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Review of Tectonic and Stratigraphic Evolution: Patagonia, South America

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ABSTRACT. Patagonia is mainly composed of the Magellan Basin surrounded by northward-trending Patagonian Cordillera to the west and eastward-trending Cordillera Darwin to the south. The stratigraphy, magmatism, metamorphism and mineralization of Patagonia were reviewed. Patagonia area consists mainly of Paleozoic to Late Jurassic basement and Late Jurassic to Tertiary marine sedimentary sequence which contains some volcanic rocks. The basement was formed by the materials accreted to the South American plate by subduction-related processes during the late Paleozoic to early Mesozoic. During Late Triassic to Jurassic times, the Paleozoic rocks were overlain by thick volcaniclastic sequence. The overlying post-Jurassic sedimentary rocks filling the Magellan Basin were deposited in three distinct environmental settings; (1) syn-rift setting during extensional tectonic; (2) late to post-rift remnant-arc-margin setting; and (3) foreland basin setting. The Patagonian batholith consisting of numerous plutons with varying lithologies is a typical example of subduction-related calc-alkaline batholith formed in active continental margin. The age of plutonism ranges from 166 to 12 Ma, with a peak occurring between 100 and 70 Ma. Existence of two major rock series, which are low-K calc-alkaline tonalitic (CAT) and normal-K calc-alkaline granodioritic (CAG), indicates that two distinct types of parental magma were involved during the formation of Patagonian batholith. Radiogenic isotope signatures represent the amount of crustal component or the degree of crustal contamination has decreased throughout the evolution of the batholith. Peak metamorphic P-T conditions of Cordillera Darwin metamorphic complex are 5-7 kbar and 525-650°C, which belongs to the kyanite stability field. P-T path from pelites represents heating by 80-100°C with loading of 0.2-3.0 kbar, whereas that from Mg-rich garnet amphibolites displays decreasing in pressure about 3 kbar with 25-50°C of heating. Such clockwise P-T trajectory indicates exhumation of metamorphic core complex during extensional tectonism. The paucity of ore deposits in Chilean Patagonia is closely related with the history of tectonic evolution in this area. The degree of erosion, which increases toward the south, may be the most important factor for deficit of ore deposit in southern South America. Existence of Mesozoic to Tertiary epithermal deposits in this area, however, represents possible development of extensive mineralization. The classification system of six metallo-tectonic terrane, related with tectonic evolution, will be helpful for designing of further exploration in this area.

Key Words: Chilean Patagonia, magmatism, metamorphism, mineralization, stratigraphy, tectonism

Introduction

Patagonia is mainly composed of the Magellan Basin surrounded by northward-trending Patagonian Cordillera to the west and eastward-trending Cordillera Darwin to the south (Fig. 1). This area has a long and complex tectonic history. Since late Paleozoic, oceanic Nazca and Antarctic plates have subducted beneath the western continental margin of South America (Forsythe 1982; Dalziel 1985). Paleozoic subduction produced mag-

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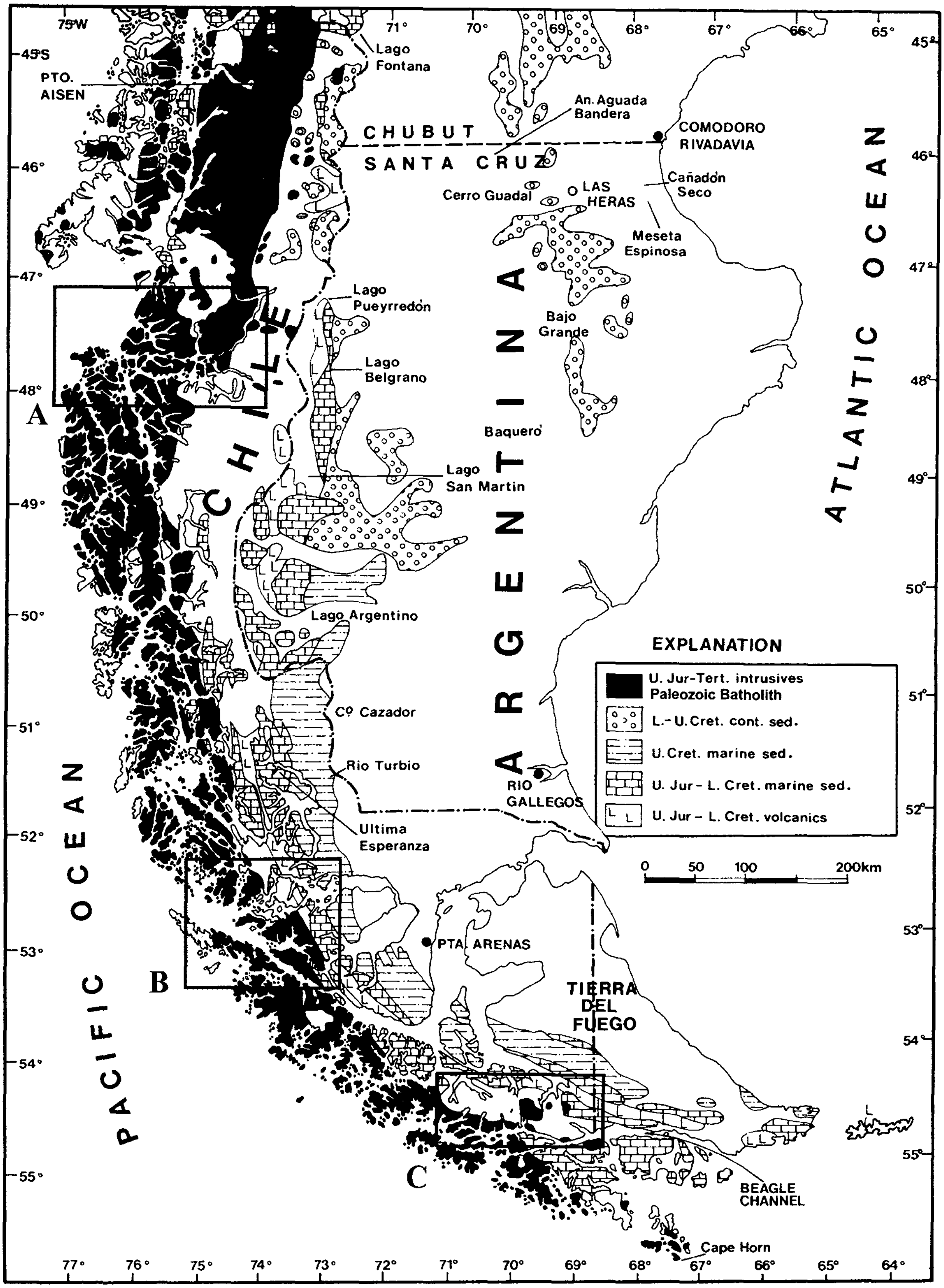

Fig. 1. Geologic map showing the Cretaceous rocks of southern Patagonia. Rectangles indicate studied Patagonian batholith A; Baker area, B; Xaultegua area, and C; Cordillera Darwin.

matic arcs east of the Patagonian batholith, but the locus of magmatism had moved westward by mid-Jurassic time with intrusion of plutons into the Paleozoic fore-arc sequence and eruption of extension-related bimodal volcanics (Bruhn *et al.* 1978). From the Late Triassic to Early Cretaceous, the southern part of Patagonia underwent extensional deformation by break-up of Gondwana, and led to development of the Rocas Verdes marginal basin (Rapela and Pankhurst 1992; Storey 1993). Subsequent arc-continent collision formed the Andes and closed the Rocas Verdes marginal basin during the Late Cretaceous time (Dalziel 1985). The Magellan Basin developed east of the Andes in foreland setting concomitant with the development of Andes during the Late Cretaceous and Tertiary. The Magellan Basin displays bow shape with NNW trend and covers about 160,000 km^2. This basin contains more than 7 km thick sedimentary sequences.

The purpose of this paper is compiling existed knowledges about the stratigraphy, magmatism, metamorphism and ore mineralization of the Chilean Patagonia area. The first part deals with the stratigraphy of the Magellan Basin. In the second part, we will review the Patagonian batholith in aspect of petrologic, geochronologic, and geochemical perspectives, that give better understanding about the nature of active continental margin calc-alkaline magmatism. The third part concerns about metamorphism of the Cordillera Darwin metamorphic complex. This will help understand the tectonic evolution of Patagonia area. The last part includes characteristics of mineralization and exploration of ore deposits in Chilean Patagonia.

Stratigraphic Synthesis through Geologic Evolution

Patagonia area consists mainly of Paleozoic to Late Jurassic basement and Late Jurassic to Tertiary marine sedimentary sequence which contains some volcanic rocks (Fig. 2). The basement was formed by the material accreted to the South American plate by subduction-related processes during the late Paleozoic to early Mesozoic (Forsythe 1982; Ling *et al.* 1985). During Late Triassic to Jurassic times, the Paleozoic rocks were overlain by thick volcaniclastic sequence (Tobifera Formation). The overlying post-Jurassic sedimentary rocks filling the basin are mainly composed of shaly component and can be divided into three major packages: (1) a syn-rift package deposited in grabens and half-grabens created during the extensional event that led to the formation of the Rocas Verdes marginal basin to the SW (Dalziel 1981); (2) a late to post-rift remnant-arc-

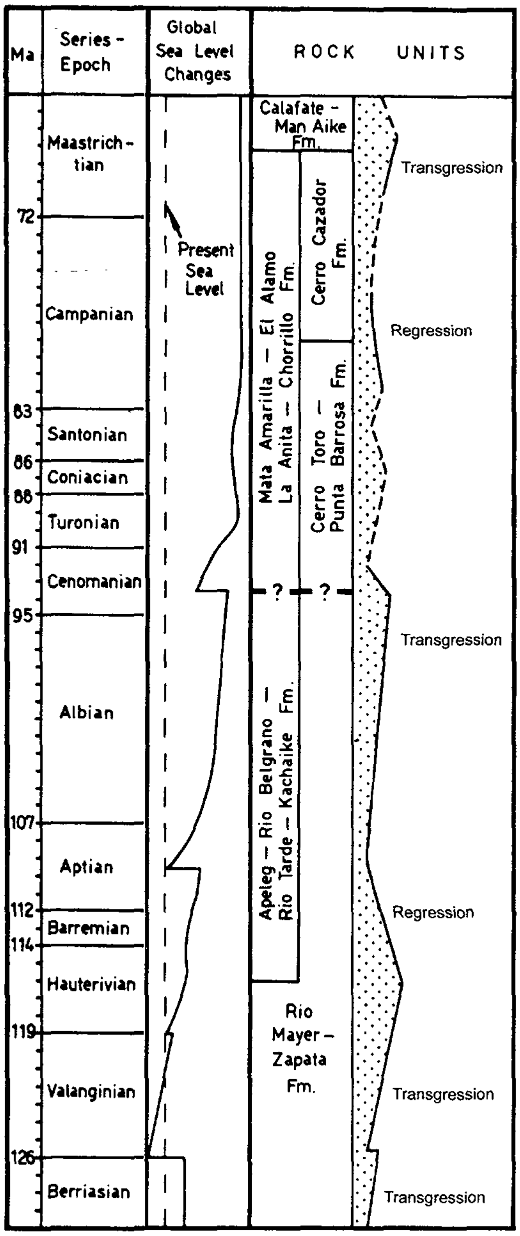

Fig. 2. Simplified Cretaceous stratigraphy with sea level change in the Magellan Basin.

margin package deposited just before and after oceanic crust was formed in the Rocas Verdes marginal sea as the area of the Magellan Basin underwent thermally driven subsidence; and (3) a foreland basin package deposited in front of the rising Andes as the basin subsided due to loading along its western and southern edges.

Paleozoic rocks

The oldest units recognized in Patagonia area include sedimentary and metamorphic rocks of early and late Paleozoic age (Halpern 1973; Forsythe 1982; Ling *et al.* 1985). This basement rocks distributed along a discontinuous belt in the Patagonian Andes and coastal Chile, and the present edges of the Magellan Basin in small areas on the western Deseado massif (Fig. 1). The Paleozoic basement rocks are mostly lower to middle greenschist-facies slates, phyllites, and mica schists derived from clayey and sandy sedimentary protoliths (Nelson *et al.* 1980). In coastal Chile, the basement includes limited suite of blueschists and less-metamorphosed, obviously allochthonous elements such as shallow-water limestones and pillow basalts with mid-ocean ridge affinities (Mpodozis and Forsythe 1983). This basement rocks underwent complex magmatism and horizontal shortening which acted together since the Late Cretaceous, to produce crustal thickening (Dalziel and Palmer 1979; Klepeis 1994). In Cordillera, major folds and thrusts developed with NNW to NW trend and provided evidence for shortening and thickening tectonics. Left-lateral faults associated with strike-slip motions also described in Cordillera Darwin, southernmost South America (Cunningham 1993; Cunningham *et al.* 1995).

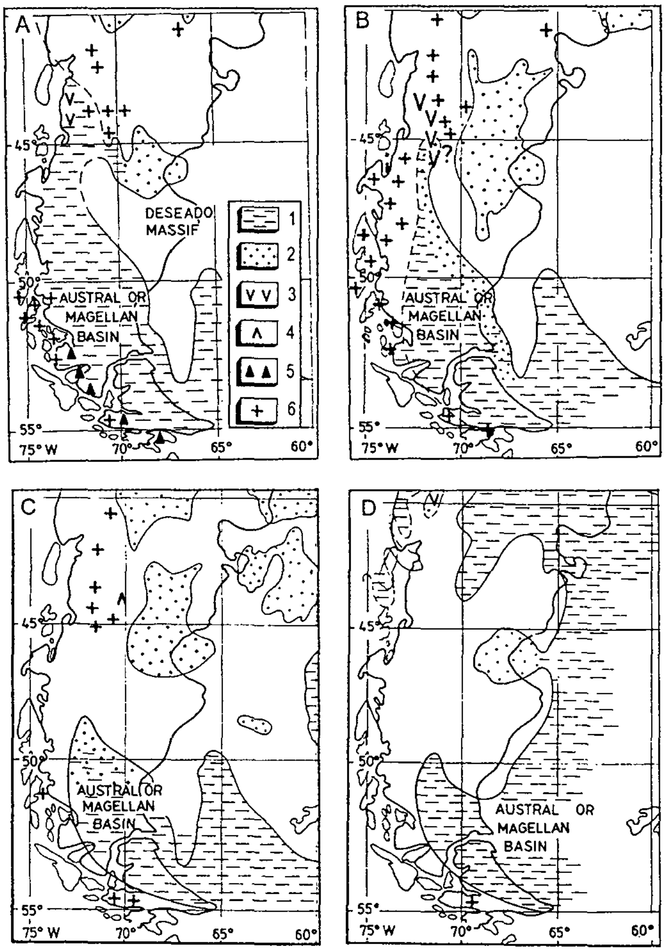

Fig. 3. Paleogeographic maps of southern South America for Cretaceous time; (A) Berriasian-Hauterivian, (B) Barremian-Cenomanian, (C) Turonian-Campanian, and (D) Maastrichtian. 1, Marine facies; 2, Continental facies; 3, Andesitic rocks; 4, Basaltic rocks; 5, Ophiolites; 6, Granitic rocks.

Triassic ? to Late Jurassic

The Tobifera Formation has a thin sedimentary sequence consisting of non-marine volcaniclastic sedimentary rocks. The main part of volcanic unit is highly variable, and consists of well-bedded tuff and sub-wave base mass flow deposits, flow-banded and massive rhyolite, scoriaceous flows, and very coarse-grained breccias. This formation overlies Paleozoic basement in large area of the Magellan Basin and is interpreted to be associated with the last stage of a Triassic to Jurassic extensional events (Bruhn *et al.* 1978). Within the Magellan Basin, these rocks are absent on some basement highs and can be over 2 km thick in intervening lows.

Tithonian-Hauterivian (Late Jurassic-Early Cretaceous)

Late Jurassic subsidence in the Rocas Verdes marginal basin (now, Magellan Basin) was followed by marine transgression and resulted in continued sedimentation throughout Cretaceous (Fig. 3A). The Springhill Formation deposited within the Rocas Verdes marginal basin during Tithonian-Berriasian

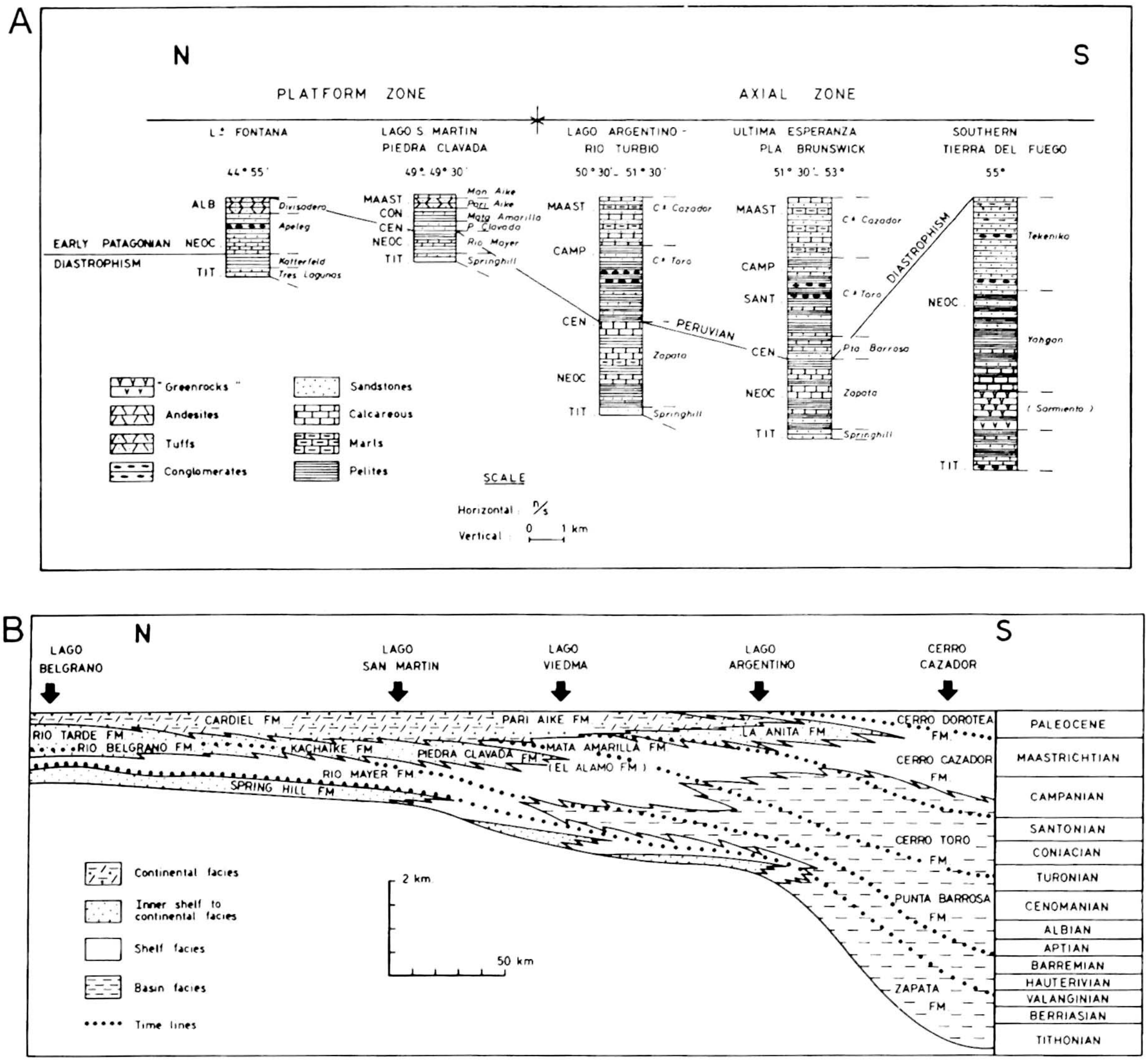

Fig. 4. Comparative stratigraphic section (A) and relation in the Cretaceous rocks of southern Patagonia (B).

time (Riccardi 1977). This formation disconformably overlies the Tobifera Formation and is generally restricted to the depressions of its irregular surface. The Springhill Formation displays retrogradational sedimentary sequence. The lower Springhill mainly consists of fluvial-deltaic sandstones, whereas the upper Springhill consists of shallow marine facies (Pittion and Gouadain 1992). This formation is regarded as main reservoir rock for hydrocarbon deposits in the Magellan Basin. It is variable in thickness from 0 to 150m, with an average of 30 to 40 m (Riccardi 1988). Locally, the basal part or even the entire formation may be missing (Fig. 4).

From the Berriasian time, the Zapata Formation, which includes marine pelites, siltstones, and turbidites, began to deposit in the submarine slope of the southwest marginal basin (Fig. 4). This formation grades laterally and southward into the Yahgan Formation, which were deposited close to the rear flank of the volcanic arc (Fig. 4). The Yahgan Formation consists of more than 3,000 m of alternating volcaniclastic turbidites and shales with intercalations of some chert and intermediate pyroclastic rocks. Toward the north, this Early Cretaceous sequence is more calcareous and fossiliferous, and has been described as the Rio Mayer Formation (Fig. 4). This sequence grades eastward into shallow marine and continental brown sandstones of the Apeleg Formation, which contains some pyroclastic and marine sediments. In the northern extreme of the Magellan Basin, this rock was named as the Katterfeld or Coyhaique Formations. These formations are regarded as main source rocks for hydrocarbon deposits in the Magellan Basin.

Barremian-Cenomanian (late Early Cretaceous)

In Barremian time, the magmatic arc of the Andean Basin (Fig. 3B) migrated eastward by probable increasing of plate motion rate (Ramos 1986). This migration was coincident with a lowstand of sea level in marginal basin (Fig. 2). During this time, a regressive sedimentary regime began in the southern South America with deposition of near-shore to continental sediments to the north of the Magellan Basin (Fig. 3B).

The Zapata Mayer Formation continuously deposited in southern part of the Magellan Basin (Figs 2, 4). In the northern part, the Rio Mayer Formation is conformably overlain by 70 to 300 m of shallow marine to continental whitish, greenish and yellowish sandstones with intercalated conglomerates, the Rio Belgrano, Rio Tarde, Kachaike, and Piedra Clavada Formations (Fig. 4). Strong magmatism including acid volcanics and plutonic intrusives was followed in north of the basin, producing the Divisadero Formation (Fig. 4). From the Late Albian time, marginal basin began to close below of 50°S and basinal axis migrated northeastward by some uplift (Bruhn and Dalziel 1977). Flysch-like deposits, the Punta Barrosa Formation, were formed as a byproduct of the uplift of the 'Paleo-Andes' to the west (Fig. 4). These deposits have been considered as the first evidence of the foreland basin stage of the Magellan Basin (Wilson and Dalziel 1983).

Turonian-Campanian (Late Cretaceous)

Deformation and uplift within the Andean Cordillera to the west caused deepening of the Magellan Basin. As a result, regressive near shore to continental sedimentation continued in the north, whereas marine sedimentation was continuous in the southern part of the basin (Fig. 3C). The main regression pattern was punctuated by at least two short-lived transgressions associated with sea-level rises probably Cenomanian-Turonian and Coniacian-Santonian ages (Fig. 2).

In the southwest, the Punta Barrosa Formation continuously deposited until Coniacian time and was composed of 250 to 400 m of alternating coarse-grained sandstones and shales. This formation grades eastward and upward into a flysch-like sequence, the Cerro Toro Formation, consisting of 2,000 m of dark pelites which commonly exhibit rhythmic alterations with thin bedded and fine-grained psammites (Fig. 4). The Cerro Toro Formation is thinning toward north and interfingerring with the Piedra Clavada, Mata Amarilla, and El Alamo Formations (Fig. 4).

Maastrichtian (late Late Cretaceous)

Marine sedimentation, largely represented by retrogradational sedimentary units, became restricted to the southern area during Maastrichtian time (Fig. 3D). Sediments were mainly derived from the south, west, and northwest, and display a progressive onlap geometry from west to east (Biddle *et al.* 1986).

The La Anita Formation deposited in the south of Lago Argentino (Fig. 4). This formation consists of yellowish and greenish marine sandstones with 350 to 1,200 m thickness. The La Anita Formation grades southward into the Cerro Cazador Formation (Fig. 4).

Paleocene

Two formations, the Cerro Dorotea and Chorrillo Chico Formations, were deposited in the Magellan Basin during Paleocene time. The Cerro Dorotea Formation is composed of grayish, greenish, and brownish shallow marine sandstones with intercalated conglomerates, which grades upward into continental beds with some coal seams. The Chorrillo Formation is composed of deep water sediments and distributed in the western part of the Magellan Basin. The Paleocene sequence forms a NW-trending sedimentary wedge which narrows to the SE and attains a maximum thickness in excess of 700 m (Fig. 5A). It displays limited areal extent confining northeast part of the basin.

Middle Eocene-Early Oligocene

Four formations, the Ballena, Tres Brazos, Lena

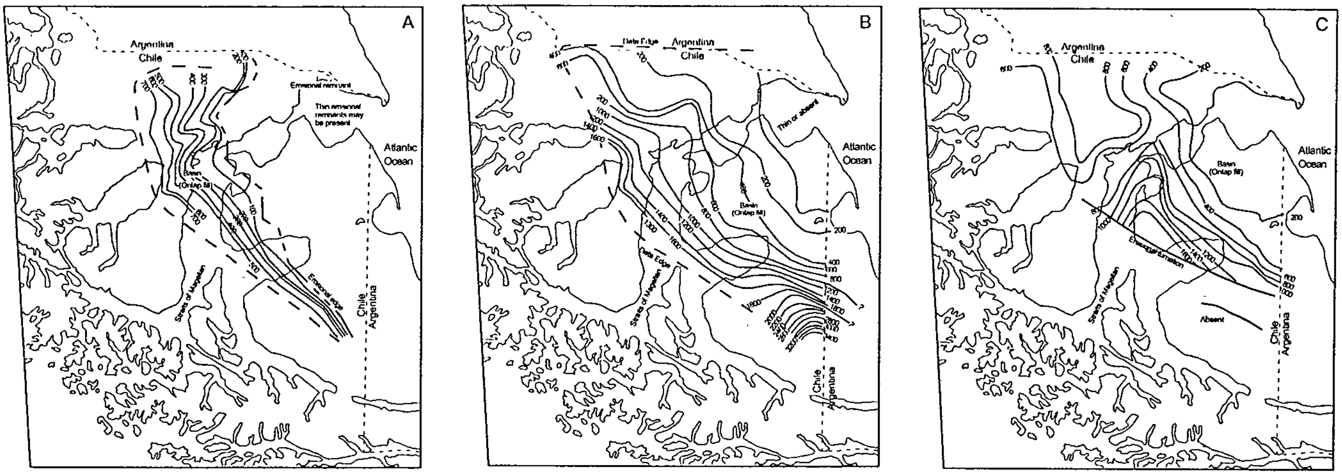

Fig. 5. Thickness of upper Mesozoic and Tertiary rocks in the Magellan Basin; (A) Late Cretaceous (Maastrichtian)-Early Paleocene (Danian), (B) Middle Eocene-Early Oligocene, and (C) Early Oligocene-Early Miocene.

Dura, and Zona Glauconitica Formations, were deposited in fan-delta environment. This sequence has a NW depositional strike (Fig. 5B). Thickness of this sequence increases gradually westward and rapidly southward in the Magellan Basin (Fig. 5B). It also display confining distribution limited to the northeast of basin. The Ballena Formation consists of fairly thick, up to 3,600 m, coarse-grained clastic rocks in southern Tierra del Fuego area, and is interpreted to be deposited in fan-delta environment. The sediment was derived from an area of high relief to the south. To the east and north of the Magellan Basin, where the thickness is thin, glauconitic sandstone known as the Zona Glauconitica Formation was distributed. Glauconitic sandstone reflects low sedimentation rate and long periods of near starvation of sediment.

Oligocene

The lower Loreto Formation was deposited in the Magellan Basin during Oligocene time. This formation forms a silty and sandy, shallowing-upward succession. It displays NW-trending wedge that thickens rapidly to the west and southwest and extends farther to the east than the older Tertiary units (Fig. 5C). To the west and south, this sequence has been extensively eroded.

Post-Oligocene

By the end of the Oligocene, deposition occurred once again basinwide in the Magellan Basin. The post-Oligocene rocks include the upper Loreto, Pampa Larga, and Magellan Inferior Formations in Chile and the Patagoniano Formation in Argentina. These units were commonly derived from the Andes to the west and south of the basin, but some came from the Deseado area to the northeast.

Magmatism: The Patagonian Batholith

One of the largest circum-Pacific batholiths is the Patagonian batholith in the southern Andes. The batholith exposes for 1,500 km along the continental margin from 41°S to 56°S. It displays a continuous curvilinear belt with 50 to 150 km wide (Fig. 1).

Lithology

The Patagonian batholith comprises typical spectrum of calc-alkaline and calcic plutonic rocks (Nelson *et al.* 1985; Bruce *et al.* 1986). Two kinds of plutonic rocks, mafic and intermediate rocks, make up the majority of the batholith. Mafic rock includes gabbro-norite, gabbro, and hornblende diorite. Intermediate rock includes hornblende-quartz diorite and biotite-hornblende tonalite. Biotite granodiorite and granite commonly comprise felsic rock, but some leucocratic granite and hypabyssal microgranite also present. Mafic xenoliths are common but not ubiquitous, and mafic dikes or irregular aphanitic bodies intrude all but the most felsic plutons. Both syn- and post-plutonic mafic dikes are present and comprise up 5 to 35% in volume within most plutons. Cross-cutting relation indicates mafic plutons, excluding dike rocks, are always older than felsic ones.

Field, petrographic, and geobarometric data of plutonic rocks from the Patagonian batholith indicate that grain size roughly reflects crystallization depth. Within Xaultegua area (Fig. 1), the youngest plutonic rocks are fine-grained granite and rhyolite; both contain miarolitic cavities indicating crystallization at very shallow depth (Bruce *et al.* 1989). Immediately older rocks are more mafic, medium-grained granodiorite, tonalite, and quartz diorite that crystallized below the epizonal environment. Medium- to very coarse-grained diorite and gabbro comprise the oldest rocks in this region. Their grain sizes indicate much deeper crystallizing depth compared to tonalite, granodiorite, granite and rhyolite.

Some of the oldest rocks contain euhedral, magmatic epidote in equilibrium with unaltered hornblende and biotite. This assemblage is interpreted to be formed from crystallization at pressures between 6 and 8 kbar using the criteria established by Zen and Hammarstrom (1984), corresponding to depths between 18 and 24 km (Bruce *et al.* 1989). These features represent decreasing trend of crystallization depth recorded in successively younger and more felsic plutons.

Emplacement age

Widely scattered ages of the Patagonian batholith (Halpern 1973; Halpern and Fuenzalida 1978; Herve *et al.* 1981; Bruce *et al.* 1986) suggest that magmatism occurred semi-continuously from about 166 to 12 Ma, with a peak occurring between 100 and 70 Ma (Fig. 6). Emplacement ages acquired from individual area, however, display discontinuous and narrow ranges compared with those of entire batholith (Weaver *et al.* 1990). This may reflect sampling bias or episodic plutonism between different areas within the batholith. Bruce *et al.* (1989) suggested that different age spectra between other areas were caused by an artifact of different uplift, and that plutonism was indeed semi-continuous throughout the evolution of batholith.

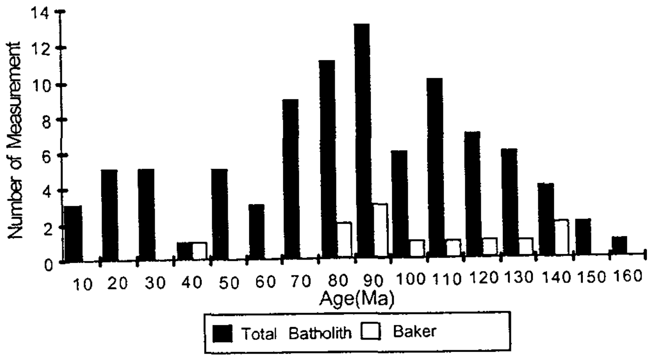

Fig. 6. Age histogram for the Patagonian batholith.

In Baker area (Fig. 1), there is no regular unidirectional migration of plutonism with time (Weaver *et al.* 1990). The oldest plutons are observed in the eastern margin of that area, whereas the next oldest plutons are concentrated in the western part. More younger plutons scattered in the central and eastern zones without any trend. The trend getting older toward both margins represents either the plutons were emplaced in extensional regime or younger plutons intruded into the main mass of the Patagonian batholith pushing away the older plutons from main locus of magmatism.

Geochemistry

The plutonic rocks of the Patagonian batholith are classified into two major rock series using the modal abundances (Lameyre and Bowden 1982). They are low-K calc-alkaline tonalitic series (CAT) and normal-K calc-alkaline granodioritic series (CAG). The CAT series mainly consists of tonalite and leucotonalite with no or little amount of K-feldspar. In contrast, CAG series contains substantial K-feldspar and comprises granite, granodiorite, and quartz monzodiorite. Existence of two different rock series represents the presence of two distinct primary magma groups.

Gabbro and most of the CAT series rocks are regarded as metaluminous, whereas two-mica granite and CAG series rocks are peraluminous according to the aluminous index (AI). Strongly peraluminous two-mica, garnet-bearing granites are considered as S-type ones produced by partial melting of

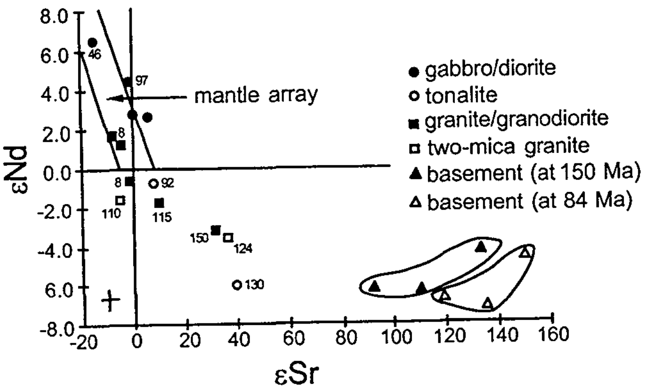

Fig. 7. εSr-εNd diagram for granitic rocks of the Baker area in the Patagonian batholith. The ages in million years are indicated. Values for three basement samples have been plotted for 150 and 84 Ma. Typical uncertainties are shown in the lower left.

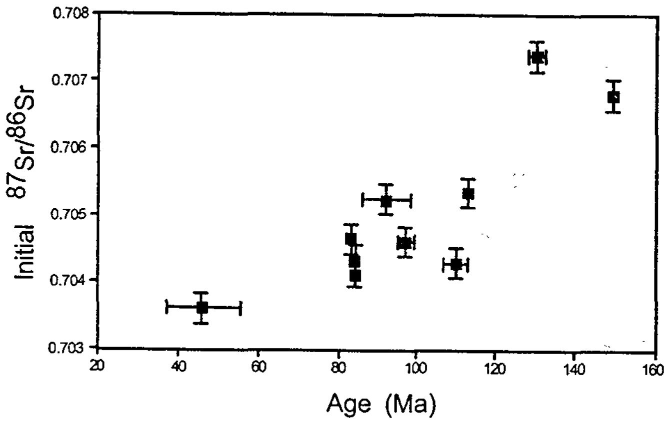

Fig. 8. Plot of initial $^{87}Sr/^{86}Sr$ ratio versus age for granitic rocks of the Baker area in the Patagonian batholith.

aluminous sedimentary rocks. CAT series rocks always contain small amount of large ion lithophile (LIL) elements, such as K, Rb, and Ba, compared with CAG series. More CaO, FeO, MgO, and TiO_2 are contained in CAT series rocks, whereas CAG series rocks contain more Zr. Major element chemistry of two-mica granite alike with that of the evolved CAG series granite. Wide scattering character of gabbro on the most variation diagrams represents its probable cumulate nature.

Initial Sr and Nd isotope values of the Patagonian batholith and basement are plotted on εSr-εNd diagram (Weaver *et al.* 1990; Fig. 7). The values for batholith define a curvilinear array ranging from εNd = 6 to –6 and εSr = –14 to 40. Positive εNd and negative εSr values of gabbro and diorite indicate depleted mantle-derived component involved in development of mafic rocks. Most of the intermediate to felsic granites have negative εNd and positive εSr values. These values represent the influence of ancient continental crust for their isotopic characteristics. Sr and Nd isotopic values from individual plutons indicate that the Patagonian batholith in the Baker area was formed by mentle-derived magma interacted with some crust-derived component.

Distinct correlation exists in the relation of age and strontium isotopic values between each pluton in the Baker area (Weaver *et al.* 1990; Fig. 8). Initial $^{87}Sr/^{86}Sr$ value decreases toward younger rock regardless of its lithology and composition. This trend represents that the amount of crustal component, or the degree of crustal contamination, has decreased throughout the evolution of the Patagonian batholith in the Baker area. The apparent decreasing of contamination may be related with the process that basement dried out by continuous dehydration and became more refractory during evolution.

Tectonic and Metamorphic Evolution: The Cordillera Drawin Metamorphic Complex

The Cordillera Darwin (Fig. 1) is the only known exposure of upper amphibolite-facies rocks that were metamorphosed during Mesozoic-Cenozoic time in the Andes, south of the equator (Darwin 1839, 1846; Kranck 1932; Nelson *et al.* 1980; Dalziel 1981; Dalziel and Brown 1989; Klepeis 1994). The metamorphic complex distributed in this province records lots of evidence that tell about tectonic and metamorphic evolution of the southern South America.

Lithology

The Cordillera Darwin metamorphic complex comprises five units; the Basement complex, the Darwin granite, the Tobifera Formation, the Yahgan Formation and the Beagle granite in ascending order (Fig. 9). The Basement complex exposed in the center of the Cordillera Darwin. This complex mainly

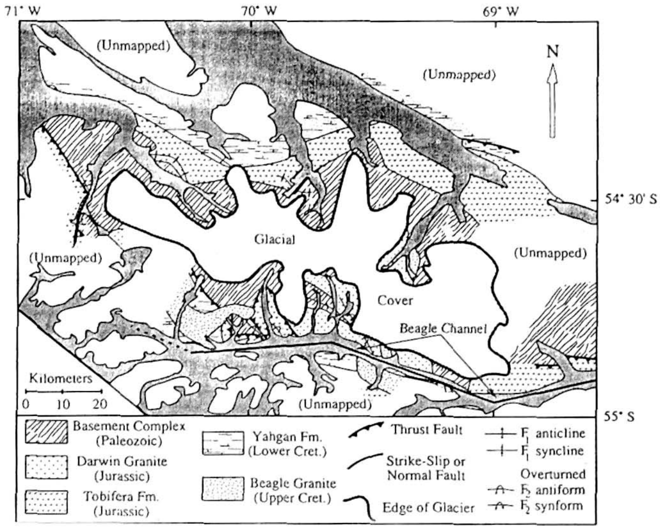

Fig. 9. Geologic map of Cordillera Darwin with major rock units and structures (adapted from Kohn *et al* 1993).

consists of phyllite and schist, but small amount of gneiss and migmatite also distributed in high metamorphic grade areas. Metapelitic rock has the mineral assemblage of staurolite, andalusite, kyanite and sillimanite, whereas garnet and amphibole are prominent in amphibolite. The Darwin granite suite, the felsic orthogneisses, exposed in the central and southern part of the Cordillera Darwin. The orthogneiss comprises biotite granite and granodiorite and is weakly foliated to nearly mylonitic. The Tobifera and Yahgan Formations unconformably overly these metamorphic core, but now crop out only in the northern part of the Cordillera Darwin. The Beagle granite suite, largely undeformed I-type plutonic rocks, intruded in the early Late Cretaceous time. This suite comprises biotite-hornblende tonalites and granodiorites.

Deformation

Four generations of deformation structure (D_B, D_1, D_2 and D_3) are recognized in the Cordillera Darwin (Nelson *et al.* 1980). The earliest (D_B) structure is restricted to the Basement complex, whereas the others (D_1, D_2, and D_3) are preserved in both basement and cover rocks.

Most of D_B structural element were obscured by following pervasive early Andean deformation and just a few pre-D_1 isoclinal folding and secondary vein-like quartz layers are observed in basement rock (Dalziel *et al.* 1989). Two main phases of Andean deformation (D_1 and D_2) occurred by obduction of ophiolitic floor of the Rocas Verdes Basin onto passive continental margin during the closure of marginal basin (Nelson *et al.* 1980; Dalziel and Brown 1989). D_1 and D_2 reactivated the basement and deformed the cover rock for the first time. D_1 is characterized by continent-vergent thrust faulting, isoclinal folding and pervasive foliation development (Nelson *et al.* 1980). D_2 produced large backfolds with Pacific-ward vergence. Prograde metamorphism in pelitic rock primarily occurred during D_2 but some of the prograde metamorphism probably occurred during D_1 as well (Nelson *et al.* 1980; Dalziel and Brown 1989; Kohn *et al.* 1993). D_3 formed crenulation cleavage in metamorphic rocks both cover rock and reactivated basement (Nelson *et al.* 1980).

Metamorphism

Although the highest grade metamorphic rocks occurred within Basement complex (Paleozoic), some lines of evidence represent late metamorphism after deposition of the Mesozoic cover rocks. No difference in metamorphic grade observed across the unconformable contact between basement and cover rock. The timing of prograde metamorphism observed in basement pelitic rocks is coincident with the D_1 and D_2 (Nelson *et al.* 1980; Dalziel *et al.* 1989; Kohn *et al.* 1993).

Metamorphic grade rapidly increases from biotite-chlorite to garnet-sillimanite grade within 10-20 km (Fig. 10). The P-T conditions of garnet- and sillimanite-zone range from 5-7 kbar and 525-550°C, to 7-9 kbar and 625-650°C in the north of the Beagle Channel (Kohn *et al.* 1993). Mineral assemblage of biotite-chlorite zone to the south of the Beagle Channel is difficult to measure the quantitative P-T conditions, but it will be much lower than high-grade metamorphic zone. Abrupt change of metamorphic grade within short distance may be caused by differential exhumation of the Cordillera Darwin. The high-grade metamorphic core underwent more exhumation compared with low-grade metamorphic

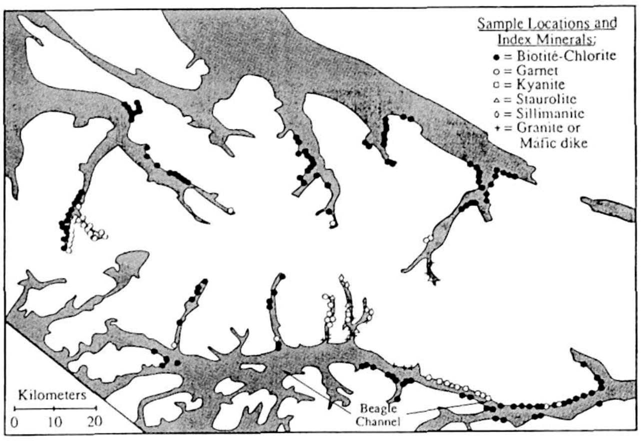

Fig. 10. Map showing the distribution of index metamorphic minerals (adapted from Kohn *et al.* 1993).

margin. Other tectonic evidence, however, suggested the presence of detachment fault along the Beagle Channel.

The P-T path of zoned garnet porphyroblasts indicates most garnet porphyroblast growing under metamorphic conditions of slight to moderate increasing in pressure (0.2-3 kbar) and great increasing in temperature (50-100°C) (Kohn *et al.* 1993). Two different mechanisms were suggested for this change. Nelson *et al.* (1980) suggested that prograde metamorphism of pelitic rock occurred by crustal thickening during thrusting (D_1) and back-folding (D_2). Dalziel & Brown (1989), however, interpreted that exhumation of metamorphic core complex caused changes in P-T condition during extensional normal faulting and shearing. Extensional faulting is also supported by discontinuity in metamorphic grade and estimated peak temperature across the Beagle Channel (Kohn *et al.* 1993).

Estimated K-Ar and ^{40}Ar/^{39}Ar ages for hornblende, muscovite and biotite within high-grade metamorphic and intrusive rocks in southern Cordillera Darwin ranging from 80 to 65 Ma (Halpern 1973; Herve *et al.* 1979; Grunow *et al.* 1992). Kohn *et al.* (1995) reported 86 to 65 Ma for ^{40}Ar/^{39}Ar cooling ages, which vary according to mineral separates and metamorphic grade. High-grade metamorphic rocks are generally younger than low-grade ones. The series of ^{40}Ar/^{39}Ar cooling ages suggested two periods of rapid cooling and differential exhumation of the Cordillera Darwin metamorphic complex (Kohn *et al.* 1995).

Tectonic Evolution

Various tectonic models were suggested for explaining the tectonic evolution of Cordilleran Darwin (Dalziel and Brown 1989; Klepeis 1994; Kohn *et al.* 1995). Dalziel & Brown (1989) suggested that the metamorphic complex rapidly uplifted through extensional unroofing of Mesozoic cover rocks along a detachment fault located beneath the Beagle Channel. During the latest Cretaceous and Tertiary, changes in far-field stresses resulted in development of the Patagonian orocline and core-complex-style exhumation of Cordillera Darwin. The tectonic regime shifted from transgression to regression by changing of plate motion, and led to local extension at the southern bend of the Andes. This model has advantage for explaining the restricted occurrence of high grade metamorphic rock in Cordillera Darwin. It is not adequate, however, for explaining the major foliation everywhere has a southern dip (Nelson *et al.* 1980) and has no principal evidence for extension is only along the southern margin of the complex (Dalziel and Brown 1989; Moore 1990).

Klepeis (1994) insisted on the importance of thrust faulting, instead of simple extension, for explaining the isolated occurrence of upper amphibolite-facies metamorphic rocks in Cordillera Darwin. The geometry of structural features observed at the surface and their sequence of deformation indicate that basement schists exposed along the northeastern edge of Cordillera Darwin uplifted along a discrete, brittle and continent-vergent thrust fault. This thrust overlies a series of thin-skinned thrusts and back thrusts that affect Mesozoic-Tertiary rocks of the Magellan foreland basin. This model provides more adequate answer for the features that could not be explained by simple extension model (Dalziel and Brown 1989).

The P-T-t history of the Cordillera Darwin metamorphic complex suggested 'wedge extrusion tectonic model' for explaining metamorphic evolution in this region (Kohn *et al.* 1995). Extensional exhumation in the southern rear of the metamorphic complex was coeval with thrusting in the north, along the margin of the complex and into the Magellan sedimentary basin (Klepeis 1994). The differential exhumation of metamorphic complex occurred initially, with staurolite-grade rocks exhuming faster than kyanite + sillimanite-grade rocks. Variations in cooling rate of metamorphic rocks through time correlate both with local deformation events (Klepeis 1994) and with changes in plate motions and interactions (Dalziel and Brown 1989). This combined mechanism resulted in metamorphic discontinuity across northwest arm of the Beagle Channel.

Mineralization: The Chilean Patagonia

Andean belt of the South America is one of the world's major mineral districts. The Republic of Chile has produced gold mainly in placer-type mines for several hundred of years from the beginning of Incas (Cuadra and Dunkerley 1991). After arrival of the Spaniards in 16th century, gold mining became a priority and reached its peak in the early 20th century. From then, mining trend was changed and copper mining became major product of Chile. World-class Andes underground porphyry mine was widely developed in northern and central Chile (e.g., El Teniente, Andina, El Salvador). However, mineral exploration of the Chilean Patagonia has been neglected by worse weather, thick vegetation cover, and poor infrastructure.

Produced and prospected metal deposits

Except a few maps published until now display no ore deposits in Chile below 40°S, whereas tectonic evolution of Patagonia represents its great potential for major mineralizations (Nelson 1996). Several resources were actually reported in this region (Ruiz 1965; Frutos and Pincheira 1986). These include stratiform Zn-Pb deposit in Toqui district (Wellmer *et al.* 1983), epithermal Au-Ag deposit in Fachinal district (Thomas 1973; Arias 1985), massive sulfide deposits in Tierra del Fuego (Anonymous 1994), and gold placer deposits in Chiloe and Tierra del Fuego (Frutos and Pincheira 1986; Emparan and Portigliati 1985; Heylmun 1993). Recently prospected ore deposits were found in El Faldeo district (Lahsen *et al.* 1994).

Placer golds are actively mining deposit in Chilean Patagonia. Discoveries of placer gold deposit were made on several islands of Tierra del Fuego area from 1868 (Fig. 1) and nearly 100 kg/month of gold were produced from 134 mines in 1883 (Martinic 1982). Mining was done from both river gravel and marine beach sediments, and the latter is small, rich, and transitory (Cuadra and Dunkerley 1991). The gold mainly originated from reworking of auriferous glacial deposits. It disposed wide area but large concentration never found (Uribe 1982).

The El Faldeo polymetallic district is developed in recent back-arc area, where situated 100 km east from the axis of Patagonian Andes (Fig. 11). Mineralization occurred in dacitic, rhyolitic tuffs and epizonal intrusions. This district comprises early epithermal gold mineralization (0.2-3.5 ppm Au) and late mesothermal Zn mineralization (2-8 wt.% Zn).

The mineralization and hydrothermal alteration of the El Faldeo district evolved through four distinct hypogenic stages. Stockwork and sulfide dissemination are recognized in mid-Jurassic intrusive and volcanic rocks of the Ibanez Formation around 12 km^2. The first hypogenic stage is characterized by propylitic replacement of primary mineral associations and disseminated mineralization of pyrite. The second stage gave rise to silicic alteration and to dissemination. Veinlets of pyrite, arsenopyrite and gold were formed under epithermal conditions (140-170°C) during this stage (Palacios *et al.* 1996). The third superposes the second stage during 142±6 Ma estimated by K-Ar analysis of whole rock (Palacios *et al.* 1996). It includes brecciation, stockwork formation and mineral dissemination, which associated with a quartz-sericite-calcite alteration and pyrite, sphalerite, Ag-rich galena and mesothermal (250-330°C) gold mineralization. The mineralized body formed during the third stage displays both stratiform and irregular shapes. The last stage mainly affected on the intrusive rock. Quartz, calcite, barite,

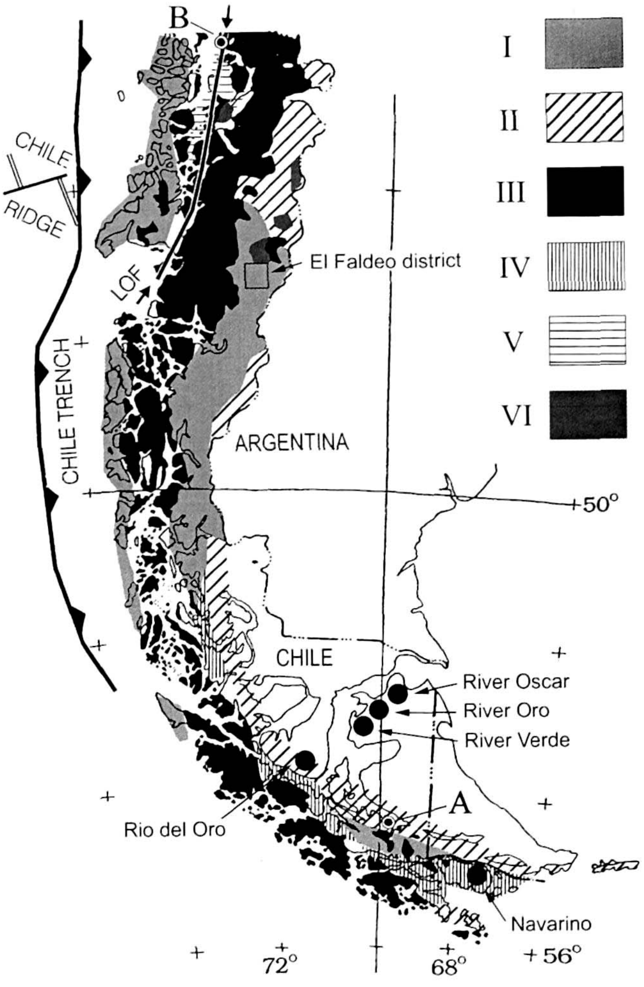

Fig. 11. Metallo-tectonic terranes of Chilean Patagonia. See Table 1 for explanation of terranes. Filled circles are placer gold deposits.

pyrite and chalcopyrite filled the open space during this stage. Supergenic alteration, which forming kaolinite, jarosite and limonite, partially overprints former hypogenic mineral assemblages.

The fluid inclusion thermometry indicates maximum depths of 100 to 800 m for the second and third hypogenic stages (Palacios *et al.* 1996). Such overprinting of higher P, T mineralization stage upon lower P, T mineralization stage could be the result of telescoping, which caused by combination of simultaneous subsidence-filling of the basin, magma emplacement and mineralization. Thickening of sedimentary sequence progressively releases high volatile pressure and increases rupture of host rock in the mineralization-hydrothermal alteration system. As a result, veinlets and hydraulic brecciations occurred during the first and third hypogenic stages (Parada *et al.* 1997).

Metallo-tectonic terranes

Six metallo-tectonic terranes were recognized in Chilean Patagonia for exploration design (Nelson 1996; Fig. 11). This regime was suggested by association of mineral resources, which similar with suggested tectono-stratigraphic terranes (Coney *et al.* 1980; Howell *et al.* 1985). Metallo-tectonic terranes are mostly developed in place related with subduction process. Each terrane was shown in Figure 1 and its characteristics with predicted deposit type were also shown in Tables 1 and 2. This classification system has a lot of advantage to design exploration programs for certain deposit types. For example, altered, pyritic Jurassic rhyolitic rock exposed over 30 km within Cordillera Darwin (A in Fig. 11). Although there is no detailed information about overlying volcaniclastic sequence (the Tobifera Formation), the geology of rhyolitic rock suggested Kuroko-type setting (deposit type 2c) and regarded as possible target for exploration (Nelson 1996). Within terrane V in Liancaque area (B in Fig. 11), sheared felsic and mafic volcanic rocks are developed in association with fuchsite-ankerite alteration. This association indicates of lode Au deposits (deposit type 2d) and suggests probable target for exploration of Liquine-Ofiqui fault zone (Fig. 11) regardless of poor investigation.

Mineral potential

The paucity of ore deposits in Chilean Patagonia is closely related with the history of tectonic evolution in this area. The degree of erosion, which increases toward the south, may be the most important factor for deficit of ore deposits in southern South America. Most epithermal system in Cretaceous Patagonian batholith, which regarded as most probable host rock, deeply eroded by continued subduction of young oceanic crust from the south over past 14 Ma or so (Cande *et al.* 1987; DeLong and Fox 1977). The Jurassic and Cretaceous volcanic and subvolcanic rocks in less eroded back-arc region, however, contain lots of epithermal systems which are evidence of extensive mineralization. Existence

Table 1. Classification of ore deposits in Suprasubduction Setting (from Nelson 1996)

Forearc related ore deposits	
1a	Accreted oceanic terranes: Cypulus-type exhalative deposits, distal exhalative Mn, ophiolite-related podiform Cr and Ni laterites
1b	Epithermal Au, Hg veins, and Sn-W-Cu veins and skarns associated with intrusions
Magmatic arc related ore deposits	
2a	Epizonal calc-alkarine systems (Cu, Mo, Au*, ±Pb, Zn, Ag), including porphyry and related breccia pipes, epithemal veins and hot springs, skarns, and mantos
2b	Batholith-related system (Pegmatites, granitic U)
2c*	Kuroko-type exhalative deposits in submarine intra-arc basins
2d	Lode gold, shear zone associated
2e	Massive magnetite
Back arc related ore deposits	
3a	Alkaline igneous systems (e.g., Au-tellurides, Mo-porphyries, and other lithophile suites)
3b	Tin-tungsten system (porphyries, veins, pipes, skarns, greisens)
3c	Disseminated sediments-hosted Au (Carlin-type)
3d*	Besshi-type exhalative deposits in backarc basins
3e	Metamorphic core complex (detachment-hosted)

*= island arc affinity, otherwise Andean affinity

Table 2. Metallo-tectonic terranes in the Southernmost Andes. Deposit types in Table 1(from Nelson 1996).

Region	Terrane description	Deposit types
I	Late Paleozoic-early Mesozoic accreted forearc terrane (include Quarternary ridge-collision related rocks)	1a, 1b, 2c?, 3d?
II	Triassic?-Jurassic volcano-tectonic rift terrane(bimodal volcanics), and Jurassic-Cretaceous volcanic-sedimentary intra-arc and backarc terranes (includes early Cretaceous shale basin south of 49°S)	2a, 2c, 3a, 3b, 3c, 3d?, 3e
III	Jurassic to early Tertiary Patagonian batholith and volcanic roof pendants	2a, 2b, 2c, 3c
IV	Mesozoic marginal basin terrane: ophiolites and volcanic clastic flysch	1a, 2c?, 3d
V	Tertiary intra-arc transtensional basins: mafic pillow lavas, ultramafics (includes sheared rocks along Liquine-Ofqui fault zone)	1a, 2c, 2d, 3d
VI	Tertiary-Recent volcanic arc	2a, 2e?

of large Tertiary epithermal deposits in western Pacific magmatic arcs also represents possible development of younger deposits without older basement (Moyle *et al.* 1990; Anderson and Eaton 1990; Clark 1990). These lines of evidence indicate great potential for further exploration in Chilean Patagonia area regardless of a few developed ore deposits below 42°S.

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References

Anderson W.B. and Eaton P.C. 1990. Gold mineralization at the Emperor Mine, Vatukoula, Fiji. In: Hedenquist J.W., White N.C., and Siddeley G. (eds), *Epithermal gold mineralization of the circum-Pacific*. Association of exploration geochemists special publication **16b:** 267-296.

Anonymous. 1994. Exploration efforts pick up steam in Argentina camp. *Northern Miner*. **80:** 11.

Arias J. 1985. Exploracion geoquimica en los fiordos del Seno de Otway (XII region, Chile). *IV Congress Geol. Chileno*. **3:** 452-478.

Biddle K.T., Uliana M.A., Mitchum R.M., Fitzgerald, M.R., and Wright R.C. 1986. The stratigraphic and structural evolution of the central and eastern Magellanes basin, southern South America. *In:* Allen P.A. and Homewood P. (*eds*), *Foreland Basins*. International Association of Sedimentologists Special Publication 8: 41-61.

Bruce R.M., Nelson E.P., and Weaver S.G. 1989. Effects of synchronous uplift and intrusion during magmatic arc construction. *Tectonophy*. **161:** 317-329.

Bruce R.M., Nelson E.P., Weaver S.G., and Lux D.R. 1986. Geochronology and petrology of the Patagonian batholith: Implications for magma genesis and arc evolution. *Am. Geophys. Union Abstr.* **67:** 412.

Bruhn R.L., Stern C.R., and DeWit M.J. 1978. Field and geochemical data bearing on the development of a Mesozoic volcano-tectonic rift zone and back-arc basin in southernmost South America. *Earth Planet. Sci. Lett.* **41:** 32-46.

Bruhn R.L. and Dalziel I.W.D. 1977. Destruction of the Early Cretaceous marginal basin in the Andes of Tierra del Fuego. *In:* Talwani M. and Pittman W.C. (eds), *Island arcs, deep sea trenches and back-arc basins*. Maurice Ewing Series 1, Am. Geophys. Union. pp. 395-405.

Cande S., Leslie R.B., Parra J.C., and Hobart M. 1987. Interaction between the Chile Ridge and Chile Trench: Geophysical and geochemical evidence. *Geophys. Res.* **92:** 495-520.

Clark G.H. 1990. Panguna copper-gold deposit. *In:* Hughes F.E. (*ed.*), *Geology of the mineral deposits of Australia and Papua New Guinea*. The Austrian Institute of Mining and Metallurgy. pp. 1807-1816.

Coney P.J., Jones D.L., and Monger J.W.H. 1980. Cordilleran suspect terranes. *Nature* **288:** 329-333.

Cuadra W.A. and Dunkerley P.M. 1991. A history of gold in Chile. *Econ. Geol.* **86:** 1155-1173.

Cunningham W.D. 1993. Strike-slip faults in the southernmost Andes and the development of the Patagonian Orocline. *Tectonics* **12:** 169-186.

Cunningham W.D., Dalziel I.W.D., Lee T.-Y., and Lawver L.A. 1995. Southernmost South America-Antarctic Peninsula relative plate motions since 84Ma: Implications for the tectonic evolution of the Scotia Arc region. *Jour. Geophys. Res.* **100:** 8257-8266.

Dalziel I.W.D. 1981. Back-arc extension in the southern Andes: a review and critical reappraisal. *Phil. Trans. Royal Society of London* **A300:** 319-315.

Dalziel I.W.D. and Brown R. 1989. Andean core complex evolution related to marginal basin collapse: implications for Cordilleran tectonics. *Geology* **17:** 699-703.

Dalziel I.W.D. and Palmer F.K. 1979. Progressive deformation and orogenic uplift at the southern extremity of the Andes. *Geol. Soc. Am. Bull.* **90:** 259-280.

Dalziel I.W.D. 1985. Collision and cordilleran orogenesis: an Andean perspective, *In:* Coward M.P. and Ries A.C. (*eds*), *Collision tectonics*. Geol. Soc. London Spec. Publ. **19:** 389-404.

Dalziel I.W.D., Birkenmajer K., Mpodozis C., Ramos V.A., and *Thomson M.R.A. 1989. Tectonics of the Scotia Arc, Antarctica. Field Trip Guidebook T180.* Am. Geophys. Union., Washington, D.C. 206 pp.

Darwin C. 1846. *Geological Note on South America*. London.

Darwin C. 1839. Narrative of the surveying voyages of His Majesty's ships Adventure and Beagle between the years 1826 and 1836, describing their examination of the southern shores of South America, and the Beagle's circumnavigation of the globe. Vol. III. *Journal and Remarks*. pp. 1832-1836.

DeLong S.E. and Fox P.J. 1977. Geological consequences of ridge subduction. *In:* Talwani M. and Pitman W.C. (*eds*), *Island arc, deep sea trenches and back-arc basins*. Maurice Edwing series I. Am. Geophys. Union. pp. 221-228.

Emparan C. and Portigliati C. 1985. Exploracion de placeres auriferous en el area del Rio Queualt, Comuna de Puerto Cisnes, XI region. IV Congreso Geol. *Chileno* **3:** 579-602.

Forsythe R.D. 1982. The Late Paleoxoic to Early Mesozoic evolution of southern South America: a plate tectonic interpretation. *Geol. Soc. London* **139:** 671-682.

Frutos J. and Pincheira M. 1986. Metallogenicas de yacimentos minerales de Chile. *In:* Frutos J., Oyarzun R., and Pincheria M. (*eds*), *Geologia y recursos minerales de Chile*. Univ. Concepcion. pp. 469-487.

Grunow A.M., Dalziel I.W.D., Harrison T.M., and Heizler M.T. 1992. Structural geology and geochronology of subduction complexes along the margin of Gondwanaland: new data from the Antarctic peninsula and southernmost Andes. *Geol. Soc. Am. Bull.* **104:** 1497-1514.

Halpern M. 1973. Regional Geochronology of Chile south of 50 latitude. *Geol. Soc. Am. Bull.* **84:** 2407-2422.

Halpern M. and Fuenzalida R. 1978. Rubidium-strontium geochronology of a transect of the Chilean Andes between latitudes 45° and 46°. *Earth Planet. Sci. Lett.* **41:** 60-66.

Herve F., Nelson E., Kawashita K., and Surez M. 1981. New isotopic ages and the timing of orogenic events in the Cordillera Darwin, southernmost Chilean Andes. *Earth Planet. Sci. Lett.* **55:** 257-265.

Herve F., Nelson E., and Surez M. 1979. Radiometric ages of granitic and metamorphic rocks of the Cordillera Darwin, region XII, Chile. *Rev. Geol. Chile.* **7:** 31-40.

Heylmun E.B. 1993. Gold in Tierra del Fuego. *California Mining*. pp. 40-42.

Howell D.G., Jones D.L., and Schermer E.R. 1985. Tectonostratigraphic terranes of the circum-Pacific region. *In:* Howell D.G. (*ed.*), *Tectonostratigraphic terranes of the circum-Pacific region*. Circum-Pacific Council for Energy and Mineral Resources. *Earth Sci. Ser.* **1:** 3-30.

Kleipeis K.A. 1994. Relationship between uplift of the metamorphic core of the southernmost Andes and shortening in the Magallanes foreland fold and thrust belt, Tierre del Fuego, Chile. *Tectonics* **13:** 882-904.

Kohn M.J., Spear F.S., Harrison T.M., and Dalziel I.W.D. 1995. ^{40}Ar/^{39}Ar geochronology and P-T-t paths from the Cordillera Darwin metamorphic complex, Tierra del Fuego, Chile. *Metm. Geo.* **13:** 251-270.

Kohn M.J., Spear F.S., and Dalziel I.W.D. 1993. Metamorphic P-T paths from Cordillera Darwin, a core complex in Tierra del Fuego, Chile. *Petrol.* **34:** 519-542.

Kranck E.H. 1932. Geological investigation of the Cordillera of Tierra del Fuego. *Acta Geographica Helsingfors.* **4:** 1-231.

Lahsen A., Palacios C, Parada M.A., Sanchez G, Townley B., and Villegas J. 1994. *Exploracion Geoquimica Estrategica en la Region de Aises.* Iternal Report. Departamento de Geologia, Univ. de Chile. 367 pp.

Lameyre J. and Bowden P. 1982. Plutonic rock type series: Discrimination of various granitoid series and related rocks. *Volcanol. Geotherm. Res.* **14:** 169-186.

Ling H.Y., Forsythe R.D., and Douglass R.C. 1985. Late Paleozoic microfaunas from southernmost Chile and their relation to Gondwanaland and forearc development. *Geology* **13:** 357-360.

Martinic M. 1982. *La tierra de Los Fuegos, Punta Arenas, Chile: Santiago, Chile.* Artegraf. pp. 45-108.

Moore T.K. 1990. *A metamorphic and kinematic study of the Cordillera Darwin metamorphic core complex, southwestern Chile.* B.Sc. Thesis. Carleton University.

Moyle A.J., Doyle B.J., Hoogvliet H., and Ware A.R. 1990. Ladolam gold deposit, Lihir Island. *In:* Hughes F.E. (*ed.*), *Geology of the mineral deposits of Australia and Papua New Guinea.* The Australian Institute of Mining and Metallurgy. pp. 1793-1805.

Mpodozis C. and Forsythe R. 1983. Stratigraphy and geochemistry of accreted fragments of the ancestral Pacific floor in southern South America, *Paleogeogr. Paleoclim. Paleoecol.* **41:** 103-124.

Nelson E.P. 1996. Suprasubduction mineralization: Metallotectonic terranes of the southernmost Andes. *In:* Bebout G.E., Scholl D.W., Kirby S.H., and Platt J.H. (*eds*), *Subduction: top to bottom.* Am. Geophys. Union. pp. 315-330.

Nelson E.P., Bruce R.M., Elthon D., Kammer D., and Weaver S.G. 1985. Regional petrologic variations in the Patagonian batholith. *Communications* **35:** 175-176.

Nelson E.P., Dalziel I.W.D., and Milnes, A.G. 1980. Structural geology of the Cordillera Darwin: Collisional style orogenesis in the southernmost Chilean Andes. *Ecol. Geol. Helv.* **73:** 27-51.

Palacios C., Parada M.A., and Lahsen A. 1996. Upper Jurassic Au-Zn mineralization in the El Faldeo district, Chilean Patagonia. *Geol. Rundsch.* **86:** 132-140.

Parada M.A., Palacios C., and Lahsen A. 1997. Jurassic extensional tectono-magmatism and associated mineralization of the El Faldeo polymetallic district, Chilean Patagonia: geochemical and isotopic evidence of crustal contribution. *Mineralium Deposita* **32:** 547-554.

Pittion J.L. and Gouadain J. 1992. *Source-rocks and oil generation in the Austral Basin.* Proceedings of the Thirteenth World Petroleum Congress, Buenos Aires. pp. 113-120.

Ramos V.A. 1986. The tectonics of the Central Andes: 30-33(S latitude. *Geol. Soc. Am. Spec. Paper* 218 pp.

Rapela C.W. and Pankhurst R.J. 1992. The granites of northern Patagonia and the Gastre fault system in relation to the break-up of Gondwana. *In:* Storey B.C., Alabaster T., and Pankhurst R.J. (*eds*), *Magmatism and the causes of continental break-up.* Geol. Soc. London Spec. Publ. **68:** 209-220.

Riccardi A.C. 1977. Berriasian invertebrate fauna from the Springhill Formation of southern Patagonia. *Neues Jahrbuch fur Geologie und Palaontologie, Abhandlungen.* **155:** 216-252.

Riccardi A.C. 1988. *The Cretaceous system of southern South America.* Geol. Soc. Am. Memoir. 168. 145 pp.

Ruiz F.C. 1965. *Geologia y yacimientos metaliferos de Chile.* Inst. Invest. Geologicas, Santiago. 305 pp.

Storey B.C. 1993. Tectonic controls on Gondwana break-up models: Evidence from the Proto-Pacific margin of Antarctica. *Tectonics* **10:** 1274-1288.

Suarez M. 1977. Notas geoquimicas preliminares del batolito Patigonico al sur de Tierra del Fuego, Chile. *Rev. Geol. Chile* **4:** 15-33.

Thomas A. 1973. *Geologia y perspectiva economica des yascimiento polimentalico Cutter-Cove, Provincia de Magallanes.* ENAMI. 15 pp.

Uribe P. 1982. *Yacimientos minerales y fuentes termales de la region de Magallanes, Chile.* Inst. Patagonia, Chile. 17 pp.

Weaver S.G., Bruce R.M, Nelson E.P., Brueckner H.K., and LeHuray A.P. 1990. The Patagonian batholith at 48°S latitude, Chile; Geochemical and isotopic variations. *Geol. Soc. Am. Spec. Paper* **241:** 33-50.

Wellmer F.W., Reeve E.J., Wentzlau E., and Westenberger H. 1983. Geology and ore deposits of the Toqui district, Aysen, Chile. *Econ. Geol.* **78:** 1119-1143.

Wilson T.J. and Dalziel I.W.D. 1983. Geology of the Ultima Esperanza fold-thrust, southernmost Andes. *U.S. Antarct. J., Ann. Rev.* **18:** 75-76.

Zen E. and Hammarstrom J.M. 1984. Magmatic epidote and its petrologic significance. *Geology* **12:** 515-518.

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