Deep Sea Drilling: Age and Composition of an Atlantic Basaltic Intrusion

Abstract. *The fission track age of a basalt recovered from beneath Campanian sediments on the lower western flank of the Mid-Atlantic Ridge is* $(15.9 \pm 1.6) \times 10^6$ *years. The major element composition of a glassy margin of the basalt is similar to that of oceanic tholeiites except for a markedly higher potassium concentration.*

This preliminary report presents data for one of several igneous rock samples from Deep Sea Drilling Project sites presently under study at the Scripps Institution of Oceanography. Although the study is by no means complete, the nature of the data is thought to justify their presentation at this time.

The sample in question is from leg 2, site 10 (32°52′N, 52°13′W; water depth, 4697 m), and was the first sample that was studied in an attempt to obtain absolute age data by the fission track method for basaltic rocks recovered in the cruise of the *Glomar Challenger*. The igneous rock recovered at site 10 has been described by Engel and Engel (*1*) as a basaltic sill as inferred from the recrystallized and metamorphosed sediment rich in calcium carbonate which extended up to several centimeters above the contact with the basalt. The total thickness of sediment overlying the basalt is 456 m. Although Engel and Engel carried out no analytical work, they tentatively identified the basalt as oceanic tholeiite after hand lens and thin section examination. The small glassy fragments received by this laboratory for fission track dating were presumably taken from the glassy margin described as being up to 2 cm thick and in contact with the sediment (*1*). The dark brown glass (black macroscopically) is palagonitized on the outer surfaces and locally along small cracks or veins. However, when shattered, the fresh surfaces exhibit a glassy luster, well-developed conchoidal fracture, and no trace of pearlitic texture; these newly broken fragments appear to be very fresh. Several of the fresh-appearing fragments were selected for dating.

The fission track method for age determination of natural glass was first described by Fleischer and Price (*2*), and the details of the procedures used in this laboratory have also been described (*3*). Ages determined in this laboratory for several samples of natural glass range from approximately 1×10^6 to 11×10^6 years and are in good agreement with ages determined by other methods (*3*). The fission track age of the sample from leg 2, site 10 (sample J-1) is calculated to be $(15.9 \pm 1.6) \times 10^6$ years. The quoted error is the standard deviation ($1\ \sigma$) calculated from spontaneous and induced track counts in the sample and the induced track count in the neutron flux monitor.

The most interesting aspect of this result is the large difference in age between the basalt and the immediately overlying sediments, which are Cretaceous and approximately 80×10^6 years old (*4*). The presence of a "baked" contact indicates that the basalt is younger than the sediment, but, in view of the relative quiescence commonly ascribed to the sea floor away from active areas such as ridge crests and fracture zones, the magnitude of the discrepancy is somewhat surprising. Site 10 is located on the lower western flank of the Mid-Atlantic Ridge adjacent to the Sohm Abyssal Plain, and, if one uses spreading rates determined from leg 2 evidence (*5*), then the igneous activity at 15.9×10^6 years should have occurred at a distance of approximately 750 km from the ridge crest and clearly could not be connected with activity at the ridge axis. The Campanian sediments immediately above the basalt may in fact not be the oldest sediments at this location, although the igneous rock was encountered approximately at the depth of the "acoustic basement" (*5*). Site 10 is located "on an exceptionally shallow point of an area typified by abyssal hills of low relief" (*4*), although it is not clear from the site report that this site actually samples an abyssal hill. However, it seems reasonable to associate the basalt dated in this study with the abyssal hills and, provided that this association is valid, the age discrepancy between the basalt and the overlying sediments lends support to the hypothesis of abyssal hill generation by small intrusive laccoliths (*6*).

Table 1. Composition of sample J-1 and average Atlantic oceanic tholeiite.

Oxide	Sample J-1	Atlantic oceanic tholeiite (*8*)
SiO_2	49.37	49.8
TiO_2	1.51	1.33
Al_2O_3	15.75	16.87
Fe_2O_3		2.07
FeO*	8.72	7.28 (9.15*)
MnO		0.16
MgO	7.67	8.01
CaO	11.80	11.38
Na_2O	2.33	2.78
K_2O	0.47	0.2

* Since the microprobe technique gives no information about the oxidation state of iron, values are arbitrarily given in terms of FeO. The data of Engel and Engel (*8*) are shown as originally reported, and also with all Fe as FeO for comparison.

The chemical composition of the glass was determined by means of the electron microprobe. Presumably the composition of the fresh glass should be a good indicator of the composition of the bulk rock. The small size of the sample made necessary a microtechnique. Standards used were well-determined mineral standards, and corrections for drift, background, absorption, and fluorescence were made with the computer program of Frazer *et al.* (*7*). For several elements, including the alkali elements, scans were made across a number of glass fragments and in all cases the glass was found to be very homogeneous. Occasional euhedral to subhedral olivine grains are present in the glass, as well as some spherulites. The analysis given in Table 1 refers only to the glass composition and not to the total composition since the small sample size made it difficult to estimate quantitatively the percentage of olivine or spherulites and to make appropriate corrections. However, the effect should not be large because the phenocrysts and spherulites certainly comprise less than 10 percent of the glassy portion.

It can be seen from Table 1 that the glass composition closely parallels the average composition of Atlantic oceanic tholeiites with one major exception: the potassium concentration is higher in sample J-1 by a factor of 2.5. This higher value is not likely to be experimental error since, when using microprobe techniques, one generally expects any error in the concentrations of alkali elements to give values lower than the true values because of the tendency of alkali elements to evaporate under the electron beam. In the work reported here this effect was eliminated by the use of a large beam size and short counting times at each sample data point. One other fact confirms that sample J-1 has a high potassium concentration relative to oceanic tholeiites, namely, that three other JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling) Atlantic basalt glasses (all from leg 3) analyzed with the microprobe at the same time as sample J-1 yielded potassium concentrations more than an order of magnitude smaller than the value for sample J-1. Similarly, a higher uranium abundance is observed in sample J-1 relative to the leg 3 glasses, as indicated by the induced fission track count in the irradiated samples. The uranium concentration of sample J-1 is approximately 0.7 part per million.

The data from one sample clearly do not justify any generalizations. Nevertheless, they do raise some interesting questions. Do basalt flows occur commonly even in areas far from the ridge crests? If so, does the magnetic anomaly pattern have a more deep-seated origin than is generally thought to be the case? Are such flows generally characterized by higher concentrations of large cations such as potassium and uranium, and do they occur only in areas typified by abyssal hills? Studies now in progress may shed light on these important questions.

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References and Notes

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Lunar and Terrestrial Ilmenite Basalt

Abstract. *A basalt hornfels from the Keweenawan Duluth complex in Minnesota contains 7 percent by weight of titanium dioxide and is similar in many respects to the Apollo 11 samples. Hornfels texture, as well as primary textures in lunar rocks, resemble those in Keweenawan rocks.*

The recent excellent paper by James and Jackson (*1*) on the petrology of the Apollo 11 samples does much to set the lunar rocks in proper perspective. The use of the mundane term ilmenite basalt to describe the rocks that are rich in TiO_2 does much in itself to dispel the earlier conception that the lunar samples simply do not resemble any known terrestrial rocks.

The moon is obviously not similar to that part of the earth with which petrologists are most familiar; hence some basic differences in chemical and mineralogical composition, reflecting unusually low P_{O_2} and P_{H_2O} for example, are not wholly unexpected. One of the striking chemical features is the high TiO_2 content, which ranges in analyses by conventional methods from 7.2 to 12.3 percent by weight (*2*). Olsen (*3*) cited chemical analyses of two pyroxene gabbros from the Adirondack Mountains as bearing some resemblance to the lunar samples. These rocks analyzed for Buddington (*4*) in the Rock Analysis Laboratory at the University of Minnesota are, as Olsen pointed out, uncommon types.

Table 1. Average of two chemical analyses of lunar sample 10017 (*9*), four analyses of lunar fines 10084 (*9, 10*), and of basalt hornfels from Minnesota (*8*).

Constituent	Sample 10017 (wt. %)	Sample 10084 (wt. %)	Basalt hornfels (wt. %)
SiO_2	40.78	42.22	41.31
Al_2O_3	8.02	13.82	12.12
TiO_2	11.77	7.49	7.04
Fe_2O_3	0.00	0.00	3.52
FeO	19.80	15.74	14.57
MnO	0.22	0.20	0.21
MgO	7.70	7.90	6.58
CaO	10.56	11.98	11.07
Na_2O	0.51	0.44	2.06
K_2O	0.30	0.14	0.16
Cr_2O_3	0.34	0.30	
P_2O_5	0.16	0.10	0.63
H_2O^+	0.00	0.00	0.44
H_2O^-	0.00	0.00	0.06
CO_2	0.00	0.00	0.05
S	0.22	0.13	0.10

James and Jackson, however, compared the lunar ilmenite basalts to terrestrial flows. They noted pronounced similarities in texture and in chemical relationships to the thick flows of Keweenawan age in Michigan (*5*). The highest value for TiO_2 reported for the Michigan flows to my knowledge is 4.30 percent by weight in a chemical analysis of a coarse-grained doleritic or pegmatitic phase of the Greenstone flow (*6*). Experience in the Rock Analysis Laboratory had revealed a close relationship between unusually high TiO_2 content and above-average concentrations of P_2O_5 and MnO. This relationship holds for the pegmatitic phases of the thick Keweenawan flows, and above-average concentrations of TiO_2 are accompanied by enrichment in phosphorus, manganese, and the alkali metals (*6*) and also in copper and zinc (*7*). The chemical and mineralogical patterns suggest that volatiles were involved in the development of the pegmatitic phases.

An even closer resemblance of a terrestrial rock to the lunar ilmenite basalts is found in a basalt hornfels from the Duluth complex in Duluth, Minnesota. Two chemical analyses are available (*8*); the more recent analysis with 7.04 percent by weight of TiO_2 is given in Table 1 together with the averages of chemical analyses for lunar samples 10017 and 10084 (*9, 10*). Taylor (*8*) determined the modal composition of the hornfels as labradorite, 42 percent; olivine, 6 percent; augite, 27 percent; and magnetite-ilmenite, 14 percent.

Schwartz (*11*) thought that the hornfels represents blocks of basaltic flows that were engulfed in the Duluth Gabbro, but Taylor (*8*) concluded that the original rock was a dikelike apophysis from the layered series in older anorthositic gabbro. The basalt dike, approximately 2 m thick, was broken up and converted to hornfels by a later intrusion of olivine gabbro. Schwartz suggested that the high content of ilmenite resulted from the addition of titanium and possibly also of iron from the gabbroic magma. He cited the earlier work of Broderick (*12*) on inclusions in the Duluth Gabbro in which the addition of large amounts of tita-