Late Paleozoic to Recent Magmatic Evolution of Northern Patagonia

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The geologic evolution of northern Patagonia is dominated by a series of complex magmatic episodes that began in the Paleozoic and continue today. An understanding is just beginning to emerge of how these magmatic events are related to the rate and obliqueness of convergence, to the dip of contemporaneous subduction regimes, to the collision of microcontinents, and to the resulting extensional-compressional regime. This paper reviews the magmatic belts between 38° and 44°S, briefly summarizes their chemistry and speculates on their tectonic setting.

A Magmatic Record of Gondwana and Andean Evolution

South of the Rio Colorado (38°S) in that part of Argentina known as Patagonia, the characteristic geomorphology is controlled by mid-Jurassic rhyolites and by Andean (Creta-

ceous to Recent) magmatic rocks, which are essentially absent north of the Rio Colorado. However, Jurassic to Recent igneous and sedimentary sequences represent only the latest events in the complex geological history of Patagonia. Paleozoic geological features also change abruptly across the Rio Colorado (cf. Turner and Baldi, 1979), suggesting that the Paleozoic evolution of Patagonia was also somewhat independent from the rest of the continent. Ramos (1984b) interpreted these differences as the result of a possible collision between a Patagonian microcontinent and the Gondwana plate during the latest Paleozoic.

The pre-Andean magmatic rocks of northern Patagonia are characterized by voluminous silicic plutonic and volcanic suites of late Paleozoic to Jurassic age (Fig. 1), which are

Figure 1: Major magmatic units of northern Patagonia. LE: La Esperanza, LC: Lihuel Calel Plateau, NNC: Nihuel Niyeu Camico.

part of the Gondwana magmatic cycle of Patagonia (Llambias et al., in Ramos, 1984a). The Jurassic silicic volcanics, which cover much of Patagonia, constitute one of the largest rhyolitic provinces in the world; they were erupted just prior to the breakup of Gondwanaland (Dalziel et al., 1987; Uliana and Biddle, 1987). Post-Gondwana magmatics include the Andean Cordilleran plutonic and volcanic series, which are related to the subduction of the Nazca plate and its Pacific forerunners. To the east, in the backarc and cratonic areas south of 38°30'S, is the Patagonian plateau basaltic series of Cenozoic age (Fig. 1). The Andean Cordilleran volcanics and the Patagonian plateau series together define the Patagonian Volcanic province (Rapela et al., in Ramos, 1984a; Rapela and Llambias, 1985).

Plutonic Belts of Northern Patagonia

All of the Gondwana and some of the Andean plutonic rocks intrude a pre-Carboniferous basement composed of schists, gneisses and syn-kinematic granitoids (Cushamen and Mamil Choique formations) whose exact age is still uncertain. Scattered K-Ar and model Rb-Sr ages indicate middle to late Paleozoic ages, whereas whole-rock Rb-Sr isochrons of metamorphic rocks from the northwestern sector suggest Precambrian ages (Linares et al., 1988). In some regions, Andean granites are emplaced into Late Jurassic-Early Cretaceous Cordilleran volcanics.

To the north of the Rio Colorado, the Gondwana plutonic belts are parallel to the modern Andean chain, but to the south of 39°S discontinuous outcrops of the Gondwana magmatic belts diverge significantly southeastwards (Fig. 2). In the transition area near 39°S, granitoid ages range from late Paleozoic to Tertiary (Munizaga et al., in press; Rapela et al., 1987). South of the Rio Colorado, two main Gondwana batholiths are recognized and are here referred to as the Somuncura batholith, which is primarily of Carboniferous age, and the Central Patagonia batholith mainly of Early Jurassic age (Fig. 1).

and Caminos, in ISGAM, 1987), where the lithology, sequence of intrusion and chemical evolution of the magmatic rocks are very similar. The two main superunits (see Cobbing and Pitcher, 1972), the La Esperanza and the Dos Lomas, were defined in the La Esperanza region to describe an older plutonic and a younger volcanic-plutonic complex, respectively (Rapela and Caminos, *ibid*).

The La Esperanza superunit is characterized by hornblende-biotite granitoids (tonalite, granodiorite and granite facies with microdioritic enclaves) with SiO₂ contents of 61-71%. These granitoids are intruded by biotite granites, some with K-feldspar megacrysts. The evolution of the superunit culminated with the intrusion of microdioritic and lamprophyric (52-60% SiO₂) dikes. The Dos Lomas superunit began with overlying andesitic lavas and dacitic and rhyolitic ignimbrites and culminated with the intrusion of high-silica leucogranites and biotite granites.

Rb-Sr whole-rock isochrons on the oldest and youngest granitoid units in both the La Esperanza and Nahuel Niyeu-Comico areas are remarkably similar, indicating that the main granitic bodies in these regions were emplaced during the Carboniferous between 326 and 317 Ma ago (Llambias et al., 1985; Caminos and Parica, 1985). K-Ar ages of granitoids and acid volcanics from neighboring sectors of the Somuncura batholith (Llambias et al., in Ramos, 1984a) suggest that the latest activity of the batholith was Permian.

The Central Patagonia Batholith

The Central Patagonia batholith is defined by discontinuous outcrops that extend southeastwards from Panguipulli Lake in Chile, where an age determination of 196 ± 20 Ma was made by Munizaga and others (in press), to the Pilcaniyeu (195 ± 5 Ma - Alonso, 1987) and Gastre (208 ± 1 Ma - Rapela et al., 1988; Harrison and co-workers, personal communication) areas in Argentina (Fig. 2), all ages quoted here being Rb-Sr whole rock determinations. South of 43°S, the batholith continues as a string of isolated outcrops, and beyond the Golfo de San Jorge basin, Rb-Sr whole rock ages of 196-191 Ma have been reported on plutonic rocks (Stipanovic et al., 1971), suggesting that the Central Patagonia batholith extends as far as the Atlantic Ocean in the region of the Deseado massif (48°S, see Fig. 2).

The overall composition of the batholith is still poorly known, but from a detailed study of the Gastre area (Rapela et al., in press) two main suites can be distinguished. The older is composed of foliated hornblende-biotite granitoids, which are mainly high-SiO₂ granodiorites. This early suite is intruded by the even more silicic Lipetren suite composed of biotite granites, hornblende granites, and leucocratic granites that commonly have protoclastic textures. Leucocratic two-mica granites have been also described in the Lipetren suite in the Pilcaniyeu area (Alonso, 1987). The Lipetren suite is best exposed in the eastern and central sectors of the batholith where it outcrops as

small and intermediate size plutons with sharp country rock contacts.

The Andean Patagonia Batholith

Since Late Jurassic times, the main locus of magmatic activity has been within and subparallel to the modern Andean Cordillera. The plutonic component of this activity is represented by the Andean Patagonia batholith (Fig. 1), which ranges in age from 160 to 8 Ma. The spatial distri-

Figure 2: Distribution and possible tectonic setting of late Paleozoic to Mesozoic magmatic rocks of Argentina and Chile. G: Golfo de San Jorge, D: Deseado Massif.

The Somuncura Batholith

Detailed field, petrological and geochemical studies have been carried out in two regions of the Somuncura batholith: the La Esperanza (Llambias and Rapela, 1984; Rapela and Llambias, 1985) and the Nahuel Niyeu-Comico areas (Rapela

Figure 3: Frequency distribution of K-Ar ages between 39°30' and 42°30'S. Data from Marshall and others (1977), González Díaz (1982), Rapela and others (1983, 1987, 1988), González Díaz and Lizuain (in Ramos, 1984a), Coira and others (1985), and Corbella (in Ramos, 1984a).

bution of this and the Gondwana batholith indicate a south-westward migration of the main locus of plutonic activity with time.

Between 39°42' and 42°S, K-Ar ages suggest that major pulses of plutonism (G1 to G5 in Fig. 3) occurred at 176-150, 140-120, 110-75, 60-30 and 16-8 Ma (Rapela et al., 1987). As shown in Figure 4, the oldest plutons occur in the eastern slope of the Andes, and ages tend to decrease westwards (González Díaz, 1982). Farther south, the zonation of the Andean Patagonia batholith is more complex, and isotopic data indicate no such unidirectional migration with time (Bartholomew and Tarney, in Harmon and Barreiro, 1984).

Geochemical studies at 41°S define at least five magmatic units (Rapela, 1987). The hornblende and biotite-bearing Lago Moreno quartz-diorite (131-122 Ma) and Los Machis granodiorite (100-75 Ma) are the most extensive units and comprise most of the batholith here. The Pireco granite (43-30 Ma) and the Tristeza leucogranite (10-8 Ma) are restricted high-level plutons with scarce biotite, which occur in the eastern slope of the Andes. The Reloncavi granitoids to the west in Chile (16-10 Ma) are less silicic and consist of gabbros, quartz diorites, diorites and tonalites (Parada et al., in ISGAM, 1987).

Gondwana Volcanics

Intermediate to acid volcanics and shallow-level leucocratic granites mark the culmination of the evolution of the Somuncura batholith (Rapela and Caminos, in ISGAM, 1987). The volcanics are equivalent in age to the Choiyoi unit (Fig. 2b), an extensive complex of latest Paleozoic to early Triassic silicic volcanic rocks and related plutons, that outcrops primarily in the eastern and central part of the main Andean Cordillera (the Cordillera Frontal) as far north as 28°S (Rapela and Llambias, 1985). Just north of the Rio Colorado, plateau rhyolites and leucogranites equivalent to the Choiyoi complex range in age from 270 to 210 Ma (Linares et al., 1980). The bulk of these rhyolites occur in a region known as the Lihuel Calel plateau (on Fig. 1). A Rb-Sr whole rock isochron of 238 ± 5 Ma (Linares et al., *ibid*) shows that the Lihuel Calel flows erupted before the emplacement of the Central Patagonia batholith.

A major period of dominantly rhyolitic volcanism began in the latest Triassic and reached its peak during the Middle Jurassic in eastern and central Patagonia (the Marifil Group of Fig. 2b). These rhyolites are equivalent to the extensive silicic volcanics of the Chon-Aike series that cover much of east-central and southern Patagonia (Fig. 2a and Gust et al., 1985). K-Ar ages reviewed by Cortés (1981) indicate that the Chon Aike volcanic rocks erupted from about 200 to 150 Ma ago, with a peak in the activity around 165 to 155 Ma (Gust et al., *ibid*). Some of these volcanic rocks are associated in time and space with a series of NNW-trending grabens (Uliana et al., 1985). In the Andean Cordilleran sector, dacitic to rhyolitic rocks about 200 Ma old occur at 39°30'S (Rapela et al., 1983).

Andean Volcanism

The well-documented early Andean Cordilleran volcanics first appeared in Late Jurassic to Early Cretaceous times (155-120 Ma). They comprise the Lago La Plata Formation, the Divisadero Group, the Montes de Oca Formation and their equivalents (Ramos et al., 1982; González Díaz and Lizuain, in Ramos, 1984a). In central Patagonia, a series of basic to acid Jurassic volcanics (the Taquetren Formation) follows the axis of the Central Patagonia batholith, defining a coherent volcanic arc association (Fig. 1). Andesitic rocks of this suite are interlayered with marine Liassic sediments, which contain Early Jurassic ammonites (Musacchio, 1981).

Several major periods of Cenozoic volcanic activity have been described just east of the modern Andean Cordillera (Rapela et al., 1988), with the oldest extending from the Paleocene to the Oligocene (Figs. 1, 3 and 5). Regionally, these older volcanic rocks define two broad belts with Paleocene to Eocene volcanism, principally in the Pilcaniyeu belt to the east, and Oligocene volcanism mainly in the El Maiten belt to the west. Temporal variations, determined by superposition in selected cross-sections, indicate that the early Tertiary episodes began with silicic associations (ignimbritic, plinian and obsidian rhyolitic facies) and ended with intermediate lava flows (stratovolcanoes and monogenetic cones).

During the Oligocene, widespread thick tuffaceous sequences and related thin sheets of ignimbrites accumulated in both the developing pull-apart Nirihuau Basin (Dalla Salda and Franzese, 1987) and the Chilean Longitudinal Depression (Fig. 5). This episode was followed by a period of relative volcanic quiescence in the Late Oligocene and Early Miocene that culminated with compressive deformation of the arc and the sedimentary basins (such as the Nirihuau), resulting in the thrusting of older Tertiary volcanic sequences over the basin (Ramos and Cortés, in Ramos, 1984a).

Major volcanic activity started again in the Middle Miocene with the eruption of silicic ignimbrites of the Collon Cura Formation around 15 Ma ago (Marshall et al., 1977). During

Figure 4: Variation of K-Ar ages across the northern sector of the Andean Patagonia batholith. The locations of dated samples are shown by solid diamonds directly above their position on the graph below. See Figure 2 for data sources.

the Pliocene-Pleistocene, volcanism again reached a maximum as large stratovolcanoes, composed mainly of basalts and andesites, were built along the North Patagonian Cordillera (Figs. 1 and 5).

The Plateau Basalt Series (Fig. 1) consists of a sequence of olivine basalts and alkalic complexes located in the back-arc and cratonic areas to the east of the Andean orogen. Radiometric ages between 40° and 43°S indicate a protracted period of volcanic activity, ranging from Late Cretaceous to Late Pliocene, with a peak in activity about 30 to 20 Ma ago (Corbella, in Ramos, 1984a). Middle to Late Miocene

activity is apparently absent in this region, and Pliocene volcanism is concentrated in the western part of the plateau (Coira et al., 1985). A similar range of ages for plateau volcanism has been reported to the south, but the peak periods are different (Ramos et al., 1982). Some of the eruptions in the eastern Meseta de Somuncura (Fig. 2) are related to NNW megafractures and grabens (Corbella, 1975), but most are not obviously related to any fault system.

Geochemical Features of Patagonian Igneous Rocks

The plutonic rocks of the Gondwana batholiths all plot in the calc-alkaline field on an AFM diagram (Fig. 6), but different superunits and units within superunits show distinct trends. For example, in the Somuncura batholith the magmatic complexes are composed of several progressively more acidic magmatic pulses that culminate with leucocratic alkali-like plutons emplaced at epizonal levels. These distinct pulses have been interpreted as periodic inputs of

Figure 5: Generalized paleogeographic reconstruction of the Cenozoic Cordilleran Series. A: Paleocene-Eocene, B: Oligocene, C: Miocene, D: Pliocene-Recent. After Rapela and others (1988).

basic magmas in a fractionating magma chamber (Rapela and Llambias, 1985). Variations can also be selected for the superunits in the Gastre area of the Central Patagonia batholith and for individual plutonic episodes in the Andean Patagonia batholith.

Although the Patagonian batholiths all show calc-alkaline affinities (Fig. 6), the Gondwana batholiths exhibit several important chemical differences from the typical I-type Cordilleran suites in the Andean Patagonia batholith. The first is that true granitic compositions are more abundant in the Gondwana batholiths, and gabbros are virtually absent. In contrast, the Andean Patagonia batholith consists principally of tonalites, quartz diorites and granodiorites. Second, the Gondwana granitoids are more enriched in large ion lithophile (LIL) elements such as alkalis, Rb and Ba, when compared to Andean rocks with similar major element compositions. The latest units of the Somuncura batholith, have alkalic-like signatures. Third, initial Sr isotope ratios of the Gondwana granites and acid volcanics are relatively high (0.7053-0.7079, Llambias et al., 1985; Caminos and Parica, 1985), suggesting that a crustal component is present in these magmas. In the southern Andean Patagonia batholith, initial Sr ratios of 0.7074 to 0.7036 decrease with age (130 to 46 Ma), indicating a progressive decrease in crustal involvement during evolution of the batholith (Weaver et al., in press).

As for the volcanic belts, the Gondwana volcanics of Carboniferous-Permian age and the Jurassic Chon Aike (eastern rhyolitic rocks) are generally richer in Si and K than their Andean counterparts (Fig. 7). Jurassic volcanic rocks of Central Patagonia (the Taquetren Formation, see Fig. 1) show a larger compositional range and generally follow a high-K calc-alkaline trend. In the Gastre area, this volcanic succession has been related to a Jurassic magmatic arc (Page and Page, 1987).

In northern Patagonia K_2O generally decreases for a given SiO_2 content with diminishing age and decreases with proximity to the western margin of the continent (compare

Figs. 1 and 7). As for the Cenozoic volcanics, K_2O decreases southward for a given silica content in the Cordilleran volcanics, regardless of age (Hickey et al., in Harmon and Barreiro, 1984; Rapela et al., 1988).

Trace element data for the Cenozoic arc and back-arc volcanic rocks show a number of interesting features that help to elucidate their origin and tectonic environment. These features are summarized in Figure 8 in a plot of Ba/Nb versus La/Nb; ratios that are higher in arc volcanic rocks than in ocean island basalts and mid-ocean ridge rocks. As expected, these ratios are relatively high in Pliocene to Recent arc rocks of the main Andean chain and relatively low in volcanic rocks from the extra-Andean plateau. Interestingly, almost all the volcanic rocks from the Paleocene to Oligocene Pilcaniyeu and El Maiten belts plot in a region intermediate between the arc volcanics and the ocean island basalts (OIB).

These data suggest either that the Tertiary volcanic rocks were erupted in a back-arc setting or that their source area was significantly different to that of the modern Andean arc at these latitudes. Furthermore, for a given SiO_2 content, trace element abundances are lowest in volcanic rocks of the Oligocene El Maiten Belt, indicating higher degrees of partial melting of the source during this period.

Cenozoic Magmatism and Subduction Geometry

A notable coincidence is that the peak of activity in the Plateau Basalt Series of the back-arc and cratonic areas east of the Andean orogen between 39° and 43°S was coeval with the breakup of the Farallon plate and the formation of the Nazca plate about 27-25 Ma ago (Cande and Leslie, 1986). This activity in the plateau is also contemporaneous with an increase in the normal component of convergence from about 4 cm/year around 25 Ma ago to about 11 cm/year some 18 Ma ago. The slip rate parallel to the margin remained low, varying from about 2 to 4 cm/year during this entire period (personal communication, S.C. Cande, 1988).

Figure 6: AFM diagrams for Gondwana and Andean granitoids, showing the boundary between the calc-alkaline (CA) and tholeiitic (TH) fields.

Several other magmatic features change with this mid-Tertiary increase in the subduction rate along the western continental margin. For example, the younger sequences of the El Maiten Belt, which erupted at roughly the same time as this increase show mild tholeiitic and alkalic trends. Kay and Rapela (1987) conclude that the mantle source of these lavas as well as that of the older Pilcaniyeu lavas had a smaller arc component than the young frontal Andean arc magmas (Fig. 7). Another difference is that widespread ignimbritic and rhyolitic eruptions occurred along the Pilcaniyeu belt during the early Tertiary (Figs. 1, 5), whereas silicic rocks are rare in the Pliocene to Recent volcanic arc and back-arc rocks of northern Patagonia.

In the Andean Patagonia batholith, the period of change from slow to fast convergence coincides with a minimum of plutonic activity (Fig. 3). Furthermore, during the period of slow convergence, plutonism was less voluminous than during the Cretaceous or the Neogene. Chemical differences also occurred, for the early Tertiary (43–30 Ma) Pireco granitoids (G4 in Fig. 3), emplaced during the period of slow convergence, are mainly monzon-granites and alkali-feldspar granites, whereas the 16–10 Ma Reloncavi granitoids (G5 in Fig. 3), emplaced during fast convergence, are more basic and closely resemble the compositions of the Neogene stratovolcanoes (Parada et al., *in* ISGAM, 1987).

Carboniferous, important volcanic and plutonic magmatic activity took place in the Somuncura batholith. This batholith and its coeval high-K volcanic suite shows calc-alkaline affinities (Figs. 6, 7) that suggest an important role for a crustal component consistent with emplacement in older continental crust. These suites contrast with the contemporaneous late Paleozoic fore-arc basins and subduction complexes with abundant mafic rocks that occur along the southwest Patagonian continental margin (Uliana et al., 1985, and see article by Hervé in this issue).

Explanation of these magmatic events requires an understanding of Paleozoic events in reconstructed Gondwanaland, particularly in South Africa. Several explanations have been advanced, the first of which suggests that these Gondwana magmatic rocks are related to a shallow-angle subduction zone located at the southern margin of Gondwana (Lock, 1980; Gust et al., 1985). Problems with this hypothesis involve differences between style of deformation and type of magmatic rocks in this region compared to those in areas of modern shallow subduction (Ramos, 1986). Furthermore, the model of Gust and others (*ibid*) ignores the existence of older crust in the Malvinas plateau and southern South America (Ramos, *ibid*). Other workers have postulated that subduction along the paleo-Pacific margin east of the present trench can explain the magmatic

activity in the Somuncura batholith (Forsythe, 1982; Uliana and Biddle, 1987, and see Fig. 2). However, the details of how such a subduction zone operated are obscure.

Alternatively, Ramos suggests (1984b, 1986) that the deformational and magmatic patterns are more easily understood if the early part of the Somuncura batholith were part of a continental arc related to a southwest-directed subduction zone that terminated in a late Paleozoic collision between Gondwana and a separate Patagonian continent (including the Antarctic Peninsula). This collision, along with those of the terranes in southwest Patagonia, represents the final stages of Gondwana formation. In this model, a second east-dipping subduction zone along the Pacific margin is needed to explain the distribution of Paleozoic plutonic rocks here (V. Ramos, personal communication, 1988). Although possible, a definable suture and other features

associated with a subduction zone have not yet been recognized in the Somuncura region. The siliceous character of the Somuncura batholith is also not typical of subduction-related plutonism.

Another possible alternative is shown in Figure 2a. Here the Late Devonian to Early Carboniferous rocks of the Somuncura batholith and plutonic rocks of similar age to the north in the Sierras Pampeanas (Rapela et al., 1988) are considered to be an inner Cordilleran arc behind a magmatic arc represented by plutonic rocks in the Andean Cordillera. The Sierras Pampeanas rocks are more alkaline than those in Patagonia but may have formed over older thicker crust. This model requires important NW-SE directed shearing and faulting during the late Paleozoic to explain the deformation in the Ventana fold belt (Fig. 1, and Martinez, 1986). Crustal melting accompanied this deformational period.

The Jurassic Central Patagonia batholith also appears to occur in a shear zone related to northwest faulting. These silicic magmas may represent crustal melts resulting from associated basaltic intrusions at depth. The location of the Central Patagonia batholith in this region correlates with a principle zone of shearing and graben formation (Uliana and Biddle, 1987).

Figure 7: Plot of K_2O versus SiO_2 with age distance from the modern trench. Data from Rapela and others, (1988; *in* Ramos, 1984a), Llambias and others (*in* Ramos, 1984a), Uliana and co-workers (1985), and Hickey and others (1986).

These observations suggest that near the end of the period of slow convergence both arc and back-arc regions were characterized by a relative lack of compression. More extensive melting in the mantle in the near and far back-arc region is suggested by the chemistry of the Oligocene to Early Miocene lavas (Kay and Rapela, 1987). The Miocene Reloncavi granitoids in the Andean Patagonia batholith in Chile and the younger Andean basaltic stratovolcanoes represent the products of the new normal subduction regime, that is still active today.

Magmatism and the Evolution of Gondwana

K-Ar ages between 340 and 380 Ma from widely spaced plutonic localities (Toubes and Spikermann, 1973; Lizuain, 1981; Rapela et al., 1987; Linares et al., 1988) in northern Patagonia suggest that plutonic activity started in this region in the Late Devonian (Fig. 2). During the Early

The Problem of the Silicic Rocks

Another important problem in Gondwana magmatic history is the origin of the widespread sequences of silicic volcanic rocks and related granites, particularly the Permo-Triassic Choiyoi Group (Fig. 2, and on Fig. 1 the Lihuel Calel plateau) and the Jurassic Chon Aike Group (the Marifil volcanics on Fig. 1). In northern Patagonia, northwest-trending grabens and half-grabens associated with continental extension roughly parallel the axes of the Somuncura and Central Patagonia batholiths and appear to be related to the silicic volcanism (Gust et al., 1985).

Gondwana rhyolitic volcanism is not restricted to northern Patagonia, for widespread Permo-Triassic rhyolites (Choiyoi Formation) and related granites north of 39°S show many features in common with the Somuncura magmatism (Rapela and Llambias, 1985). Likewise, silicic Jurassic volcanism extends throughout most of Patagonia (Gust et al., *ibid*).

Some understanding of these magmatic events may be reached by analogy with the Cenozoic history of northern Patagonia and from recent work on Gondwana magmatism by S.M. Kay, V. Ramos, M. Mpodozis and P. Sruga. Likewise, Gondwana silicic magmatism was contemporaneous with a period of minimal subduction along much of the modern South American margin (Fig. 2). During this time, widespread accumulation of basaltic magmas at the base of the lower crust, produced perhaps by thermal blanketing of a super-continent (Gurnis, 1988), resulted in extensive melting. Unlike the Cenozoic basalts, the Gondwana mafic magmas in the main intruded the relatively new (Paleozoic) accreted crust that had not been depleted in low melting components. Subsequent melting of this undepleted crust led to the production of the extensive Gondwana silicic magmas, which were either erupted or ponded in the middle to upper crust to form a ductile cap trapping the basaltic magmas below.

Figure 8: Ba/Nb and La/Nb ratios in Tertiary to Recent volcanic rocks of northern Patagonia (40° to 43°S). Patterned region in ocean island basalt box (OIB) is for samples of plateau basalts from 45°-47°S (data from Hawkesworth, 1979). Circled field labelled "Plateau" includes unpublished data from plateau basalts. ARC-F and ARC-S are fields for frontal and secondary volcanoes in the Pliocene to Recent arc (data from Hickey et al., 1986, and in press). Samples from the Pilcaniyeu-El Maiten belts indicated by open squares (Oligocene) and solid circles (pre-Oligocene).

Summary

The breakup of Gondwana and the opening of the South Atlantic during the Late Jurassic-Early Cretaceous were related in time to a westward shift in the axis of magmatism from the Central Patagonia batholith to the Andean belt closer to the Pacific margin (Fig. 2). Extensive mid-Jurassic silicic volcanism was followed by the opening of a marginal basin to the south in the western Pacific margin, and subsequently by the emplacement of the Andean Patagonia batholith (Dalziel, 1981; Dalziel et al., 1987).

The age of the oldest oceanic lithosphere in the South Atlantic (130 Ma according to Rabinowitz and La Brecque, 1979) is about the same as the early main unit of the Andean Patagonia batholith. Major tectonic re-arrangement occurred in the South Atlantic Mid-Late Jurassic, associated with the subduction of the proto-Pacific oceanic lithosphere and intimately linked to the fragmentation of Gondwana (Dalziel et al., 1987).

The ultimate origin of the Patagonian Gondwana magmatic belts is still a matter of speculation. In simple terms, the history of northern Patagonia can be explained in terms of an earlier Paleozoic subduction regime, followed by a late Paleozoic to early Mesozoic phase in which extensive crustal melting was associated with a period of relaxation and extension. Renewed subduction during the late Mesozoic and Cenozoic accounts for more recent events.

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