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21. Concentrations of Rb, Sr, Sm, and Nd and all the other rare-earth elements were determined by inductively coupled plasma mass spectroscopy in aqueous solutions of the rock samples, with internal standards and verification of results against rock standards such as BCR-1. Errors in these analyses are usually ±2%. Analytical clean laboratory procedures and mass spectrometric techniques for Sr- and Nd-isotopic measurements are similar to those reported in A. R. Basu *et al.* [(*Earth Planet. Sci. Lett.* **100**, 1 (1990)]. The notation $\epsilon_{Nd}(t)$ refers to 0.1-mil deviations of $^{143}Nd/^{144}Nd$ from bulk earth calculated at 17 Ma with standard parameters. Errors in the Sr- and Nd-isotopic ratio measurements are usually ±30 and ±15, corresponding to the last two digits, respectively.
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Contribution of Oceanic Gabbros to Sea-Floor Spreading Magnetic Anomalies

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The contribution of oceanic gabbros, representative rocks for layer 3 of the oceanic crust, to sea-floor spreading magnetic anomalies has been controversial because of the large variation in magnetic properties. Ocean Drilling Program (ODP) Leg 118 contains a continuous 500.7-meter section of oceanic gabbro that allows the relations between magnetization and petrologic characteristics, such as the degree of metamorphism and the magmatic evolution, to be clarified. The data suggest that oceanic gabbros, together with the effects of metamorphism and of magmatic evolution, account for a significant part of the marine magnetic anomalies.

The location of the magnetized rocks of the oceanic crust that are responsible for sea-floor spreading magnetic anomalies has been a long-standing problem in geophysics (*1–3*). The recognition of these anomalies was a keystone in the development of the theory of plate tectonics. Our present concept of oceanic crustal magnetization is much more complex than the original, uniformly magnetized model of Vine-Matthews-Morley (*1–12*). Magnetic inversion studies indicated that the upper oceanic extrusive layer (layer 2A, 0.5 km thick) was the only magnetic layer and that it was not necessary to postulate any contribution from the sheeted dike complex (layer 2B, 1.0 km) or from the intrusive layer (layer 3, 4.5 km) (*13–15*). Direct measurements of the magnetic properties of the oceanic rocks from the sea floor, however, have shown that (i) the magnetization of layer 2A is insufficient to give the required size of observed magnetic anomalies and (ii) some contribution from lower intrusive rocks is necessary (*1–3, 16*). The magnetic data of oceanic intrusive rocks have been equivocal, in part because studies were conducted on unoriented dredged and ophiolite samples and on intermittent Deep Sea Drilling Project (DSDP)/ODP cores (*1–3, 6–12*). In this study, we describe the magnetic properties of lower intrusive rocks, using the oceanic gabbros recovered during ODP Leg 118 (hole 735B at the Southwest Indian Ridge). With an extremely high recovery rate of 87%, Leg 118 gabbros may represent an excellent type section for layer 3 at this site (*17–19*).

Analysis of the rocks showed that their measured blocking temperatures were near 580°C; this value implies that the remanence is primarily carried by a low-titanium magnetite. Many of the natural remanent magnetizations (NRMs) were, however, altered: NRM inclinations were about equally divided between normal and reversed polarity, whereas all samples showed a reversed stable inclination with an average of 66° ± 5°, slightly deeper than that expected from the location of hole 735B (33°S). The unstable component of normal polarity is probably drilling-induced remanence, and the in situ magnetization may be close to the stable reversed magnetization. The stable remanence of reversed polarity (estimated average of 1.6 A/m), probably acquired during the crystallization of gabbros and

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subsequent metamorphism in a relatively short single polarity epoch, is capable of contributing significantly to the magnetic anomaly of the whole crustal section (*18*).

Although metamorphism is known to lower the magnetization of oceanic basalts markedly (*20–22*), earlier studies suggested that metamorphism did not appreciably alter the magnetic characteristics of oceanic gabbros (*7, 8, 11*). However, our results show that metamorphism noticeably changes magnetic properties (Fig. 1, A to D). The gabbros, except for some brecciated horizons, have been metamorphosed to amphibolite facies (*23*). We consider the volume ratio of mafic metamorphic minerals to total mafic minerals (the percentage of secondary mafic minerals) as an indicator of the degree of metamorphism. The samples show fairly wide variation in metamorphic degrees and initial compositions (Fig. 2, A and B). The degree of metamorphism decreases with depth; the uppermost gabbros are almost completely metamorphosed, whereas, except for the base of the section, samples from lower depths are fresh. The anorthite content of plagioclase shows fairly wide variation (Fig. 2B). The observed striking heterogeneity in the degree of metamorphism may have resulted from seawater circulation along cracks from which hydration proceeded outward.

The NRM intensities first increased as the proportion of metamorphic minerals increased, showed a broad peak at 20 to 40% metamorphic minerals, and then decreased dramatically with a further increase in the percentage of metamorphic minerals (Fig. 1A). The overall change in magnetization is greater than an order of magnitude. A similar but slightly broader tendency may be observed for magnetic susceptibilities (Fig. 1B). This result indicates that there would be more and less magnetic phases in the moderately and highly metamorphosed samples, respectively, compared to fresh samples. Koenigsberger ratios (*Qn*), which provide a maximum estimate of the in situ–induced magnetization, are substantially larger than unity; such values indicate that the total magnetization at any metamorphic degree is dominated by a remanent magnetization (Fig. 1C). The median demagnetizing field (MDF), the peak alternating field at which half of the original remanence is demagnetized, is a parameter that characterizes the stability of NRM. Most MDFs are greater than 20 mT, an indication that the rocks are stable against the alternating field (Fig. 1D). Fresh samples show higher MDFs, whereas moderately and highly metamorphosed samples have lower MDFs; thus, the remanence may become less stable at higher degrees of metamorphism.

To estimate the potential contribution

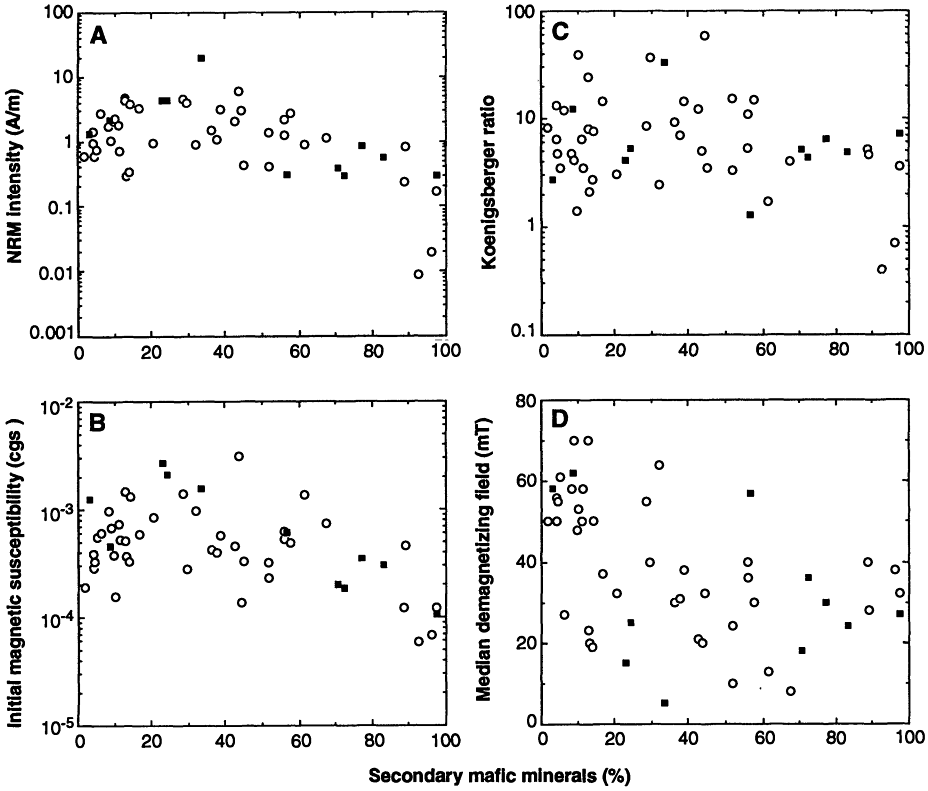


Fig. 1. Relations between the percentage of secondary mafic minerals (percentage of secondary mafic minerals in total mafics) and magnetic properties of gabbros; ○, olivine gabbro and troctolite; ■, Fe-Ti oxide gabbros. (**A**) NRM intensity; (**B**) initial magnetic susceptibility; (**C**) Koenigsberger ratio; (**D**) median demagnetizing field. NRMs of the samples that show negative (normal) inclinations are altered significantly by the secondary magnetic components probably acquired during drilling. We therefore excluded those samples, which are mainly Fe-Ti oxide gabbros, and used mostly olivine gabbros, representative rocks for hole 735B. Samples for magnetic measurements were obtained from the top of each section of the hole and the ratio of various rock types may represent the overall population of hole 735B (*29*).

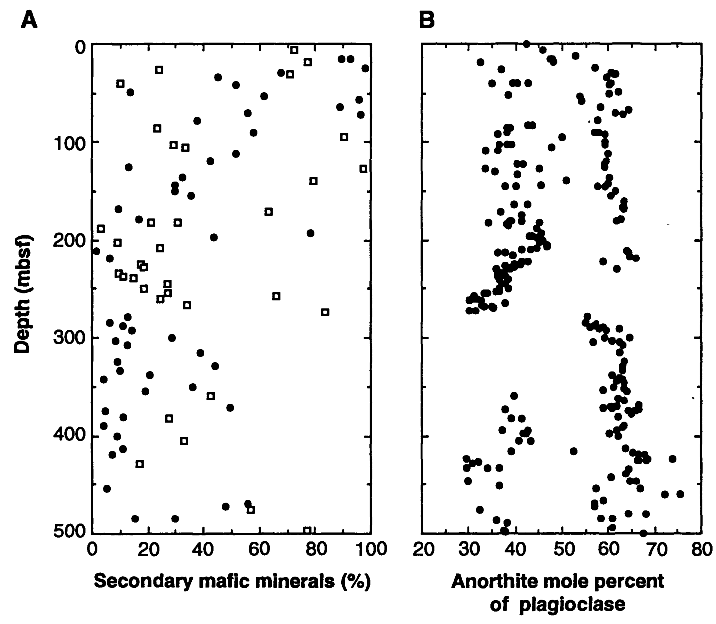
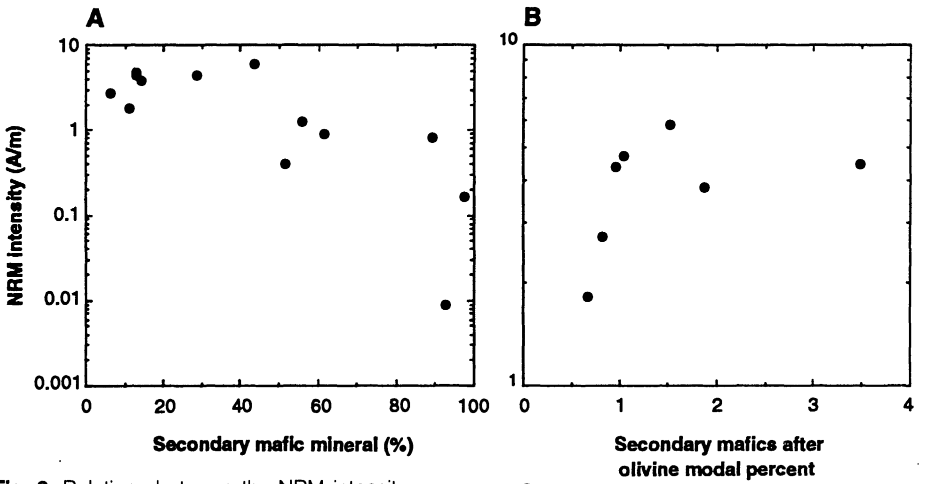


Fig. 2. Depth (in meters below sea floor) versus (**A**) the percentage of secondary mafic minerals and (**B**) anorthite mole percent of plagioclase in gabbros from ODP Leg 118, hole 735B; ●, olivine gabbro and troctolite; □, Fe-Ti oxide gabbros. The percentage of secondary mafic minerals is linearly related to the modal percent of total secondary mafic minerals (mostly amphiboles), excepting extremely plagioclase-rich or plagioclase-poor samples.



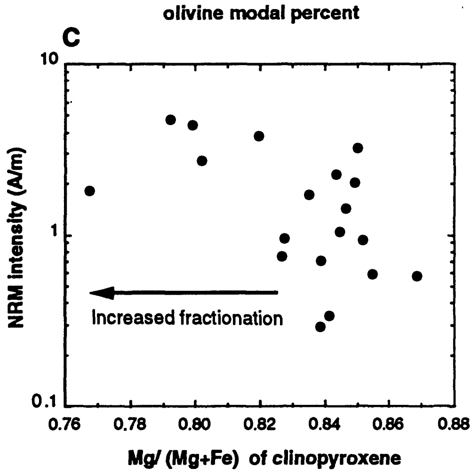


Fig. 3. Relations between the NRM intensity and (**A**) the percentage of secondary mafic minerals, (**B**) the modal percentage of secondary mafics replacing olivine (0.725 < Mg# of clinopyroxene < 0.825), and (**C**) Mg# of clinopyroxene (secondary mafic minerals <20%). Mg# of clinopyroxene represents the degree of magma evolution from which gabbros were crystallized. In (A) olivine gabbros containing clinopyroxene with Mg# 0.725 to 0.825, a representative olivine gabbro for hole 735B section, were distinguished from those shown in Fig. 1 to take out compositional effects on NRM intensity. In (B) gabbros with secondary mafic minerals less than 50% of total mafic minerals are shown to illustrate the effects of olivine alteration on NRM intensity. The increase in magnetization may correspond to the appearance of magnetite by reaction between olivine and plagioclase. In (C) fresh olivine gabbros containing less than 10 modal percent secondary mafic minerals are shown. The data selected in (C) illustrate the effect of composition, resulting from magmatic evolution of gabbros, on NRM intensity.

Table 1. Magnetization model for oceanic gabbros; *N*, number of samples used for calculation. AM and GM are arithmetic and geometric means, respectively. Layer 3A contains relatively evolved gabbros with various degrees of metamorphism, whereas layer 3B is composed of primitive gabbros with limited metamorphism.

Layer	Thickness (km)	*N*	Remanent magnetization (A/m)	
			AM	GM
3A	2.0	41	1.76	1.05
3B	2.5	7	1.27	1.12
Layer 3 (total)	4.5	48	1.49	1.09

of oceanic gabbros to marine magnetic anomalies, we focused on NRM intensities. The systematic change in NRM intensities observed (Fig. 1A) is basically a result of the difference in the degree of metamorphism: data from representative rocks with a limited range of mineral chemistry exhibit similar trends (Fig. 3A). However, magnetization may increase by about an order of magnitude as gabbros evolve from troctolite to olivine gabbro during the initial differentiation (Fig. 3C), which may explain the relatively broad range of magnetization at a certain metamorphic degree (Fig. 1A). Petrographic data suggest that the magnetic carriers in fresh gabbros are magnetite crystallized from the magma and tiny magnetite grains formed in plagioclase during the initial cooling (*10*). The abundance of these magnetite grains increases as the magnesium number [Mg#, Mg/(Mg + Fe)] of clinopyroxene decreases. Secondary magnetite occurring in reaction zones between olivine and plagioclase is an important phase through moderate metamorphism and may be responsible for the increase in magnetization observed in moderately metamorphosed gabbros (Fig. 3B). Further increase in metamorphic degree is characterized by the disappearance of primary and secondary magnetite and the appearance of brown to greenish-brown hornblende with relatively higher concentrations of Fe and Ti. Such changes result in a decrease in magnetization with higher metamorphic degrees.

We suggest that the degree to which oceanic gabbros contribute to marine magnetic anomalies strongly depends on both the primary component and the metamorphic degree. In Table 1 we present a preferred model. Taking the chemical and physical structure of layer 3 into consideration, we separated it into (i) relatively evolved gabbros affected by a moderate to high degree of metamorphism as a representative of layer 3A and (ii) more primitive gabbros with limited metamorphism as layer 3B. We consider the entire 735B section as representative of layer 3A gabbros because of various degrees of metamorphism as well as initial compositions (Fig. 2). For layer 3B, fresh primitive samples have been taken from the hole 735B section, which may provide a maximum estimate of magnetization for layer 3B (Table 1).

The contribution of serpentinite in layer 3 has not been considered in our model (Table 1). Serpentinite is known to possess a sufficiently intense stable magnetization to contribute to the anomaly (*7, 11*). We suggest, however, that serpentinite is probably more important for magnetic anomaly at a wavelength longer than the lineated magnetic anomalies because of the relatively long time scale for the acquisition of magnetization (*24*). Most of the Fe-Ti oxide gabbros that showed intense magnetization were also excluded from our analysis because their NRMs were dominated by the drilling-induced remanent magnetization (*18, 25*). Many Fe-Ti oxide gabbros, which commonly contain coarse-grained magnetite, have acquired significant viscous remanence (*18*). This result suggests that these rocks could contribute both positively and negatively to the lineated magnetic anomalies. Viscous remanent magnetization may also act as a strong induced magnetization because it is aligned in the direction of the Earth's present magnetic field.

The average magnetizations of 1.76 A/m over 2.0-km-thick layer 3A and of 1.27 A/m over 2.5-km-thick layer 3B yield a value of 1.49 A/m over a 4.5-km-thick oceanic gabbroic layer (Table 1) (*26*). If there is no contribution from layer 2, this would correspond to a magnetization of 1.12 A/m for a 6-km-thick oceanic layer; such a value would account for a large part of the magnetization obtained from the inversion of surface, deep tow, and satellite magnetic observations (*3, 27, 28*). These data, together with earlier results that show that the magnetization of the upper oceanic layer is insufficient, suggest that the source of the lineated magnetic anomalies must reside in most of the oceanic crust and that a significant contribution must come from oceanic gabbros.

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24. Peridotite initially has no magnetite. During the process of serpentinization, which is considered to occur over a long time scale, it acquires chemical remanent magnetization with the formation of magnetite.
25. The relatively large amount of Fe-Ti oxide gabbro recovered from hole 735B was not what we expected to obtain from the oceanic gabbroic layer before drilling.
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Homobatrachotoxin in the Genus *Pitohui*: Chemical Defense in Birds?

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Three passerine species in the genus *Pitohui*, endemic to the New Guinea subregion, contain the steroidal alkaloid homobatrachotoxin, apparently as a chemical defense. Toxin concentrations varied among species but were always highest in the skin and feathers. Homobatrachotoxin is a member of a class of compounds collectively called batrachotoxins that were previously considered to be restricted to neotropical poison-dart frogs of the genus *Phyllobates*. The occurrence of homobatrachotoxin in pitohuis suggests that birds and frogs independently evolved this class of alkaloids.

A variety of organisms are known to produce or sequester noxious compounds that can be used for defensive purposes. Until recently, no examples of chemical defense were known among birds although there are many examples in all other vertebrate classes. In 1990 we discovered that the hooded pitohui, *Pitohui dichrous*, contained in its feathers and muscle tissue a toxic substance that could function as a defensive chemical. The toxin caused numbness, burning, and sneezing on contact with human buccal and nasal tissues during collection and preparation of specimens. Local New Guineans referred to the bird as a "rubbish bird" that should not be eaten unless it was skinned and specially prepared (*1*). We have since collected tissue of three species of the genus, and we report the results of bioassays of toxicity and the identification of the toxin as a steroidal alkaloid.

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Feathers, skin, striated muscle, uropygial gland, heart-liver (combined), and stomach with contents were separated from individual hooded pitohuis, variable pitohuis (*P. kirhocephalus*), and rusty pitohuis (*P. ferrugineus*) (*2*). Each tissue was stored separately in 100% ethanol and later was macerated and washed with 100% ethanol. These crude ethanol extracts were concentrated so that 100 μl of extract were equivalent to 100 mg of tissue.

We conducted bioassays by injecting ethanol extracts subcutaneously into the hindquarters of mice (*3*). The effect of the injection was monitored for 3 hours or until death. These assays showed that in all three species the skin and feathers of the pitohuis were most toxic, the striated muscle was much less toxic, and the heart-liver, stomach, intestines, and uropygial gland were least toxic (Table 1). Concentrations of the toxin varied interspecifically, and of the three *Pitohui* species the hooded pitohui was most toxic, the variable pitohui was less toxic, and the rusty pitohui was least toxic (Table 1). In the variable pitohui, tissues of an adult were more toxic than tissues of an immature bird.

After fractionation of extracts of feathers, skin, or muscle by acid-base partitioning (*4*), only the alkaloid fraction was toxic to mice. Alkaloid fractions from skin and muscle were then examined by gas chromatographic–mass spectral analysis, thin-layer chromatography, and direct probe mass spectrometry. Thin-layer chromatography revealed the presence in skin of a single alkaloid that gave a blue color reaction with modified Ehrlich's reagent identical to that of homobatrachotoxin (*5*). That alkaloid cochromatographed with homobatrachotoxin (R_f 0.50), and the mass spectrum (*6*) was also identical to that of homobatrachotoxin; these results confirmed the identity of the major *Pitohui* toxin in skin. Toxic effects of the alkaloid fractions from skin were virtually identical to those of homobatrachotoxin, causing partial paralysis of hind limbs, locomotor difficulties, and prostration at low dosages (<0.01 μg of homobatrachotoxin) and tonic convulsions and death at higher doses (>0.03 μg of homobatrachotoxin).

Homobatrachotoxin (Fig. 1) is a member of a family of steroidal alkaloids collectively called batrachotoxins. Batrachotoxin (R_f 0.45), a closely related member of the same family of toxins, was not present. Homobatrachotoxin was also present in muscle tissue but at much lower concentrations, consonant with the lower toxicity of muscle extracts. Batrachotoxins depolarize nerve and muscle cells by activating Na^+ channels (*7*) and thus irritate sensory neurons in buccal tissue (*1*).