A re-examination of the typology of peraluminous granite types in intracontinental orogenic belts

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ABSTRACT: Conventional rock classification diagrams do not distinguish the variety of peraluminous rock series. Moreover, peraluminous granite types have not been clearly discriminated in recent revisions. The study of several peraluminous series in different intracontinental orogenic belts reveals that four distinct groups can be defined. Using an A–B diagram, these four groups are: (1) highly peraluminous granitoids (*hP*) characterised by high A values and typified by an increase in peraluminosity toward the most mafic varieties; (2) moderately peraluminous granitoids (*mP*) which occupy the intermediate field and generally show increasing peraluminosity towards the most felsic varieties; (3) low peraluminous granitoids (*lP*) which plot in the lowest part of the peraluminous field defining negative slope trends; (4) highly felsic peraluminous granites (*fP*) with poorly defined variation trends.

In intracontinental orogenic belts, the genesis of peraluminous granitic series is favoured by the abundance of fertile crustal protoliths, mainly metapelites, metaigneous rocks and metagreywackes. The difficulty of attaining temperatures in excess of 950°C at lower crustal levels during the tectonothermal evolution of thickened crust, inhibits the partial melting of more basic sources. Although the physical parameters of the melting process influence their chemical and mineralogical characteristics, source rock composition ultimately determines the degree of peraluminosity of the granitic series.

KEY WORDS: collisional orogenic magmatism, crustal protoliths, granite classification.

Conventional rock classification diagrams (e.g. TAS and K_2O–SiO_2 plots) do not distinguish the variety of peraluminous rock series and recourse is frequently made to the peraluminosity index of Shand (1927). Also, recent alphabetic classifications of granitoids (MISA classification) which are more genetically biased do not overcome the simple dichotomy between peraluminous and metaluminous series. Rocks in which the molecular proportion of Al_2O_3 is higher than $CaO+Na_2O+K_2O$ are termed peraluminous (Shand 1927). Usually, but not necessarily, they have normative corundum and such characteristic modal phases as biotite, muscovite, garnet, cordierite and aluminium silicates. Most felsic igneous rocks are peraluminous (Debon & Le Fort 1983), but generally the Al_2O_3 excess is due to biotite alone (Miller 1985). Igneous rocks containing aluminium phases other than biotite, though common and widespread, are subordinate. The difference in degree of peraluminosity in felsic igneous rocks has been discussed by several authors (Debon & Le Fort 1983; Miller 1985) in order to establish different peraluminous series and, more importantly, since the publication of the I- and S-type classification scheme of Chappell & White (1974), to discuss petrogenetic problems related to the origin and significance of those igneous rocks with strongly peraluminous compositions.

Debon & Le Fort (1983) used a binary diagram with a peraluminosity parameter $A=Al-(K+Na+2Ca)$ and a differentiation index $B=Fe+Mg+Ti$ and suggested criteria for achieving a rigorous chemical-mineralogical definition of aluminous associations, but without stating how many types of peraluminous series can be found.

Miller (1985) proposed a classification of peraluminous granites using the AFM diagram in which he established two main fields: strongly peraluminous (Ps) and weakly peraluminous (Pw) series, each with different mineralogical characteristics. This kind of classification diagram has the problem that several igneous series cross both the Ps and Pw fields as the differentiation index increases.

Recently Barbarin (1996) made a revision of the genesis of peraluminous granites in which the starting point was the consideration that the most significant volumes are made up of only two types produced by extensive anatexis of crustal rocks. However, we show below that from detailed study of several orogenic segments it is possible to recognise at least four types of peraluminous granitoids. We also attempt to show that the complex diversity of felsic magmatism may be best classified by the use of an A–B diagram.

1. Variety of peraluminous series

In order to establish the diversity of crustally derived peraluminous series, granitic samples from several areas have been selected and plotted on an A–B (Debon & Le Fort 1983) diagram (Fig. 1). First, peraluminous granitoids from the Spanish Central Region have been plotted, as they have been thoroughly studied from a mineralogical, isotopic and geochemical point of view (Villaseca & Barbero 1994; Villaseca *et al.* 1998) and also because it is possible to distinguish the four types of peraluminous granites that can be found in an orogenic segment (Fig. 1a). On Figure 1b, several series from the Lachlan Fold Belt in Australia are assembled, and on Figure 1c other granitic series from different orogenic segments are plotted for comparison.

It is noticeable that, despite the fact that the four types of granitic series defined in the Spanish Central Region can be found in other orogenic sectors, granite researchers have focused their attention on the simple peraluminous versus metaluminous dichotomy (associated with the I- and S-type petrogenetic discussion), or have distinguished only two types

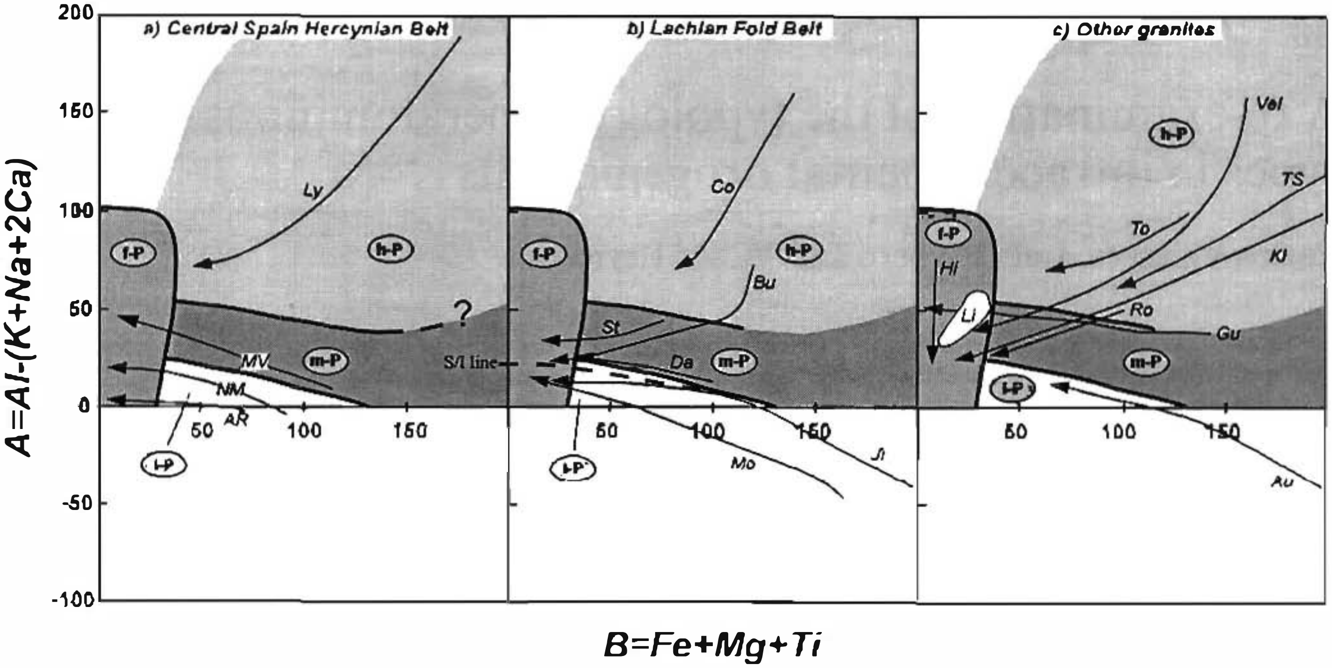

Figure 1 A-B diagram (modified from Debon & Le Fort 1983) for different granitic series: (a) Central Spain Hercynian Belt: Ly (Layos granite, Barbero & Villaseca 1992), MV, NM and AR (Mora-Ventas, Las Navas del Marqués and La Atalaya Real plutons, Villaseca *et al.* 1998). (b) Lachlan Fold Belt series: Co, St and Mo (Cooma, Strathbogie and Moruya series, Chappell *et al.* 1991), Bu and Ji (Bullenballong and Jindabyne, Hine *et al.* 1978) and Da (Dalgety suite, White *et al.* 1977; Chappell *et al.* 1991). (c) Other granites: To (Tourem, Holtz & Barbey 1991), Ki (Kinsman suite, Clark & Lions 1986), Ro (Royère, Stussi & Cuney 1993), Gu (Guéret, Debon & Le Fort 1983), Au (Moldanubian IB I-type suite, Liew *et al.* 1989), Li (Limousin, Leger *et al.* 1990), Hi (Himalayan leucogranites, Debon & Le Fort 1983), Ts (Trois Seigneurs, Wickham 1987), and Vel (Velay, Williamson *et al.* 1997). Fields are: *hP* (highly peraluminous), *mP* (moderately peraluminous), *lP* (low peraluminous), *fP* (felsic peraluminous). Dotted line on figure 1B is the I/S boundary line.

of peraluminous granites: peraluminous granodiorites and anatectic leucogranites (Lameyre 1988). Barbarin (1996) has named these two types CPGs (peraluminous cordierite-bearing tonalites to monzogranites) and MPGs (peraluminous two mica monzogranites and leucogranites), respectively.

1.1. Highly peraluminous granitoids (*hP*)

In this field, granitic series with a high degree of peraluminosity plot as defining a typical positive trend, i.e. increasing peraluminosity towards the most mafic varieties. This corresponds to the typical S-type trend (White & Chappell 1988). Nevertheless, only a few S-type suites or supersuites from the Lachlan Fold Belt clearly plot in this field, particularly the Cooma and Bullenbalong suites from the Kosciusko batholith (Hine *et al.* 1978; Chappell *et al.* 1991) (Fig. 1b). In other orogenic sectors, although more scarce, such granites are not absent. Thus, in the Spanish Central Region, the Layos restite-rich granitoids plot in this *hP* field (Barbero & Villaseca 1992). In other Hercynian sectors, the Trois Seigneurs granites in the Pyrenees (Wickham 1987), the Tourem cordierite-bearing granites in northern Portugal (Holz 1989), the Velay anatectic granites (Williamson *et al.* 1997) and the most mafic facies of the Royère granite (Stussi & Cuney 1993), both in the French Massif Central, are examples of this *hP* type (Fig. 1c). Far from the Hercynian orogen, the Kinsman intrusive suite of the eastern USA (Clark & Lyons 1986) also belongs to this group (Fig. 1c).

All these granitic suites are characterised by the presence of aluminous mineral phases other than biotite, which in several cases can be the most abundant mafic phase. Cordierite or garnet (almandine–pyrope series) are the most typical aluminous phases, but it is not unusual to find accessory sillimanite. In general, two mica granites *sensu stricto* are scarce as most of the *hP* granites are characteristic of high-T catazonal areas, equivalent to regional migmatite terrains or regional aureole granites (White & Chappell 1988). Cordierite from this type of *hP* granite is texturally and chemically different from that of other peraluminous granites, reflecting its peritectic origin in contrast with the late magmatic origin of cordierite in higher level peraluminous granites (Williamson *et al.* 1997). Another remarkable characteristic of the *hP* type, especially seen in the most peraluminous suites from catazonal areas (Layos, Cooma, Tourem, Trois Seigneurs, Velay), is its great heterogeneity and the abundance of restitic enclaves.

1.2. Moderately peraluminous granitoids (*mP*)

These granites occupy an intermediate field in the A-B diagram generally showing negative slope trends, i.e. increasing peraluminosity towards the more differentiated samples. Most of the Australian moderately peraluminous S-types plot in this field (e.g. Dalgety suite, White *et al.* 1977). The Strathbogie suite from Central Victoria also plots in this field but with a positive slope, without reaching such high A values as those of the *hP* type (Fig. 1b). Hercynian cordierite-bearing monzogranites (Hercynian S-type after Pitcher 1983), such as the Marguerite and Guéret plutons in the French Massif Central (Debon & Le Fort 1983) or Mora-Ventas and Hoyo de Pinares plutons in the Spanish Central Region, are representative granitoids of this moderately peraluminous type (Fig. 1a and c). This is the field of peraluminous granodiorites (Lameyre 1988), also called CPG types (Barbarin 1996).

Most of the granites which plot in this field are biotite-bearing varieties, generally with another mineral phase more aluminous than biotite as an accessory phase. Cordierite is the most common accessory mineral, whilst in highly fractionated types, muscovite may be dominant together with garnet of the almandine–spessartine series or other low-temperature AFM minerals such as andalusite or tourmaline. Microgranular enclaves are conspicuous in these granites, usually being less than 1% of the area of outcrop.

1.3. Low peraluminous granitoids (*lP*)

The lowest part of the peraluminous field is occupied by the low peraluminosity series and by the most evolved terms of those series which evolve from metaluminous to slightly peraluminous compositions, in either case defining negative slope trends in the A–B diagram (Fig. 1). Felsic I-types from the Lachlan Fold Belt such as the Moruya and Jindabyne supersuites (Hine *et al.* 1978; Chappell *et al.* 1991), together with several differentiated calc-alkaline suites (for example the Quérigut in France and Mont Givens in California, as referred to by Debon & Le Fort 1983), plot within this *lP* field. In the Hercynian area from Central Spain, several plutons with characteristic accessory amphibole and allanite in the less evolved granodiorite facies plot in this narrow field of low peraluminous granites (see for example La Atalaya Real, La Cabrera and Las Navas del Marqués plutons, Fig. 1a). Some transitional I-types of the Moldanubian Batholith
(Liew *et al.* 1989) and some Caledonian I-types (Pitcher 1983) are among granites that plot in this *lP* field. It is noticeable that the more evolved facies of this type of series can be markedly more peraluminous than the rest of the series and thus they sometimes bear aluminium-rich minerals (see, for example the garnet peraluminous I-types and garnet–andalusite I-types from the Namungo felsic pluton, Chappell *et al.* 1991, or the garnet–cordierite leucocratic facies of La Cabrera I-type pluton, Villaseca & Barbero 1994).

Mineral chemistry of AFM phases common to the *mP* and *lP* granites is a powerful tool for distinguishing both types of granites, especially

as cordierite, garnet or aluminium silicate in the *mP* types, or amphibole (or allanite) in the *lP* types are not present in a particular variety. Biotites of *lP* type have characteristically lower peraluminosity with respect to those of the *mP* types, the latter plotting within the alumino-potassic field in the Mg versus total Al diagram (fig. 2 from Nachit *et al.* 1985).

When cordierite appears in both *mP* and *lP* types, it usually has textures and compositions which indicate a magmatic origin, and which are quite different from those of the *hP* types. Those cordierites from *lP* differentiated types (La Cabrera pluton in the Spanish Central Region) have lower Al_2O_3 and alkali contents, especially Na, than cordierites from the *mP* types with similar X_{Fe} composition (Villaseca & Barbero 1994). As in the *mP* types, mafic microgranular enclaves are widespread.

1.4. Highly felsic peraluminous granitoids (*fP*)

In this region of the A–B diagram, all the above-described peraluminous series converge. Several granitic and volcanic series (see, for example, the Macusani rhyolites, Pichavant *et al.* 1988) are exclusively composed of very acidic members and thus project within the *fP* type field, generally not showing a typical variation trend. Nevertheless, some tend to show vertical trends and correspond to the traditionally termed anatectic leucogranites (Lameyre 1988) or MPG types (Barbarin 1996). The most representative of this *fP* type are the Himalayan-type leucogranites (Le Fort *et al.* 1987), and also the Limousin leucogranites in the European Hercynides of France (Leger *et al.* 1990) and some of the Cervatos anatectic leucogranites in the Spanish Central Region (Barbero & Villaseca 1992).

Both the paucity of mafic minerals in these highly felsic types and their emplacement level influence the petrographic characteristics of these rocks. Thus, the parautochthonous leucogranites, poorly segregated from their source region, can present a high-temperature mineral paragenesis with typical Mg-cordierite, almandine-pyrope garnet or sillimanite. This kind of high-temperature mineral paragenesis is found in most of the *hP* types from anatectic areas. On the other band, in the more allochthonous epizonal leucogranites (Himalaya or Limousin), the AFM mineral parageneses are of lower temperature and pressure, and minerals tend to show aplopegmatitic textures and also higher volatile contents, typically being represented by two mica and tourmaline-bearing granitoids.

2. Discussion

2.1. Relationship with other classification schemes

On Figure 1b an I/S boundary line has been drawn using the data of I- and S-types from the Lachlan Fold Belt where this nomenclature originated. It can be observed that this I/S line coincides with the boundary line between *mP* and *lP* types proposed in this work. Both lines show a negative slope in the diagram and do not coincide with the peraluminous–metaluminous division. There is not an absolute limit in peraluminosity dividing the fields of *mP* and *lP* types and the boundary is a function of the degree of differentiation of the granite, as stated by Chappell & White (1992). The good discrimination of this *mP*–*lP* line between accessory cordierite-bearing and amphibole-bearing granites reinforces this division.

The petrogenetic connotation of the I–S terminology has made its adoption in other orogenic belts debatable. Furthermore, although there is, as noted above, a strong similarity between the compositions of the Lachlan Fold Belt when c
and the European Hercynian Belt granitic series, the volumes of the several granitic series found in each orogen are different (Fig. 2). In the Lachlan Fold Belt, the *hP* types constitute around one-third of the exposed granites (the Bullenballong suite alone has 11,200 km², Chappell *et al.* 1991) and were emplaced at epizonal levels (sometimes even with associated volcanic rocks) in contrast to the less than 5% of *hP* types in the European Hercynides, where they are typically catazonal plutons related to migmatitic areas. In further contrast, in the European Hercynian Belt, the most abundant types fall in the *mP* and *lP* fields, some of them close to the boundary between the I-types and S-types from the Lachlan Fold Belt. This has led to the classification of some European Hercynian granites as a transitional series (Liew *et al.* 1989).

Apart from intracontinental orogenic zones, where peraluminous granites are really dominant, granitic batholiths also appear above subduction zones at continental margins. Nevertheless, in subduction settings peraluminous series are very scarce, although some peraluminous granites can be generated as a result of differentiation from calc-alkaline series composed mainly of gabbros to granodiorites. The projection of the continental margin calc-alkaline batholiths in the A–B diagram would show that the majority of the data plot in the metaluminous field, with the most acid varieties plotting in the *lP* field (see examples in Debon & Le Fort 1983). This is a consequence of the higher abundance of intermediate rocks in the continental plate margin orogens (Fig 2). Contrasts in the abundance of petrographic types between different orogenic batholiths have led to the difficulty of reconciling the different nomenclatures. Several attempts to reconcile these different nomenclatures have been made, as for example the distinction of Pitcher (1983) between Cordilleran I-types, equivalent to the calc-alkaline suites from continental margins, and

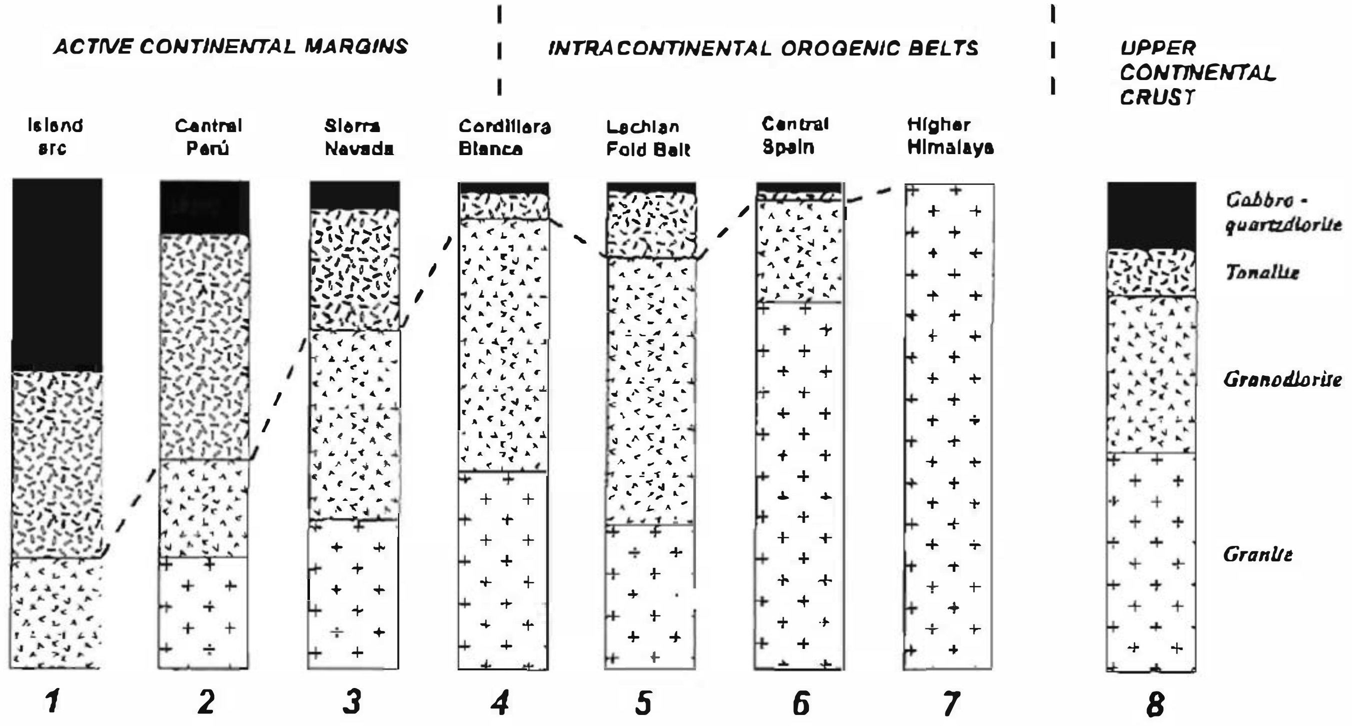

Figure 2 Comparison of relative volumes of gabbro-quartzdiorite, tonalites, granodiorites and granites between active continental margins and intracontinental orogenic batholiths. Estimates are based on geological maps and petrographic description of the batholiths (1, 3, 4, 5), other relative volumes are detailed by the authors (2, 6, 7, 8). 1 = New Britain Island arc (Whalen 1985). 2 = Peruvian Coastal Batholith (Pitcher *et al.* 1985). 3 = Sierra Nevada Batholith (Bateman *et al.* 1963). 4 = Cordillera Blanca Batholith (Petford & Atherton 1996). 5 = Bega Batholith, Lachlan Fold Belt (Chappell *et al.* 1991). 6 = Central Spain Hercynian Belt (Villaseca *et al.* 1998). 7 = Higher Himalaya (Le Fort *et al.* 1987). 8 = Averaged upper continental crust (Wedepohl 1991). Tonalites are the most abundant rock type in coastal batholiths (Pitcher *et al.* 1985; Barker & Arth 1990) but granodiorites dominate in inboard batholiths of active continental margins (Bateman *et al.* 1963; Saleeby *et al.* 1990). Cordillera Blanca Batholith lies inboard of the Peruvian Coastal Batholith, directly over the massively thickened Andean continental crust (Petford & Atherton 1996), in transition to intracontinental line separates felsic (≥65% in volume of felsic minerals) from more mafic rocks.

Caledonian I-types, more typical of intracontinental zones, which usually plot in the *lP* field of Figure 1.

2.2 Protolith type and the origin of peraluminous series

It has become progressively apparent that the main mechanism for generating important volumes of acid peraluminous granitoids is via melting of crustal rocks, including basic mantle-derived protoliths (i.e. Miller 1985; Petford & Atherton 1996). In continental crustal settings, the three main protoliths which can produce important volumes of acid peraluminous magmas include metasediments (metapelites), quartz-feldspathic metaigneous rocks (greywackes and orthogneisses) and basic metaigneous (amphibolites). On Figure 3 different compositional fields for these protoliths and the compositional paths of several melting experiments have been represented. When melting occurs at low melt fractions, it is possible for the composition of the melts to plot in the *fP* field irrespective of the nature of the source protolith. Even metaluminous metaigneous rocks such as reported by Conrad *et al.* (1988) and Beard *et al.* (1993) and amphibolites as reported by Ellis & Thompson (1986), Beard & Lofgren (1991), Patiño Douce & Beard (1995) and Springer & Seck (1997), are able to produce peraluminous felsic melts at low melting fractions and in water-deficient conditions. In general, all the melts produced at low melting fractions are indistinguishable, although it is possible to observe a tendency of pelite-derived melts to plot on the upper part of the *fP* field (Fig. 3). Anatectic granitic series *sensu stricto* have few opportunities to become more differentiated by crystal fractionation and usually do not define clear paths in the *fP* field. On the other hand, as stated earlier, *fP* granites could be highly fractionated magmas of the *mP* or *lP* series instead of primary anatectic leucogranites. So, the assumption that two mica leucogranites form a different magmatic suite should be carefully studied in each particular case, as the *mP* and *lP* peraluminous granitoid types could grade into highly felsic peraluminous leucogranites (Barbarin 1996).

As the melting fraction increases, primary components of the protolith become progressively incorporated into the melt and thus, in the peraluminous granitic series, the more mafic rocks of the suite better image their source (Chappell & White 1992).

When pelitic protoliths are melted, the compositional paths of the resultant series mainly correspond to restite unmixing lines and plot inside the *hP* field (see Cooma, Layos or Kinsman series). In fact, when a large amount of restite is retained in the crystal–liquid mush, the resultant composition could be similar to that of the pelitic source (Fig. 3). Nevertheless, some *hP* types do not necessarily involve melting of a pelitic protolith. Experimental data from Holtz & Johannes (1991) demonstrated that particular metaigneous protoliths (i.e. peraluminous orthogneisses) could also generate series which plot in the lower part of the *hP* field. In fact, the Tourem granites in northern Portugal have been interpreted in this way (Holtz & Barbey 1991). The possibility of generating *hP* types from felsic metaigneous sources has been used as an argument against the equivalence of strongly peraluminous granite and S-type (metasedimentary derived) granite (Miller 1985; Clemens & Wall 1981). Metasedimentary

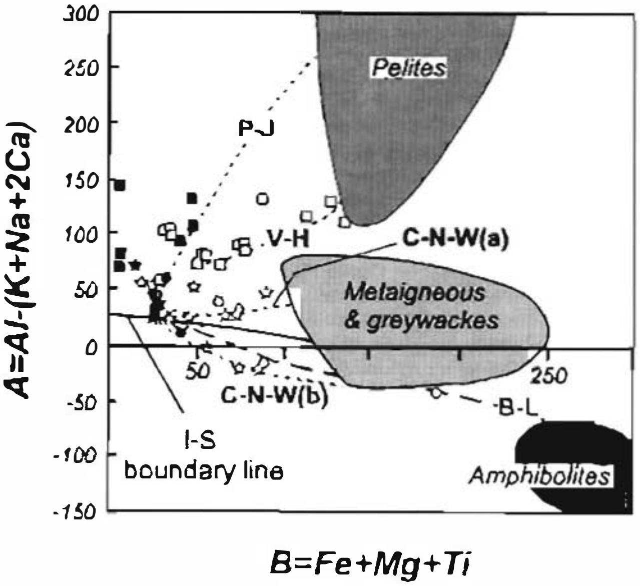

Figure 3 A–B diagram showing the projection of several crustal protoliths and the corresponding experimental melting data; squares: pelite-derived melts (Wickham 1987; Vielzeuf & Holloway 1988; Patiño Douce & Johnston 1991); stars: acid metaigneous- and greywacke-derived melts (Holtz & Johannes 1991; Conrad *et al.* 1988; Beard *et al.* 1993; Patiño Douce & Beard 1995, 1996; Gardien *et al.* 1995); circles: metabasic-derived melts (Ellis & Thompson 1986; Beard & Lofgren 1991; Wolf & Wyllie 1994). Filled symbols represent low melt fraction (< 20% melting) results. Dotted lines represent progressive melting fraction for different experiments: P-J = HQ-36 pelite from Patiño Douce & Johnston (1991); V-H = pelite from Vielzeuf & Holloway (1988); C-N-W(a) = peraluminous greywacke from Conrad *et al.* (1988); C-N-W(b) = metaluminous dacite from Conrad *et al.* (1988); B-L = amphibolite sample 466 from Beard & Lofgren (1991). Other fields as in Figure 1.

and/or strongly peraluminous metaigneous protoliths are both sources for *hP* type granites.

Here another question arises: Is it possible to generate a *hP* type via exhaustive fractionation of any other liquid? Stussi & Cuney (1993) considered this possibility for the plutonic complex of La Rôyere (French Massif Central). Theoretically, fractionation of peraluminous minerals could produce an *hP* trend. The main problem with this hypothesis is that crystallisation of the majority of the peraluminous AFM phases in granitic melts (garnet, cordierite, muscovite, aluminium silicates) is produced at late stages, close to the solidus conditions of the magma, as evidenced from petrographic studies (Villaseca & Barbero 1994) as well as from experimental data (Clemens & Wall 1981; Shimura *et al.* 1992). This makes very unlikely the separation of peraluminous minerals in a magmatic system, which is highly viscous when it is close to being fully crystallised.

In general, *mP* and *lP* types could be generated from any kind of crustal protolith, as deduced from Figure 3, or even by mixtures of them (Patiño Douce & Beard 1995; McCarthy & Patiño Douce 1997). Partial melting of several kinds of metaigneous rocks under variable water conditions could generate *mP* type peraluminous granodioritic magmas (Conrad *et al.* 1988; Beard & Lofgren 1991). In addition, experiments demonstrate that peraluminous liquids can be produced by dehydration melting of some metaluminous amphibolites under lower crustal conditions (Beard & Lofgren 1991; Wolf & Willey 1994; Patiño Douce & Beard 1995; Springer & Seck 1997). Nevertheless, it seems that only metabasic protoliths could generate metaluminous intermediate rocks of the *lP* suites. As experimentally demonstrated by Beard & Lofgren (1991), 30% melting of an amphibolitic protolith under water-undersaturated conditions would produce a tonalitic melt with values of the A and B parameters of −36 and 181 respectively, which are very close to the original composition of the parental magmas of several of the *lP* series represented in Figure 1 (Fig. 3). None of the peraluminous crustal protoliths (pelites, greywackes or acid metaigneous rocks) could generate such a parental melt for *lP* types.

Mechanisms other than pure crustal melting could generate peraluminous magmas, as stated in the reviews of Miller (1985) or Barbarin (1996), but it seems unlikely that they could generate large batholiths of peraluminous felsic granites. It is reasonable to assume that the physical parameters of the partial melting process influence the mineral paragenesis and the composition of the melt, but nevertheless it is the composition of the source rock which ultimately determines to which peraluminous granite type the series will belong.

2.3. The role of the tectonic setting in the partial melting process

Assignment of different peraluminous granite types to specific tectonic settings as some researchers suggest, emphasising the prevailing role of the physical parameters of partial melting over the nature of the sources on their genesis (Pitcher 1983; Barbarin 1996), has to take into account the common presence of different coeval peraluminous granitoids in some intracontinental orogenic belts as exemplified by European Hercynian segments like the Spanish Central Region. As previously stated, the main factors controlling the typology of peraluminous granitic series are the nature of the source rock and the physical parameters of the melting process. Both factors vary depending on the tectonic setting in which the granites are generated. This is the foundation for the tectonic-based classification schemes made by several authors as Pitcher (1983), Maniar & Piccoli (1989) and Rogers & Greenberg (1990), among others.

In active continental margins, basic protoliths are more abundant in comparison to inner continental crustal segments. This is the result of the accumulation of basic rock due to underplating of basic materials at the base of the crust or to accretion of the subducted oceanic slab. The origin of the Cordilleran batholiths is usually explained as a two-stage model, in which the first stage is the creation of a mafic crustal underplated layer followed by a second stage of extensive lower crustal melting (Pitcher 1993; Petford & Atherton 1996). The presence of important volumes of basic protoliths at continental margins implies that the amount of peraluminous melts generated must be of minor importance.

The more felsic nature of the continental crust involved in intracontinental collisional orogens, being mainly composed of pelites, greywackes and acid-intermediate meta-igneous layers, implies a higher fertility for producing peraluminous melts via dehydration melting reactions. For instance, experimental results show that at around 950°C at the Moho, a pelitic protolith could produce as much as 50–60% of peraluminous melt, and a metagreywacke or metatonalitic gneiss could produce around 20–35% of melt. Under the same conditions, metabasic protoliths could only produce around 10% of granitic melt (see fig. 1 in Gardien *et al.* 1995).

Tectonothermal models for crustal thickening indicate that at the base of the crust the temperatures reached are not usually higher than 950°C, which makes the melting of a basic protolith, if present, difficult (Thompson & Connolly 1995). The production of greater volumes and a complexity of peraluminous granitic series is enhanced in such a tectonic setting.

3. Acknowledgements

Revision and comments made by Bernard Bonin, Wallace Pitcher and Ed Stephens on a previous version have greatly increased the quality of this work. This paper has also benefited greatly from detailed comments by Peter E. Brown and an anonymous reviewer. This research was financially supported by the PB96-0661 Project of the Ministerio de Educación y Cultura of Spain.

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