

Andes and Lake District are rich in temperate rainforest species that grow at an elevation below 1,400 m.

Deciduous forests grow in semi-alpine to alpine areas and occupy the vegetation line ranging from an elevation of 600 m to Lake District. Conditions suitable for deciduous forests are not only little rainfall but also good draining and a harsh winter season.

The steppe zone hems the eastern side of Cordillera with low vegetation on the whole. This zone, also called pampa, is distributed with slow-growing, hardy bushes. Concentrations of low trees are seen on riverside.

Chapter 3 General geology, ore deposits and mining activities

3-1 General geology

3-1-1 General geology of Argentina

Concerning the geology of the survey area, reference was made mainly to the 1/2,500,000-scale all-Argentina geological map issued by SEGEMAR in 1997 and the 1/1,000,000-scale MAPA de Recursos Minerales del Area Fronteriza Argentina-Chilena entre los 34° y 56°S (Zanettini et al., 1999) issued by SEGEMAR in cooperation with SERNAGEOMIN of Chile in 1999. For the geotectonic evolution, reference was made to the CD-ROM version of the Metallogenic Map of Argentina (Zappettini, 1998) issued by SEGEMAR in 1998. In addition to the above, relatively rich data are available for every province, including the 1/400,000-scale Geologia y Metalogenesis del Orogeno Andino Central (Mendéz et al., 1995) covering the area extending from lat. 32° to 40°S (Appendix-1).

An entire geological terranes map of the South American continent by Zappettini (1998) is shown in Fig. I-3-1. The Argentine territory is considered to be formed by tectono-stratigraphic, allochthonous terranes that were initially separate (e.g., Ramos, 1996). The accretion of these geological terranes and the simultaneous progress of geological phenomena are characterized by extensive tectonic movements due to subduction of ophiolitic rocks, deformation, metamorphism, and the creation of wide tectonic corridors with the development of shear zones. The post-accretional evolution consists of the development of intra-cratonic basins with marine and continental deposits, the creation of intracontinental rifts and the post-collisional and extensional magmatism. It is also characterized by a persistent magmatic arc activities related to the Pacific plate subduction.

Geologically, the Argentine territory can be roughly divided into five terranes: the Rio de la Plata Craton, Pampia, Cuyania, Chilenia and Patagonia.

The Rio de la Plata Craton is composed of a number of small geological terranes, which were collided during 2,300 to 1,900 Ma. And these were consolidated and amalgamated by the Transamazonic orogeny in the Lower Proterozoic.

The Pampia terrane consists of basically marble basement with schists and gneiss, which are the metamorphic equivalents of a sequence deposited in a stable margin about 900 to 1000 Ma. In the Upper Proterozoic about 750 Ma, it collided and accreted against the Rio de la Plata Craton.

The Cuyania terrane, also called Cuyania-Precordillera, was formed by high- and low-grade metamorphic rocks, which were metamorphosed between 900 and 1100 Ma, and early Paleozoic sedimentary rocks. It contains an area with a suture zone indicating accretion of the Cuyania and Precordillera terranes during the Proterozoic. The Cuyania and Pampia terranes were accreted about the end of Ordovician which is indicated by the magmatic arc previous to the suture.

The nature of the Chilenia basement is masked by igneous and metamorphic rocks of the Upper Paleozoic and remains unclarified. It includes a basement with evidence of deformation and metaphorphism between 500 and 415 Ma, covered by Silurian sediments. It accreted against Cuyania in the Upper Devonian. The suture is marked by numerous ophiolite fragments. The plutonics and the partly andesitic volcanics represent the magmatic arc previous to the suture.

Patagonia is formed by two terranes: the Somuncura and Deseado, which could have collided in the Lower Paleozoic Famitnian Orogeny. It was preceded by a magmatic arc related to the subduction of the Deseado massif. Patagonia was entirely joined to the rest of the Argentine territory during the Upper Paleozoic, and it was the last large accreted fragment. The Permian plutonism of the Somuncura group would correspond to the magmatic arc previous to the suture. The location of the suture in the western sector is obliterated by the post-accretional magmatism as well as by the sequences and arc rocks from the Mesozoic and Cenozoic eras. Its position is controversial, and it could be positioned in a NE-SW direction, which would agree with the distribution of Permian igneous activity, or it could continue in a NW-SE direction, consistent with the Maipo magnetic anomaly.

3-1-2 General geological of the survey area

The geological map by SEGEMAR (1997) is shown in Fig. I-3-2 and its legend in Fig. I-3-3. Table I-3-1, which is a summary of Fig. I-3-3, provides the simplified stratigraphy of the area corresponding to that actually surveyed. The geological outline of this area is given below on the basis of these findings and the geological descriptions by Zanettini et al. (1999):

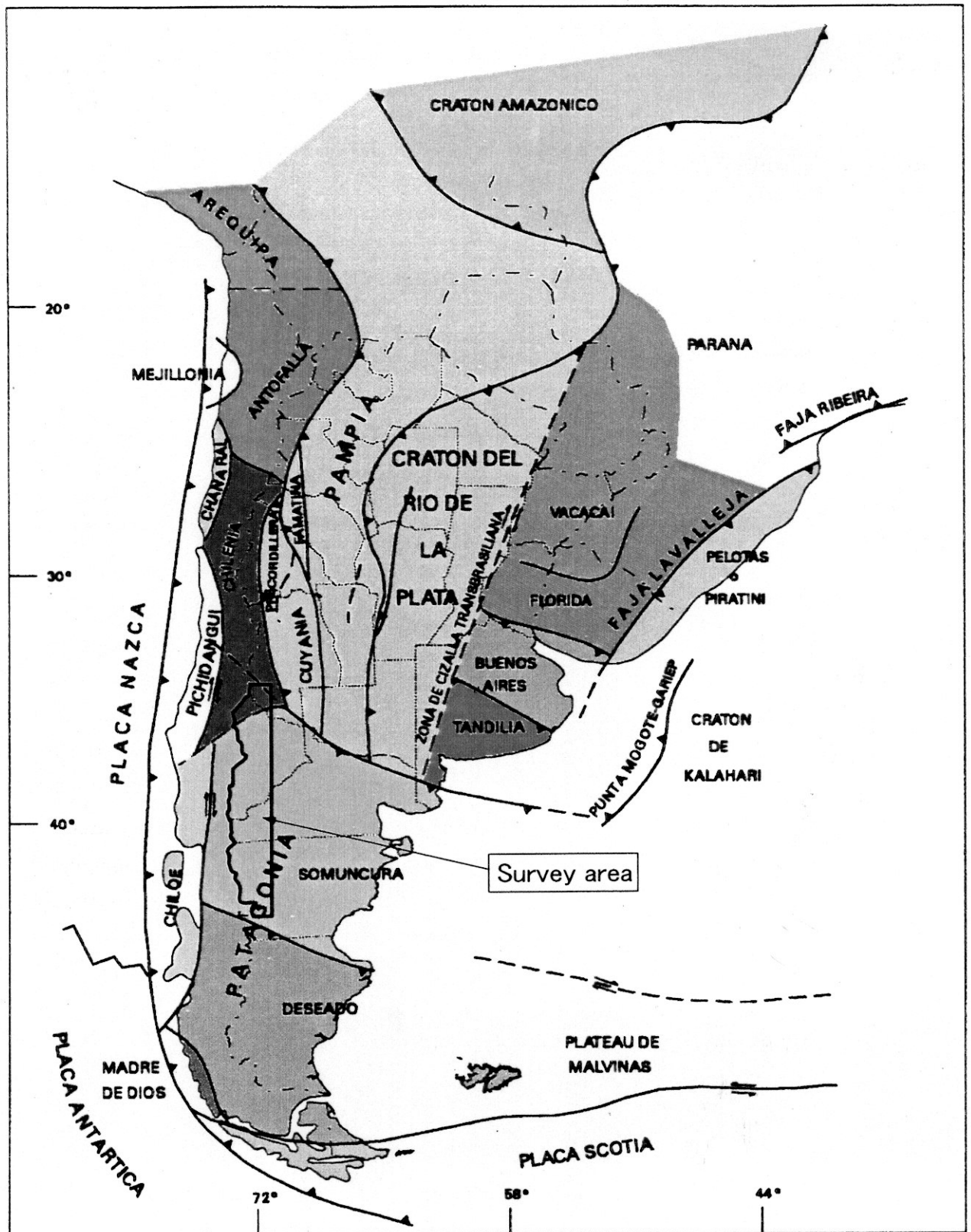


Fig. I-3-1 Accretionary terranes of the southern region of South America (SEGEMAR, 1998; after Ramos, 1988; Kraemer et al., 1995; Ramos, 1996; Bahlburg y Herve, 1997).

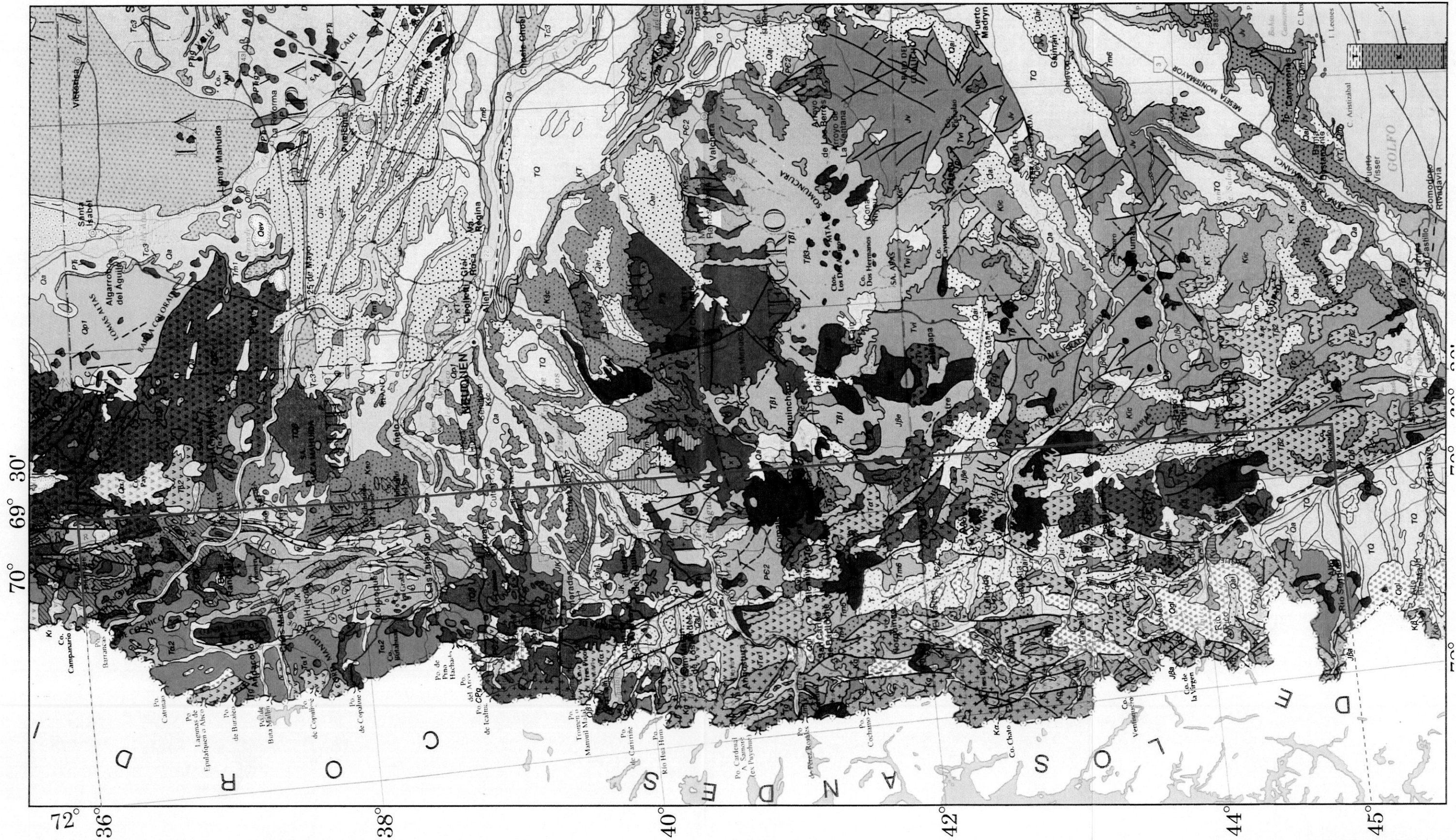
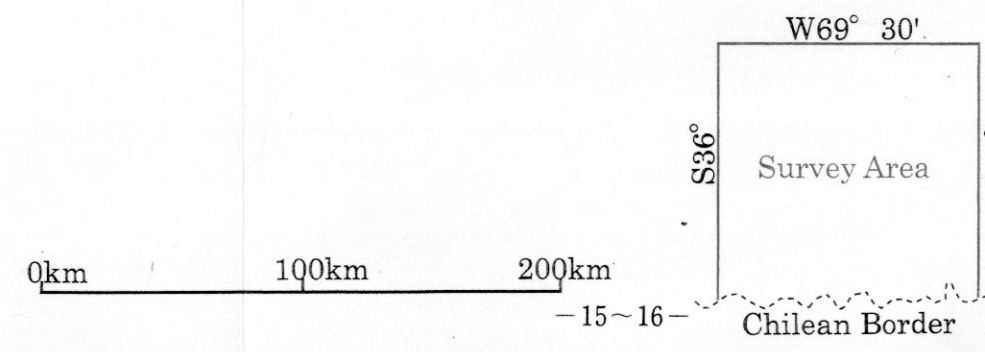
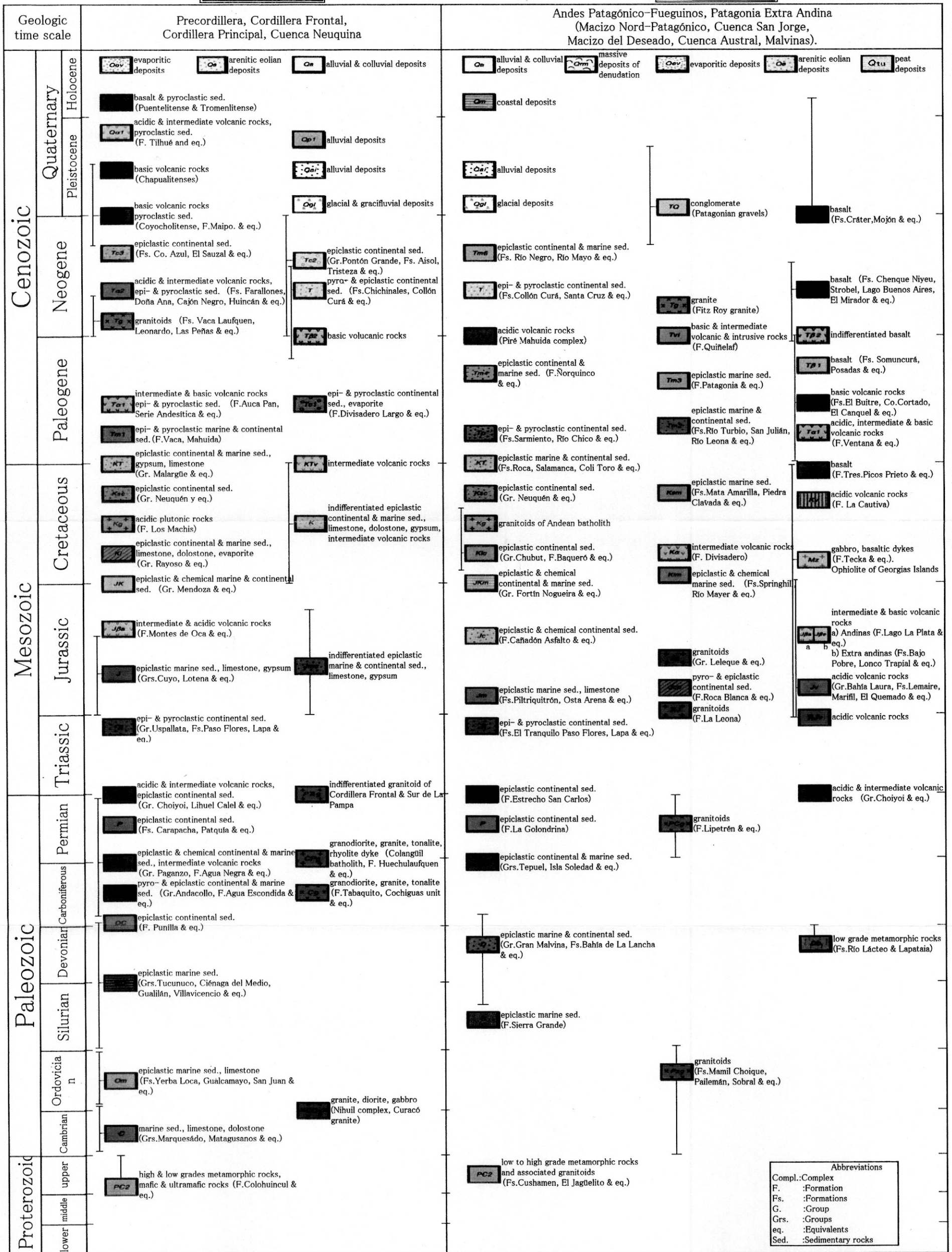
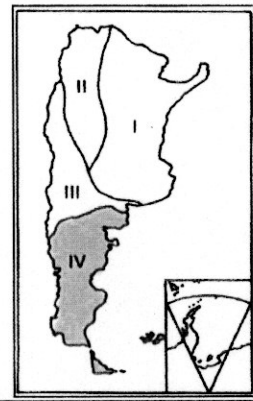
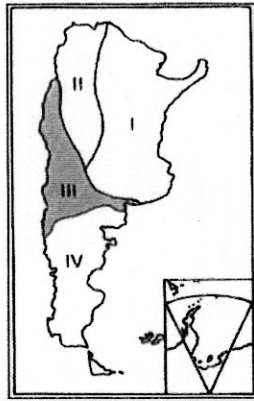


Fig.I-3-2 Geological Map of the survey area





Abbreviations
 Compl.:Complex
 F.:Formation
 Fs.:Formations
 G.:Group
 Grs.:Groups
 eq.:Equivalents
 Sed.:Sedimentary rocks

Fig. I-3-3 Legend for the geological map of the survey area

Table I-3-1 Simplified stratigraphy of the survey area.

Period	Epoch	Neuquen Province		Rio Negro - Chubut Provinces	
		Stratigraphy	Intrusive	Stratigraphy	Intrusive
Quaternary	Holocene	Depositos aluviales y coluviales (Qa : alluvium and colluvium)		Depositos aluviales y coluviales (Qa : alluvium and colluvium)	
	Pleistocene	Depositos glaciares y glaciares (Qgl : glacial and glacial deposits) Campos basálticos de Zapala (TQβ : basic volcanic rocks)		Depositos glaciares y glaciares (Qgl : glacial and glacial deposits)	
Tertiary	Neogene	Fm. Cajón Negro (Tα 2 : acidic, intermediate volcanic rocks)	Granitoides (Tg : granitoids)	Fm. Collón Curá (T : continental sedimentary rocks)	
	Paleogene	Serie Andesítica, Fm. Auca Pan (Tα 1 : intermediate, basic volcanic rocks)		Fm. Ventana (Tα 1 : acidic, intermediate, basic volcanic rocks)	
Mesozoic	Cretaceous	Grupo Neuquén (Ksc : continental sedimentary rocks)	Plutonitas ácidas (Kg : granitoids)	Fm. Tres Picos Prieto (Kβ : basalt) rocks)	Granitoides del Batolito Andino (Kg : granitoids)
		Grupo Rayoso (Ki : marine and continental sedimentary rocks with limestone, dolomite, evaporite)		Fm. Divisadero (Kα : intermediate volcanic rocks)	
	Jurassic	Grupo Mendoza (JK : marine and continental sedimentary rocks)	Granitoides (Jg : granitoids)	Fm. Lago la Plata (Jβ a : basic, intermediate volcanic rocks)	Granitoides (Jg : granitoids)
	Triassic	Grupo Cuyo (J : marine sedimentary rocks with limestone and gypsum)		Fm. Osta Arena (Jm : marine sedimentary rocks with limestone)	
Paleozoic	Permian	Grupo Choiyoi (PTR : acidic, intermediate volcanic rocks with continental sedimentary rocks)	Granitoides (CPg : granitoids)	Grupo Choiyoi (PTR : acidic, intermediate volcanic rocks)	Granitoides (PCg : Granitoids)
	Carboniferous	Grupo Andacollo (C : marine and continental sedimentary rocks)		Grupo Tepuel (CP : marine and continental sedimentary rocks)	
Proterozoic	Devonian				Granitoides (PZg : Granitoids)
	Silurian				
	Ordovician				
	Cambrian				
		Fm. Colohuincul (PC2 : low to high grade metamorphics, mafic and ultramafic rocks)		Fm. Cushamen (PC2 : low to high grade metamorphics and associated granitoids)	

Marks of geological unit, such as "Kg", are common to Figure I-3-2, I-3-3 except PTR and PC2. PTR and PC2 correspond to PR and PC2 of figure I-3-2, I-3-3 respectively.

1) Proterozoic (PC2)

In the survey area, the Proterozoic exposes in a small scale to the south of Paso de Pino Hachado of Neuquen province, in the proximity of San Carlos de Bariloche of Rio Negro province, and in Chshamen of Chubut province. Forming the basement of the survey area, these comprise low- and high-grade metamorphic rocks such as phyllite, schist and gneiss, and intruded by granite to granodiorite. They underwent complex metamorphism and have quartz and pegmatite veins. The result of a Rb-Sr radiometric dating of the sample taken near Huechlafquen Lake of Neuquen province, revealed 714 ± 10 Ma (Parica, 1986). They are called the Colohuincul formation in Neuquen province and the Chshamen formation in Chubut province.

2) Cambrian to Ordovician (PZg)

In the survey area, the granitoids of Cambrian to Ordovician are distributed in the east of Chshamen of Chubut province, and its northwestern distribution extends to the territory of Rio Negro province.

3) Carboniferous (C, CP)

In the survey area, the Carboniferous is distributed in Andacollo of Neuquen province, and Tecka to Jose de San Martin of Chubut province. They consist of the marine and continental conglomerates, shales, sandstones and a small amount of limestone, containing fossils. In Andacollo, these rocks are intercalated with andesitic tuff layers. The total thickness is as large as about 2,000 m. In Neuquen province, it is named the Andacollo group (C), overlain by the Permian unconformably. In Chubut State, it is named the Tepuel group (CP), overlain by the Jurassic unconformably.

4) Permian to Triassic (CPg, PCg, PTR)

In the survey area, the distribution of the Permian to Triassic extends to the proximity of Andacollo and to the west of Zapala of Neuquen province, and to the east of Ñorquinco of Rio Negro province. It is comprised of granitoids intruding in early Permian and the volcanic rocks of the upper Permian to Triassic closely associated with these granitoids. The granitoids (CPg, PCg) of tonalite to granite revealed 278 ± 10 Ma and 264 ± 8 Ma (Caminos et al., 1979, 1982). The volcanics are named the Choiyoi group (PTR), composed of andesitic to rhyolitic lavas and pyroclastic rocks. Fossils of continental plants were discovered from the basal conglomerate and sandstone. The thickness of the Choiyoi group reaches 550 to 1,800 m. Radiometric dating revealed 252 ± 14 Ma and 232 ± 10 Ma (Caminos et al., 1979, 1982). These granitoids and volcanics were probably produced by the plate subduction from the Pacific Ocean side in the extensional tectonic setting.

5) Jurassic terrane (J, Jm, J β a, Jg, Mz)

In the survey area, the Jurassic is distributed intermittently between Andacollo and Zapala and to the south of Zapala of Neuquen province, and also intermittently distributed between Epuyen and Lago Fontana of Chubut province. These comprise sedimentary rocks, volcanic rocks and plutonic rocks. The plutonic rocks consist of granitoids and gabbro.

The sedimentary rocks comprise clastic sedimentary rocks, limestone and evaporite, and include basic volcanics among them. Part of them gradually shifts to a continental sediments, representing the sediments of a stage in which an oceanic basin is transformed into land in the age of island arc regression. According to the faunal contents, it is known that these rocks belong to the Pliensbachian to Kimmeridgian ages (Emparan et al., 1992, etc.). They are called the Cuyo group (J) in Neuquen province and the Osta Arena formation (Jm) in Chubut province.

The distribution of volcanic rocks is extensive in the south of lat. 40°S and further continues to Cape Horn, outside of the survey area, along the Andes cordillera. These comprise rhyolite containing ignimbrite, dacite, andesitic and basaltic lavas, and pyroclastic rocks. In the survey area of Chubut province, andesitic and basaltic rocks are dominant. It is named Lago la Plata formation (J β a). The rocks form a part of the most extensive acidic volcanic terrane in the world, genetically linked to the extensional processes that led to the break-up of the Gondwana continent.

The distribution of granitoids (Jg) in this area is small in scale and found in Varvarco of Neuquen province, and in the proximity of Leleque of Chubut province. The age of the latter rocks was determined at 195 Ma (Gordon and Ort, 1993). They are composed of tonalite, granodiorite and granite, which are calc-alkali granite having a normal K₂O content and aluminous character.

Gabbro (Mz) is distributed over the Sierra de Tepuel to the southeast of Tecka of Chubut province. These rocks are composed of banded gabbro rocks (Page, 1984) and gave thermal metamorphism to the Carboniferous sedimentary rocks (CP). Outside the survey area, ophiolite sequence is distributed between lat. 50° and 55°S on the Chilean side. It is considered as belonging to the Upper Jurassic to Lower Cretaceous, because it is contained in the Jurassic sedimentary rocks and overlain by the Cretaceous sedimentary rocks; U-Pb radiometric dating gave results of 140 to 137 Ma (Stern et al., 1992). It is also estimated that the gabbro rocks in the survey area belong to the same period.

6) Upper Jurassic to Cretaceous terranes (JK, Ki, Ksc, Kim, K α , K β , Kg)

In the survey area, the Cretaceous is distributed from Mendoza province to the southwest of Zapala of Neuquen province. In Rio Negro and Chubut provinces, it is

distributed along the Chilean border to the west of the survey area. It comprises sedimentary, volcanic and granitic rocks.

Sedimentary rocks area divided into the lower group belonging to the late Jurassic Tithonian age to early Cretaceous Albian age, and the upper group belonging to the Late Cretaceous Cenomanian to Campanian ages. In Neuquen province, the lower group is further divided into the Mendoza group (JK) and the Rayoso group (Ki) in ascending order. In Chubut province, the lower group is named the Apeleg formation (Kim). Although different in property by their respective sedimentary basins, these comprise shale, calcareous rocks and a small amount of sandstone. In the Aptian and Albian ages, evaporite and a small amount of continental shale were deposited. The average thickness is about 4,500 m. In Neuquen province, the upper group is named the Neuquen group (Ksc), which comprises sandstones, shale and a small amount of continental conglomerates. The thickness of the group reaches 1,600 m.

Volcanic rocks are mainly distributed in Chubut province, comprising the Divisadero formation ($K\alpha$) consisting of andesitic volcanics and the Tres Picos Prieto formation ($K\beta$) consisting of basaltic volcanics. The Tres Picos Prieto formation is intercalated with sedimentary rocks and is considered a product of late Cretaceous volcanism (Page, 1980).

Granite rocks (Kg) are extensively distributed along the Chilean border in Rio Negro and Chubut provinces. Radiometric dating of the rocks showed a value of around 100 Ma (e.g., Ramos, 1983). They are calc-alkali monzogranite closely associated with the plate subduction along the active margin of the continent. Also, in relation to the Campana Mahuida porphyry Cu deposit in Neuquen province, the distribution of andesite porphyry of 74 Ma is known (Sillitoe, 1977).

7) Paleogene ($T\alpha 1$, Tg)

In the survey area, the Paleogene is distributed in the northwest of Neuquen province, and intermittently from San Martin de los Andes in the southwest of Neuquen province to Tecka of Chubut province, via San Carlos de Bariloche of Río Negro province. It comprises volcanic rocks and granitoids.

The volcanic rocks ($T\alpha 1$) are named the Serie Andesítica in the northwest, and the Auca Pan formation in the southwest of the Neuquen province. And the Ventana formation in Río Negro and Chubut provinces. The Serie Andesítica mainly comprises andesite lavas and the pyroclastic rocks. It includes continental sediments which vertebrata fossils are found. The thickness of the Auca Pan and Ventana formations is as large as more than 1,000 m, showing vertical and horizontal rock facies variations. In the west, andesitic rocks are dominant accompanied by basaltic rocks while rhyolitic rocks are dominant in the east. These are calc-alkali rocks of medium-K to high-K.

For the granite rocks (Tg), radiometric dating gave the results of 50 to 7 Ma (e.g., Pesce, 1981; Llambías and Rapela, 1989). The granitic rocks of the Paleogene distribute in the form of small bodies in Andacollo and Cerro Caicayen in the northwest of Neuquen province. The granitic rocks of the Neogene will be mentioned later.

8) Neogene (T α 2, T, TQ β , Tg)

In the survey area, the Neogene is extensively distributed in the northwest of Neuquen province. It is also distributed from the southwest of Neuquen province to the west of San Carlos de Bariloche of Río Negro province, from Ñorquinco of Río Negro province to the east of Leleque of Chubut province. These comprise volcanic rocks, sedimentary rocks and granitic rocks.

Volcanic rocks are the Cajón Negro formation (T α 2) distributed from the northwest end of Neuquen province to the mountains in the west of Zapala, and the Campos Basálticos de Zapala (TQ β) distributed around of Zapala. These are calc-alkali rocks accompanying island arc orogeny. The Cajón Negro formation erupted around 2 Ma. It mainly comprises andesitic to basaltic lavas and agglomerates and accompanies a small amount of acidic lavas and ignimbrites. They form the eroded stratovolcanos. The volcanic activity of the Campos Basálticos de Zapala continued to the Pleistocene, and around the Lago Laguna Blanca in the southwest of Zapala, it continued to the Holocene. It is mainly composed of basaltic lavas and accompanied by pyroxene andesite and dacite.

Sedimentary rocks distribute in the range from Ñorquinco of Río Negro province, to the east of Leleque of Chubut province. These are named the Collón Curá formation (T). Its basement consists of thick conglomerates and changes to shale and sandstone. It mainly comprises continental sediments but has some local marine sediments, producing many plant fossils as well as mammal fossils.

Concerning the granitic rocks (Tg), radiometric dating gave the result of 15 Ma and 7 Ma (e.g., Munizaga et al., 1985). These are mainly distributed in the Chilean side beyond the border, and in the survey area, only a part is distributed in a small scale in the northwest of Neuquen province and along the Chilean border in the area bordering Neuquen and Río Negro provinces.

9) Quaternary (TQ β , Qgl, Qa)

Concerning the Quaternary in the survey area, basaltic rocks (TQ β) have been already mentioned, which started activity in the Neogene. The Quaternary mainly comprises the glacial sediments (Qgl) of the Pleistocene and the alluvium and colluvium (Qa) of the Holocene. The glacial sediments are distributed filling depressions in mountain regions along the border with Chile while the alluvium and colluvium are distributed in the low land along