LATE CENOZOIC VOLCANISM AND PETROGRAPHIC PROVINCES IN THE ANDES AND ANTARCTICA

by

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(with 1 Table and 5 Text-figures)

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Introduction

In the southeast sector of the circum-Pacific orogenic belt, late Cenozoic volcanism has taken place at several regions along the Andes to Antarctandes through the subantarc islands of the Scotia arc, as shown in Fig. 1. Various types of volcanoes such as strato-volcanoes, shield-volcanoes, lava domes, pyroclastic cones, calderas, pyroclastic plateau, and lava plateaux, are found in this area. Their total number probably exceeds 450, and about one sixth of them still retain their activity. The rocks of this area are generally regarded to comprise basalt, andesite, dacite, and rhyolite. Alkali basalt and its derivatives are also present on the continental side. There is a systematic variation of rock types across the orogenic belt, as has been noticed by KUNO (1966). However, the most important variation of the nature of volcanism and rock types are remarked longitudinally along the orogenic belt as a whole. This short note deals with a brief description of the late Cenozoic volcanism and the petrographic provinces in this area on the basis of published data including about 240 major element chemical analyses of rocks.

Late Cenozoic Volcanism in the Andes, Scotia arc, and Antarctica

The Pacific margin of the South American continent is rimmed by double mountain arcs: the coastal range and the Andes mountains which are separated by a narrow longitudinal depression (central valley). Volcanism in the Pliocene to Quaternary occurs only along the Andes. This situation, together with the existence of a deep-sea trench and active seismicity whose epicentral plane dips under the continent, indicates that the Andes are a similar tectonic feature to the double island arcs of the circum-Pacific belt, e.g. the Japanese Islands (MINATO and others ed., 1965). The Andean volcanic zone is divided into three major regions: the northern, central, and southern Andes, which are separated by two regions where neither volcanoes nor longitudinal depression can be found. (CASERTANO, 1963; KATSUI and GONZÁLEZ, 1968; PÉREZ and AGUIRRE, 1969)

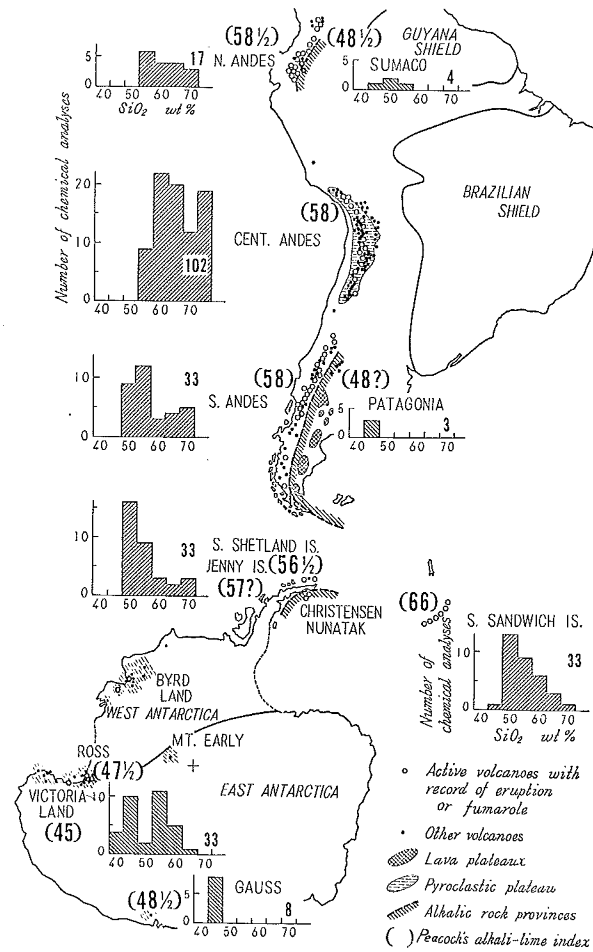

Fig. 1

Distribution of volcanoes and available chemical analyses of rocks in the Andes-Scotia arc-Antarctica. Peacock's alkali-lime indices are shown in parentheses. Source of data: *Northern Andes.* HANTKE and PARODI (1966), PICHLER and ZEIL (1969). *Central Andes.* JENKS and GOLDICH (1956), AHLFELD and BRANIŠA (1960), ZEIL and PICHLER (1967), GUEST (1968, 1969), KATSUI and GONZÁLES (1968), PICHLER and ZEIL (1969). *Southern Andes.* QUENSEL (1912), LARSSON (1940), KITTLE (1944), GONZÁLEZ and VERGARA (1962), CASERTANO (1963), KLERKX (1965), KATSUI and KATZ (1967). *Patagonia.* TYRRELL (1932), QUARTINO (1957). *South Sandwich Islands.* TYRRELL (1931, 1945). GASS and others (1963), BAKER (1968). *South Shetland Islands.* HAWKES (1961a, b), BAKER and others (1969), KATSUI and GONZÁLEZ (in press). *Other Antarctic regions.* FENNER (1938), STEWART (1956), BERINGHAUSEN and NEUMANN VAN PADANG (1960), DOUMANI (1964), FORBES and KUNO (1965).

The northern Andes comprise about 40 strato-volcanoes, some of which are still active, e.g. Purace, Reventador, and Cotopaxi. They are composed of andesite, dacite and rhyolite which appear to belong to a calc-alkalic series, while on the continental side of the volcanic belt, volcanoes consisting of alkalic rocks are rarely found. Sumaco, an active strato-volcano, is an example which consists of tephrite (HANTKE and PARODI, 1966).

In the central Andes, thick rhyolitic ignimbrite sheets of Upper Miocene to Lower Pleistocene age form a high extensive plateau ('altiplano') up to about 4,500 m above sea level. These ignimbrites cover uplifted Mesozoic rocks, extending over an area of more than 15×10^4 km^2, and their total thickness reaches 800 – 1,000 m in some places (JENKS and GOLDICH, 1956; HOLLINGWORTH, 1964; ZEIL and PICHLER, 1967; KATSUI and GONZÁLEZ, 1968; GUEST, 1969). This is probably the largest Cenozoic ignimbrite mass in the world. About 260 Quaternary volcanic cones and lava domes project above the 'altiplano'. Most of the higher volcanoes in the world are concentrated in the central Andes, actually more than 30 volcanoes exceeding 6,000 m in elevation. However, each volcanic edifice is itself less than 2,000 – 2,500 m in true height. Nevados Ojos del Salado (6,885 m above sea level), for example, is the highest volcano in the world. The relief from the ignimbrite base does not exceed 2,000 m. Some of the volcanoes in the central Andes still retain fumarolic activity, but quite few eruptions have been recorded in historic times. These volcanoes are commonly composed of calc-alkali andesite or latite-andesite and rhyodacite, but no basalt has been found (KATSUI and GONZÁLEZ, 1968; PICHLER and ZEIL, 1969).

The southern Andean region comprises many strato-volcanoes, lava domes and small lava plateaux, about 60 in number, of these more than 20 volcanoes are still active and frequent eruptions have been recorded in historic times (CASERTANO, 1963). The most striking feature in this region is abundant occurrence of high-alumina basalt associated with andesite of the calc-alkali series, while rhyolite is rarely found (LARSSON, 1940; KATSUI and KATZ, 1967; KATSUI and GONZÁLEZ, 1968). Tholeiitic basalt, however, does not occur in this region, although KUNO (1966, p. 16) supposed that most of the southern Andean rocks are of a tholeiitic derivation. On the continental side of the southern Andes, shield volcanoes cinder cones and lava plateaux are present. They appear to have already ceased their activity. These Patagonian volcanoes are mostly composed of alkali olivine-basalt (TYRRELL, 1932; QUARTINO, 1957).

The Andean folding can be traced from the Cape Horn through the Scotia arc to the Antarctic Peninsula. This connection, the South Sandwich Islands, forms an intra-oceanic single island arc with a deep-sea trench on its convex side. This arc was probably formed by the bending and fragmentation of narrow Mesozoic belts which lagged behind as the continents drifted westwards, as has been discussed by HAMILTON (1966) and others. The South Sandwich Islands are made up of a dozen of strato-volcanoes of recent origin (BAKER, 1968). Volcanism and seismicity are very active in these islands, and a recent submarine eruption has also been reported (GASS and others, 1963). The rocks consist of abundant tholeiitic basalt, andesite and a minor dacite, all of which are characteristically poor in alkalis, especially in potash (BAKER, 1968).

The South Shetland Islands, lying off the Antarctic Peninsula, contain several composite strato-volcanoes including Deception Island which recently erupted along the ring fractures of caldera (VALENZUELA and others, 1968; BAKER and others, 1969). These volcanic islands are composed of olivine-basalt and andesite, all of which are rich in soda, but their mineralogy is similar to that of high-alumina basalt and its derivatives (HAWKES, 1961 a and b; KATSUI and GONZÁLEZ, in press). Towards the south, there is Jenny Island which also consists of basalt and andesite (GOURDON, 1914). On the concave side of the Antarctic Peninsula, James Ross Island and other islands of Recent volcanic origin are scattered along the Weddell Sea coast (DAVIES, 1956). One of them, Christensen Nunatak, is composed of trachybasalt (BERNINGHAUSEN and NEUMANN VAN PADANG, 1960).

Many high strato-volcanoes project through the ice of Marie Byrd Land in the interior of west Antarctica. Some of them built calderas at the eruption center. Other strato-volcanoes, cinder cones and lava flows are scattered along the edge of the east Antarctica: in the mountains of Victoria Land, the Ross Sea area, and the Transantarctic Mountains (STEWART, 1956; HAMILTON and BOUNDETTE, 1962; DOUMANI, 1964; NICHOLS, 1970). These volcanoes are formed on the continental rocks of older orogenic belt. Mt. Erebus of Ross Island alone has several records of eruption during 1841 – 1947, although other several volcanoes of Marie Byrd Land, Victoria Land, and Ross Sea, still appear to retain their activity (BERNINGHAUSEN and NEUMANN VAN PADANG, 1960; NICHOLS, 1970). Mt. Erebus and other volcanoes of Ross Island consist of alkali olivine-basalts, trachyte, kenyte, and phonolite. Mt. Early, the world's southernmost volcano, is composed of olivine-basalt (DOUMANI, 1964). The lavas vary considerably in composition throughout this region, forming a large alkalic province, in which alkali basalt, trachyte, tephrite, and phonolite are representative rocks. Olivine fourchite has also been reported from Volcano 116 in northwestern Marie Byrd Land (FENNER, 1938). Ultramafic inclusions are frequently found throughout this region (DOUMANI, 1964; FORBES and KUNO, 1965). Towards the interior of the east Antarctic shield, no volcano has been found except Mt. Gauss, a dissected volcanic neck composed of leucite-basalt which belongs to an extremely potassic suite (REINISCH, 1906).

Chemistry of volcanic rocks

About 240 major-element chemical analyses now available are shown in Fig. 1, in which they are represented by histograms versus silica content for each region. In order to find the nature of rocks in each respective region, Peacock's alkali-lime index is calculated and is shown in the same figure. The index for the South Sandwich Islands is 66, i.e. most calcic. This extremely calcic value is comparable to that for the Quaternary volcanic rocks of Izu-Mariana Islands and Pacific side of northern Japan, where low-alkali tholeiite predominates (MINATO and others ed., 1965). The values for the Andes and Antarctandes are around 57 – 58, while the alkalic rocks on the continental side have indices less than 50.

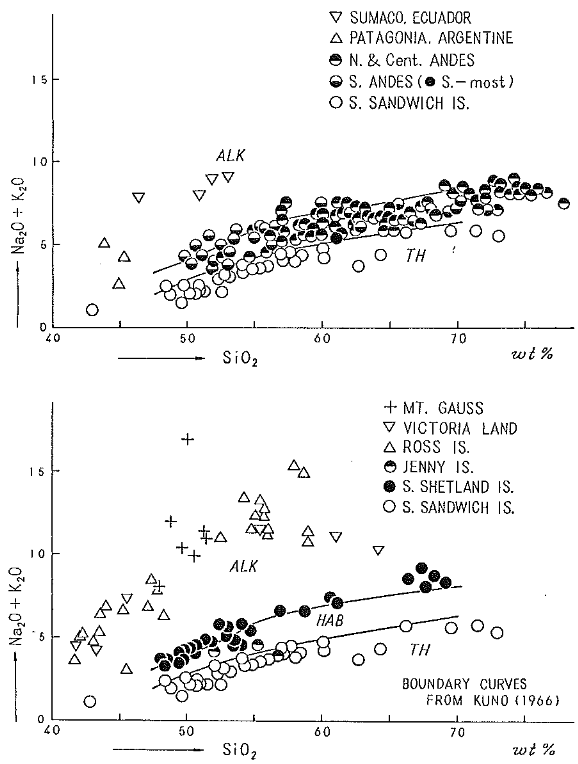

Fig. 2
Variation diagram for total alkalis versus silica.

Three rock suites as classified above, are also well represented in variation diagrams for total alkali plotted against silica (Fig. 2). The rocks of the South Sandwich Islands are generally poor in alkalis, as has already been demonstrated by BAKER(1968). The Andean and Antarctandean rocks are moderate, whereas plots of alkalic rocks of the continental side fall in the higher field. The boundaries between the three rock suites coincide closely with those between tholeiite, high-alumina basalt, and alkali rock series and their respective derivatives for Japanese and other volcanic rocks (KUNO, 1966). This relationship suggests that the three rock suites have been derived from the respective parental basaltic magmas.

In reviewing the circum-Pacific belt, a certain relationship seems to exist between occurrence of a particular rock suite and a geotectonic feature (Table 1). In the intra-oceanic, single island arcs, where both volcanism and seismicity are very active, the eruption of low-alkali tholeiite is characteristic, as exemplified in South Sandwich Islands and other areas. A complete zonal

Table 1: Mode of occurrence of three basalt magma types in the circum-Pacific belt.

Tholeiite (low-potassic)	High-alumina basalt (with or without high-alk.tholeiite)	Alkali olivine-basalt
S.Sandwich Islands Tonga Islands Mariana Islands	absent	
Eastern Japan	Kuriles	Kamchatka
absent	Western Japan Cascades Andes	Aleutians Cent.America Antarctandes

arrangement of the three rock suites is found in eastern Japan and Kurile-Kamchatka (KATSUI, 1961; KUNO, 1966) which are typical double island arcs with inner oceanic basin. However, in the double island arcs developed at continental margins, low-alkali tholeiite is absent or quite scarce, and high-alumina basalt (with or without high-alkali tholeiite) in turn accompanies alkaline rocks on the continental side, as represented in the Andes, Antarctandes and other areas. This pattern of rock associations throughout the area discussed here and other circum-Pacific regions is probably related to the growth of continent. The South Sandwich Islands may represent the early stage of development of island arc, as has been stated by BAKER (1968). Under such active island arcs, low-alkali tholeiite magma may be generated at a shallow depth in the upper mantle, whereas on the continental margin, more alkalic magmas would be produced at a deeper level probably due to the descending geotherm, as suggested by an experimental result of KUSHIRO (1964).

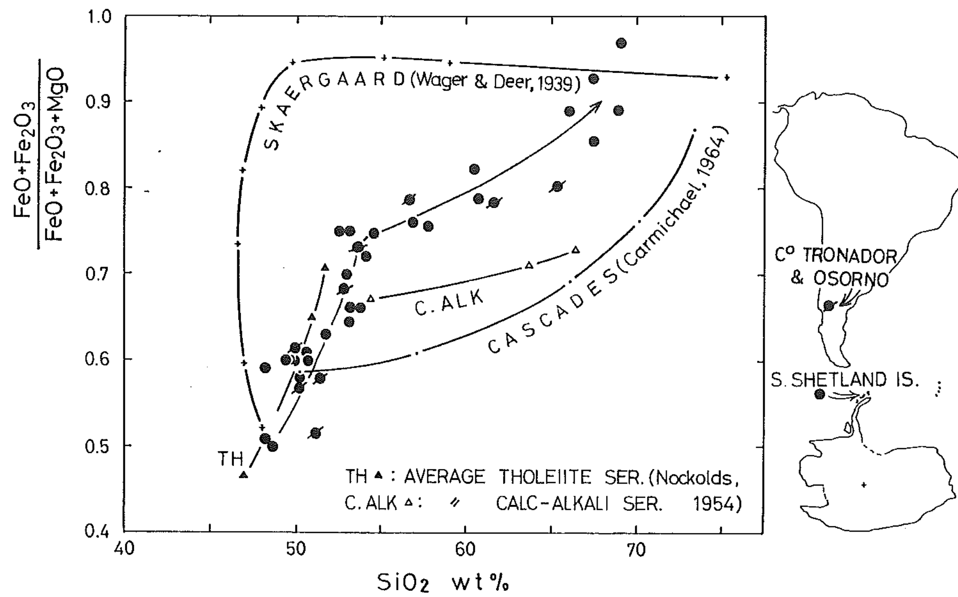

Fig. 3
Osborn's diagram for the rocks of Cerro Tronador and Osorno of southern Andes and South Shetland Islands.

It is true that the most of the volcanic rocks erupted along the orogenic belts are of calc-alkali series. However, even in the orogenic belts, there are some rock suites which should claim direct parentage from original basalt magmas. The rocks of the South Sandwich Islands are considered to have derived by fractional crystallization of a primary low-alkali tholeiitic magma (BAKER, 1968). It is also suggested that the rocks of the South Shetland Islands and some volcanoes of the southern Andes have derived by fractional crystallization of a primary basaltic magma which is more alkalic and high-aluminous in nature. The trend of fractionation involves marked iron enrichment in the middle stage of crystallization of magma (Fig. 3).

Towards north from the southern Andes, however, the feature of volcanism is converted into eruption of abundant intermediate-acid rocks, most of which are of calc-alkali series (*see* histograms of Fig. 1). The central and northern Andean rocks are mainly of this series. As shown in Fig. 4, calc-alkali rocks of

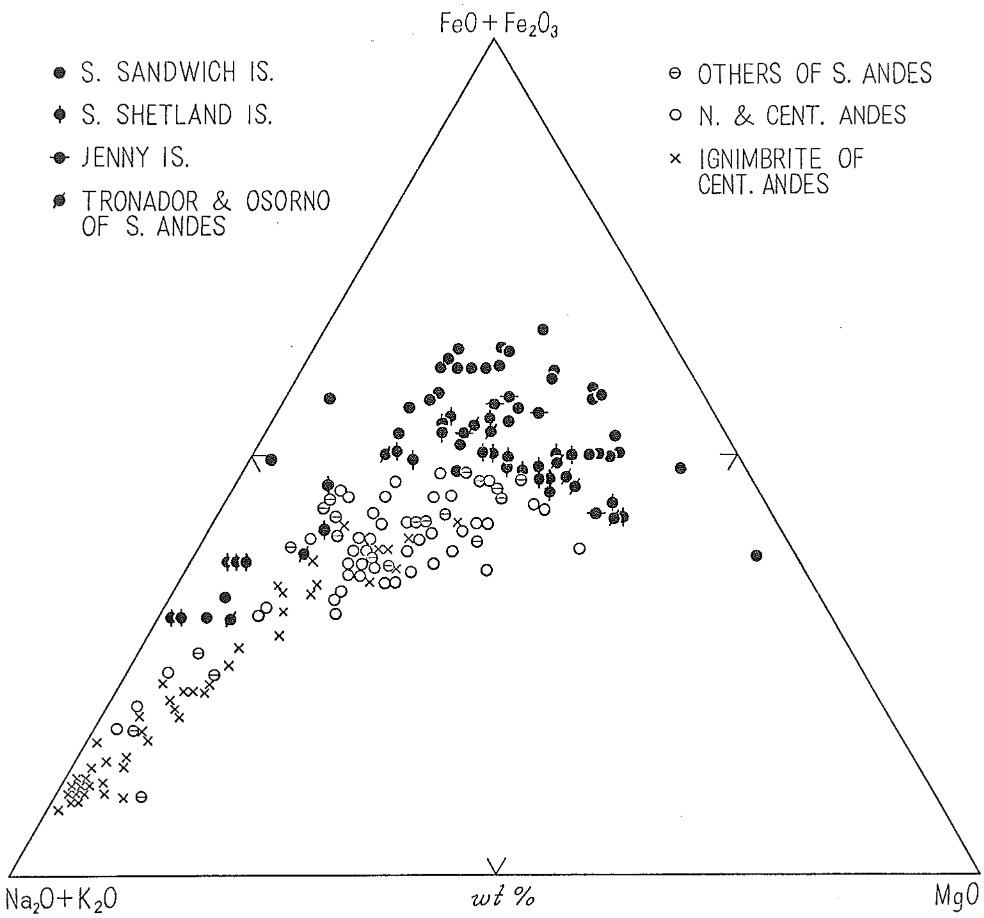

Fig. 4
Triangular variation diagram for MgO – ($FeO + Fe_2O_3$) – ($Na_2O + K_2O$) (weight %).

the Andean rocks (open circles and crosses) dc not follow the fractionation course of tholeiite and high-alumina basalt magmas (solid circles) which involves iron enrichment at the middle stage. A high oxygen partial pressure or a high water-vapour pressure during crystallization may explain this calc-alkali trend. Petrographic feature of the central Andean rocks, however, does not indicate that these rocks have derived from a magma through simple process with complete equilibrium, but suggest that assilimation of wall rock by magma or partial fusion of basement rocks have been taken place (ZEIL, 1963; KATSUI and GONZÁLEZ, 1968).

It is worthy to note here that towards the north from the southern Andes the Andean mountain roots become thick, and in the central Andes the roots are supposed to reach a depth of 60 – 70 km, judging from Bouguer anomaly (minus 300 – 380 mgals) (DRAGIĆEVIC and others, 1961; Univ. de Chile, 1963). (Fig. 5) Accordingly, a basaltic magma ascending through such deep mountain roots would have been more effectively subjected to contamination by wall rocks.

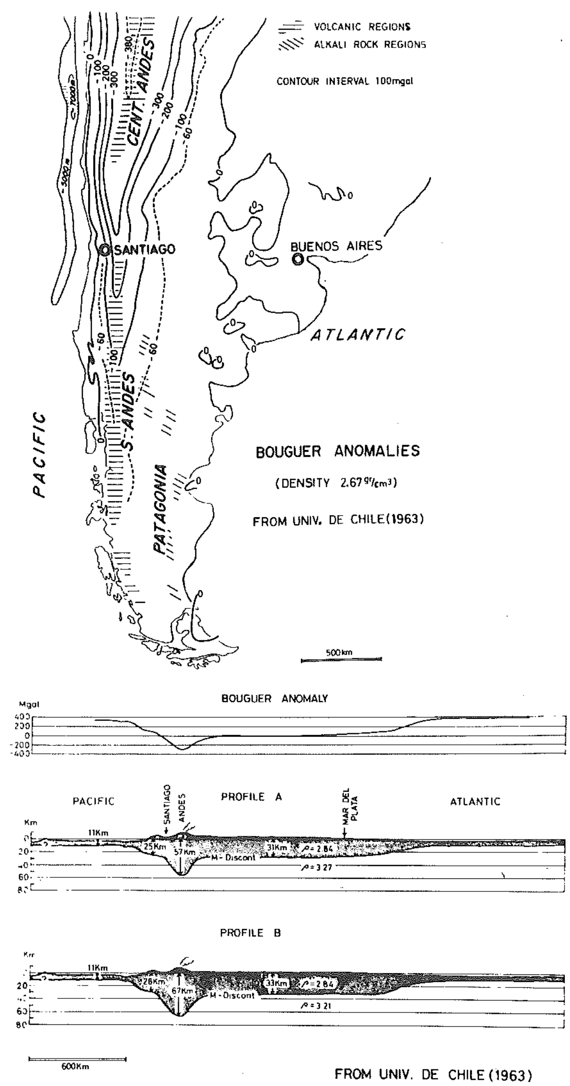

Fig. 5
Bouguer anomaly (upper) and estimated profiles (lower) of South America (after Univ. de Chile, 1963).

In the central Andes, however, the hypothesis of a basaltic parentage may be excluded, because actual basalt is so far unknown there, whereas a large amount of rhyolitic ignimbrite forms an extensive plateau as mentioned above. For this reason, an hypothesis involving a process of melting of such thickened crust is more plausible as an explanation for the origin of a large volume of acid calc-alkali rocks (KATSUI and GONZÁLEZ, 1968). The same opinion based on trace-element chemistry has been presented by SIEGERS and others (1969), EL-HINNAWI and others (1969) and PICHLER and ZEIL (1969). In this connection, an alternative hypothesis that melting in the Benioff zone could yield large volumes of acid-intermediate magma has also been proposed by HAMILTON (1969) on the basis of the process described by GREEN and RINGWOOD (1966). Further studies including the structure and the thermal state of the crust and mantle and isotope geochemistry are still required to provide a definite conclusion.

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BIBLIOGRAPHY

AHLFELD, F. and L. BRANIŠA (1960): Geología de Bolivia. La Paz, Instituto Boliviano de Petroleo, 245p.

BAKER, P.E. (1968): Comparative volcanology and petrology of the Atlantic island-arcs. Bull. volcan., Ser 2, 32, No. 1, 189 – 206.

BAKER, P.E., T.G. DAVIES, and M.J. ROOBOL (1969): Volcanic activity at Deception Island in 1967 and 1969. Nature, Lond., 224, No. 5219, 553 – 60.

BERNINGHAUSEN, W.H. and M.N. VAN PADANG (1960): Catalogue of the active volcanoes of the world including solfatara fields. Part X. Antarctica. Naples, Intern. Assoc. Volcanology, 32p.

CASERTANO, L. (1963): Catalogue of the active volcanoes of the world including solfatara fields. Part XV. Chilean continent. Naples, Intern. Assoc. Volcanology, 55p.

DAVIES, W.E. (1956): Antarctic stratigraphy and structure. (In CRARY, A.P., L.M. GOULD, E.O. HUBERT, H. ODISHAW, and W.E. SMITH, ed. Antarctica in the International Geophysical Year. Washington, D.C.

American Geophysical Union, 44 – 51.) [Geophysical monograph No. 1.]
DOUMANI, G.A. (1964): Volcanoes of the Executive Committee Range, Byrd Land. (In ADIE, R.J., ed. Antarctic geology. Amsterdam, North-Holland Publishing Company, 666 – 75.)
DRAGÍCEVIC, M., E. KAUSEL, C. LOMNITZ, H. MEINARDUS, and L. SILVA (1961): Levantamiento gravimetrico de Chile. An. Fac. Cienc. Fis. Mat., Univ. Chile, 18, 221 – 42.
EL-HINNAWI, E.E., H. PICHLER and W. ZEIL (1969): Trace element distribution in Chilean ignimbrites. Contr. Mineral. and Petrol., 24, 50 – 62.
FENNER, C.N. (1938): Olivine fourchites from Raymond Fosdick Mountains, Antarctica. Bull. Geol. Soc. Am., 49, No. 3, 367 – 400.
FORBES, R.B. and H. KUNO (1965): The regional petrology of peridotite inclusions and basaltic host rocks. Upper Mantle Symposium, New Delhi, 1964, 161 – 79.
GASS, I.G., P.G. HARRIS, and M.W. HOLDGATE (1963): Pumice eruption in the area of the South Sandwich Islands. Geol. Mag., 100, No. 4, 321 – 30.
GONZÁLEZ F., O. and M. VERGARA M. (1962): Reconocimiento geologico de la Cordillera de los Andes entre los paralelos 35° y 38° lat. Sur. Publ. Inst. Geol., Univ. Chile, No. 24, 121 pp.
GOURDON, E. (1914): Sur la constitution mineralogique de l'ile Jenny (Antarctique). C.r. hebd. Seanc. Acad. Sci., Paris, 159, 369 – 71.
GREEN, T.H. and A.E. RINGWOOD (1966): Origin of the calc-alkali igneous rock suite. Earth & planet. Sci. Lett., 1, No. 4, 307 – 16.
GUEST, J.E. (1968): Banded pumice in a Chilean ignimbrite. Geol. Mag., 105, No. 2, 177 – 85.
GUEST, J.E. (1969): Upper Tertiary ignimbrites in the Andean Cordillera of part of the Antofagasta province, northern Chile. Geol. Soc. Am. Bull., 80, No. 3, 337 – 62.
HAMILTON, W. (1966): Formation of the Scotia and Caribbean arcs. Intern. Upper Mantle Project. Report of symposium on Continental Margins and Island Arcs. Ottawa, 1965, 178 – 87.
HAMILTON, W. (1969): The volcanic central Andes – a modern model for the Cretaceous batholiths and tectonics of western North America. Intern. Upper Mantle Project: Proceedings of the Andesite Conference. Oregon, 1968, 165 – 84.
HAMILTON, W. and E.L. BOUDETTE (1962): Quaternary alkaline basalt-trachyte province, Marie Byrd Land and South Victoria Land, Antarctica. Proc. Intern. Symp. Volcan., Japan, 18 – 19.
HANTKE, G. and A. PARODI (1966): Catalogue of the active volcanoes of the world including solfatara fields. Part XIX. Colombia, Ecuador and Peru. Naples, Intern. Assoc. Volcanology, 73p.
HAWKES, D.D. (1961a): The geology of the South Shetland Island: I. The petrology of King George Island. Scient. Rep. Falkld Isl. Depend, Surv., No. 26, 28p.

HAWKES, D.D. (1961b): The geology of the South Shetland Islands: II. The geology and petrology of Deception Island. Scient. Rep. Falkld Isl. Depnd. Surv., No. 27, 43p.

HOLLINGWORTH, S.E. (1964): Dating the uplift of the Andes of northern Chile. Nature, 201, No. 4914, 17 – 20.

JENKS, W.F. and S.S. GOLDICH (1956): Rhyolitic tuff flows in southern Peru. J. Geol., 64, No. 2, 156 – 72.

KATSUI, Y. (1961): Petrochemistry of the Quaternary volcanic rocks of Hokkaido and surrounding areas. J. Fac. Sci., Hokkaido Univ., Ser. 4, 11, 1 – 58.

KATSUI, Y. and O. GONZÁLEZ F. (1968): Geología del area neovolcanica de los Nevados de Payachata. Consideraciones acerca del volcanismo Cenozoico Superior en los Andes Chilenos. Publ. Inst. Geol., Univ. Chile, No. 29, 61p.

KATSUI, Y. and O. GONZÁLEZ F. (in press): Estudio integral del volcanismo cenozoico en el territorio chileno antartico.

KATSUI, Y. and H.R. KATZ (1967): Lateral fissure eruptions in the southern Andes of Chile. J. Fac. Sci., Hokkaido Univ., Ser. 4, 13, 433 – 48.

KITTLE, E. (1944): Estudios geologicos y petrograficos sobre los volcanes de la region cordilleran del sur de Mendoza y del grupo del Descabezado. An. Mus. Nac. Hist. Nat., B. Aires, 41, 71 – 190.

KLERKX, J. (1965): Etude petrologique de lavas des volcan Villarrica, Calbuco, Osorno, Llaima (Chili Central). Annls Soc. Geol. Belg., 88, 451 – 70.

KUNO, H. (1966): Lateral variation of basalt magma types across continental margins and islands arcs. Bull. Volcan., Ser. 2, 29, 195 – 222.

KUSHIRO, I. (1964): The system diopside-forsterite-enstatite at 20 kilobars. Yb. Carnegie Instn. Wash., No. 64 (1963 – 64), 101 – 08.

LARSSON, W. (1940): Petrology of interglacial volcanics from the Andes of northern Patagonia. Bull. Geol. Inst., Univ. Uppsala, 28, 192 – 405.

MINATO, M., M. GORAI, and M. HUNAHASHI, ed. (1965): The geologic development of the Japanese Islands. Tokyo, 445p.

NICHOLS, R.L. (1970): Geomorphology of Antarctica. Antarctic Map Folio Series, Folio 12, Geology, Amer. Geogr. Soc., New York.

PÉREZ D'ANGELO, E. and L. AGUIRRE LE BERT (1969): Relación entre estructura y volcanismo cuaternario andino en Chile. Intern. Upper Mantle Symposia, Mexico, 1968, No. 22-B, 39 – 46.

PICHLER, H. and W. ZEIL (1969): Die quartäre 'Andesit'-Formation in der Hochkordillere Nord-Chiles. Geol. Rdsch., 58, 866 – 903.

QUARTINO, B.J. (1957): El basalto olivinico del Cerro el Pedrero, Chubut. Revta Asoc. Geol. Argent., 12, 233 – 64.

QUENSEL, P.D. (1912): Geologisch-petrologische Studien in der patagonischen Cordillera. Bull. Geol. Inst., Univ. Uppsala, 11, 1 – 114.

REINISCH, R. (1906): Petrographische Beschreibung der Gaussberg-Gesteine. Dt. Sudpol-Exped., 2, Ht. 1, 73 – 87.

SIEGERS, A., H. PICHLER and W. ZEIL (1969): Trace element abundances in the 'Andesite' formation of northern Chile. Geoch. Cosmoch. Acta, 33, 882 – 887.

STEWART, D. (1956): On the petrology of Antarctica. (In CRARY, A.P., L.M. GOULD, E.O. HULBURT, H. ODISHAW, and W.E. SMITH, ed. Antarctica in the International Geophysical Year. Washington, D.C., American Geophysical Union. 52 – 74.) [Geophysical monograph No. 1.]

TYRRELL, G.W. (1931): Report on rock specimens from Thule Island, South Sandwich Islands. 'Discovery' Rep., 3, 191 – 97.

TYRRELL, G.W. (1932): The basalts of Patagonia. J. Geol., 40, No. 4, 374 – 83.

TYRRELL, G.W. (1945): Report on rocks from west Antarctica and the Scotia arc. 'Discovery' Rep., 23, 37 – 102.

UNIVERSIDAD DE CHILE (1963): Gravity chart of the southern Andes. Instituto de Geofisica y Sismologia, Univ. de Chile, Santiago.

VALENZUELA A., E., L. CHAVEZ, B., and F. MUNIZAGA V. (1968): Informe preliminar sobre la erupción de isla Decepción ocurrida en diciembre de 1967. Inst. Antartico Chileno, Boletin No. 3, 3 – 14.

ZEIL, W. (1963): Die Verbreitung des jungen Vulkanismus in der Hochkordillere Nordchiles. Geol. Rdsch., 53, 731 – 57.

ZEIL, W. and H. PICHLER, (1967): Die Känozoische Rhyolith-Formation in mittleren Abschinitt der Anden. Geol. Rdsch., 57, 48 – 81.

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