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Lower Tertiary tholeiitic basalts from southern New Caledonia

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SUMMARY. Eocene tholeiitic basalts occur throughout the length of New Caledonia where their emplacement preceded that of the peridotite massifs. In the south, two areas of basaltic rocks are intimately associated with Eocene sediments, which have been overridden by the peridotites. The aphyric, holocrystalline basalts consist of plagioclase, clinopyroxene, titanomagnetite, and minor quartz together with their abundant alteration products, which include epidote and uralite. The chemical compositions of these rocks fail to show agreement with oceanic tholeiitites, as suggested by earlier writers, although strong similarities exist with the basalts of the Papuan Ultramafic Belt.

BASALTS of Lower Tertiary age are widespread in New Caledonia and constitute one of the major occurrences of this rock type in the south Pacific (fig. 1). Routhier (1953) recorded basaltic flows, pillow lavas, pyroclastic deposits, volcanogenic argillites, cherts, and intercalated sediments as outcropping more or less continuously over 200 km of the east coast of the island between Bourail and Koumac; to these rocks he ascribed a vague Palaeogene age. The structural and stratigraphic relationships of the basalts are important in that these rocks appear to underlie the large, perched, peridotite massifs of the eastern coast of New Caledonia (Routhier, 1953; Brothers and Blake, 1973; Rodgers, 1974). In fact, Brothers and Blake (1973) regard the basalts as a structural, rather than a stratigraphic unit, but Guillon and Routhier (1971) point to difficulties in interpreting these rocks as allochthonous (i.e. a nappe).

In the south of the island Guillon (1969) and Guillon and Routhier (1971) have mapped less conspicuous related volcanics, which occupy a similar structural position beneath the peridotites of the vast Massif du Sud. The present account is largely concerned with these little-known basalts.

A third, important group of related Tertiary basalts have been recognized by Brothers and Blake (1973) as being associated with blue-schist metamorphics of their 'melange zone' in central and western New Caledonia.

General relationships

All the lavas examined in the present study have been overthrust by the front of the peridotite sheet that now forms the Massif du Sud. Consequently, all are sheared or deformed to a greater or lesser extent. Further, all are associated in some way with Eocene sediments, either as sheared basalt pods in deformed sedimentary sequences or as sedimentary inclusions in mildly deformed volcanogenic deposits.

Due north of Presqu'île Noumea, ultramafics occur in contact with folded and fractured Cretaceous sediments and volcanoclastic beds and Eocene basalts and sediments. Within the main bulk of the sediments several distinct volcanogenic horizons have been mapped by Tissot and Noesman (1958). The attitude of these horizons conforms with the regional deformation pattern of Presqu'île Noumea as deduced by Fromager, Gonord, and Guillon (1967), where the Tertiary cover forms a

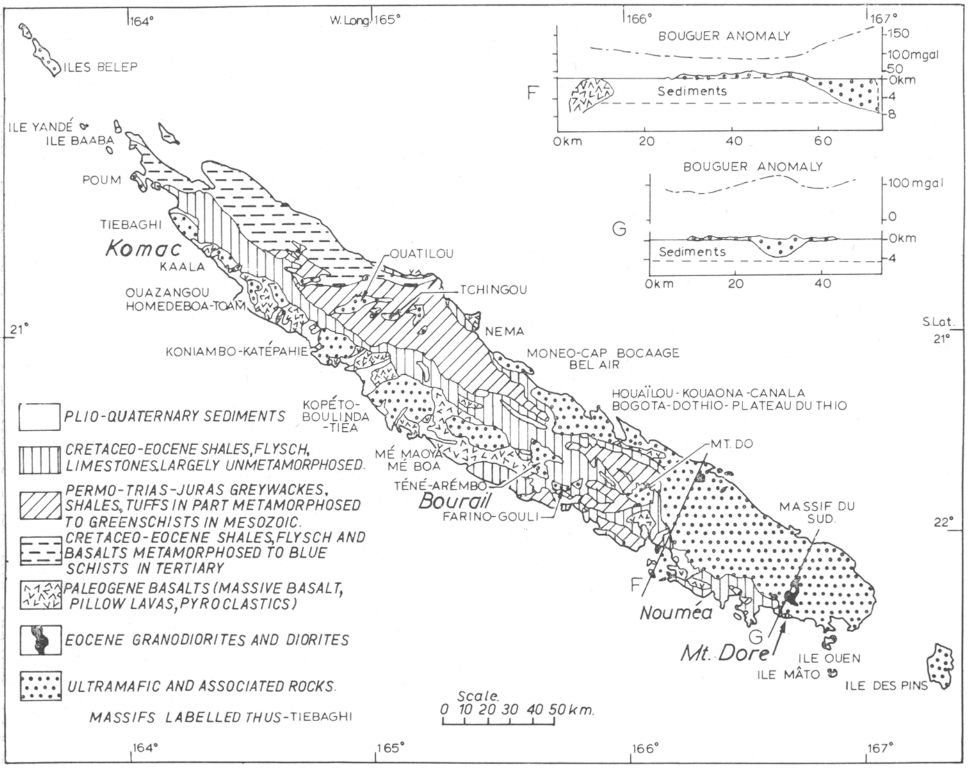

FIG. 1. Geological sketch-map of New Caledonia.

series of isoclinal folds whose axial planes dip gently to the NE. As one approaches the ultramafic front the extent of deformation increases strongly although an over-all regional strike of NW.–SE. is maintained. In the south-eastern corner of Mt. Dore a chaotic assemblage of Eocene flysch, phthanites, and basalts is exposed in a series of road cuts. Vertical and overturned beds are associated with lensoid masses of basalt and a series of sheared isoclinal folds. Guillon (1969) mapped all of the eastern corner of this mount to show harzburgite thrust over basalt. Avias (1955, 1956a, b) has described numerous xenolithic blocks of country rock from within the sheared basal serpentinized zone of the peridotites. A number of these, collected in the course of the present study, proved to be identical with sheared basalt-derived material from below the thrust plane (cf. Routhier, 1953).

Pointe Nokoué, in the extreme south-west corner of Ile Ouen, is formed from two low mounds, about 45 m high, consisting of altered and sheared lavas, crushed pillow forms, and plugs of pyroclastic debris. Veins of epidote, quartz, and jasper are abundant. The hillocks are separated from the rest of the island by a broad, 2 m Flandrian terrace (Ndjii). This terrace conceals the contact of the basalts with the dunites and metagabbros of the hinterland, which have been thrust over the volcanics from the NE. with the thrust plane dipping at about 20° in that direction.

In none of the areas examined were feeder vents obvious. Brothers and Blake (1973) have already noted that vents are not known from elsewhere on the island.

Age

The sometimes conflicting evidence for the stratigraphic age of the New Caledonian basalts has been admirably documented by Guillon and Routhier (1971), although sometimes ignored by later writers. This evidence and its interpretations fall into two basic categories:

The upper Eocene flysch of the Noumea and Bourail basins is interdigitated with the lavas and contains fresh, detrital plagioclase and pyroxene derived from the basalts. This was the main evidence used by Routhier (1953) to give to the basalts their Palaeogene age.

Sediments, intimately associated with the basalts, contain a Palaeocene microfauna near Nepoui while *Inoceramus* has been recovered from similar sediments near Bourail. Brothers and Blake (1973) appear to regard this latter find as significant. However, in both these cases the sedimentary inclusions are probably allochthonous intraclasts.

Guillon and Routhier (1971, p. 9) conclude: 'les basaltes sont certainement postèrieurs au Crétacé superieur et, a notre avis, également a l'Éocene I [lower Eocene].' In other words, despite extensive research in the island by numerous field workers, little further advance has been made with this particular problem than had Routhier (1953) when he assigned his original Palaeogene age.

Recently, Guillon and Gonord (1972) presented three absolute ages for the basalts from K/Ar isotopic studies: Moindou, 51 ± 7 Myr; Bourail, 59 ± 6 Myr; and Oua-Tom, 42 ± 2 Myr. They regarded these ages as discordant and elected to plot the isochron: $A^{40}/A^{36} = f(K^{40}/A^{36})$, yielding an age of $38{\cdot}5 \pm 1{\cdot}5$ Myr, i.e. close to the Oligocene–Eocene boundary, as opposed to the Mid Eocene minimum age given by the raw dates quoted above.

The validity of using this isochron technique with only three data, which do not comply with the criteria of Hayatsu and Carmichael (1970) and which have been derived from highly altered rocks, is questionable. For example, the authors give no indication of the level of the atmospheric argon component, nor is their range of potassium concentration wide. As such, the variation between the samples may be explicable in terms of simple argon loss. The data and their results should be regarded as no better than their minimum age, which in this instance may well be the date of the alteration of the basalts rather than their emplacement.

An alternative explanation of the discordance might perhaps be found in an interpretation in which all ages are assumed to be correct and are merely dates on a time-transgressive scale involving both emplacement and alteration of the basalts, which probably occupied most of the Eocene.

Petrography

All thin sections of the dense, aphyric rocks examined in the course of this study proved to be holocrystalline, with numerous anhedral grains of quartz, laths of plagioclase and amphibole, skeletal and irregular titanomagnetite and sulphides, and occasional crystals of augite set in a sub-ophitic and intergranular to intersertal matrix. Grains seldom exceed 1 mm in length. Phenocrysts are absent, as are olivine and orthorhombic and pigeonitic pyroxenes. Alteration is marked by the widespread development of chloritic minerals, uralitization of pyroxenes and some saussuritization of the feldspars. Apart from a comparative lack of augite, the lavas of southern New Caledonia possess a similar mineralogy and texture to those described by Routhier (1953) from the north-west coast of the island. They also correspond in mineralogy with the less altered rocks of the Thiem massif, but here Espirat (1963) recorded a coarser, doleritic texture.

The average modal composition of four specimens of Nokoué lava was found to be: plagioclase 39 %, augite 4 %, amphibole 35 %, magnetite 10 %, quartz 5 %, chlorite and indeterminate alteration products 7 % (alteration products were counted as parent material, where this could be determined).

Plagioclase showed a compositional range of An_{48-60}, with the majority of specimens about An_{55}. Untwinned grains were observed in a few instances but the common habit was small, twinned laths showing alteration and corrosion and carrying numerous inclusions resulting from saussuritization. Some of these inclusions proved to be epidote, calcite, clay minerals, albite, and white mica.

Routhier (1953) notes that the plagioclase in the flysch of Eocene II (Upper Eocene) has a similar composition to those in the basalts, from which they were presumably derived. In contrast the plagioclases of the Trias-Jura greywackes and pre-Eocene volcanics have a much lower anorthite content (An_{35}).

Augite is comparatively rare, as opposed to descriptions from the northern volcanics. This is undoubtedly due to the widespread development of uralitization in the southern rocks. Small fresh crystals occurred at infrequent intervals in all sections but the remnants of once larger crystals showed almost total replacement by actinolite. The optical properties, $2V_\gamma = 42°$, $\gamma : c = 35°$, $\beta = 1{\cdot}682$, indicate an augite *sensu stricto* and are in broad agreement with the findings of Routhier (1953) and the microprobe analyses of New Caledonian basalt pyroxenes given by Challis and Guillon (1971). These four analyses show an average pyroxene composition of $Ca_{43{\cdot}2}Mg_{40{\cdot}8}Fe_{16{\cdot}0}$.

Amphibole occurs as abundant green pleochroic crystals. Much is actinolitic, being uralite after pyroxene, but the extent of uralitization was difficult to assess as it is possible that two stages of uralitization may be present. Routhier (1953) considered that much, if not all, of the green amphibole of the north-western basalts was primary hornblende. Challis and Guillon (1971), in a brief description of the basalts, failed to mention the mineral, but Guillon and Gonord (1972) noted the presence of brown hornblende. X-ray examination of the southern basalts of the present study revealed actinolite to be the most common amphibole. Oliver (1951) and Rodgers (1973) both considered that a different amphibole can result from the initial stages of uralitization of orthopyroxene, as opposed to clinopyroxene. Further, they both noted that the initial amphibole tends to closely pseudomorph the original pyroxene. Thus, in the northern basalts two different pyroxenes or one pyroxene with two different habits may well have been present. Subsequently, two different uralites or two different habits of the same uralite may have been confused as primary or secondary amphiboles (cf. Rodgers, 1973). At Pointe Nokoué it is doubtful if any primary amphibole exists.

Quartz occurred as a primary mineral in all thin sections examined. Grains range in size from 0·01 to 0·4 mm diameter. Some are equidimensional but most are anhedral and irregular, often growing in and around other minerals and filling the interstices between them. A number of the grains showed a biaxial interference figure with a positive optic axial angle of about 5°.

Secondary veining and uralitization. Quartz and quartz–epidote veins, ranging in size from several centimetres across to less than a millimetre, seam the southern basalts, particularly around Pointe Nokoué. Late-stage calcite veins are particularly concentrated in strongly jointed (and sheared) basalt. These latter veins may be derived from the carbonate-rich waters of the lagoon and need not be related, as are probably the epidote and quartz veins, to any late-stage hydrothermal or deuteric activity.

In thin section the quartz–epidote veins can be seen to consist of large, anhedral, strongly biaxial quartz crystals containing numerous solid and fluid inclusions. Some of these crystals are cut by later-stage veinlets of a finer character. Epidote occurs as bladed, radiating crystals, irregular aggregates and, also, as single isolated crystals; it ranges from anhedral to subhedral in habit and up to 8 mm in size. The average $2V_{\alpha}(81°)$ is somewhat low, lying in the clinozoisite range.

Some veins contain ragged and altered crystals of actinolite, whose appearance contrasts with both that of the associated epidote and of the fresh uralite in the adjacent basalt.

With the development of epidote largely restricted to relatively thin veins in these southern lavas, it would appear that the processes of epidotization have been restricted to basalt immediately adjacent to joints and lines of weakness through which the hydrating fluids moved. The processes of chemical alteration and breakdown of the primary minerals in the basalt have worked outwards from these veins. Remnants of uralite and unaltered quartz are all that remain of the original, uralitized rock. The feldspars have been made over into epidote by saussuritization (cf. Harpum, 1954).

Petrochemical considerations

The chemical composition and CIPW norm of the Pointe Nokoué lava are given in Table I along with similar data for two published analyses of the New Caledonian basalts and some comparative data from Cann (1971) and Rodgers (1974). Although the alteration of the Nokoué sample was quite pronounced in thin section, a not unreasonable agreement of norm and mode exists and oxidation is not appreciable.

TABLE I. *Analyses and weight norms of New Caledonian basalts and some of their possible equivalents*

	1	2	3	4	5	6
SiO_2	51·5	49·80	49·04	49·61	50·11	50·4
TiO_2	1·4	1·10	0·80	1·43	1·10	1·20
Al_2O_3	12·2	11·35	13·64	16·01	12·40	13·5
Fe_2O_3	3·5	4·30	2·51	—	3·44	3·77
FeO	9·1	8·65	5·74	11·49*	7·83	7·92
MnO	0·08	0·22	0·21	0·18	0·17	0·18
MgO	7·2	7·50	13·52	7·84	9·41	7·23
CaO	10·1	10·90	10·25	11·32	10·42	10·1
Na_2O	2·2	2·22	1·29	2·76	1·90	2·68
K_2O	0·5	0·40	0·27	0·22	0·39	0·07
P_2O_5	0·05	0·17	0·07	0·14	0·10	0·10
CO_2	—	—	—	—	—	0·08
H_2O^+	1·3	2·55	2·0	—	1·95	2·28
H_2O^-	0·5	2·55	2·0	—	0·32	0·29
Total	99·63	99·51	99·44	—	99·53	99·80
Na_2O/K_2O	4·4	5·6	4·8	12·5	4·9	38·3
Fe_2O_3/FeO	0·38	0·50	0·36	—	0·43	0·48
qz	7·0	3·5	2·6	—	5·3	6·4
or	3·0	2·2	1·7	1·3	2·3	0·4
ab	18·6	18·9	11·0	23·4	16·1	22·7
an	21·9	19·7	30·3	30·7	24·2	24·6
di	16·1	27·3	5·8	21·1	11·9	8·6
hy	21·8	16·1	39·4	3·8	27·7	23·6
ol	—	—	—	17·9	—	—
ap	3·1	4·8	3·0	—	4·6	5·4
il	2·7	2·1	1·5	2·7	2·1	2·3
mt	5·1	0·3	3·1	—	5·0	5·5

1. Basalt, Pointe Nokoué, Ile Ouen. Anal: K. A. Rodgers.
2. 'Basaltic andesite', Bourail. Routhier (1953).
3. 'Basaltic andesite', Avias (1955).
4. Mean of 94 ocean-floor basalts, Cann (1971).
5. Average New Caledonian tholeiite, Rodgers (1974).
6. Average Papuan tholeiite, Rodgers (1974).

These factors suggest that apart from the hydration changes accompanying uralitization of the pyroxenes, the rock exhibits many of the petrographic and chemical characters obtaining at the time of emplacement.

Routhier (1953) and Avias (1955) referred to the lavas as basaltic-andesites. More recently, Guillon and Routhier (1971) have referred to them as tholeiites. Calculation of the basalt's innumerable petrochemical parameters gives a clear statement of their sub-alkaline basaltic nature, showing that they would not be out of place in many of the better-known tholeiitic provinces of the world. Although over-saturated, in that they contain small amounts of normative and modal quartz, their Niggli quartzhal values (from −9 to +10) show them to be close to the limits of silica saturation and they plot close to the plane of silica saturation in the tetrahedron diopside–forsterite–nepheline–silica.

Challis and Guillon (1971) drew attention to the similarity of the low alkali ratio (K_2O/Na_2O) of the New Caledonian rocks and those of 'l'ensemble des tholeiites oceaniques' (p. 42). Subsequently, Brothers and Blake (1973) regarded some, if not all, of the basalts as oceanic crust. Close inspection of the existing chemical analyses of the New Caledonian basalts reveals decrepancies between these data and those of oceanic tholeiites (cf. Table I). Typically ocean-floor basalts show low K_2O, TiO_2, P_2O_5, rather high Al_2O_3, and very high Na_2O/K_2O ratio (Engel *et al.*, 1965; Cann, 1971). The New Caledonian rocks lie far outside standard deviations given for these oxides and ratio. For example, the maximum Na_2O/K_2O ratio for New Caledonia is 5·6 while the average given by Cann for ocean-floor basalt is 12·5. Certainly the low alumina in the New Caledonian lavas is not characteristic of ocean-floor rocks. The agreement is slightly better when comparisons are made with mildly alkaline tholeiitic basalts from the flanks of submarine volcanoes although it is still far from good. It can perhaps be noted that no volcanic rocks of comparable age and petrography were encountered in the course of JOIDES Leg 21 in the south-west Pacific (Burns and Andrews, 1973). It must be concluded that evidence to support an interpretation of the New Caledonian rocks as ocean-floor basalts is lacking at the moment.

Calc-alkaline basalts, lacking in olivine and containing modal quartz, are rare both within the Pacific basin and around its periphery. Examples have been reported from some islands, e.g. Guam, Nuiafolou, and Japan, but not in any great volume, such as occurs in New Caledonia. The closest relatives are to be found in those described from the Papuan Ultramafic Belt by Davies (1968, 1971) but here the alkali ratio is much higher although other oxides are of a comparable level. The close similarity of the basalts of these two areas suggests a common origin as exemplified by the intimate association of both volcanic groups with peridotites (Rodgers, 1974). Unfortunately, statistically sufficient trace-element and isotopic studies necessary to assist in establishing the basalts' relationships and origins are lacking. Further, detailed large-scale field mapping, such as advocated by Thayer (1967) for ophiolitic suites, is clearly needed in the Eocene of New Caledonia to confirm the postulated structural and stratigraphic relationships of the basalt. Such a study would be particularly useful in ascertaining whether or not feeder vents are present on the island, such as the studies of Crenn (1953) suggest. The apparent absence of such features is perhaps not unexpected when the tectonic history of the volcanics is taken into account.

The probable origin of the basalts may be found in their relationship to the peridotites that overthrust them. The dominant substrate for these peridotites is a non-cumulate harzburgite, deficient in Na, K, Ca, and Al (Rodgers, 1974). This substrate probably represents dead-burned pyrolite, largely depleted of its basalt component, and which is now represented both in the cumulate plutonics formed on this substrate and in the basalts whose eruption preceded emplacement of the peridotite sheet.

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