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DREDGED ROCKS ALONG A CROSS-SECTION IN THE SOUTHERN NEW HEBRIDES ISLAND ARC AND THEIR BEARING ON THE AGE OF THE ARC

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1. Introduction

The New Hebrides archipelago represents a north-south orientated island arc situated in the southwest Pacific. The arc faces west and comprises a trench and an active line of volcanoes (Fig. 1). The seismicity shows a Benioff plane dipping eastwards beneath the arc (Dubois 1969, Pascal 1974).

Previous dredging attempts across island arcs have been mainly confined to the trench slope e.g. in New Britain, the Mariannas and the New Hebrides by Petelin (1964), in Tonga by Fisher and Engel (1969), in the New Hebrides by Luyendyk et al (1974) and recently in the Mariannas and Yap trenches by the R.V. Mendeleev. Tuffs, basalts and sometimes, though not in the New Hebrides trench, dolerite, gabbro and serpentinite have been collected from these trenches.

In the present study dredged samples (Fig. 2 and 3, table 1) are described from a cross-section of the main structural units which constitute the New Hebrides arc (Karig and Sharman 1975, Dugas et al., this volume). These are :- the trench, the imbricate zone, the frontal arc fore-horst, the active volcanic line (Central Chain) and, at the rear, a rifted trough or inter-arc basin (Karig and Mammerickx, 1972) known as the Coriolis Trough (Dubois et al 1975, 1976).

Basaltic andesites and fine tuffs barren of foraminifera were collected in the upper part of the imbricate zone of the trench (at locality GO 329 D) ; Luyendyk et al (op cit) collected slightly more basaltic lavas from the same zone to the west of Efate and the Torres Islands. Samples from the upper slope of the fore-horst (GO 330 D) comprised fine tuffs bearing foraminifera of Pleistocene age (Table IV).

Dredging of the western scarp of the Coriolis Trough (GO 335 D) adjacent to the active volcanic line, produced andesites, pyroclastic breccias and tuffs with foraminifera of late Pliocene age. The axial region of this trough (GO 331 D, GO 336 D) yielded only tuffs with Pleistocene forams. From the eastern scarp of the Coriolis Trough were dredged basalts, pyroclastic breccias, biocalcarenite with Upper Miocene to Recent forams (GO 333 D, GO 334 D), and tuffs with Lower-Middle and late Middle Pliocene to early Upper Pliocene forams (GT1 3 D).

2. Petrography of the lavas and pyroclastics

The dredged lava samples range (Table II) from ankaramite and porphyritic basalt (with 48 - 49 % SiO_2) on the eastern scarp of the Coriolis Trough to andesites (60 - 61 % SiO_2) on the western scarp of the trough. Basaltic andesites (54 % SiO_2) occur in the imbricate zone of the trench.

The phenocryst mineralogy of the samples has been determined by microprobe analyses

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(Table III, Figs. 4 and 5). In the basalts and their associated pyroclastic breccias (GO 334) plagioclase phenocrysts (An 87) coexist with diopsidic augite and olivine. The basaltic andesites (GO 329) contain plagioclase averaging An47 together with augite and coexisting hypersthene. In the andesites (GO 335) the plagioclase phenocrysts range from An67 to An54 and occur in association with augite and subcalcic augite.

Groundmass minerals comprise labradorite, augite and ore in the basalts. In the basaltic andesites the groundmass plagioclase averages An43 however low-calcium pyroxenes were not recognized. The andesites contain groundmass plagioclase of An47 together with hypersthene, pigeonite and ore.

A. - The imbricate zone (GO 329)

Dredged basaltic andesites (Table II) from the imbricate zone generally contain fewer than 10 % phenocrysts. These consist of small laths and microphenocrysts of andesine (An47, Table III) small fresh euhedra of augite, microphenocrysts of hypersthene and occasionally of ore. Groundmasses vary from pilotaxitic to intersertal, the latter types containing a base of almost opaque dark brown glass. Groundmass pyroxene and ore characteristically assume acicular habits, and variolitic clusters of pyroxene and plagioclase (An43) are commonly developed. The abundant small vesicles are unfilled.

B. - Western scarp of the Coriolis Trough (GO 335)

Rocks dredged from the western scarp comprise glassy, poorly porphyritic lavas of two main types. Those with pilotaxitic groundmasses and less than 10 % phenocrysts are the most common and are represented in Table II by all four andesite analyses. Their phenocrysts are of oscillatory zoned plagioclase averaging An54 together with augite and ore microphenocrysts. Groundmasses consist of a felt of plagioclase microlites (An46) with hypersthene, pigeonite and ore ; mafics are acicular as in the basaltic andesites of the imbricate zone and together with plagioclase may form variolitic clusters. Vesicles are unfilled but ore and pyroxene needles frequently project across them.

The second and less dominant petrographic type has hyalopilitic groundmasses and between 10 to 30 % phenocrysts. Phyric plagioclase, oscillatory zoned and with an average An67 composition coexists with clinopyroxene phenocrysts of faintly pleochroic augite and subcalcic augite. The groundmass consists of fresh, pale brown glass in which are studded microlites of plagioclase together with ore and clinopyroxene granules. Vesicles are partly infilled by microcrystalline zeolite.

The two pyroclastic rocks from the western scarp comprise different types of breccia. One is an autobreccia or vein breccia in which highly angular fragments of fresh yellowish microlitic glass are veined and cemented by microcrystalline carbonate. The other is a pyroclastic breccia composed mainly of angular clasts of fresh pale yellow microlitic glass, occasionally with dark red "rhyolitoid" banding. Subordinate clasts are of flow-banded pilotaxitic or glassy lava. The matrix is of finely comminuted angular glass clasts set in a fibrous, possibly pumiceous base.

C. - Eastern scarp of the Coriolis Trough (GO 334 and 333)

Rocks from the upper part of the eastern scarp (GO 334) range from ankaramite (334 D5, Table II) with abundant augite phenocrysts up to 8 mm in length accompanied by completely serpentinised olivine and rare plagioclase (An87, Table III). At the other extreme is feldsparphyric basalt (334 D1, Table II) with 55 % highly sericitised, labradorite laths, fresh augite euhedra and serpentinised olivine. Porphyritic basalts average about 20 % plagioclase, intensely sericitised, together with subordinate clinopyroxene and pseudomorphed olivine. The groundmasses of these lavas have intergranular textures and basaltic proportions of labradorite, augite and ore. Groundmass alteration of the ankaramite and feldsparphyric lavas has resulted in oxidation of the ore, but in the porphyritic basalts the plagioclase and clinopyroxene are also affected, and much interstitial chlorite, quartz, epidote and carbonate is present. The albite composition of the plagioclase phenocrysts in 334 D4 (Table III) indicates that this alteration is associated with spilitisation of the rock. In the highly altered sample 334 D3 micropegmatitic veins of quartz, untwinned feldspar and carbonate are present.

Samples from the lower part of the eastern scarp (GO 333) are dominantly of ankaramitic basalts and olivine-basalts, with phyric constituents averaging 25 % augite, 15 % pseudomorphed olivine and 5 % plagioclase. Subordinate porphyritic basalts contain 20 % plagioclase and 10 - 15 % mafics. Groundmass textures are intergranular, with plagioclase

frequently forming orientated microphyric laths. Ore and augite form abundant small euhedra and granules and in one sample (333 D12) small pseudomorphed olivine granules are present. Most of the samples contain much secondary chlorite and other turbid alterational material in the interstices of the groundmass.

The three pyroclastic samples are also from the lower part of the eastern scarp. They represent lithic tuff grading to pyroclastic breccia and contain angular/subrounded clasts of highly oxidised ankaramitic basalt. Phenocrysts in the lava clasts (333 D3, Table III) are dominantly of augite-endiopside composition (Fig. 5) and are accompanied by pseudomorphed olivine and plagioclase. The matrix of the breccias is poorly sorted, consisting of silt or sand-sized fragments of pumice and scoria and finer comminuted glass shards probably representing an ash component. Vesicles in the pumiceand scoria have chlorite infillings.

D. - Comparison of dredged samples with rocks from Tanna, Aneityum and Futuna

There are strong petrographic similarities between the glassy, vesicular lavas from the imbricate zone (329) and the western scarp of the Coriolis Trough (335) and the subaerial basaltic-andesites and andesites of the Pleistocene-Recent Siwi Group of Tanna (Carney and Macfarlane, in prep.). Petrographic features in common include hyaline to pilotaxitic groundmasses in which ore and pyroxene assume acicular habits, and a high degree of vesicularity.
Plagioclase phenocrysts are larger and more abundant in the Tanna rocks, but olivine is characteristically rare or absent in all three localities. Rhyolitoid banding, found in glassy clasts from the dredged pyroclastic breccia 335 D5, is also known in certain intensely welded agglomeratic horizons in the Siwi Group.

The porphyritic basalts from the eastern scarp of the Coriolis Trough (334 and 333) contain ankaramitic varieties very similar to those of Futuna, an island located on the crest of the same scarp further to the north (Fig. 1). The general range of feldsparphyric, prophyritic and ankaramitic basalts with intercalated pyroclastic breccias is also similar to that of Tanna and Aneityum.

One characteristic feature of the eastern Coriolis Trough dredged samples which is not found in the terrestrial volcanics is the high degree of alteration in the groundmass of the lavas and the almost ubiquitous infilling of vesicles in the scoriaceous component of the pyroclastic rocks.

3. Phenocryst chemistry

Microprobe analyses of pyroxenes from the dredged lavas (Table III) show in Figure 4 a trend from endiopside to subcalcic augite. The occurrence of pigeonite and hypersthene in the groundmass of andesites from the western scarp of the Coriolis Trough suggests strong affinities to the pigeonitic, series of Kuno (1968). Plagioclase phenocrysts (Fig. 5) show a range from andesine in the andesites and basaltic andesites to bytownite in the ankaramitic basalts. Oscillatory zoning in a plagioclase from one of the basalts extends over a range from sodic labradorite to andesine.

4. Geochemistry of the lavas

An AFM plot of lavas, quenched glasses and phenocrysts from the dredged samples presented in Figure 6 shows a broad trend of iron enrichment within the tholeiitic field of the New Hebrides Central Chain lavas (Carney and Macfarlane, this volume). However the apparent low peak of iron enrichment of the Coriolis Trough basalts (e.g. 334 D1) may also be comparable to the "tholeiitic low-iron" trend noted in lavas from the outlying eastern islands (including Futuna) and Eastern Belt of the New Hebrides (Carney and Macfarlane, this volume).

The total alkalies vs silica diagram of Figure 7 (in which are also included two samples dredged from the trench by Luyendyk et al, op cit) suggests that the dredged samples are related more to the low-alkali Futuna trend than to the higher-alkali field of the Tanna lavas. The Aneityum andesites, and also those of the Mt. William Formation of Erromango (Colley and Ash, 1971), have been affected by late hydrothermal activity which may have caused alkali leaching ; similarly the two basalts with variable alkali contents from the eastern scarp of the Coriolis Trough are from a sequence affected by spilitisation.

In the potash/silica diagram of Figure 8, the dredged samples compare once again with the Futuna trend rather than to the higher-potash trend of the Tanna lavas. The two samples from the imbricate zone may show a displacement towards a potash trend even lower than those from the Coriolis Trough and Futuna.

In TiO_2 content the samples dredged in this study range (Table II) from 0.43 to 0.85 % which compares with that of Tanna and Aneityum but may be slightly lower than Futuna (0.82 - 0.96 %) ; these ranges are appropriate to either the calc-alkaline or the "Island Arc Tholeiite" series of Jakes and Gill (1970). Na_2O/K_2O ranges of 2 to 2.5 for the Coriolis Trough (excluding 334 D5, which has a value of 35) compare with those of 2-3 for Futuna, 2-6 for samples from the imbricate zone and 1-6 for the Tanna and Aneityum lavas ; the more restricted ranges for the Coriolis Trough and Futuna rocks are appropriate to the calc-alkaline series of Jakes and Gill, while those from the imbricate zone and Tanna/Aneityum span both the calc-alkaline and "Island Arc Tholeiite" series of those authors. The difficulties of classifying rocks on such criteria are well demonstrated by the sample 335 D4 (from the andesite succession of the western scarp of the Coriolis Trough) in which microprobed interstitial glass with a distinctly alkaline Na_2O/K_2O ratio of 1.00 (according to the parameters of Jakes and White, 1969) coexists with augite and subcalcic augite phenocrysts typical of an overall tholeiitic mineralogy.

5. Palaeontology of dredged tuffs and limestones

The dredged tuffs contain a rich foraminiferal microfauna of which the dominant species are planktonic (faunal determinations by G.W. Huges ; see Table IV). Only the latter have an age range which is sufficiently restricted to be of precise stratigraphic value. Although these stratigraphic ranges are based only upon the available foraminifera, and the number of species is restricted and poorly represented in a single thin section, they are in good agreement with identifications on the nearby islands (Carney and Macfarlane, in prep). The species found in the tuffs are characteristic of muddy to silty sediments deposited in deep water. Of the limestones, only GO 333 11 and 12 contain the larger benthonic foraminifera which are usually found in an inner shelf reefal environment (Hughes, 1973). The rock matrix is organic and calcareous with fragments of hermatypic calcareous algae and is typical of an inner shelf reefal environment ; a medium to high-energy regime is suggested by the lack of any inorganic contaminants.

A. - Foraminiferal evidence bearing on the age of the dredged samples - a summary

Faunal identifications (Table IV) suggest that samples dredged from the imbricate zone of the trench and from the axis of the Coriolis Trough are of Pleistocene age, those from the western scarp of the Coriolis Trough are of late Pliocene, and rocks from the eastern scarp of this trough are probably no older than the Middle Pliocene. These findings are summarised, and samples with diagnostic species are listed, as follows :

GO330D (Samples 2,3,4) : From the upper part of the imbricate zone - Pleistocene.
GO335D (Samples 13-15) : Western scarp of Coriolis Trough - late Pliocene.
GO331D (Samples 5-10) : Axial zone of Coriolis Trough - Pleistocene.
GO336D (Samples 16-21) : Axial zone of the Coriolis Trough - Pleistocene.
GO333D (Samples 11-12) : Eastern scarp of the Coriolis Trough - Upper Miocene to Recent.
GT13D (Sample 3 A) : Eastern Scarp of the Coriolis Trough - Lower to Middle Pliocene.
GT13D (Sample 6) : Eastern Scarp of the Coriolis Trough - late Middle to early Upper Pliocene.

6. Age relationships between dredged samples and terrestrial volcanism

Table V presents the results of a series of age determinations on lavas from Tanna and Futuna. The latter's age of 1.80 ± 0.05 m.y. is consistent with its position at the crest of a 3000 m high escarpment, the lower part of which is occupied by lavas and tuffs for which foraminiferal age determinations (GT13D) discussed above indicate an age no older than Middle Pliocene.

The earliest *in situ* lavas yet dated from this area are the subaerial basaltic sequences of the Green Hill Volcanics on Tanna. Their age of 2.5 m.y. (Table V) represents the initial emergence of this Central Chain island and post-dates a major tectonic phase in the central part of New Hebrides dated at approximately 4.0 m.y. which is thought (Carney and Macfarlane, this volume) to relate to the onset there of the subduction regime at present responsible for the Central Chain volcanism.

The age relationships between the Tanna and Coriolis Trough lavas may be of some significance in determining the various stages in the emplacement of the "new" lithosphere beneath this part of the New Hebrides. Recent estimates of the rate of conver-

gence of the eastwards-moving lithosphere at the New Hebrides Trench by Dubois et al (in press) average between 10 and 12 cms/yr.. Assuming a convergence of 10 cms/yr, and inferring that the inception of the Coriolis Trough volcanism in the Middle to Upper Pliocene (about 3-4 m.y.) coincided with the arrival of lithosphere some 300 kms beneath it, it can be calculated from Pascal's (1974) observations on the dip of the Benioff Zone that the lithosphere was in position beneath Tanna by about 5-6 m.y. and had first commenced its descent at about 7-8 m.y. These estimates suggest that early Pliocene formations should underlie the Green Hil Volcanics of Tanna, and it is interesting here to note the occurrence, beneath the inferred stratigraphically equivalent"Plateau Formation" of Erromango, of conglomerates containing lava clasts dated (Colley and Ash, 1971) at between 4-9 to 5-5 m.y.

Following the 1-8 m.y. volcanism on Futuna island a major faulting episode took place which was probably related to uplift of the eastern shoulder of the Coriolis Through. This tectonic event is presumably a consequence of rifting and may have been responsible on Tanna for a Plio-Pleistocene tilting and down-faulting of the eastern margin of the Green Hill Volcanics (Carney and MacFarlane, in prep.). Subsequent volcanisms on Tanna at 0-7 (Table V) and about 0-2 m.y. were associated with regional uplift and eastwards tilting of the island. These movements suggest a low-amplitude warping of the crust which may, in a general way, be associated with further tectonism within or along the Coriolis Trough.

7. Conclusions

The dredged rocks comprise a sequence of extrusive basalts, basaltic-andesites and andesites. A submarine origin for the samples from the eastern scarp of the Coriolis Trough is implied by the spilitisation of some of them, however the occurrence of reef limestone clasts in the dredge hauls of GO 333 may also suggest a period of emergence either during or after the volcanism. Samples from the western scarp and the imbricate zone in contrast do not show this alteration, and many have unfilled vesicles.

Petrographically, there are some similarities between the andesites and basaltic-andesites from the western scarp and imbricate zone, and both localities have yielded identical lava types to those of the Pleistocene-Recent Siwi Group of Tanna. The eastern scarp basaltic sequences are similar to those on Futuna island.

Geochemically the dredged lavas all lie on the low-iron, low-alkalies trend of Futuna, and thus differ from the Tanna suite which, while more "tholeiitic" in its iron-enrichment, is at the same time more alkalies-rich. The lavas from the Coriolis Trough interarc basin have a tholeiitic mineralogy, however their Na/K ranges are more appropriate to those of alkaline and calc-alkaline rocks. In their low-potash trend when compared with the Tanna rocks, the Coriolis Trough and Futuna lavas show a negative correlation of potash content with distance away from the trench ; this has been noted previously by Mallick (1973) for the islands of Gaua and Mere Lava in the north of the archipelago, and has been attributed by Carney and Macfarlane (this volume) to the larger degrees of partial melting beneath the interarc basins to the east of the Central Chain.

Assuming a constant convergence rate of 10 cms/yr for lithosphere at the New Hebrides Trench, the inception of the Coriolis Trough interarc basin at about 3-4 m.y. can be extrapolated backwards in time to indicate the commencement of the present subduction regime at about 7-8 m.y. The first thermal effects of this subduction were probably felt beneath the Central Chain island of Tanna at about 5-6 m.y. These age ranges are in approximate agreement with a major tectonic phase inferred elsewhere to have affected the central part of the New Hebrides at about 4-0 m.y. Subsequent tectonic movements affecting the southern islands of the Central Chain may be related to warping associated with the development of the adjacent Coriolis Trough interarc basin.

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Table I - Dredgings details

DREDGING Locality n°	STRUCTURAL UNIT	NATURE	Initial Satellite position of the dredge		Final Satellite position of the dredge		DEPTHS IN METERS	
			Latitude	Longitude	Latitude	Longitude	Initial	Final
GO 329 D	Imbricate zone	Basaltic andesites and Tuff	20°48'5 S	168°56'8 E	20°47'0 S	168°59'9 E	4700	4000
GO 330 D	Frontal arc	Tuff	20°35'8 S	169°19'6 E	20°34'8 S	169°21'3 E	1900	1500
GO 335 D	West horst of the Coriolis Trough	Andesites, Pyroclastic breccia and Tuff	20°38'0 S	169°56'6 E	20°38'4 S	169°55'0 E	2050	1330
GO 331 D	Axial zone of the Coriolis Trough	Tuff	20°00'8 S	170°15'2 E	20°00'8 S	170°14'5 E	2440	1940
GO 336 D	" "	Tuff	20°39'5 S	170°03'0 E	20°40'0 S	170°05'6 E	2160	1900
GTI 3	East Horst of the Coriolis Trough	Tuff	19°30'8 S	170°00'5 E	19°28'0 S	170°07' E	2690	1750
GO 333 D	" "	Basalt, Pyroclastic breccia, Tuff	19°59'5 S	170°21'6 E	19°59'6 S	170°22'8 E	2150	1340
GO 334 D	" "	Biocalcarenite	19°59'4 S	170°22'6 E	19°59'7 S	170°23'0 E	1440	1140

Table II - Chemical analyses

	GO 329 D5	GO 329 D6	GO 335 D6	GO 335 D7	GO 335 D8	GO 335 D9	GO 334 D1	GO 334 D5	Luyendyck et al D14	Luyendyck et al D16
SiO_2 %	54.40	54.30	60.00	60.50	60.40	60.80	49.70	47.90	50.11	52.73
Al_2O_3 %	15.00	15.10	13.95	13.80	13.80	13.85	16.05	11.15	18.56	15.79
Fe_2O_3 %	3.25	3.80	2.15	2.40	2.40	1.90	3.80	2.75	5.89	6.03
Fe O %	6.20	5.75	5.85	5.65	4.85	5.40	5.30	4.40	5.74	6.27
Mg O %	4.10	4.25	1.75	1.75	1.55	1.50	7.60	13.20	3.10	3.50
Ca O %	8.95	9.25	4.65	4.80	4.30	4.25	7.40	13.15	9.98	7.63
Na_2O %	3.30	3.10	4.40	4.35	3.85	3.95	3.30	1.75	2.44	3.50
K_2O %	0.84	0.84	2.35	2.45	2.55	2.40	1.30	0.05	1.39	0.64
TiO_2 %	0.85	0.81	0.79	0.80	0.71	0.71	0.59	0.42	0.90	1.85
MnO %	0.18	0.28	0.19	0.09	0.56	0.23	0.15	0.15	0.15	0.26
P_2O_5 %	0.17	0.15	0.40	0.41	0.36	0.44	0.09	0.05	0.14	0.30
H_2O- %	0.72	1.11	0.95	0.51	1.37	1.05	0.81	3.09	1.28	0.85
H_2O+ %	1.29	1.20	1.84	1.55	2.77	2.37	2.99	1.87	0.63	0.47
Total %	99.25	99.94	99.27	99.06	99.48	98.85	99.09	99.84	100.31	99.82

Table III - Microprobe analyses

	GO 329 D 7			GO 333 D 3			GO 334 D 4			GO 334 D 5			GO 335 D 4		
	24	23	20	167	170	174	116	117	121	146	151	152	2	6	14
SiO2	56.27	52.37	51.59	52.41	52.53	48.94	66.82	51.96	51.89	46.47	51.15	52.30	51.58	48.55	50.23
TiO2	0.05	0.22	0.34	0.17	0.19	0.59	0.02	0.30	0.28	0.03	0.31	0.26	0.08	0.87	0.53
Al2O3	27.35	0.88	1.69	2.46	2.06	14.03	20.28	2.91	2.60	33.20	2.52	1.92	30.31	5.20	4.50
Cr2O3	0.02	0.03	0.06										0.01	0.05	0.17
FeO	0.64	24.33	14.21	4.86	6.06	10.36	0.11	6.41	7.10	0.79	6.99	6.05	0.86	14.43	11.11
MgO	0.05	20.70	13.78	17.47	18.04	7.63	0.05	16.97	16.67	0.36	17.85	16.91	0.14	12.33	16.26
CaO	9.84	1.93	18.20	22.26	20.73	11.61	0.69	21.88	21.25	17.19	20.22	22.05	13.36	17.95	17.50
Na2O	5.82	0.04	0.33	0.19	0.17	1.89	10.85	0.20	0.20	1.56	0.17	0.20	3.71	0.35	0.25
K2O	0.35	0.01	0.08	0.01	0.03	0.74	0.10	0.03	0.02	0.04	0.00	0.00	0.07	0.02	0.01
Total	100.39	100.52	100.28	99.83	99.81	95.79	98.92	100.66	100.01	99.64	99.21	99.69	100.12	99.75	100.44
Si	2.529	1.964	1.946	1.923	1.930		2.953	1.903	1.915	2.151	1.900	1.931	2.348	1.847	1.862
Al	1.449	0.039	0.075	0.106	0.089		1.056	0.126	0.113	1.811	0.110	0.084	1.626	0.233	0.197
Ti	0.002	0.006	0.010	0.005	0.005		0.001	0.008	0.008	0.001	0.009	0.007	0.003	0.025	0.015
Fe	0.024	0.763	0.448	0.149	0.186		0.004	0.196	0.219	0.031	0.217	0.187	0.033	0.459	0.345
Cr	0.001	0.001	0.002										0.000	0.002	0.002
Mg	0.003	1.157	0.775	0.955	0.988		0.003	0.926	0.917	0.025	0.988	0.931	0.009	0.699	0.899
Ca	0.474	0.078	0.736	0.875	0.816		0.033	0.859	0.840	0.853	0.805	0.873	0.652	0.732	0.695
Na	0.508	0.003	0.024	0.014	0.012		0.930	0.014	0.014	0.140	0.012	0.014	0.327	0.026	0.018
K	0.020	0.000	0.004	0.000	0.001		0.006	0.001	0.001	0.002	0.000	0.000	0.004	0.001	0.000
Total	5.010	4.011	4.020	4.027	4.027		4.986	4.033	4.027	5.014	4.041	4.027	5.002	4.024	4.033

24 : plagioclase phenocryst - 23 : pyroxene phenocryst - 20 : pyroxene groundmass - 167 : pyroxene phenocryst - 170 : pyroxene groundmass - 174 : glass inclusion in pyroxene - 116 : plagioclase average - 117 : pyroxene groundmass - 121 : pyroxene phenocryst - 146 : plagioclase phenocryst - 151 : pyroxene groundmass - 152 : pyroxene phenocryst - 2 : plagioclase phenocryst - 6 : pyroxene groundmass - 14 : pyroxene phenocryst.

Analytical method : The minerals and the glasses in the thin sections were analysed with a 9-speetrometer A.R.L. electron micropobe at Smithsonian Institution, Department of Mineral Sciences. This system uses corrections based on the method of Bence and Albee (1968). All readings are corrected by on-line PDP-11 computer. A 15 KV accelerating potential, 0.15. A beam current and 10 seconds count time were used during the analyses. 7 analyses were made on GO 329 D specimens, 16 analyses on GO 335 D specimens, 22 analyses on GO 334 D specimens and 24 analyses on GO 333 D specimens.

Table IV - Foraminifera identifications by G.W. HUGHES

PLANKTONIC SPECIES :	GO 329 D	GO 330 D			GO 331 D					GO 333 D			GO 335 D			GO 336 D					GTI 3 D	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Globigerinella aequilateralis			X	X						X				X		X	X	X					
Globorotalia acostaensis acostaensis																	X						
pseudopima				X																			
crassaformis oceanica				X						X					X		X						
cultrata cultrata				X													X			X			
(kummerform)																	X						
menardii			X							X							X	X			X		
falconensis																	X						
hirsuta				X						X													
humerosa				X						X							X						
tosaensis			X	X				X							X		X	X		X			X
truncatulinoides				X						X							X						
tumida								X									X						
flexuosa																	X						
multicamerata																							X
Globigerinoides conglobatus		X		X					X	X			X	X			X					X	
elongata				X													X						
immatura				X																			
obliquus			X	X						X							X						
ruber				X	X					X							X						
sacculifer				X						X					X		X					X	
forma α																	X						
trilobus		X		X			X	X	X	X			X		X	X	X	X	X		X		
Pulleniatina obliquiloculata		X		X				X		X													X
Sphaeroidinella dehiscens dehiscens		X	X	X			X	X					X				X		X				
immatura										X							X						
Sphaeroidinellopsis subdhiscens																						X	X
Orbulina universa		X	X	X			X	X	X	X			X	X	X	X	X	X	X	X	X	X	
Candeina nitida				X						X													

BENTHONIC SPECIES :	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Textularia sp. cf. sagittula																	X						
Pyrgo depressa				X													X						
murrhyena																	X						
sp.		X																					
Spiroloculina sp.																			X				
Triloculina oblonga																	X						
Lagena laevis										X													
sulcata spicata										X													
Orthomorphina sp.				X																			
Rectoglandulina torrida																	X						
Fissurina exsculpta				X																			
marginata										X													
sp.				X																			
Sphaeroidina bulloides				X																			
Bolivina robusta										X							X						
sp.											X												
Rectobolivina papula										X													
Euvigerina aculeata										X													
Siphouvigerina interrupta																	X						
Operculinella venosa											X												
Cycloclypeus carpenteri											X	X											
Planulina wuellerstorfi										X													
Pleurostomella alternans				X																			
Classidulina laevigata										X													
Globocassidulina oblonga				X													X						
Melonis affinis										X													
Ceratobulimina pacifica				X																			

Table V - Age determinations of lavas from Tanna and Futuna islands.

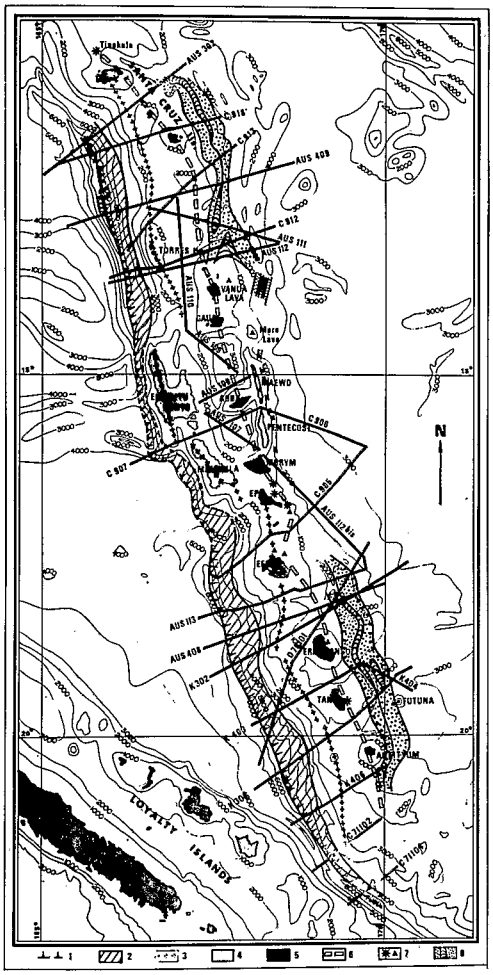
Sample	Location	Formation	Nature	m (g)	K %	$\frac{40_A \text{ total}}{36_A}$	$\frac{40_A^*}{40_A \text{ total}}$ %	$\frac{40_A^*}{(A/g)}$	K/A age m.y.B.P.	Mean value	Paleont.
TAC 105	TANNA	Melen Tukosmeru Volcanics	olivine basalt	5.147	1.06	132.6	5.8 %	0.938×10^{11}	0.085	0.090 ± 0.015 (may be older)	Pleis-tocene
-	-	-	-	5.334	-	317.9	7.2. %	1.102×10^{11}	0.100		
TAC 100	TANNA	Melen Tukosmeru Volcanics	porphyritic basalt	6.106	0.37	304.1	3.0 %	2.209×10^{11}	0.580	0.650 ± 0.100	Pleis-tocene
-	-	-	-	6.098	-	305.2	3.3 %	2.700×10^{11}	0.700		
FMAC 56	FUTUNA	Futuna Volcanics	hornblende basaltic-andesite	5.093	1.09	483.3	39.0 %	2.019×10^{12}	1.79	1.80 ± 0.05	Plio-Pleis-tocene
				4.892	-	352.2	16.5 %	2.035×10^{12}	1.80		
TAC 64	TANNA	Green Hill Volcanics	aphyric basalt	5.210	0.94	349.9	15.7 %	2.380×10^{12}	2.44	2.45 ± 0.05	Plio-cene
				4.778	-	354.5	16.8 %	2.386×10^{12}	2.45		

Analytical techniques :

The Potassium-Argon ages have been carried out in the associated C.N.R.S.-C.E.A. Laboratory of the Centre des Faibles Radioactivités, Gif-sur-Yvette, 91, France.

They have been determined by comparison between the given samples and some gaseous standards, calibrated themselves against international mineral standard Bern 4M (Bocquet et al 1974). The Potassium analyses were carried out by the atomic absorption method, the accuracy being better than 2 %. For the Argon measurements, the mass-spectrometric volumetric method was used (without isotopic dilution with 38 A). Each measurement on a mineral Argon sample is followed by a control measurement on an atmospheric Argon sample under the same pressure, in order to determine the isotopic response of the mass-spectrometer (which leads to measured 40/36 rations different from the exact value 295,5.

All 36 A mineral signals are assumed to be due to atmospheric contamination.



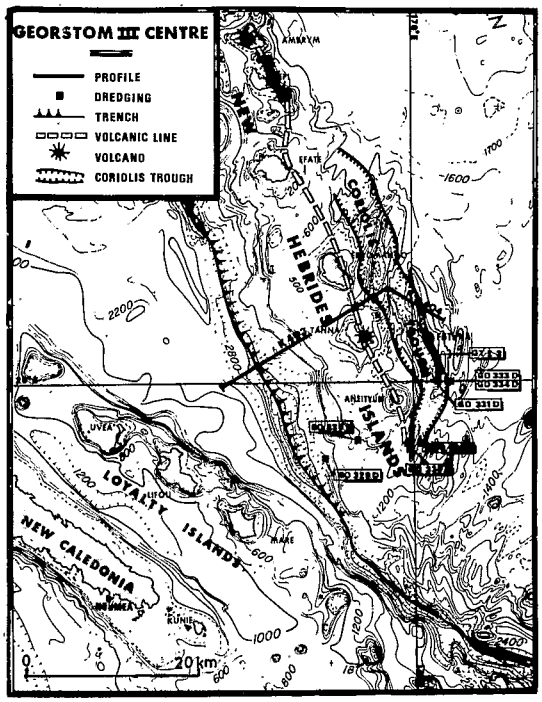


Fig. 2 - Dredgings and profiles locations.

Fig. 1 - The New Hebrides arc and profiles on Scripps O.I. bathymetric map - 1 : subduction, 2 : imbricate zone, 3 : summit of the trench slope, 4 : older volcanics, 5 : Pliocene - Recent volcanics, 6 : active volcanic line, 7 : craters, 8 : horst and trough zone.

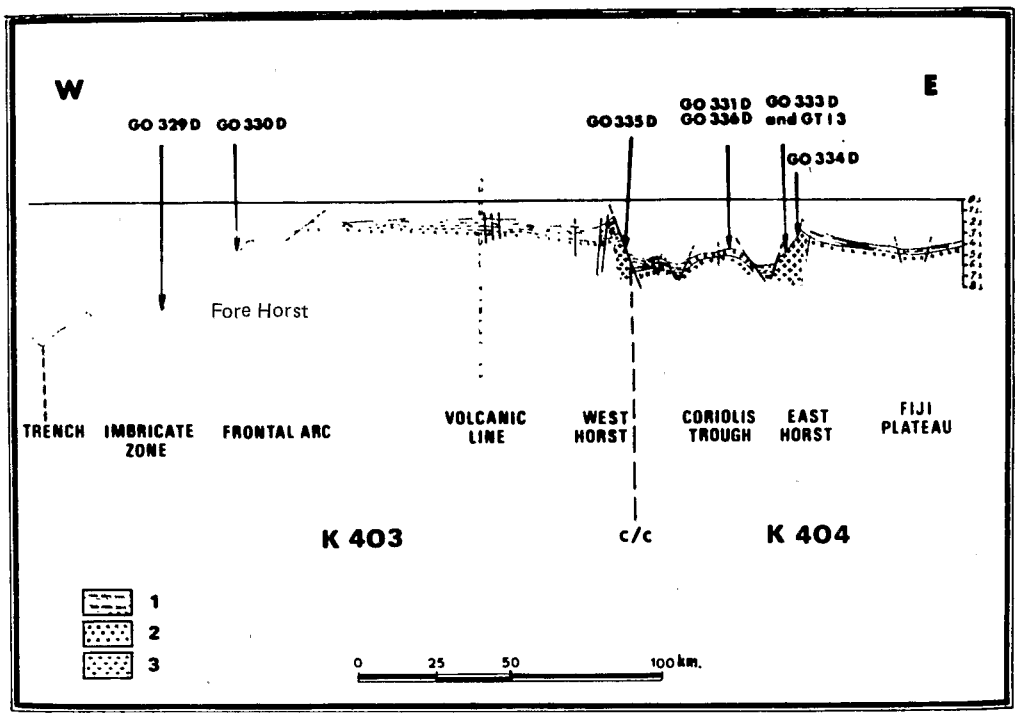


Fig. 3 - Dredging positions on a seismic reflexion profile - 1 : unconsolidated tuff, 2 : acoustic basement, 3 : probable lava and tuff successions.

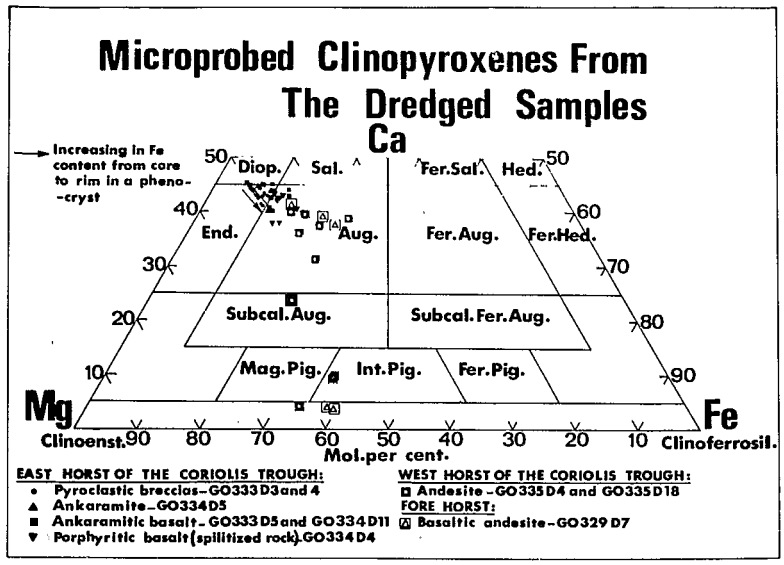


Fig. 4 -

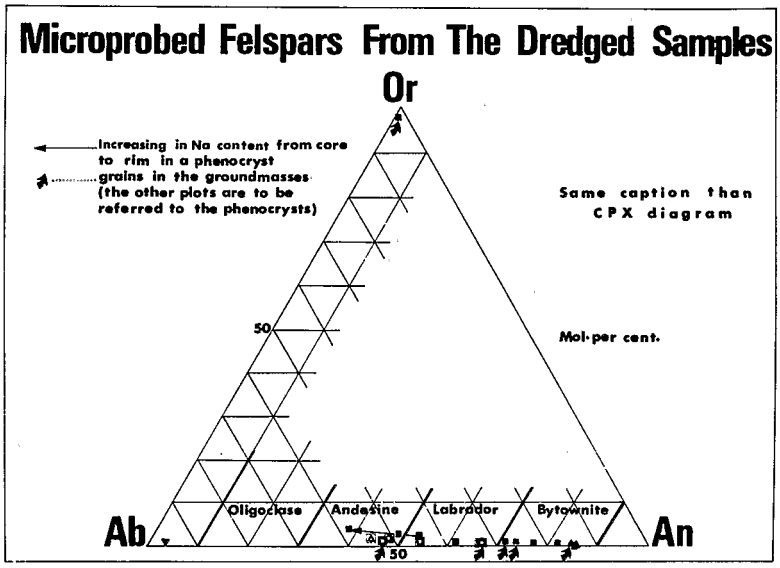


Fig. 5 -

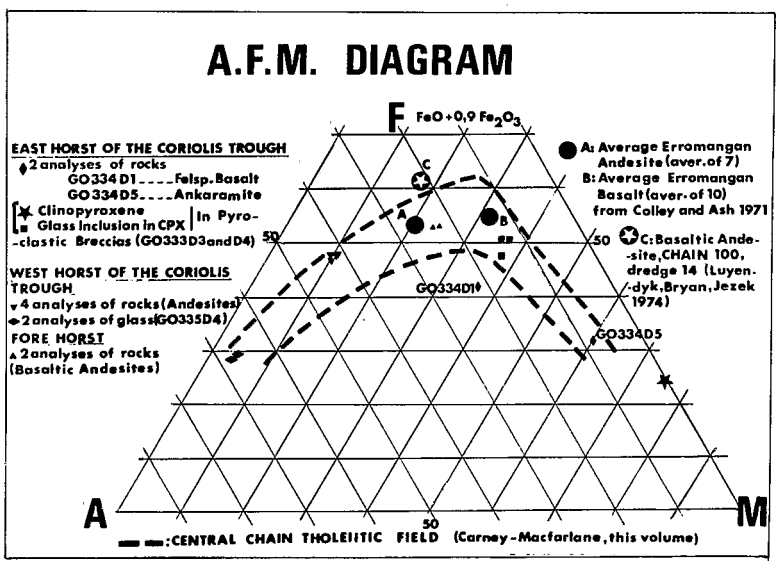


Fig. 6 -

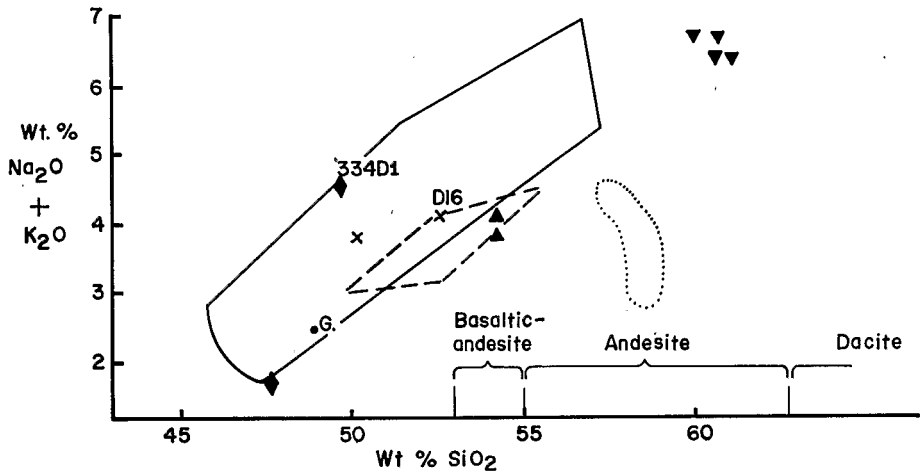


Fig. 7 - Alkalies versus SiO_2 diagram of dredged samples and of rocks from Tanna, Aneityum, Futuna islands.

Field boundaries: (from Carney and Macfarlane, in prep)

Tanna basalts and andesites; Aneityum basalts.

Futuna lavas

Aneityum andesites

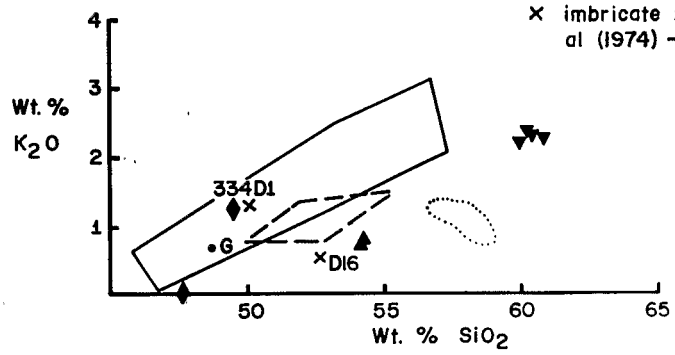
SYMBOLS

As in Fig.6 with the addition of:

•G Glass from Cpx in G0333 D3 (Table III)

× Basaltic rocks dredged from the imbricate zone by Luyendyk et al (1974) — see Table II.

Fig. 8 - K_2O versus SiO_2 diagram of dredged samples and of rocks from Tanna, Aneityum, Futuna islands.



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