# ISOTOPIC EVIDENCE FOR A MIDDLE TO LATE PLIOCENE AGE OF THE CORDIERITE GRANITE ON AMBON, INDONESIA[1]

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## ABSTRACT

Priem, H. N. A., P. A. M. Andriessen, N. A. I. M. Boelrijk, E. H. Hebeda, C. S. Hutchison, E. A. Th. Verdurmen & R. H. Verschure (1978). Isotopic evidence for a Middle to Late Pliocene age of the cordierite granite on Ambon, Indonesia. Geol. Mijnbouw, 57, p. 441-443.

Rb-Sr dating of the pair whole-rock/biotite from the cordierite-bearing granite on Ambon (Moluccas, E. Indonesia) yields an age of 3.3 ± 0.1 Ma with initial $^{87}Sr/^{86}Sr = 0.7221$. The K-Ar age of the biotite is 3.8 ± 0.2 Ma (ages based upon the constants recommended by Steiger & Jäger, 1977). A Middle to Late Pliocene age can thus be assigned to the granitic magmatism.

## INTRODUCTION

The geology of the island of Ambon (Moluccas, E. Indonesia) has been described in considerable detail by VERBEEK (1905). From this source and subsequent contributions by BROUWER (1927), JAWORSKY (1972) and KUENEN (1949) the geological framework of the island may be summarized as follows (see also VAN BEMMELEN, 1949).

The oldest rocks on the island are a strongly folded sequence of sandstones, shales and intercalated fossiliferous limestones of Late Triassic age. This sequence is cut by dikes and larger intrusions of 'diabase' (diorite porphyrite and doleritic andesite). The other major rock units of the island are ultrabasic masses (peridotites and minor gabbros), cordierite-bearing granites, and a series of cordierite-bearing volcanics ranging in composition from dacites through andesites to minor basalts (the so-called 'ambonites').

Interbedded foraminiferal sediments indicate that the 'ambonites' represent volcanic activity in the Pliocene, possibly up into the Quaternary. The age relations of the ultrabasic rocks and the granites are uncertain. According to Verbeek, the peridotite and the 'diabase' should be placed together; if so, then the peridotite should also be younger then the Late Triassic sediments. The absence of peridotite detritus in the sediments supports a post-Triassic age for the ultrabasic masses. Regarding the age relations between the peridotite and the granite, Verbeek reports that the peridotite is cut and contact-metamorphosed by thin veins and larger masses of the granite at Tandjong Seri (southern coast of Leitimor). This observation is confirmed by Dr. Tony Barber of Chelsea College (personal communication), who reports here a definite intrusive contact with granite containing xenoliths of peridotite. However, one of us (C.S.H.) gained the impression that the relationship at this locality is tectonic with ultrabasic rocks faulted or thrust against sheared mylonitized granite.

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## THE GRANITE AND ANALYTICAL RESULTS

Samples of cordierite-biotite granite were collected by one of us (C.S.H.) from a coastal exposure about 1 km west of the city of Ambon on the north coast of the peninsula Leitimor. On the map by Verbeek ultrabasic rocks are shown here, but the granite underlies them and outcrops on the coast. The granite contains many dark metasedimentary (but no ultramafic) xenoliths at this locality. One sample devoid of xenoliths was used for isotopic dating (University of Malaya collection no. 8843). Its major components are quartz, plagioclase, large anhedral perthitic anorthoclase, biotite and cordierite, with minor amounts of colourless mica (partially replacing the cordierite), sillimanite, opaque ore, zircon and apatite. The plagioclase is strongly zoned, with compositions ranging from about $An_{80}$ to $An_{50}$ in the core and from about $An_{35}$ to $An_0$ in the rim; the compositional range $An_{50}$ to $An_{35}$ appears to be absent. VAN BEMMELEN (1949) explained the presence of cordierite and sillimanite in the Ambon granites as resulting from the assimilation of country rock by the intruding granitic magma. The peculiar nature of the plagioclase crystals may also be ascribed to assimilation, leading to the incorporation in the granitic magma of xenocrysts of calcic plagioclase (from the country rock or possibly during mixing with a partially crystalline basic magma) upon which the 'granitic' plagioclase has grown.

X-ray fluorescence spectrometric analysis at the University of Malaya of another sample (collection no. 8714) gave a composition of 68.92% $SiO_2$, 0.55% $TiO_2$, 15.46% $Al_2O_3$, 0.65% $Fe_2O_3$, 3.30% FeO, 0.08% MnO, 1.64% MgO, 2.74% CaO, 2.34% $Na_2O$, 3.11% $K_2O$, 0.11% $P_2O_5$, 0.11% $SO_3$, and 0.92% loss on ignition (total 99.93). $Fe_2O_3$ was obtained by titration. C.I.P.W. norm values (100% anhydrous): qu, 33.63; cor, 3.56; or, 18.57; ab, 20.01; am, 13.01; mt, 0.95; il, 1.06; ap, 0.26; pr, 0.08; en, 4.13; Fs, 4.73. Crystallization index, 16; differentiation index, 76. The high normative corundum illustrates the peraluminous nature of this granite. For the cordierite a composition has been reported of 7.42% MgO, 33.13% $Al_2O_3$, 50.86% $SiO_2$, and 8.43% FeO (HUTCHISON, 1977).

Rb-Sr measurements were made on the whole-rock and the separated biotite. The biotite was also analyzed according to the K-Ar method. All analyses were made in duplicate. Rb and Sr isotopic analyses were made on a computer-controlled VARIAN CH5 mass-spectrometer with Faraday cage collector and digital output. Measurement of the Rb and Sr contents was performed by X-ray fluorescence spectrometry for the whole-rock, using a Philips PW 1450/AHP automatic hardware programmed spectrometer and pressed-powder pellets (mass absorption corrections for both sample and external standard based upon the Compton scattering of the MoK$\alpha$ primary beam; see VERDURMEN, 1977), and isotope dilution techniques for the biotite. K-analyses were made by flame photometry with lithium internal standard and CsAl buffer. Argon was extracted in a bakeable glass vacuum apparatus and determined by isotope dilution techniques in a VARIAN GD-150 mass-spectrometer.

The analytical errors are estimated to be within 2% for K, 2% for Ar, 1% for XRF Rb/Sr, 0.05% for $^{87}Sr/^{86}Sr$, and 1% for isotope dilution Rb and Sr. For the age calculations the newly recommended set of decay constants is used (STEIGER & JÄGER, 1977): $\lambda^{87}Rb = 1.42 \times 10^{-11}a^{-1}$; $\lambda^{40}K\beta = 4.962 \times 10^{-10}a^{-1}$; $\lambda^{40}K_e = 0.581 \times 10^{-10}a^{-1}$; isotopic abundance $^{40}K = 0.01167$ atom %.

The following data were obtained:

*Whole rock*

| | |
|---|---|
| Rb | 158 ppm |
| Sr | 112 ppm |
| Rb/Sr (m/m) | 1.415 |
| $^{87}Sr/^{86}Sr$ | 0.7223 |

*Biotite*

| | |
|---|---|
| Rb | 608 ppm |
| Sr | 2.17 ppm |
| $^{87}Sr/^{86}Sr$ | 0.7601 (calculated from isotope dilution runs) |
| K | 7.32% |
| radiogenic $^{40}Ar$ | $1.94 \times 10^{-3}$ ppm (atm. $^{40}Ar$ = 64% total $^{40}Ar$) |

From these data a Rb-Sr age of 3.3 ± 0.1 Ma can be calculated for the pair whole-rock/biotite, with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7221, and a K-Ar age of 3.8 ± 0.2 Ma for the biotite (errors based upon the estimated analytical errors given above).

## DISCUSSION

The K-Ar age is significantly higher than the Rb-Sr age, possibly due to a different response of the biotite Rb-Sr and K-Ar systems towards the cooling history of the magma, or to some excess radiogenic Ar. Nevertheless, there can be little doubt that the biotite dates point to an age of the order of 3.5 Ma for the time that the magma was cooled down far enough far the biotite to become closed towards its Rb-Sr and K-Ar systems. The actual intrusion of the granitic magma must thus be older, but in view of the geological relationships a prolonged cooling history of the magma after its emplacement is highly improbable. Following the time-scale for the Neogene of the Australian region recently proposed by MCDOUGALL & PAGE (1975), it can thus be concluded that the granite intrusion took place in the Middle to Late Pliocene, supporting Van Bemmelen's suggestion that the intrusion of the cordierite-bearing granites is genetically related to the effusion of the Pliocene volcanics (the 'ambonites'). The high initial $^{87}Sr/^{86}Sr$ ratio confirms that assimilation of country rock (cordierite gneisses according to Van Bemmelen) played an important role during the emplacement of the granitic magma, as is also reflected in the presence of minerals such as cordierite and sillimanite.

The granitic magmatism and associated volcanism on Ambon appear to coincide with the beginning of the development of the Timor Trough to the south, supposedly when the Australian plate collided with the Sunda arc (WHITFORD ET AL., 1977). Continuing geophysical analysis of the Banda Sea reveals the presence of thick continental crust in several places (BOWIN ET AL., 1977), and CARDWELL & ISACKS (in press) now relate the geology of Ambon to southwesterly subduction from the Seram Trough.

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