PETROLOGY AND GEOCHEMISTRY OF THE JUAN FERNANDEZ ISLANDS, SOUTH EAST PACIFIC

by
P. E. BAKER
Department of Geology, University of Notthingham,
Nottingham NG7 2RD, UK
and
F. A. KEYVAN-SCOCOUHI
Department of Earth Sciences, University of Leeds,
Leeds, LS2 9JT, UK

AGE RELATIONS

The Juan Fernandez archipelago lies in the southeastern sector of the Nazca Plate some 700 km west of the Chilean port of Valparaiso (Fig. 1). It comprises the deeply dissected volcanic island of Robinson Crusoe (formerly Masatierra), its off-lying islet of Santa Clara and the younger shield volcano of Alexander Selkirk (formerly Masafuera) which lies 150 km to the west. The islands appear unrelated to any major structural features of the ocean floor and it is concluded that they are the products of isolated intra-plate volcanism.

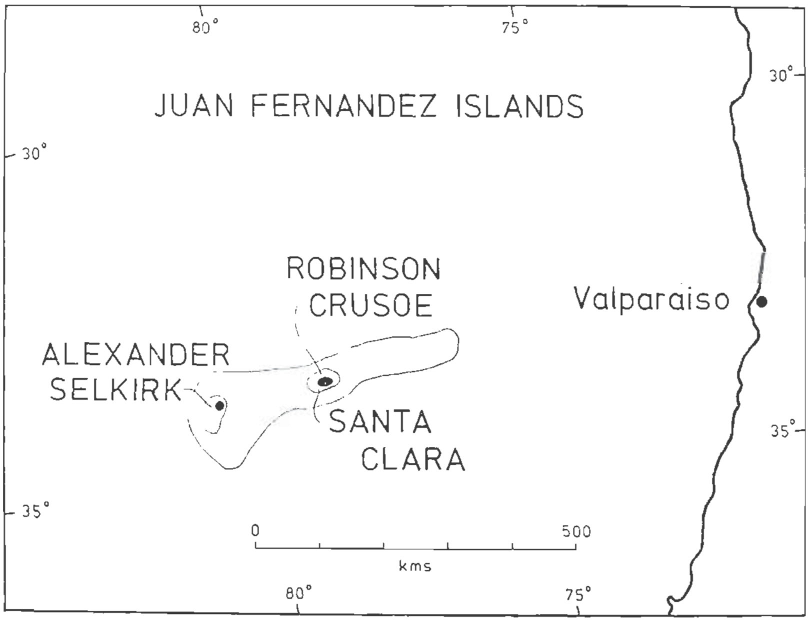

Fig. 1 — Location map of the Juan Fernandez archipelago.

A potassium-argon age determination on a dolerite from the north eastern part of Robinson Crusoe gave an age of approximately 5 Ma (personal comunication D. C. Rex, Leeds University) and although no radiometric ages are available for Alexander Selkirk its general morphology would seem to suggest an age of less than 1 Ma. If this is so then the age relations between the tyo islands are consistent with easterly motion of the Nazca Plate over a fixed «hot spot» with a minimum motion of about 2 cm per year. On the same longitude but some 500 km north of here the age relationship and apparent plate motion finds a parallel in the twin islands of San Felix and Sam Ambrosio. These two islands are only 30 km apart suggesting a motion of the order of 10 cm per year. (GONZALEZ-FERRAN et al., 1979).

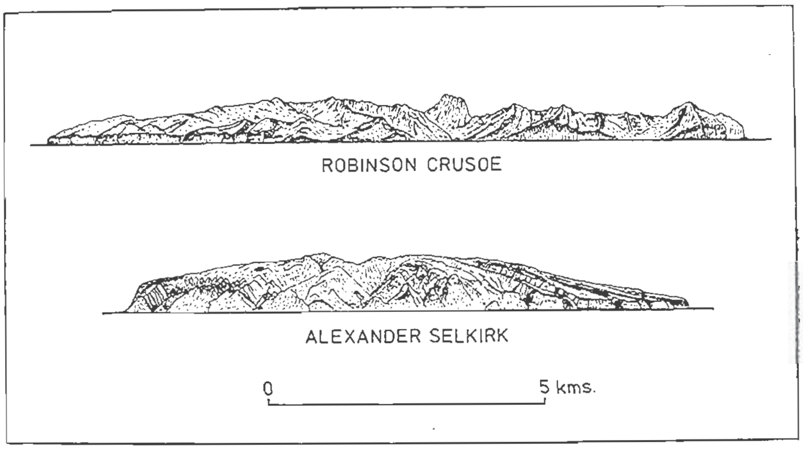

Fig. 2 — Sketches to illustrate contrasting morphologies of the two main islands of the Juan Fernandez archipelago. Robinson Crusoe viewed from the north-east and Alexander Selkirk from the east.

In spite of the general contrast in degree of erosion of the islands of Robinson Crusoe and Alexander Selkirk (Fig. 2) minor activity has apparently persisted to more recent times on the former, notably on the south-western peninsula. There are no records of any historic volcanic activity on either of the islands but there is a report of a submarine eruption off Robinson Crusoe in 1835 (SKOTTSBERG, 1956).

MORPHOLOGY

Robinson Crusoe (48 sq. km) is a forested island with sharp relief and a very irregularly embayed coastline. The main part of the island extends for about 12 km in a NW-SE direction and is about 3 km wide. Near the north-western end a ragged peninsula about 1 km wide reaches for some 6 km to the south west. From their dips, the lavas and pyroclastics of the main part of Robinson Crusoe appear to have been derived from at least four separate volcanic centres which are now represented by the caldera structures forming the major indentations along the northern coastline. The north-westerly alignment of the four calderas is roughly parallel with the trend shown by numerous features in the South Pacific such as the Chile Rise, the Tuamotu Ridge and various fracture zones. The largest of these caldera structures forms a great amphitheatre around Bahia Cumberland and is overlooked by Cerro Yunque (922 m), the highest peak on the island. A number of tangential dykes, probably associated with the ring fracturing are exposed in places around the caldera rim. (Fig. 3).

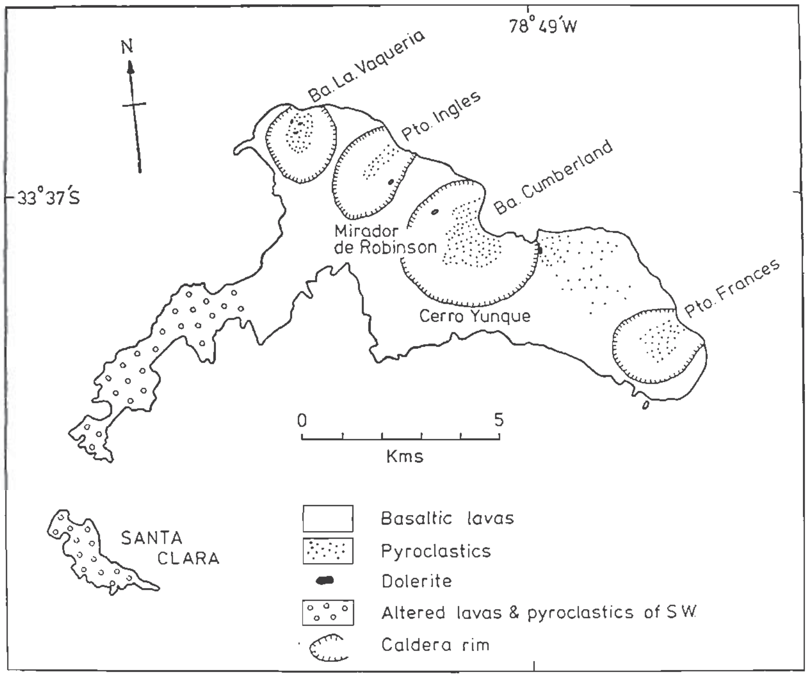

Fig. 3 — Simplified geological sketch map of Robinson Crusoe and Santa Clara.

Broad open valleys cut back into the other three volcanic centres of La Vaqueria, Puerto Ingles and Puerto Frances. At the northernmost point of the island vertical sea cliffs some 300 m high expose a section of lava flows and interbedded scoria with numerous cross-cutting dykes connected with the La Vaqueria centre. A series of rhythmically layered dolerite sills are exposed in the main valley running across the caldera floor.

The south-western peninsula of Robinson Crusoe contrasts sharply in relief with the main part of the island. The promontory lies only between 50 and 150 m above sea-level and there is scarcely any forest cover. From this gently undulating surface rise a number of small hills which are probably remants of parasitic centres. The lavas and tuffs of this area have undergone extensive hydrothermal alteration unlike most of their counterparts to the north-east. The small island of Santa Clara (2 sq. km) can be regarded as an extension of the south-western peninsula of Robinson Crusoe, from which it is separated by a shallow channel about 2 km wide. It is deeply eroded and composed for the most of part rubbly decomposed lavas and tuffs cut by numerous dykes.

Alexander Selkirk (52 sq. km) reaches 1615 m above sea level and has a dome shaped form. It is roughly oval in plan and has a relatively smooth coastline lacking the embayments of its neighbours. It has the appearance of a relatively young shield volcano, with radiating valleys cutting into primary constructional surfaces.

PETROGRAPHY

Although dominantly basaltic, the lavas show a considerable compositional range from basanitoids, with more than 10 % normative nepheline to alkali basalts, olivine tholeiites, quartz tholeiites and hawaiites. Accumulative varieties, particularly picrite basalts are common but hawaiites (as defined by normative andesine) are the most abundant rock-type : more evolved types are rare but a single trachyte has been reported from Alexander Selkirk (Quensel 1912 ; McBirney and Williams, 1969). The basanitoids are all porphyritic rocks with phenocrysts of both olivine and clinopyroxene. The basalts are mostly porphyritic, mainly picrites, but aphyric varieties occur in the vicinity of Puerto Frances. Plagioclase phenocrysts occasionally predominate in some of the basalts at Puerto Ingles and at La Pina near Puerto Frances. On the whole the hawaiites are less porphyritic than the basaltic rocks and typically show a rather patchy or directive texture with flow banding. Plagioclase becomes a much more conspicuous component in these more differentiated rocks. Melting experiments (dry) carried out by N. Chapman at the Department of Earth Sciences, Leeds University, on picrite 17908 from Puerto Frances showed olivine as the liquidus phase over the 1-10 kb range and the temperature intervals 1300-1150°C. At pressures below 2 kb olivine was joined by plagioclase at 1150° but above 8 kb clinopyroxene precipitated before plagioclase.

Core compositions of olivines in the lavas reach Fo_{88} but the margins are invariably zoned eg. to around Fo_{60}. Clinopyroxenes usually have a pinkish-brown colour and a TiO_2 content of 2.75 % is recorded in one instance : their Al_2O_3 content is consistently around 5 %. The clinopyroxenes from the lavas are augites clustering around composition of Ca_{46} Mg_{41} Fe_{13}. Plagiodare is mostly zoned within the range An_{60}-An_{40}.

Small weathered ultramafic blocks are found at various localities within Cumberland caldera but they are most concentrated in a basanitoid flow in Queb Piedra Agujeriada. The blocks include lherzolites, harzburgites and dunites. The lherzolites contain olivine (Fo_{92}), enstatite, diopside, augite (Ca_{42} Mg_{52} Fe_6) and spinel. Exsolution features are common in the orthopyroxene.

GEOCHEMISTRY

Examples of the chemical composition of Juan Fernandez lavas are presented in Table 1. The more distinctive features of the Juan Fernandez suite are as follows:

a) TiO_2 contests are high, reaching over 4 % in two of the quartz tholeiites (hawaiites) from Cumberland caldera. The values are, however, comparable with those in the lavas of Easter Island.

b) There is marked variation in Fe/Mg ratios, with the most pronounced iron enrichment being evident in the quartz tholeiites. However, iron concentration does not attain the high values reached in either Easter Island (BAKER et al., 1974) or the Galapagos Islands (McBIRNEY and WILLIAMS, 1969).

c) Enrichment in the incompatible elements Ba, Sr, Rb, Nb and Zr is especially marked in a group of alkalic lavas from Robinson Crusoe. However, these elements fail to discriminate between some of the undersaturated lavas and the tholeiites.

d) $^{87}Sr/^{86}Sr$ ratios are almost entirely within the range 0.702-0.703, the lowest value being obtained on one of the more differentiated hawaiites from Alexander Selkirk.

e) Chondrite-normalised rare earth element patterns show LREE enrichment. The basanitoids and alkali basalts show higher overall concentrations of REE and more pronounced enrichment in the lighter elements than the tholeiites.

f) Apart from the trachyte, K_2O reaches its maximum value (> 2 %) in the basanitoids although even the tholeiites are more alkali rich than their Hawaiian counterparts.

g) Although relatively few analyses are available from Alexander Selkirk and Santa Clara it would appear that tholeiitic varieties are more prevalent on these islands than on Robinson Crusoe.

A wide compositional spread such as that observed on Juan Fernandez seems to characterise isolated intraplate volcanoes and may be related to a rapidly changing geothermal gradient affecting both depth and degree of melting. Superimposed on this, polybaric fractionation would appear to be responsible for much of the compositional range observed in the archipelago. Variation in the more mafic lavas can be ascribed almost exclusively to fractionation of magnesian olivine. However, at higher pressures (above 8 kb) clinopyroxene which appears as phenocrysts in the basanitoids is also likely to have played a part. Separation of plagioclase may have exercised some influence on compositional relations in the more evolved rocks.

REFERENCES

BAKER, P. E., BUCKLEY, F. and HOLLAND, J. G., 1974 : Petrology and geochemistry of Easter Island. Contrib. Mineral .and Petrol., 44, p. 85-100.

GONZALEZ-FERRAN, O., REX, D., BAKER, P. E., KAUSEL, E. and GONZALEZ, C., 1979 : San Felix and San Ambrosio Islands : an active hot spot in the Easter volcanic chain. Hawaii Symposium on Intraplate volcanism and submarine volcanism, Hilo, Hawaii, p. 14. (Abstr.).

McBIRNEY, A. R. and WILLIAMS, H., 1969 : Geology and petrology of the Galapagos Islands. Geol. Soc. Am. Mem., 118, 197 pp.

QUENSEL, P., 1912 : Die Geologie der Juanfernandezinseln. *Bull. Geol. Instn. Univ. Upsala 11*, p. 252-290.

SKOTTSBERG, C., 1956 : The Natural History of Juan Fernandez and Easter Island 1. Upsala, 438 pp.

TABLE 1

REPRESENTATIVE CHEMICAL ANALYSES WITH SELECTED TRACE ELEMENTS AND PARTIAL CIPW NORMS OF LAVAS FROM THE JUAN FERNANDEZ ISLANDS

		17910	*17919*	*17908*	*17881*	*18001*	*17854*
	SiO_2	43.31	44.97	42.47	47.44	46.84	50.03
	TiO_2	3.01	2.59	2.84	3.24	3.35	3.38
	Al_2O_3	14.40	13.72	13.28	14.90	14.40	15.60
	Fe_2O_3	2.85	2.77	3.50	3.54	7.06	3.02
	FeO	8.57	8.71	7.74	7.55	4.88	7.67
	MnO	0.20	0.22	0.19	0.15	0.14	0.13
	MgO	10.22	10.59	13.35	6.74	5.97	5.53
	CaO	10.40	9.29	11.20	11.28	10.27	8.94
	Na_2O	3.96	3.88	2.33	2.86	1.45	3.53
	K_2O	1.74	1.72	0.49	0.71	0.79	1.13
	H_2O+	0.68	0.66	1.81	0.47	2.42	0.49
	H_2O-	0.24	0.37	0.94	0.31	0.78	0.19
	P_2O_5	0.75	0.83	0.58	0.45	0.49	0.60
	TOTAL	100.36	100.32	100.72	99.64	98.84	100.24
PPM	Ba	n.d.	750	450	n.d.	250	n.d.
	Nb	83	89	15	32	38	31
	Rb	41	53	3	7	14	20
	Sr	850	850	630	460	470	510
	Zr	330	360	240	210	230	300
PART NORM	Qz	—	—	—	—	9.59	0.30
	Ne	15.23	10.76	4.61	—	—	—
	Hy	—	—	—	6.31	8.63	13.37
	Ol	16.20	16.93	21.32	4.20	—	—

17910 : Alkali basalt, Puerto Frances, Robinson Crusoe.
17919 : Basanitoid, La Vaqueria, Robinson Crusoe.
17908 : Alkali basalt, Puert oFrances, Robinson Crusoe.
17881 : Olivine tholeiite, west side, Puerto Ingles, Robinson Crusoe.
18001 : Quartz tholeiite, north side of Bahia del Padre, Robinson Crusoe.
17854 : Hawaiite, south of settlement, Alexander Selkirk.