitic rocks: granites of crustal or mainly crustal origin (1), calc-alkaline granites (2), K-calc-alkaline granites (2a), subalkaline granites (3), subsolvus alkaline granites (4), hypersolvus alkaline granites (5).

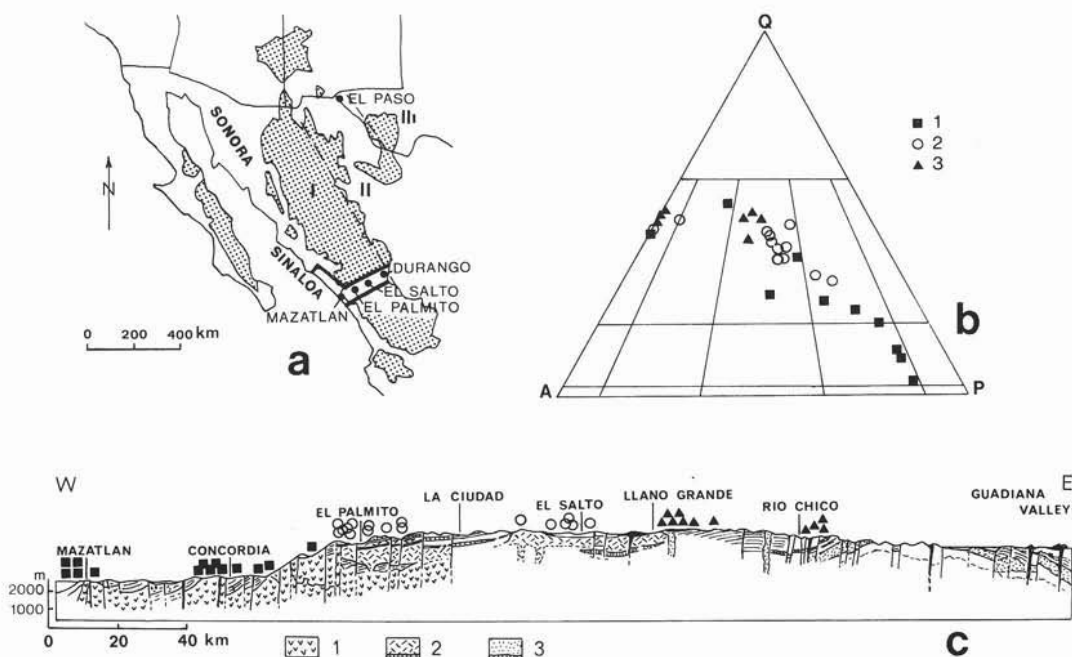


Fig. 6. — Location of the studied area in Mexico (a): zone I = upper volcanic supergroup province in the Sierra Madre Occidental, II = eastern Chihuahua and westernmost Texas provinces, III = alkalic province of Trans-Pecos Texas, after McDOWELL and CLABAUGH, 1979. Distribution of the analyzed samples in the Q-A-P diagram — normative data — (b): 1 = Cretaceous-early Tertiary volcanic and batholithic rocks, 2 and 3 = mid Tertiary volcanic rocks. Cross section of the Sierra Madre Occidental between Mazatlan and the Guadiana Valley (c) after McDOWELL and CLABAUGH, 1979, with location of the studied samples: 1 = 102-45 m.y., 2 = 28-23 m.y., 3 = 32-28 m.y.

T.E.T. permits to precise the belonging to a genetic group (Fig. 5). Only one sample is necessary for obtaining a characteristic trend.

III. The Magmatic zoning

The mean points distribution of zircon populations from granites sampled in the same area visualizes very clearly the contrast previously mentioned by PITCHER (1979) for acidic magmas in «alpinotype», «andinotype» and «hercynotype» environments. Moreover, the comparison between the different typologic characteristics (mean points $\bar{A}$, $\bar{T}$; T.E.T.) lead to define magmatic zonings in ancient orogens (PUPIN, 1981, 1982, 1983, 1985; PUPIN and WERNICK, 1987; WERNICK et al., 1987).

Several examples of magmatic zoning are proposed. They are characterized by the abundance or scarcity of granitic bodies and/or associated rhyolites, the importance of crustal

anatexis, the temperature and water content of the melts - especially concerning calc-alkaline granites:

- Cainozoic period: Mexico, New Caledonia, Western Alps, Elba-Tuscany;
- Hercynian cycle: French Massif Central, Brittany, Corsica-Provence, Morocco;
- Caledonian cycle: Belgium
- Brasiliano cycle (late Precambrian): southern Brazil.

1 - Mexico (Sierra Madre Occidental)

The analysed rocks had been sampled in the Sierra Madre Occidental of Mexico along a cross-section between Mazatlan and Durango (Fig. 6a). The rocks belong to the three main units described by McDOWELL and KEIZER (1977), McDOWELL and CLABAUGH (1979) (Fig. 6c) and differ in ages:

- The oldest ones Cretaceous to early Tertiary (102-45 m.y.), correspond to the

western calc-alkaline volcanites (andesites, dacites, rhyolites) and batholithic rocks (granodiorites and diorites);

- the youngest ones are Tertiary (32-23 m.y.) tufs and rhyolites (32-28 m.y.: Llano Grande to Guadania Valley in the west; 28-23 m.y.: El Palmito to Llano Grande in the central part). In the Q.A.P. diagram, these rocks show increasing silica and alkali contents when going away from the trench (Fig. 6b).

Considering the mean points distribution in the typological diagram (Fig. 7 and 8), the same zoning is observed. It can be noticed that:

- 1) anatectic magmas are absent;
- 2) the populations have high $\bar{T}$ indices indicating high temperatures of crystallization

from relatively dry magmas;

- 3) the mean points distribution shows a linear inferior limit with increasing $\bar{T}$ indices correlated with increasing depth of the subduction zone.

2 - Brazil (*Dom Feliciano belt*)

The Dom Feliciano fold belt (Brasiliano cycle, late Precambrian) runs parallel to the atlantic coast of southern Brazil (Santa Catarina, Rio Grande do Sul) and Uruguay.

A zircon typology study (nearly one hundred samples) together with lithochemical and petrographic data (PUPIN and WERNICK, 1987; WERNICK et al., 1987) allowed the recognition of the following main groups of granitoids (Fig. 9) in the brazilian part of this

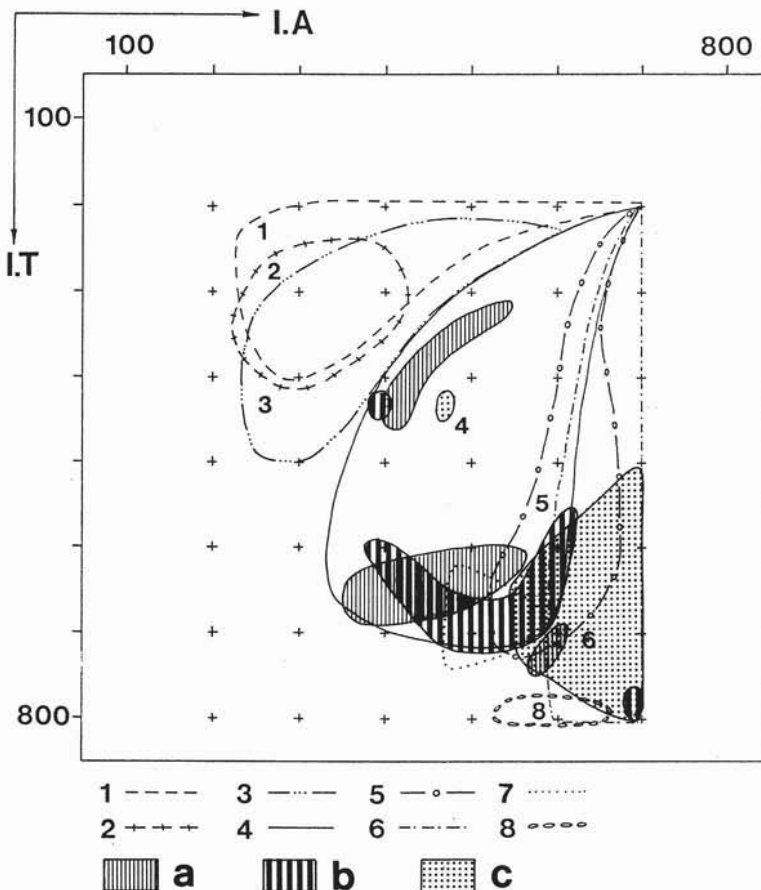


Fig. 7. — Distribution of zircon populations: (a) Cretaceous-early Tertiary volcanic and plutonic rocks, (b) and (c) mid Tertiary rhyolites and tufs (a, b, c correspond respectively to the 1, 2, 3 units of Fig. 6).

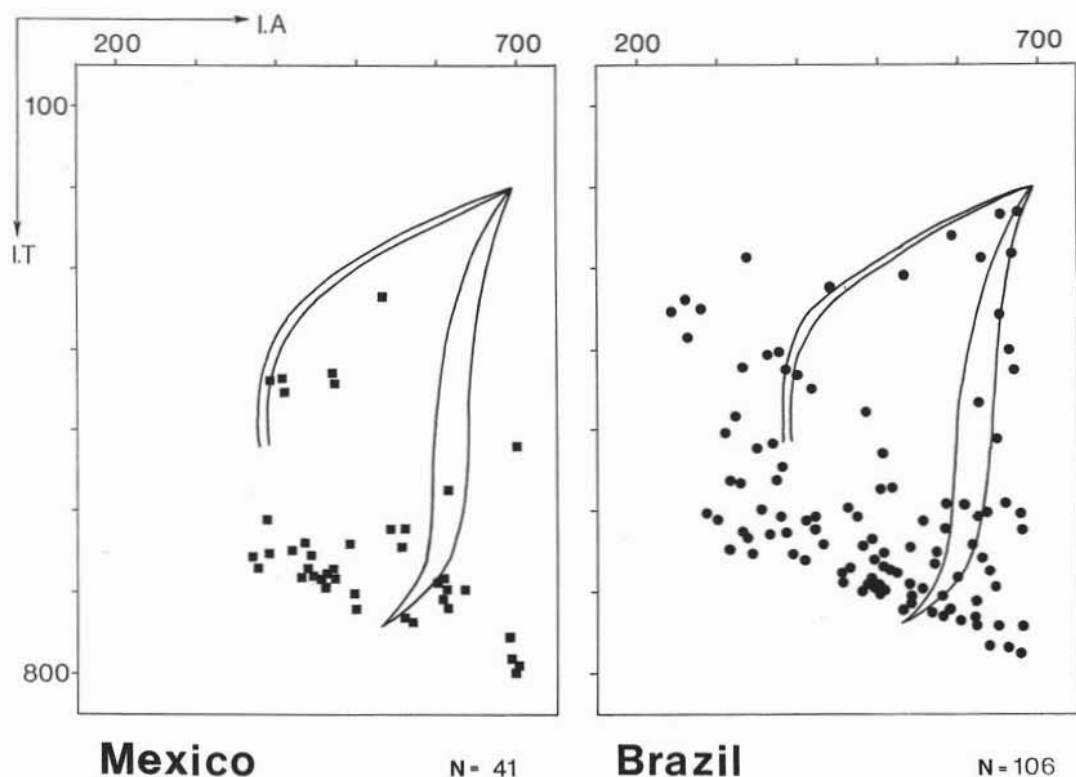


Fig. 8 — Mean points distribution of magmatic rocks from Mexico (Sierra Madre Occidental) and Brazil (Dom Feliciano belt).

belt:

- 1) anatectic granites and b) diorites, tonalites and low temperature calc-alkaline (Coastal batholith in Rio Grande do Sul);
- 2) medium to high temperature calc-alkaline granitoids of normal to K-rich composition (central part of the magmatic arc);
- 3) subalkaline K-rich granitoids and syenites, common in the western part of the belt;
- 4) alkaline granites.

Thus, zircon typology reveals a clear magmatic zoning, this being more complete in Rio Grande do Sul. The mean points distribution shows mainly high $\bar{T}$ indices (Fig. 8b) and the same oblique linear inferior limit than for the volcanic rocks from Mexico.

The different domains defined by the typological evolutionary trends (mean T.E.T. and T.E.T. distribution; Fig. 10a, b) are quite equivalent to these for similar rocks from Hercynian and Permian plutonism of western Europe. The similarity with the Mexican

orogenic area is reinforced by the scarcity of crustal anatectic rocks which is in strong contrast to the great amounts of crustal granites occurring in the French Hercynides (PUPIN, 1985). As in Mexico, the increasing depth of the supposed subduction zone (JOST et al., 1984; Fig. 11) is correlated with the development of the {100} prism (Fig. 12), that is to say the increasing of $\bar{T}$ indices. The geotectonic polarity indicated by the lower oblique line in the zircon typological diagram points to a former trench situated east to the present shoreline.

3 - Western Alps

In the Western Alps, alpine granitic rocks are rare and associated with tonalites in the Bergell and Adamello massifs. The calc-alkaline magmatism had been proposed (i.e. GIRAUD, 1983) to be related with the disappearance of a limited oceanic crust in the

piedmontese domain (Fig. 13). In such a model, these granites, granodiorites and tonalites were emplaced very near the suture zone.

The granodiorites and granites are typically calc-alkaline of trend 4a (Fig. 14a), with low $\bar{T}$ indices indicating low temperatures of crystallization and a relatively high water pressure. The two-mica Novate granite appears to be of anatectic origin and so, not related with the previous trend.

If we compare the plutonites of Adamello with the trends obtained for andesitic suites (andesites, dacites, rhyolites) (GIRAUD et al., 1980) of central volcanoes in the world, the

accordance is good and the diorites-tonalites appear to be plutonic equivalents of the andesites-dacites (Fig. 14b). Granodiorites and granites follow this trend at lower $\bar{T}$ indices, confirming the fractional crystallization suites. It is noticeable that these granites are clearly distinct from the calc-alkaline granites with higher $\bar{T}$ indices, often linked with huge volumes of calc-alkaline ignimbrites which crop out generally at greater distances from the suture zone.

4 - New Caledonia

A similar example with a relatively limited

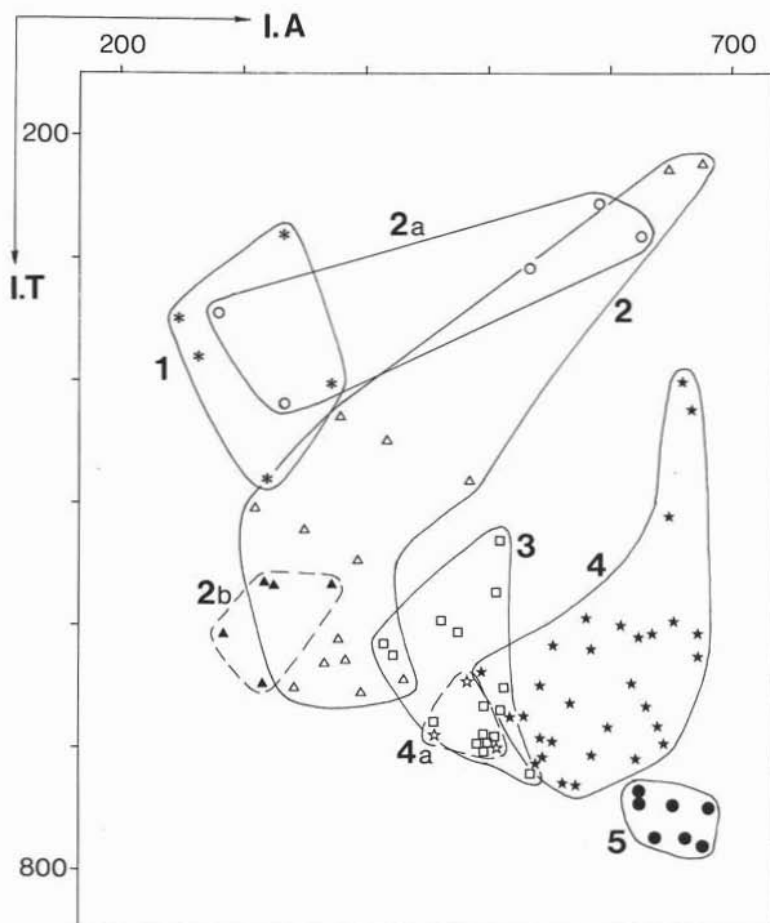


Fig. 9. — Distribution of main genetic groups of plutonic rocks in the Dom Feliciano belt, Brazil: anatectic granites (1), calc-alkaline granites of the 4a trend (PUPIN, 1980) (2) and associated diorites (2b), Caçapava calc-alkaline granite (2a), calc-alkaline and K-calc-alkaline granites of the 4b-c trends (3), subalkaline granites (4) and associated syenites (4a), alkaline granites (5).

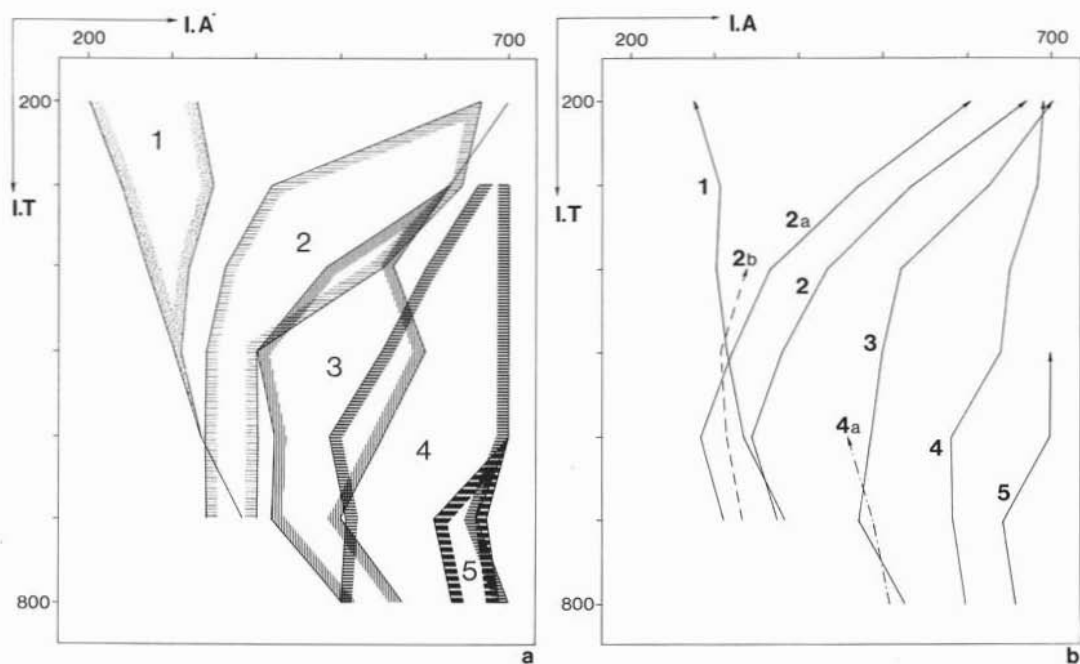


Fig. 10. — Distribution of T.E.T. (a) and mean T.E.T. (b) for granitic rocks of southern Brazil (1 to 5 correspond to the Fig. 9).

subduction and a very little distance between the trench zone and the intrusions may be given by New Caledonia during Alpine orogeny. Tonalites and granodiorites were intruded at 25 m.y. just after the emplacement of the peridotites nappe (GUILLOU in

ALLÈGRE, 1980; PARIS, 1981) (Fig. 15). A tonalite of Saint-Louis and three granites of Saint-Louis and Koum were studied. These rocks are typical of the calc-alkaline trend 4a and quite similar to those of the Adamello massif (Fig. 15).

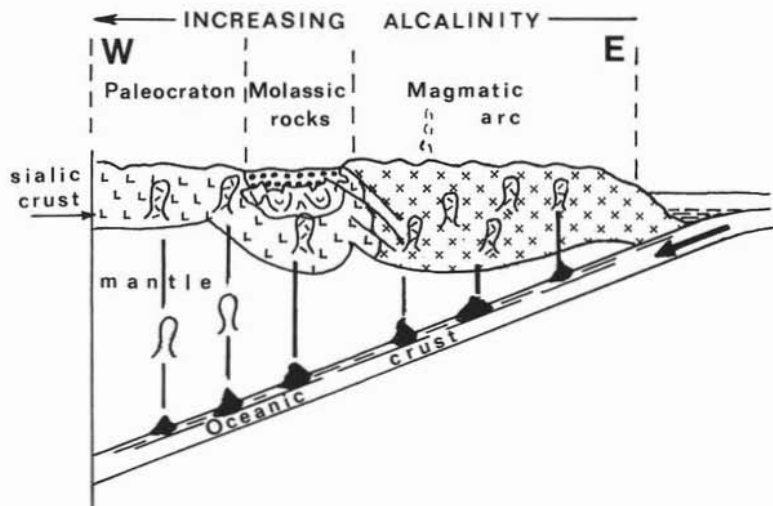


Fig. 11. — Geodynamic model proposed by JOST et al., 1984 for the Dom Feliciano belt, southern Brazil.

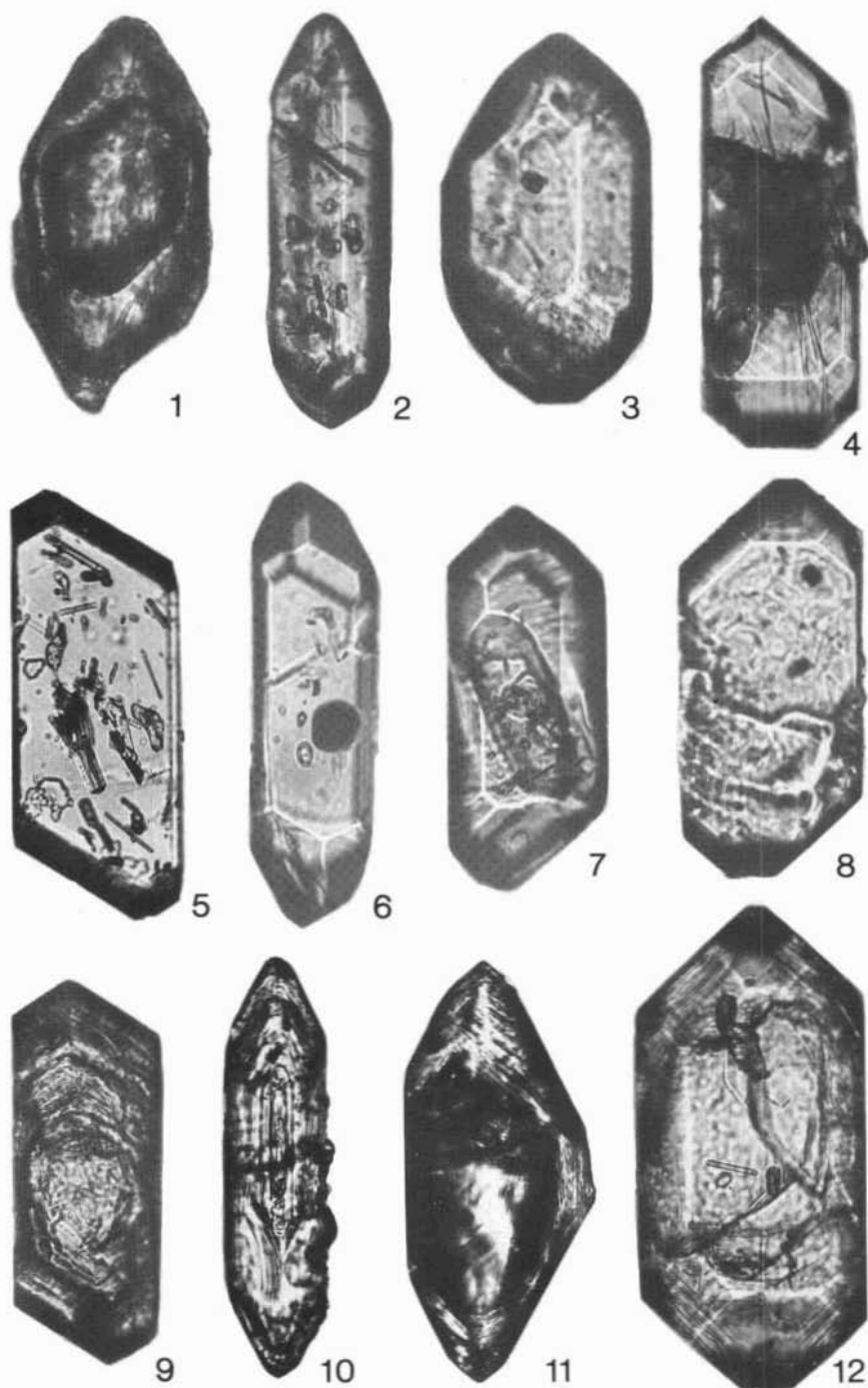


Fig. 12. — Typologic modifications indicating geodynamic polarities: 1-4: Dom Feliciano belt, Brazil (1: S1, anatectic granite, Coastal Batholith; 2: S12, calc-alkaline granite, 4a type, Coastal Batholith; 3: S18, K-calc-alkaline granite, Valsungana; 4: S24, subalkaline granite, Rio Chacao), 5-8: Elba-Tuscany, Italy (5: G1, calc-alkaline granite, 4a type, Monte Capanne, Elba; 6: S2, anatectic granite, Giglio; 7: S19, calc-alkaline granite, Gavorrano; 8: S24, subalkaline to alkaline volcanites, Monte Amiata and Vitorchiano); 9-12: Massif Central, France (9: S5, calc-alkaline granodiorite, 4a type, Sidobre; 10: L1, anatectic leucogranite, Saint-Sylvestre; 11: S1, anatectic monzogranite, Margeride; 12: S19, K-calc-alkaline granite, Aigoual, Cevennes). The range of crystal sizes is 0.14 - 0.25 mm.

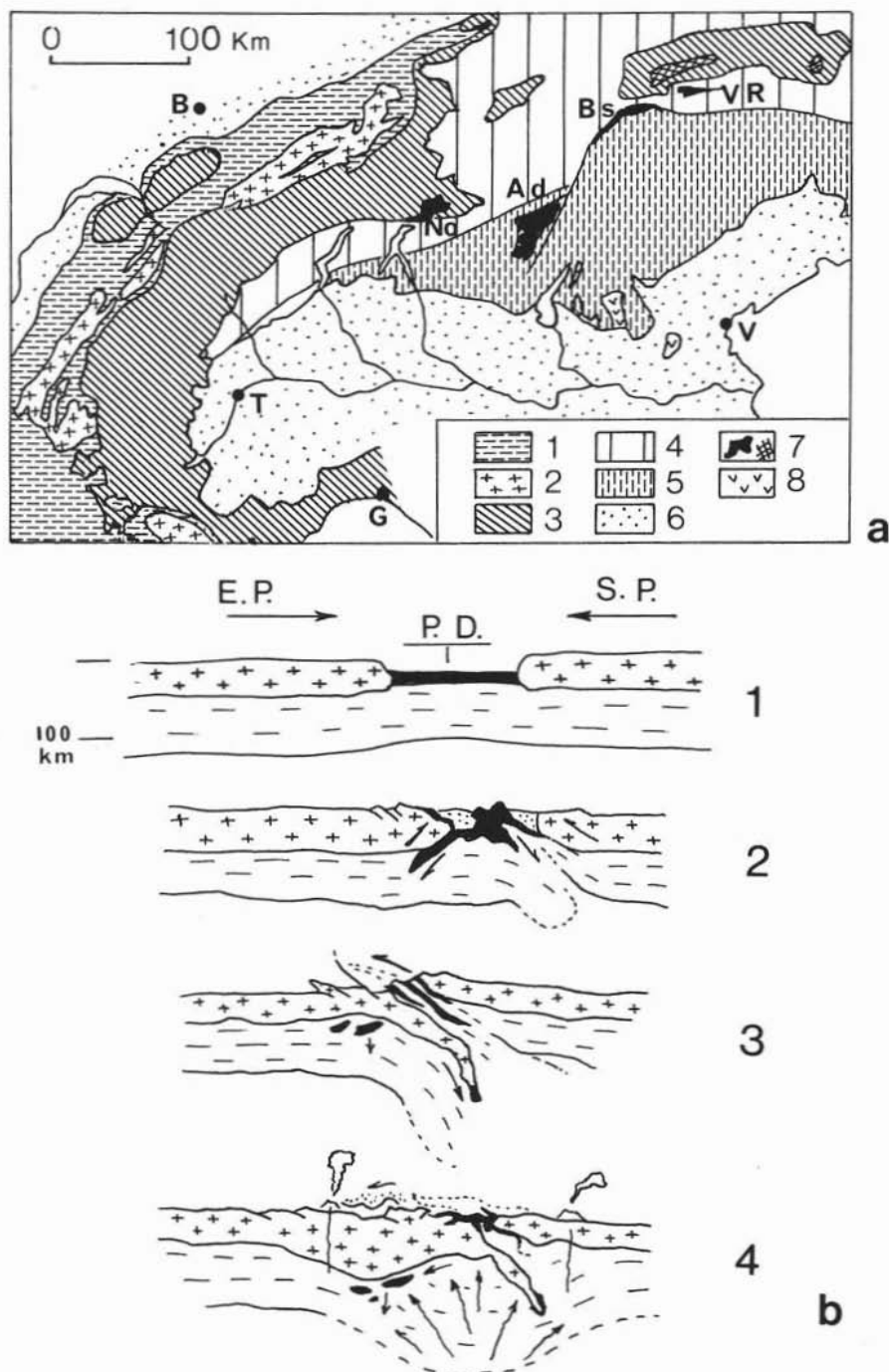


Fig. 13. — (a) Tonalitic line in western Alps (after RAGUIN, 1970): Ad: Adamello, Bs: Bressanone, No: Novate, Bergell, VR: Vedrette di Ries; B: Bern, G: Genova, T: Torino, V: Venezia; 1: Helvetic, 2: pre-Alpine massifs, 3: Penninic, 4: austro-Alpine, 5: Dinarides, 6: late Tertiary, 7: Alpine granitoids, 8: Tertiary volcanism. (b) Geodynamic evolution of the Alpine chain (after GIRAUD, 1983): E.P.: European plate, S.P.: south-Alpine plate, P.D.: piedmontese domain. Situations at 100 m.y. (1), 90 m.y. (2), 60 m.y. (3), 35 m.y. (4).

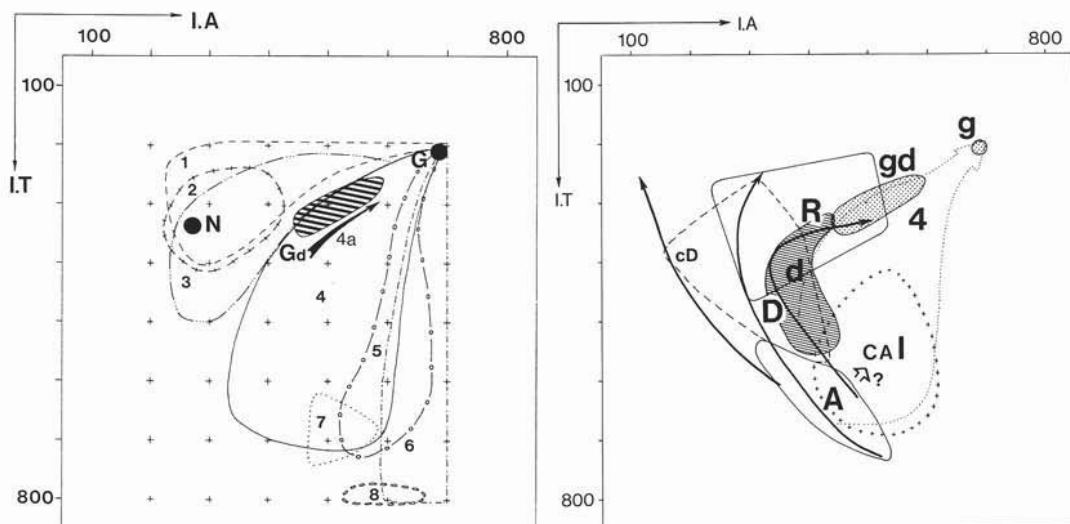


Fig. 14. — (a) Mean points distribution of granodiorites (Gd) and granites from Adamello (4a calc-alkaline trend; data after HANSMANN et al., 1983, HANSMANN, 1986, PUPIN, unpubl.). Similar results had been obtained by BARTH et al., 1987 on the Rensen pluton, S. Tirol. N: Novate two mica granite. (b) Comparison between the plutonic series of Adamello: quartz diorites, tonalites (d), granodiorites (gd), granites (g) and the andesitic series from the central volcanoes (differentiation T.E.T. indicated by arrows — GIRAUD et al., 1980 —: andesites (A), dacites (D), cordierite-bearing dacites (cD), rhyodacites-rhyolites (R). Granitic calc-alkaline field (stock 4) and related calc-alkaline ignimbrites (CAI) after PUPIN, 1980. For references about Adamello, see BIANCHI et al., 1970, CALLEGARI and DAL PIAZ, 1973, DUPUY et al., 1982.

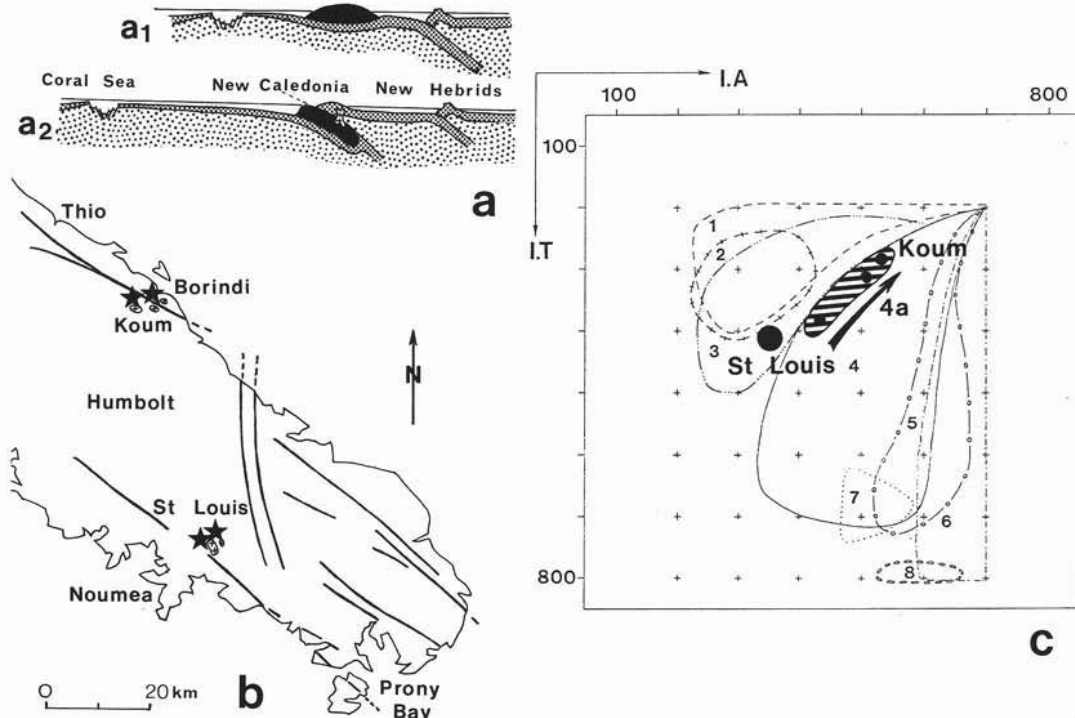


Fig. 15. — (a) Geodynamic setting in New Caledonia (after GUILLOU in ALLEGRE, 1980); pre (a1) and post (a2) eo-Oligocene. (b) Samples location and (c) mean points distribution of tonalite and granodiorites from Saint-Louis and Koum (4a calc-alkaline trend).

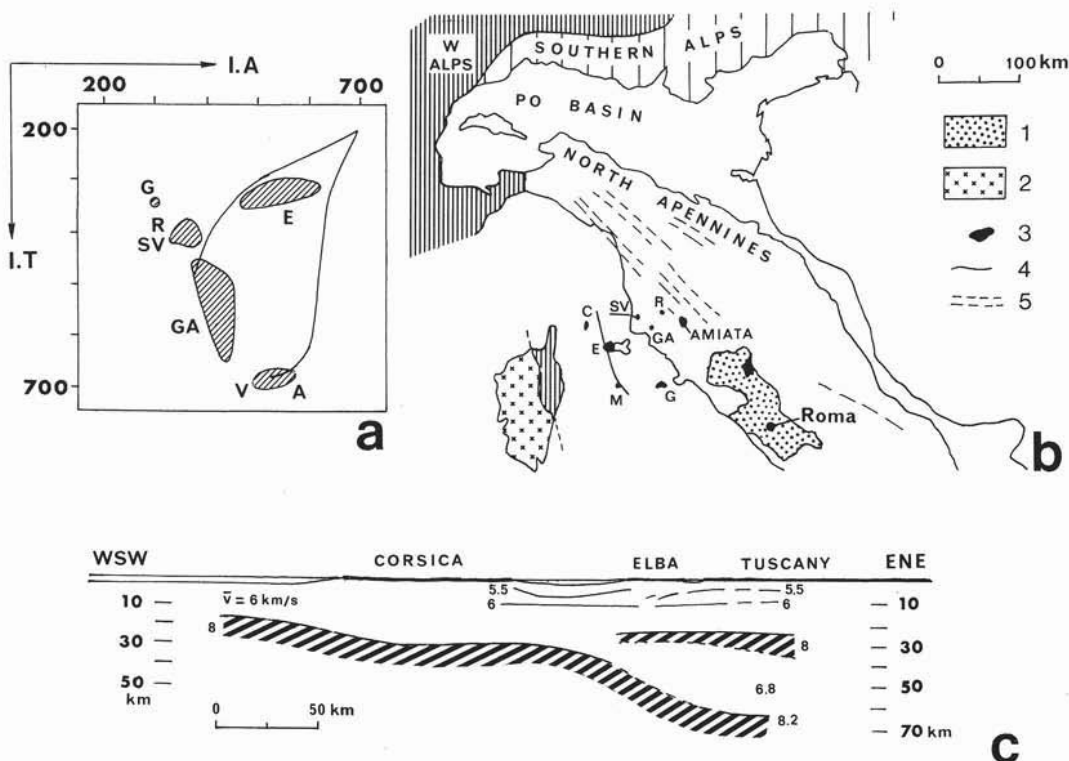


Fig. 16. — Mean points distribution (a) of studied samples from Elba-Tuscany (b): A = Monte Amiata, E = Elba, G = Giglio, Ga = Gavorrano, R = Roccastrada, SV = San Vincenzo, V = Vitorchiano; 1 = alkali potassic volcanism of the Roman Province (1,7 m.y. to present), 2: Corsica massif, 3: intracrustal acidic magmatism of the Tuscan Province (8,7-0,4 m.y.), 4: Northern Tyrrhenian geosuture, 5: main tensional faults (or grabens) (b after BARBERI and INNOCENTI, 1980, simplified). Cross section with velocity depth (c) after LETZ et al., (1977).

5 - Elba-Tuscany

A more complex example concern the magmatism of Elba-Tuscany in Italy since 8 million years. Composed of plutonites (Elba granite and microgranites, Gavorrano and Botra ai Marmi granites) and volcanites (San Vincenzo, Roccastrada, Monte Amiata) (RITTMAN, 1962; DUPUY, 1970; MORELLI, 1975; DI GIROLAMO, 1978) (Fig. 16), this magmatism is interpreted as a lithosphere consumption zone during the presumed rotation of the Corsica-Sardinia block (as a fragment of the European plate) up to its collision with the Adriatic microplate (MORELLI, 1975; BOCCALETTI and GUAZZONE, 1972). As hybrid granitic rocks exist (calc-alkaline granite of Monte Capanne, Elba), it could be assumed that a very limited subduction-like process worked at the

beginning of the underthrusting of the Corsican plate. The development of magmatism followed in space and time the end of the underthrusting during several m.y. (8 m.y. - Elba - to 0.2 m.y. - Monte Amiata -).

From west to east, zircon typology gives a good zoning with successively: calc-alkaline granite (Monte Capanne) and microgranitic dykes of Elba with low $\bar{T}$ indices near the presumed suture zone (BARBERI and INNOCENTI, 1980), anatectic granites and rhyolitic ignimbrites such as Giglio, San Vincenzo and Roccastrada, calc-alkaline granites such as Gavorrano and finally K-subalkaline or alkaline volcanites such as Monte Amiata or Viterbo. These last rocks could belong to the alkaline magmatism of Central Italy (LOCARDI and MITTEMERGER, 1969; BARBERI and INNOCENTI, 1980; TURI, 1987).

So, when going away from the western suture zone, a very clear increase of $\bar{T}$ indices appear (Fig. 17a), directly linked with the depth of the Moho from 40 to 65 km given by geophysical data after LETZ et al., (1977) (Fig. 16). The modifications registered on

zircon typology are presented on Fig. 12.

6 - French Massif Central and Brittany

In this Hercynian domain of western Europe, a very clear zoning can be deduced

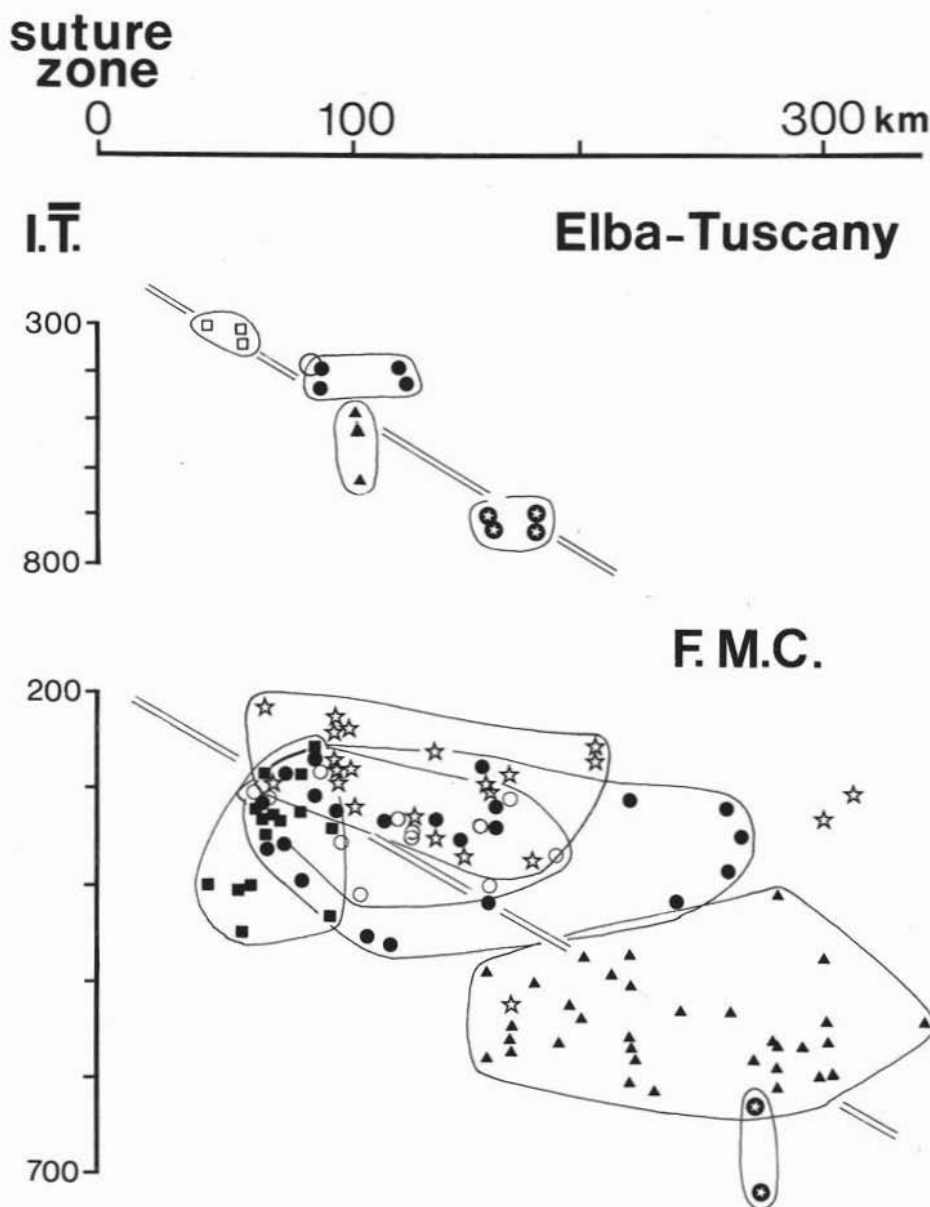


Fig. 17. — Relationship between $\bar{T}$ indices and distances from the supposed suture zones in Elba-Tuscany and the French Massif Central (F.M.C.): calc-alkaline granites, 4a trend (squares), anatectic granites of groups 1 (stars), 2 (open circles) and 3 (filled circles), calc-alkaline and K-calc-alkaline granites (triangles), alkaline and continental tholeiitic rocks (encircled stars).

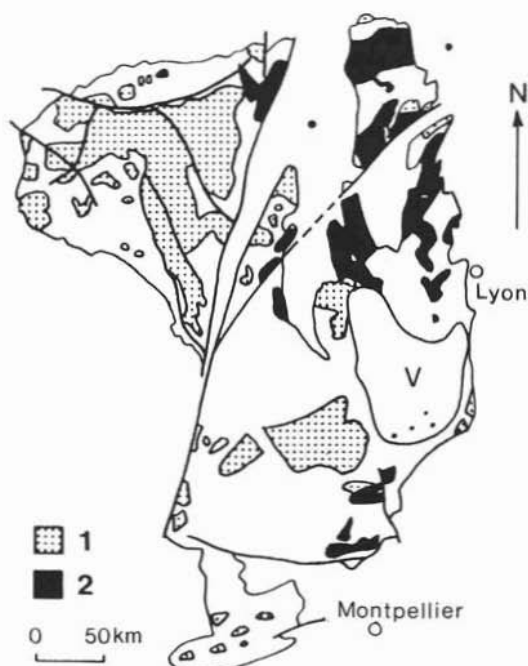


Fig. 18. — Distribution of granites with $\bar{T}$ values of zircon populations < 450 (shaded [1]) and > 450 (black [2]) in the French Massif Central; V = the late Hercynian emplaced Velay anatectic diapiric dome (AUTRAN and PETERLONGO, 1979) (after PUPIN, 1985).

from zircon typology data ever when considering the populations with $\bar{T}$ indices lower or greater than 450 (Fig. 18) (PUPIN, 1985).

An increasing of $\bar{T}$ indices clearly appears from west to east in the same way than in Elba-Tuscany (Fig. 17b). In detail, the French Massif Central shows from west to east the succession of tonalites and calc-alkaline granites with low $\bar{T}$ indices, anatectic granites of the groups 1 to 3 (PUPIN, 1980), calc-alkaline and K calc-alkaline granites with higher $\bar{T}$ indices crystallized from hotter and drier magmas (PUPIN, 1981, 1985).

Moreover, a very clear bimodality of the orogenic magmatism, as well as in Brittany, is underlined by zircon typology data (Fig. 19).

The southern part of Brittany is characterized by Hercynian anatectic granites of groups 1-2, the northern by anatectic granites of group 3, followed by calc-alkaline, K calc-alkaline and subalkaline granites with

high $\bar{T}$ values (PUPIN, 1985).

As previously, modifications on zircon typology are presented Fig. 12.

IV. The plutonic zoning model

Results obtained on several orogenic domains, clearly distinct in space and time, show that we can propose for plutonic rocks (granitoids) the model of a more or less complete magmatic zoning. This zoning reveals the ancient geodynamic polarity and is composed, from the trench or the suture zone to the external part of the overthrusting plate, of:

- tonalites and calc-alkaline granites (4a trend, PUPIN, 1980) with low $\bar{T}$ indices corresponding to the andesitic suites;
- anatectic granites of groups 1-2 (aluminous leucogranites and (sub) autochthonous monzogranites);
- mainly anatectic porphyritic granites of group 3 with idiomorphic cordierite;
- calc-alkaline and K calc-alkaline granites with high $\bar{T}$ indices of group 4 (4b-4c);
- subalkaline granites of group 5.

Often a tensional magmatism follows in time the orogenic one and sometimes these successive magmatic activities show some overlapping with contemporaneous or subcontemporaneous calc-alkaline or anatectic and alkaline products. In such a case, the alkaline acidic magmas are frequently perturbed by the very recent crustal orogenic activity and the feldspar mineralogy is generally subsolvus (i.e. Corsican subsolvus granites, BONIN, 1980; early Permian alkaline dykes and volcanites, Provence-Esterel, PUPIN, 1976 and unpublished data; Kagenfels granites, RÈVE, 1985; Baveno granites, northern Italy, CAIRONI, 1985; Combeynot granite, Pelvoux massif, Western Alps, COSTARELLA, 1987). The alkaline intrusions can constitute logically a last zone after the K calc-alkaline and/or subalkaline ones, as in southern Brazil (WERNICK et al., 1987); nevertheless, they often overlap the orogenic magmatic arc, mainly the zones of calc-alkaline and K calc-alkaline granites with high $\bar{T}$ indices zircon populations (i.e. Provence-Corsica, PUPIN, 1985).

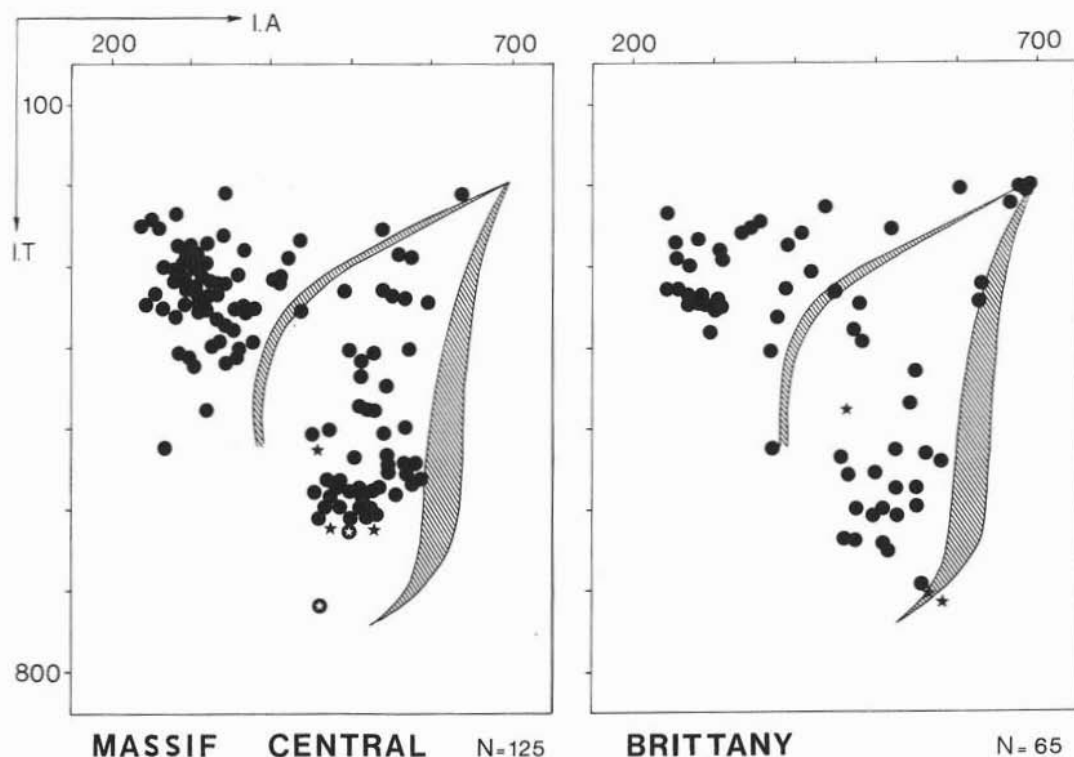


Fig. 19. — Mean points distribution of zircon populations from Hercynian acidic magmatic rocks from the French Massif Central (a) and Brittany (b). Black circles = granites, encircled stars = Brevenne granites, black stars = rhyolites, N = number of examined samples.

The plutonic zoning model can be applied to other orogenic sites, with the aim of determining geodynamic polarities. Three examples can thus be presented; they concern the Hercynian granitoids of Provence-Corsica and Morocco and the Caledonian magmatism of Belgium.

1 - Corsica-Provence

The two successive main magmatic activities of Corsica: the orogenic calc-alkaline Hercynian one and the anorogenic Permian one are very well separated by the typologic diagram (Fig. 20). In comparison with calc-alkaline granites and rhyolites of Mexico-Brazil and French Massif Central-Brittany, Corsica clearly appears to be nearer the second case and thus would correspond to a fragment of a collisional chain. This collision could follow only a relatively limited subduction process.

A zoning exists in Corsica, with the higher $\bar{T}$ indices registered in the north-east, the lower in the south-west. It fits well with the major petrographic and geochemical domains defined by ORSINI (1976, 1980). This zoning is better defined when considering together Corsica and Provence, with Corsica in its prerotational position (Fig. 21). From west to east, the complete zoning corresponds to tonalites and associated calc-alkaline granites of Figarets-Hermitan, anatectic intrusive porphyritic granites of Rouet - Plan de la Tour - Gigaro and calc-alkaline granites of Saint-Antonin and Camarat (PUPIN, 1976; TOURÉ et al., 1983; AMENZOU and PUPIN, 1986; AMENZOU, 1988). A west-east polarity can thus be deduced in conformity with the polarities found for Brittany and the French Massif Central (PUPIN, 1985), the suture zone being probably in the west as proposed by LAMEYRE and AUTRAN (1980).

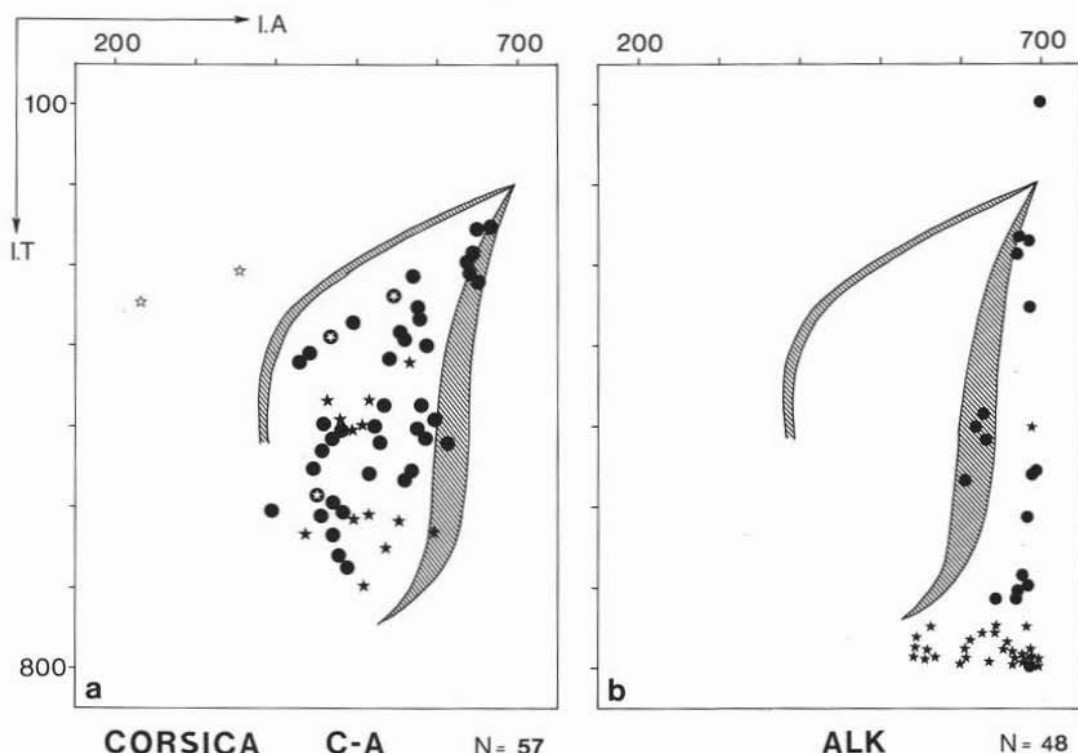


Fig. 20. — Corsica: mean points distribution of zircon populations from (a) Hercynian calc-alkaline dioritic (encircled stars), granitic (black circles) and rhyolitic (black stars) rocks, migmatites (white stars), (b) alkaline Permian granitic (black circles) and rhyolitic (black stars) rocks (some rhyolites from Esterel have been added); N = number of examined samples.

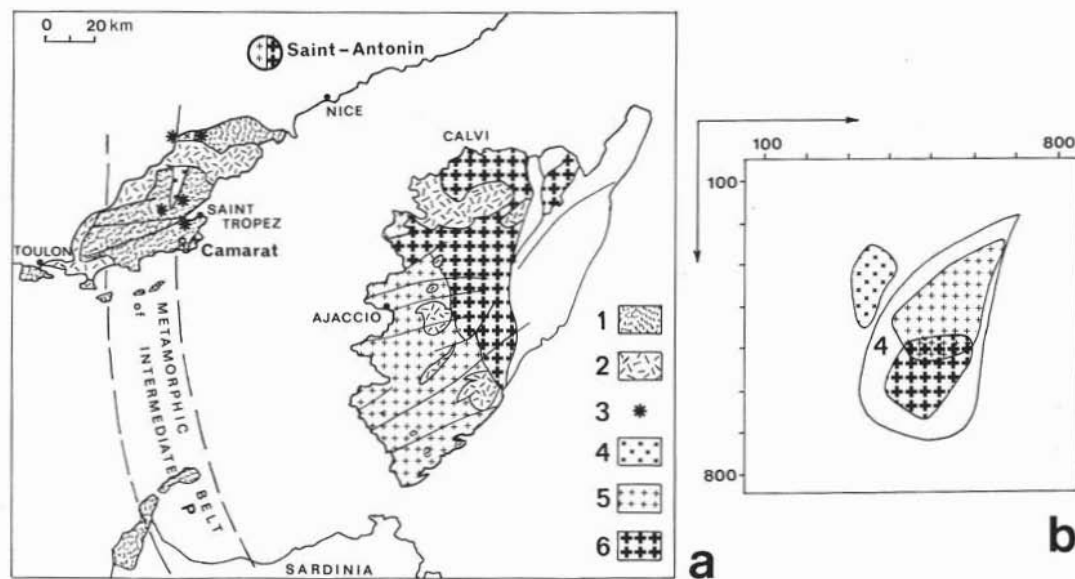


Fig. 21. — Magmatic zoning (a) of Provence-Corsica with (1) metamorphic rocks, (2) Permian, (3) Hercynian tonalites and associated granites, (4) anatectic granites of group 3: Rouet-Plan de la Tour-Gigaro, (5) calc-alkaline granites with $\bar{T} < 500$, (6) calc-alkaline and K calc-alkaline granites with $\bar{T} > 500$. Corsica-Sardinia block in its pre-derive position (data after WESTPHAL et al., 1976, TOURÉ et al., 1981, PUPIN, 1985, AMENZOU et al., 1986). Corresponding mean points distribution of zircon populations (b), 4 = calc-alkaline granites domain.

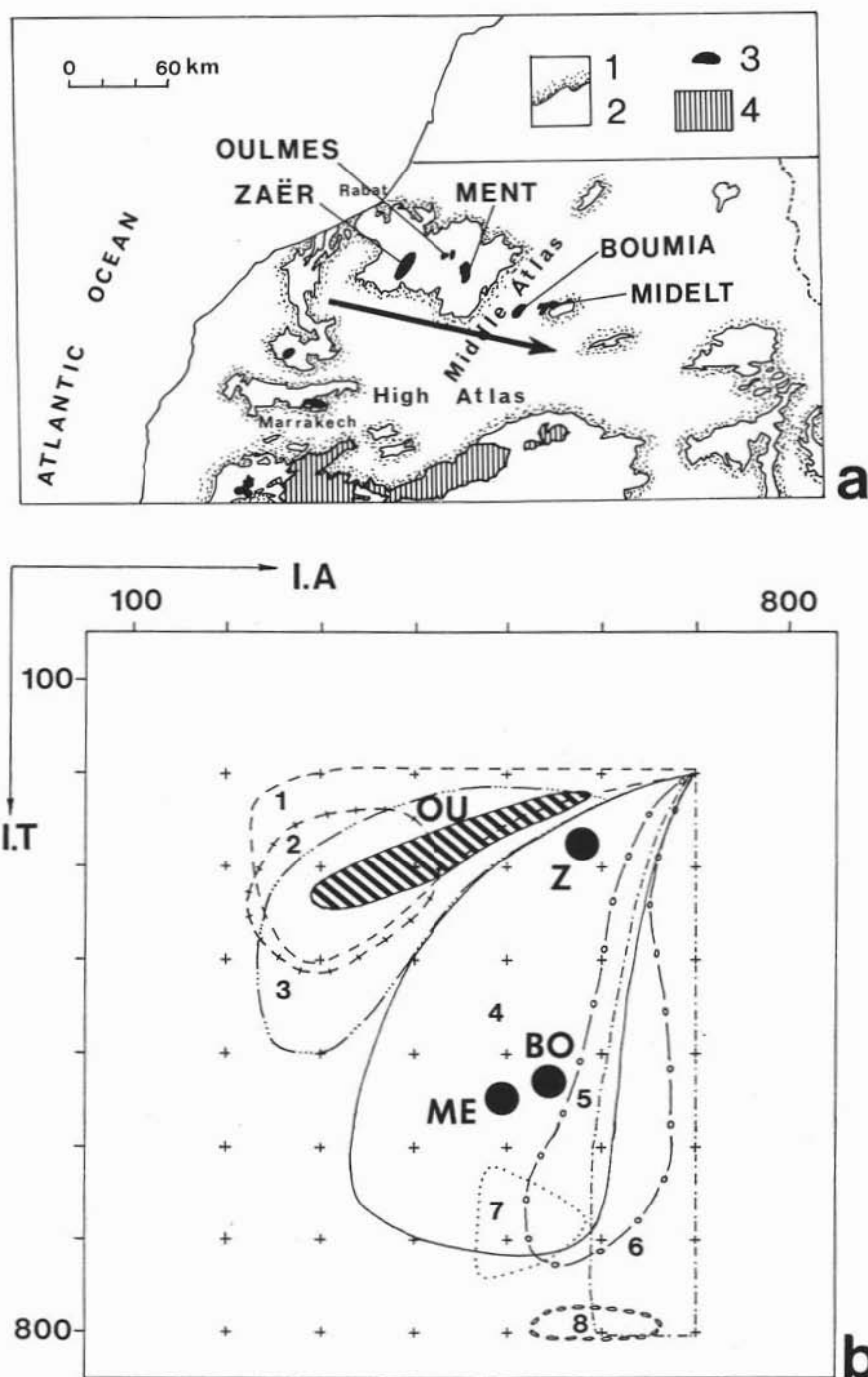


Fig. 22. — Magmatic zoning of Hercynian granites in the Middle Atlas of Morocco (a): map after VOGEL and WALKER, 1975: 1 = younger rocks, 2 = Paleozoic, 3 = Hercynian granites, 4 = Precambrian. Mean points distribution (b) of zircon populations of Zaër (Z), Oulmès (OU), Ment (ME) and Boumia (BO) granites (for references about Morocco, see VOGEL et al., 1976, PIQUÉ, 1979).

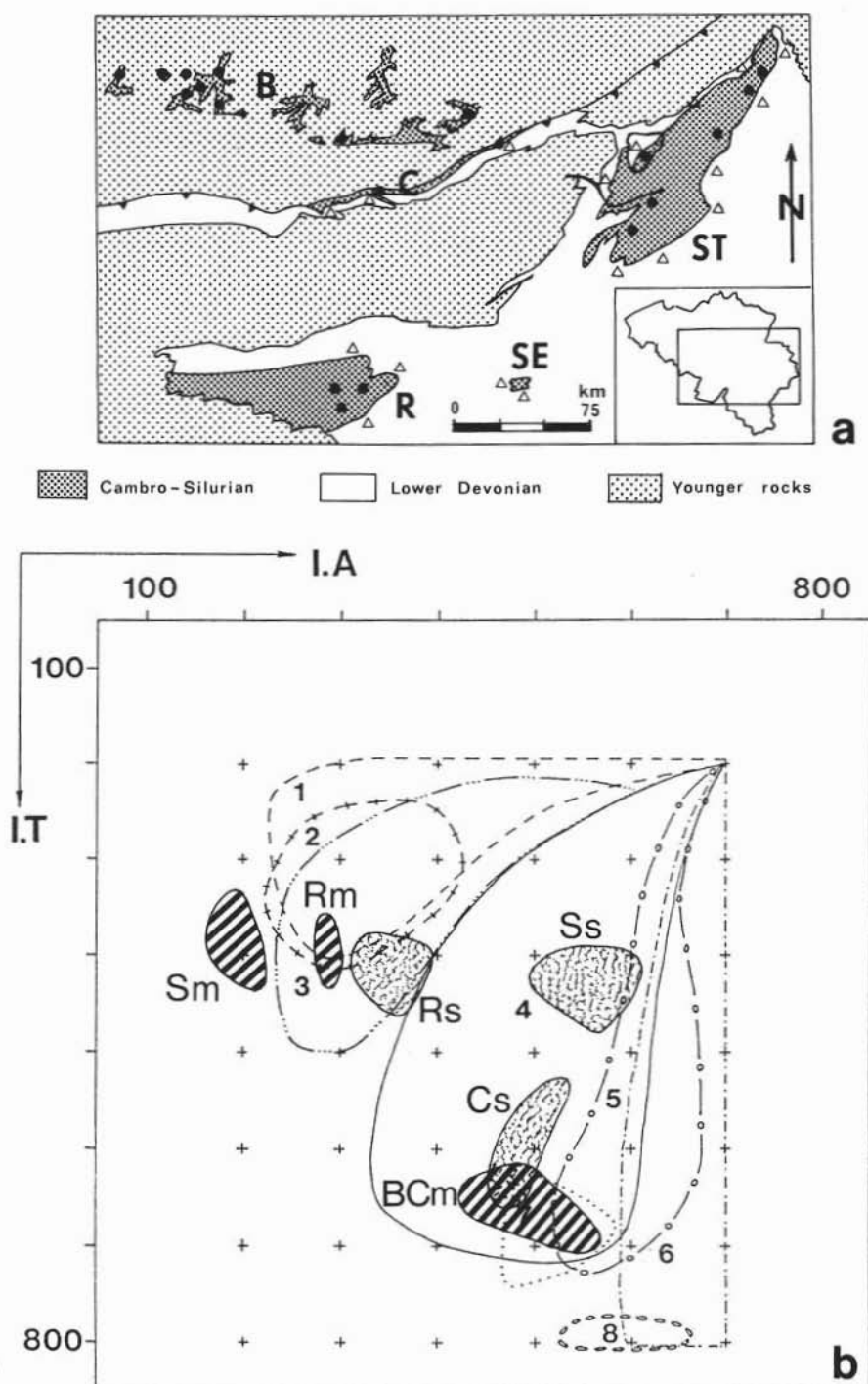


Fig. 23. — Analyzed samples in Belgium (a): magmatic rocks (circles) and Gedinian sandstones (triangles); B = Brabant, C = Condroz, R = Rocroi, SE = Serpont, ST = Stavelot: Mean points distribution (b) of zircon populations: magmatic rocks from Brabant-Condroz (BCm), Rocroi (Rm) and Stavelot (Sm), Gedinian sandstones from the Condroz (Cs), Rocroi-Serpont (Rs) and Stavelot (Ss) regions. For references about Belgium, see CORIN, 1965, FIEREMANS, 1982).

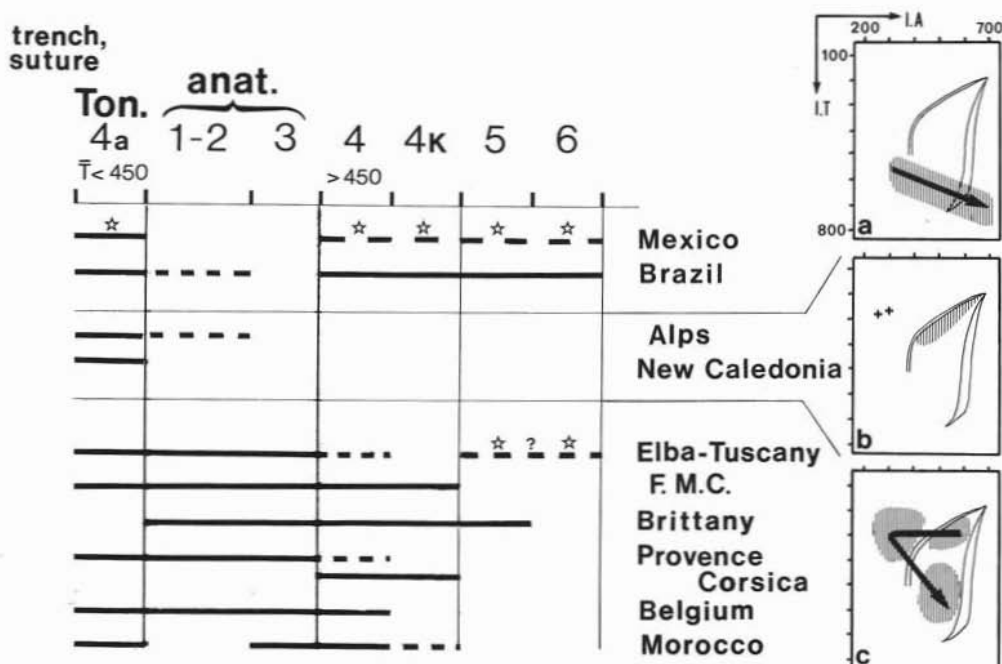


Fig. 24. — Synthetic scheme of magmatic zoning deduced from zircon typology data (1 to 6 = corresponding granitic groups, hatched lines = poorly represented, stars = rhyolites and rhyolitic ignimbrites. On the right: hatched area = main distribution fields of mean points, arrows = geodynamic polarity when going away from the trench or suture zone.

2 - Morocco

Four massifs were studied among the Hercynian granites of the Middle Atlas of Morocco. The typologic data define a zoning with a west-east polarity (Fig. 22): the low $\bar{T}$ calc-alkaline granite of Zaër is followed eastwards by the anatectic granite of Oulmes and the high $\bar{T}$ calc-alkaline granites of Ment and Boumia.

3 - Belgium

A last example concerns the Caledonian magmatism of Belgium with the study of magmatic rocks in the Brabant, Rocroi and Stavelot massifs, and of Gedinian sedimentary rocks around them (Fig. 23) (FIEREMANS, 1982). These last detritals often show monogenic or (sub) monogenic zircon populations exhibiting magmatic characteristics with euhedral crystals indicating a limited transportation from the source rocks.

The global results reveal a clear magmatic zoning with a polarity directed from the south/south-east to the north: tonalites and low $\bar{T}$ calc-alkaline granites or rhyolites, anatectic granites and finally high $\bar{T}$ calc-alkaline granites or rhyolites in the Brabant and Condroz areas. Such a zoning is quite similar to those previously observed for example in the French Massif Central and Brittany.

Thus, the zircon typology method applied to the Caledonian magmatism of Belgium would indicate the existence of a paleocollision chain with a possible limited previous subduction, the supposed paleosuture being emplaced in the south or south-east.

V. Discussion and conclusion

The different examples presented here in different orogenic contexts, with a more or less abundant magmatism, lead to the classification in three main types (Fig. 24):

1) A long lasted subduction followed (or not) by a very limited collision process. This case is characterized by the absence or quasi-absence of aluminous granites derived from the anatexis of the sialic crust. Calc-alkaline, K calc-alkaline and subalkaline granites and rhyolites are well represented. The zircon populations have mainly very high $\bar{T}$ indices, with a linear inferior limit showing increasing of $\bar{T}$ indices from the trench zone towards the external domains of the overthrusting plate and giving the geodynamic polarity (Fig. 24a).

2) A very short lasted subduction or underthrusting of an oceanic lithospheric fragment in a compressional context followed (or not) by a collisional process. Typical plutonites are tonalites and calc-alkaline granites of the 4a trend with low $\bar{T}$ indices, emplaced very near the trench or the suture zone. Western Alps and New Caledonia correspond to this case. The scarcity of magmatic rocks avoids the possibility to define a polarity (Fig. 24 b).

3) A short lasted subduction followed by main collision processes. Anatectic granitic rocks are very abundant and associated with calc-alkaline, K calc-alkaline and more rarely subalkaline granites. On a general mean, the $\bar{T}$ indices of the rocks are lower than in case (1).

The zonings are more or less complete (Fig. 24c) but in any case the geodynamic polarity is given by the increase of $\bar{T}$ indices from the ancient trench or suture zone (French Massif-Central, Brittany, Provence-Corsica, Morocco, Belgium, Elba-Tuscany).

After the collision and the end of the subduction, a lot of intrusions are represented by various calc-alkaline or K calc-alkaline granites (late or post-tectonic). The peculiar repetitive organization of such granites seems to be related systematically with the memory of the ancient subduction: such a possibility can be realized only if the subduction structure persists a long time after the subduction has stopped, or if the magmas mobilized at the end of the subduction only emplaced a long time later, in a tensional regime. In any case, the lower $\bar{T}$ of the populations — observed when collision processes are underlined by an important

anatectic magmatism — indicate a more or less important interaction (hybridization with anatectic products, role of crustal fluids) between the mobilized crust and the different types of granites from which the zoning is deduced.

Thus, zircon appears to be a good tool to discuss the origin of granites and granites appear to be good criteria to determine the polarity of ancient orogens.

The magmatic zonings of granites and tonalites have been determined over distances of about 150 to 400 km, quite similar to distances observed for volcanites in orogenic zones.

The frequencies and the typological characteristics of these granites vary largely with the duration of the subduction, the importance of the collision, the possibility of tensional events after the collision — favouring the emplacement of various magmas (i.e. Elba-Tuscany) —, the compositions of the mother rocks, but this fact appears to be only of second order considering the repetitive zonings observed.

The three main types observed remember very well, for acidic magmas, the trilogy proposed by PITCHER (1979) in Alpinotype, Andinotype and Hercynotype environments.

So granites, but also acid paleovolcanites or orthogneisses (in which magmatic zircon populations are often preserved, PUPIN, 1976) are major possibilities for the understanding of ancient orogens. Such criteria, directly linked with deep fundamental structures, are of interest notably for the study of very complex orogenic domains as i.e. the Hercynian belt in western Europe, the patchwork distribution of the magmatism probably resulting from the involvement of several microplates. Thus, acid magmatism is likely to provide excellent criteria of polarity capable of solving the problems of paleogeodynamics and must be taken into account more widely in the future.

REFERENCES

- ALLÈGRE C. (1980) - *Les ophiolites ou la recherche des océans perdus. La dérive des continents*. Pour la Science, Belin éd., 83-96.

- AMENZOU M. (1988) - *Les granitoïdes hercyniens du massif des Maures (Var, France). Etude géologique et minéralogique. Implications génétiques*. Thèse, Univ. Nice, 280 pp.
- AMENZOU M., PUPIN J.P. (1986) - *Le granite de Camarat (Maures, Var, France): un ensemble polygénique, zone clé entre la Provence et la Corse*. C. R. Acad. Sc. Paris, t. 303, série II (8), 697-700.
- AUTRAN A., PETERLONGO J.M. (1979) - *Massif Central (France). Livret guide 26th Int. Geol. Congr. Rev. Sc. Nat. Auvergne*, 45, 123 pp.
- BAIRD A.K., BAIRD K.W., WELDAY E.E. (1974) - *Chemical trends across Cretaceous batholithic rocks of southern California*. Geology, 2, 493-496.
- BARBERI F., INNOCENTI F. (1980) - *Volcanisme néogène et quaternaire*. Italie, Livret guide exc. 122 A, 26th. Int. Geol. Congr., Paris, 99-104.
- BARRIERE M., CHAURIS L. (1971) - *Individualisation de trois ensembles structuraux dans le massif granitique de Ploumanach (Côtes du Nord)*. C. R. Acad. Sc. Paris., t.273, série D, 1779-1782.
- BARRIERE M. (1977) - *Le complexe de Ploumanach*. Thèse Doct. Etat, Univ. Brest, 291 pp.
- BARTH S., OBERLI F., MEIER M. (1987) - *Calc-alkaline magma genesis recorded by Zircon U-Pb: A high-resolution study of the periadriatic Rensen pluton*. E. U. G. IV, Strasbourg. Terra Cognita 7 (2-3), 159.
- BATEMAN P.C., DODGE F.C.W. (1970) - *Variation of a major chemical constituent across the central Sierra Nevada Batholith*. Geol. Soc. Am. Bull., 81, 409-420.
- BIANCHI A., CALLEGARI E., JOBSTRAIBIZER P.G. (1970) - *I tipi petrografici fondamentali del plutone dell'Adamello*. Mem. Ist. Geol. Min. Univ. Padova, 27, 1-148.
- BOCCALETTI M., GUAZZONE G. (1972) - *Gli archi appenninici, il Mar Ligure e il Tirreno, nel quadro della tettonica dei bacini marginali retro-arco*. Mem. Soc. Geol. It., 11, 201-216.
- BONIN B. (1980) - *Les complexes acides alcalins anorogéniques continentaux: l'exemple de la Corse*. Thèse Doct. Etat, Univ. Paris VI, 756 pp.
- BOWDEN P., BATCHELOR R.A., CHAPPELL B.W., DIDIER J., LAMEYRE J. (1984) - *Petrological, geochemical and source criteria for the classification of granitic rocks: a discussion*. Physics Earth Plan. Int., 35, 1-11.
- CAIRONI V. (1985) - *Characterization of different granitic facies in the Baveno-Mottarone pluton by means of the typologic study of zircon populations*. Rend. Soc. Ital. Min. Petrol., 40 (2), 341-352.
- CALLEGARI E., DAL PIAZ G. (1973) - *Field relationships between the main igneous masses of the Adamello intrusive massif (northern Italy)*. Mem. Ist. Geol. Min. Univ. Padova, 29, 1-39.
- CARPEN A.J., GAGNOL I., MAILHE D., PUPIN J.P. (1987) - *L'Uranium marquer de la croissance cristalline: mise en évidence par les traces de fission dans les zircons gemmes d'Espaly (Haute Loire, France)*. Bull. Minéralogie, 110 (4), 459-463.
- CHAPPELL B.W., WHITE A.J.R. (1974) - *Two contrasting granite types*. Pacific Geol., 8, 173-174.
- CORIN F. (1965) - *Atlas des roches éruptives de Belgique*. Verh. Geol. Belg., 4, 190 pp.
- COSTARELLA R. (1987) - *Le complexe annulaire alcalin de Combeynot (Massifs cristallins externes, Alpes françaises), témoin d'un magmatisme en régime distensif*. Pétrogéochimie et signification géodynamique. Thèse, Univ. Grenoble, 268 pp.
- DEBON F., LE FORT P. (1983) - *A chemical-mineralogical classification of common plutonic rocks and associations*. Transactions of the Royal Society of Edinburgh: Earth Sciences, 73, 135-149.
- DIDIER J., DUTHOU J.L., LAMEYRE J. (1982) - *Mantle and crustal granites: genetic classification of orogenic granites and the nature of their enclaves*. Journ. Volc. Geoth. Res., 14, 125-132.
- DI GIROLAMO P. (1978) - *Geotectonic settings of Miocene - Quaternary volcanism in and around the Eastern Tyrrhenian Sea Border (Italy) as deduced from major element geochemistry*. Bull. Volcanol., 41 (3), 229-250.
- DODGE F.C.W. (1972) - *Trace element contents of some rocks of the Sierra Nevada batholith*. U.S. Geol. Surv. Bull., 1314.
- DUPUIS C. (1972) - *Relations entre les grands ensembles structuraux du complexe granitique de Ploumanach - Ile Grande (Côtes du Nord), leur radioactivité et leur thermoluminescence naturelle*. Ann. Soc. Geol. Nord, XCII, 29-40.
- DUPUY C. (1970) - *Contribution à l'étude des fractionnements géochimiques des alcalins, des alcalino-terreux et du gallium au cours des processus magmatiques. Exemple: les roches intrusives et effusives de Toscane et du Latium septentrional (Italie)*. Thèse Doct. Etat, Univ. Montpellier, 341 pp.
- DUPUY C., DOSTAL J., FRATTA M. (1982) - *Geochemistry of the Adamello Massif (Northern Italy)*. Contrib. Mineral. Petrol., 80, 41-48.
- FIEREMANS M. (1982) - *Sedimentologie, Tektoniek en metamorfose van het gedinniaan langs de zuidrand van het massief van Stavelot*. Doct. Univ. Cath. Leuven, Belgium, 165 pp.
- GAGNOL I. (1987) - *Typologie et géochimie du zircon dans les laves alcalines différenciées*. Thèse, Univ. Nice, 228 pp.
- GILL J., GORTON M. (1973) - *A proposed geological and geochemical history of eastern Melanesia*. In Coleman ed., The western Pacific, 543-566.
- GIRAUD J.D., PUPIN J.P., TURCO G. (1980) - *Caractères morphologiques du zircon dans les séries volcaniques calco-alcalines d'après l'exemple liguro-sarde. Implications pétrogénétiques*. C. R. Acad. Sc. Paris, t. 290, série D, 823-826.
- GIRAUD J.D. (1983) - *L'arc andésitiques paléogène des Alpes Occidentales. Pétrologie, Volcanologie, Géodynamique*. Thèse Doct. Etat, Univ. Nice, 378 pp.
- HANSMANN W., OBERLI F., STEIGER R.H. (1983) - *U-Pb ages on zircon from the southern Adamello*. Mem. Soc. Geol. Ital., 26, 319-321.
- HANSMANN W. (1986) - *U-Pb Datierungen an Zirkonen und Thoriten aus einer magmatischen Gesteinssuite am Beispiel des südlichen Adamello (Norditalien)*. Diss. E.T.H. N° 8077, Zürich, 192 pp.
- ISHIHARA S. (1977) - *The magnetite series and ilmenite series granitic rocks*. Min. Geol., 27, 293-305.
- ISHIHARA S., ULRICKSEN C.E. (1980) - *The magnetite series and ilmenite series granitoids in Chile*. Min. Geol., 30, 183-190.

- JAKES P., WHITE A.J.R. (1972) - *Major and trace element abundances in volcanic rocks of orogenic areas*. Geol. Soc. Amer. Bull., 83, 29-40.
- JOST H., FRANTZ J.C., WERNICK E. (1984) - *Implicações geotectônicas da variação composicional, temporal e regional dos granitoides do ciclo brasileiro do escudo sul-riograndense*. Anais do XXXIII Congr. brasil. de geol., Rio de Janeiro, 2978-3000.
- KUNO H. (1959) - *Origin of cenozoic petrographic provinces of Japan and surrounding areas*. Bull. Volcanol., 20, 37-76.
- LAMEYRE J. (1980) - *Les magmas granitiques, leurs comportements, leurs associations et leurs sources*. Livre jubilaire Soc. Géol. Fr. Mém. H. S., 10, 51-62.
- LAMEYRE J., AUTRAN A. (1980) - *Les granitoides de France*. In: Autran A., Dercourt J. Ed., *Evolution géologique de la France*. Colloque C7, Géologie de la France, 26th Int. Geol. Congr., Paris, 52-97.
- LAMEYRE J., BOWDEN P. (1982) - *Plutonic rock type series: discrimination of various granitoid series and related rocks*. Journ. Volc. Geoth. Res., 14, 169-186.
- LEFEVRE C. (1979) - *Un exemple de volcanisme de marge active dans les Andes du Pérou (Sud) du Miocène à l'actuel (zonation et pétrogenèse des andésites et des shoshonites)*. Thèse Doct. Etat, Univ. Montpellier, 555 pp.
- LETZ H., REICHERT C., WIGGER P. (1977) - *Results of two seismic refraction lines in the northern Apennines (Lines 1 and 3)*. Boll. Geofisic., XIX, 75-76 (4), 225-232.
- LOCARDI E., MITTEMPERGER M. (1969) - *The meaning of magmatic differentiation in some recent volcanoes of Central Italy*. Bull. Volcanol., XXXIII (3), 1-12.
- MCDOWELL F.W., KEIZER R.P. (1977) - *Timing of mid-tertiary volcanism in the Sierra Madre Occidental between Durango City and Mazatlan, Mexico*. Geol. Soc. of Amer. Bull., 88, 1479-1487.
- MCDOWELL F.W., CLABAUGH S.E. (1979) - *Ignimbrites of the Sierra Madre Occidental and their relation to the tectonic history of western Mexico*. Geol. Soc. Amer. Spec. Pap. 180, 113-124.
- MCKENZIE D.E., CHAPPELL B.W. (1972) - *Shoshonitic and calc-alkaline lavas from the Highlands of Papua, New Guinea*. Contr. Mineral. Petrol., 35, 50-62.
- MORELLI C. (1975) - *Geophysics of the Mediterranean*. Newsletter of the Cooperative Investigations in the Mediterranean n° 7, Monaco, 29-111.
- MIYASHIRO A. (1975) - *Island arc volcanic rock series: a critical review*. Pétrologie, 1 (3), 177-196.
- ORSINI J.B. (1976) - *Les granitoides hercyniens corso-sardes: mise en évidence de deux associations magmatiques*. Bull. Soc. Géol. Fr., 18, 1203-1206.
- ORSINI J.B. (1980) - *Le batholite corso-sarde: anatomie d'un batholite hercynien. Composition, structure, organisation d'ensemble. Sa place dans la chaîne varisque française*. Thèse Doct. Etat, Univ. Marseille, Saint-Jérôme, 486 pp.
- PAGEL M., LETERRIER J. (1980) - *The subalkaline potassic magmatism of the Ballons massif (Southern Vosges, France): shoshonitic affinity*. Lithos, 13, 1-10.
- PARIS J.P. (1981) - *Géologie de la Nouvelle-Calédonie. Un essai de synthèse*. Mémoire B.R.G.M. n° 113.
- PEARCE J.A., HARRIS N.B.W., ROGERS N.W., TINDLE A.J. (1987) - *Trace element signatures of the petrogenesis and intrusive settings of granitic rocks*. Ric. Scient. e Educ. Perm. Suppl. n° 59a. pp. 136-137.
- PIQUE A. (1979) - *Evolution structurale d'un segment de la chaîne hercynienne: la Meseta marocaine nord-occidentale*. Thèse Doct. Etat, Univ. Strasbourg, 253 pp.
- PITCHER W.S. (1979) - *The nature, ascent and emplacement of granitic magma*. J. Geol. Soc. London, 6, 627-662.
- PUPIN J.P., TURCO G. (1970) - *Observations nouvelles sur les nuclei et le zonage des cristaux de zircon. Problèmes génétiques qui en découlent*. Schweiz. Mineral. Petrogr. Mitt., 50 (3), 527-538.
- PUPIN J.P., TURCO G. (1972a) - *Une typologie originale du zircon accessoire*. Bull. Soc. Fr. Minéral. Cristallogr., 95, 348-359.
- PUPIN J.P., TURCO G. (1972b) - *Le zircon accessoire en géothermométrie*. C. R. Acad. Sc. Paris. t.274, série D, 2121-2124.
- PUPIN J.P., TURCO G. (1975) - *Typologie du zircon accessoire dans les roches plutoniques dioritiques, granitiques et syénitiques. Facteurs essentiels déterminant les variations typologiques*. Pétrologie, I (2), 139-156.
- PUPIN J.P. (1976) - *Signification des caractères morphologiques du zircon commun des roches en pétrologie. Base de la méthode typologique. Applications*. Thèse Doct. Etat, Univ. Nice, 394 pp.
- PUPIN J.P. (1980) - *Zircon and Granite Petrology*. Contrib. Mineral. Petrol., 73, 207-220.
- PUPIN J.P. (1981) - *A propos des granites potassiques*. C. R. Acad. Sc. Paris, t.292, série II, 405-408.
- PUPIN J.P. (1982) - *Zircon, granite petrology and plate tectonics*. Intern. Colloq. C.N.R.S., «Geochemistry and Petrology of Granitoids», Clermont-Ferrand, 2 pp., unpubl.
- PUPIN J.P. (1983) - *Granites as indicators in plate tectonics*. E. U. G. II, Strasbourg, Terra Cognita 3 (2-3), 135.
- PUPIN J.P. (1985) - *Magmatic zoning of Hercynian Granitoids in France based on Zircon Typology*. Schweiz. Mineral. Petrogr. Mitt., 65, 29-56.
- PUPIN J.P., WERNICK E. (1987) - *Magmatic zoning of granitoids in the Dom Feliciano foldbelt (Southern Brazil) based on zircon typology*. E. U. G. IV, Strasbourg, Terra Cognita 7 (2-3), 276.
- RAGUIN E. (1970) - *Pétrographie des roches plutoniques dans leur cadre géologique*. Masson ed., Paris, 239 pp.
- RÈVE J.M. (1985) - *Répartition de l'Uranium et du Thorium dans les roches alcalines des Vosges du Nord*. Thèse Doct. 3° cycle, Univ. Paris-Sud, Orsay, 136 pp.
- RITTMANN A. (1962) - *Sur les ignimbrites en Italie*. Arch. Sc. Suisse, t.14, 3, 423-433.
- SINHA A.K., ZIETZ I. (1982) - *Geophysical and geochemical evidence for a hercynian magmatic arc, Maryland to Georgia*.
- TOURÉ S., GIRAUD J.D., PUPIN J.P. (1981) - *Contribution à l'étude des formations paléogènes sub-alpines: origine des galets et blocs de granites du synclinal de Saint-Antonin (Alpes-Maritimes)*. C. R. Acad. Sc. Paris, t.293, série II, 691-694.
- TURI B. (1987) - *Geochimica Isotopica dell'ossigeno e dello stronzio nelle vulcaniti potassiche della regione comagmatica romana*. Geocronologia e Geochimica Isotopica, Gargnano 1986, Ric. Scient. e Educ.

- Perm., suppl. n° 52, Univ. Milano, 133-157.
- VOGEL T.A., WALKER B.M. (1975) - *The Tichka Massif, Morocco - an example of contemporaneous acidic and basic plutonism*. Lithos, 8, 29-38.
- VOGEL T.A., WILLIAMS E.R., PRESTON J.K., WALKER B.M. (1976) - *Origin of the late Paleozoic plutonic massifs in Morocco*. Geol. Soc. of Amer. Bull., 87, 1753-1762.
- WERNICK E., PUPIN J.P., WEBER-DIEFENBACH K., FERREIRA C.J. (1987) - *Regional magmatic zoning of granitoids in the Dom Feliciano belt, late precambrian of southern Brazil: lithochemical and zircon typology data*. Intern. Symp. on Granites and Assoc. Mineral., Salvador (Bahia), 75-80.
- WESTPHAL M., ORSINI J.B., VELLUTINI P. (1976) - *Le microcontinent corso-sarde, sa position initiale: données paléomagnétiques et raccords géologiques*. Tectonophysics, 30, 141-157.