S3-46

187571

P.3

N89-22198

30 ANORTHOSITES: CLASSIFICATION, MYTHOLOGY, TRIVIA, AND A SIMPLE UNIFIED THEORY

L.D. Ashwal, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058

Ashwal and Burke (1) offered a provisional classification of anorthosite, which is given here in Table 1 along with the general characteristics of each type. I use this as a basis to discuss and dispel certain misconceptions about anorthosites. I also include here in Table 2 some interesting facts about terrestrial anorthosites for those interested in world records.

Myth #1. There was a distinct anorthosite "event" in the late Proterozoic.

Terrestrial anorthosites are commonly perceived as uniquely Precambrian rocks which formed during a catastrophic anorthosite "event" about one billion years ago (2). This myth probably owes its origin to the fact that in the Grenville Province of the Canadian Shield, a terrane unusually rich in anorthosite, many (but certainly not all) of the massifs have been strongly deformed and metamorphosed by the intense late Proterozoic Grenvillian orogeny, a probable Tibetan-style continent-continent collision. The Grenvillian event effectively reset isotopic systems including K-Ar, Rb-Sr, U-Pb, and even to some extent Sm-Nd. There has been some success, however, particularly with the whole-rock Sm-Nd method, in revealing pre-metamorphic ages (3). It is clear that even highly deformed massifs such as in the Adirondacks, N.Y. pre-date the Grenvillian event, and if the interpretation of Ashwal and Wooden (3) is correct, as much as 300 Ma may separate emplacement of the Marcy anorthosite massif and the younger metamorphism. In any case, reliable ages of anorthosite massifs in the eastern Canadian Shield range between about 1.1 and 1.65 Ga (4,5), and possibly as old as 2.55 Ga, if the River Valley anorthositic pluton of the southwestern Grenville Province (6) is considered a true massif. There is no evidence, therefore, for a distinct anorthosite event. Massif-type anorthosites do seem to be, however, a strictly Proterozoic phenomenon, and a satisfactory explanation for this is as yet unavailable. If other anorthosite types are included, it may be stated that anorthosite has been produced over the entire range of geologic time, and is forming today (Table 1).

Myth #2. Anorthosites are a major constituent of the lower crust.

There has been and continues to be, in the minds of many, an unfair connection between anorthosites and granulite facies metamorphism. Perhaps this is because the better known, or more easily accessible occurrences have been punished this badly. In addition, or possibly as a result, a popular hypothesis for the origin of massif-type anorthosites invloved intrusion, crystallization, and cooling of the massifs in the lower crust (e.g. 7). Decades of work in the relatively inaccessible parts of Labrador by E.P. Wheeler and S.A. Morse and their colleagues show that the voluminous anorthosites of the Nain Province were emplaced into the upper crust, at depths no more than about 5 km (8,9). More recently it has been shown on the basis of oxygen isotopic measurements that the Adirondack anorthosite, although metamorphosed to high pressure granulite facies, was originally emplaced at a shallow level, probably less than 10 km depth (10). Although deep emplacement of anorthosite is a possibility in some cases, these appear to be the exception rather than the rule.

A related myth holds that anorthosite can form as a refractory residue during anatectic melting within the crust. There is some support for this hypothesis from high pressure experimental petrology (11), and the idea of residual anorthosite after extraction of broadly granitic melts from the deep crust has been incorporated into some widely accepted tectonic models of Tibetan-style continental collision zones (e.g. 12). There is no convincing evidence that ANY known anorthosite formed in this way. Rather, anorthosites are plutonic igneous rocks which crystallized from mantle-derived silicate magmas.

Several authors have speculated that anorthosite should be a substantial (12,13), if not a major (11,14) constituent of the lower continental crust. Seismic studies (15) permit, but do not prove this. Admittedly, some deep crustal terranes exposed at the surface do contain anorthosite (e.g. Adirondacks, West Greenland, South India), but as discussed above, this is a vagary of collisional tectonics. Many high-grade terranes, such as New Quebec (16) are anorthosite-free. The relative paucity of anorthosite among lower crustal nodule suites of kimberlites and alkali basalts also argues against an anorthositic lower crust. There is no reason, therefore, to suspect that anorthosite is any more abundant in the lower crust than it is on the Earth's surface.

Myth #3. Archean anorthosites are metamorphosed equivalents of layered mafic intrusions.

A variety of origins have been proposed for Archean calcic anorthosites (summarized in ref. 17). One popular notion, based primarily on the Fiskenaesset anorthosite of West Greenland, and subsequently extended to other occurrences, is that these anorthosites represent metamorphosed and deformed equivalents of anorthosite-bearing layered intrusions ("stratiform type") such as the Bushveld or Stillwater (18). The differences among these two anorthosite types far outweigh their similarities. Archean anorthosites are characterized by a distinctive texture consisting of equant, calcic plagioclase megacrysts in a mafic groundmass which is commonly basaltic in composition. This texture can be recognized in nearly all Archean anorthosite occurrences, even in those affected by high grade metamorphism (e.g. 19), and is absent from anorthosite-bearing layered intrusions. Although there is some overlap in plagioclase composition between the two anorthosite types, Archean anorthosites are uniformly highly calcic (Table 1). In contrast to Archean anorthosites, layered mafic intrusions are not temporally restricted (Table 1). The tectonic setting of Archean anorthosites is still poorly understood, but many are associated with mafic volcanic units of greenstone belts, suggesting the probability of an oceanic setting (20,21).

A Simple Unified Theory

Basalt is a mantle-derived partial melt of peridotite. A similar fundamental statement about the origin of anorthosite cannot be made with equal certainty. Anorthositologists cannot yet agree as to whether the parental melts of anorthositic rocks were crustal- or mantle-derived, let alone what the composition of these melts was. I believe, however, that sufficient geological, petrological, mineralogical, geochemical, and isotopic information exists about anorthosites of all types to make a general statement concerning their origin: "anorthosites are cumulates of plagioclase feldspar from mantle-derived basaltic magmas." I offer this simple statement as a provisional hypothesis applicable to <u>all</u> anorthosite types, both terrestrial and extraterrestrial.

REFERENCES: (1) Ashwal LD and Burke K (1987) Lunar Planet. Sci XVIII, 34-35. (2) Herz N (1969) Science 164, 944-947. (3) Ashwal LD and Wooden JL (1983) Geochim Cosmochim Acta 47, 1875-1885. (4) Ashwal LD and Wooden JL (1983) Nature 306, 670-680. (5) Ashwal LD and Wooden JL (1985) in Tobi AC and Touret JLR (eds) NATO ASI Series, v. 158, 61-74. (6) Ashwal LD and Wooden JL (1987) EOS 68, 430. (7) Whitney PR (1978) in Fraser JA and Heywood WW (eds) Geol. Surv. Canada Paper 78-10, 357-366. (8) Morse SA (1982) Amer Mineral 67, 1087-1100. (9) Berg JH (1977) J. Petrol 18, 399-430. (10) Valley JW and O'Neil JR (1982) Nature 300, 497-500. (11) Green TH (1968) N.Y. State Museum Sci. Serv. Mem 18, 23-29. (12) Dewey JF and Burke KCA (1973) J. Geol 81, 683-692. (13) Collerson KD and Fryer BJ (1978) Contrib. Mineral. Petrol. 67, 151-167. (14) Frith RA and Currie KL (1976) Can. J. Earth Sci. 13, 389-399. (15) Smithson SB and Brown SK (1977) Earth Planet. Sci Lett. 35, 134-144. (16) Percival JA (1987) this volume. (17) Myers JS (1985) Gronl. Geol. Unders. Bull. 150, 72 pp. (18) Windley BF (1969) Mem. Amer. Assoc. Petrol. Geol. 12, 899-915. (19) Phinney WC, Morrison DA, and Maczuga DE (1986) in deWit MJ and Ashwal LD (eds) L.P.I. Tech. Rept. 86-10, 174-176. (20) Phinney WC, Morrison DA, and Maczuga DE (1987) this volume. (21) Morrison DA, Maczuga DE, Phinney WC (1986) EOS 67, 1265.

Table 1. Anorthosite Types and Characteristics

Type	Texture	mol.% An	Ages (Ga)	Ore Deposits	Examples
Archean	equant megacrysts up to 30 cm	75–90	2.7–3.75	Cr, Fe-Ti	Bad Vermilion L, Ont; Sittampundi, India
Proterozoic (Massif-Type)	laths up to 1 m	40–65	1.0–1.7+	Fe-Ti	Marcy, N.Y.; Nain, Labrador
Stratiform	variable	50–80	0.1–2.7	Cr, Pt, Fe-Ti, V	Stillwater, Montana; Dufek, Antarctica
Oceanic (a) mid-ocean ridge	adcumulate	68–75	0.0	—	mid-Atlantic, mid-Indian ridges
(b) ophiolite	adcumulate	78–82	0.44–0.04	—	Bay of Islands, Newfoundland
Inclusions (a) cognate	variable	variable	0.0–1.2	—	Gardar dikes, Greenland
(b) xenolithic	variable	variable	?	—	Beaver Bay diabase, Minnesota
Extraterrestrial	adcumulate	95–98	~4.4	?	Lunar crust

Table 2. Anorthosite Trivia

Oldest:	3.75 Ga Manfred Complex, Yilgarn Block, Western Australia
Youngest:	0.00 Ga Mid-Atlantic, Mid-Indian, Mid-Cayman Ridges
Largest:	> 15,000 km^2 Cunene massif, Angola
Most Punished:	Sittampundi anorthosite (Archean), India (plag > cor + liq)
Most Profitable:	Bushveld Layered Intrusion, South Africa (Pt, Cr, Fe, Ti, V)