Gallery of Geology—the Basalt of Broken Tank: an aphyric, ophitic basalt of the Rio Grande rift

The photomicrograph below was made from a thin section of the "basalt of Broken Tank" (Chamberlin et al. 2002), a distinctive aphyric ophitic basalt in the Socorro, New Mexico, region of the Rio Grande rift. Geologic and chronologic data indicate the basalt of Broken Tank was erupted onto a gravelly piedmont slope near San Antonio about 8.5 m.y. ago and then flowed 12 mi northward into an intermittent lake basin (playa) near Socorro. Where interbedded in playa muds, the same 8.5 Ma ophitic basalt was initially called the "basalt of Bear Canyon" (Osburn and Chapin 1983), a formation name now abandoned (Chamberlin et al. 2002).

In cross-polarized light, the interference color (birefringence) of different mineral species and of each individual mineral grain (crystal) is determined by the unique optical properties of that mineral species—in conjunction with the optical orientation of that particular crystal within the thin section. The optic axis of the dark-gray pyroxene crystal (near middle of frame) is nearly perpendicular to the plane of the thin section, which allows concentric compositional zones (greenish bands) to be observed. The zoned crystal demonstrates that the bulk composition of the residual liquid (magma) was changing during the crystallization

process, a common expression of magmatic differentiation. Thin white lines have been drawn around the larger (~1 mm) pyroxene crystals to show their extent, overall prismatic shape, and relationship to enclosed or partially enclosed feldspar crystals. In three dimensions, the subophitic pyroxene crystals and elongate plagioclase laths must form an interlocking array that causes this dense lava to be extremely elastic and difficult to fracture, even when forcefully struck with a large sledge hammer (a distinctive field characteristic of the basalt of Broken Tank).

The photomicrograph was made with cross-polarized light in order to reveal a distinctive ophitic to subophitic texture. Ophitic texture is characterized by plagioclase laths (gray and white) largely or entirely enclosed in pyroxene (p) grains (Jackson 1997). Individual crystals of pyroxene (p) are here defined by their uniform interference colors (light brown, dark gray, blue-red, and orange). Subophitic is the igneous texture involving plagioclase laths only partly enclosed by pyroxene grains (Jackson 1997). Relatively large and conspicuous crystals (phenocrysts) are notably absent in this aphyric basalt. Most basalt flows contain sparse olivine phenocrysts approximately 1–2 mm long.

The fine crystal size, lack of distinct olivine phenocrysts, and ophitic texture of the Broken Tank lava flow implies that the source magma was superheated (above or at its liquidus temperature,

~1,200°C) at the time of eruption. Essentially all (99.9%) of these small crystals were formed at the surface of the earth as the lava was rapidly quenched. Most of this dense, nonvesicular rock is formed by plagioclase (~70%) and augitic clinopyroxene (~20%). Very fine to fine (0.01–0.3 mm) olivine crystals (o), whose interference colors range from bright green to yellow, pink, and blue, form about 5–7% of the rock. The rare (~0.1%) larger crystals (~0.3 mm) of olivine may have formed within the magma during its ascent through the crust. Except for trace minerals (apatite, chromite, chlorite, and clays), the remainder of rock (~3%) consists of small opaque (black) crystals of iron-titanium oxide (i) and small patches of dark-gray felted glass (g) that has partially devitrified.

As part of the Mars Science Laboratory (MSL) rover, a highly polished, 3-mm-thick, 4.2-cm disk made from the basalt of Broken Tank is scheduled to go to Mars next November as an onboard reference standard (monitor) for the Alpha Particle X-ray Spectrometer http://msl-scicorner.jpl.nasa.gov/Instruments/APXS/. The large and relatively thick disk was made to survive vibrations (without fracturing) during the rocket launch. It is the ophitic texture of the basalt of Broken Tank that makes it extremely dense and hard, suitable for the long and demanding trip to Mars (Burkemper et al. 2008).

It is suggested here that ophitic and subophitic textures in basaltic lavas represent rapid eutectic crystallization of relatively rare superheated MgO-rich basaltic magmas that are essentially 100% liquid (aphyric) at time of eruption. Ophitic textures in basaltic intrusions, such as diabase dikes and the margins of gabbroic plutons, have long been attributed to rapid cooling of the basaltic magma (Wager 1961; Tegner et al. 1993). However, cooling rate cannot be the only controlling factor in ophitic rocks. Virtually all basalt flows are quickly chilled at the earth's surface, but most basalt flows exhibit intergranular textures in association with sparse olivine phenocrysts (Williams et al. 1954, p. 39). The common occurrence of olivine phenocrysts implies that most basaltic lavas are not superheated at the time of eruption. Two aphyric basalts in New Mexico, the alkaline basalt of Broken Tank (Chamberlin et al. 2002) and the subalkaline basalt of Chamisa Mesa (Chamberlin and McIntosh 2007), both display distinctive ophitic to subophitic textures. These very limited observations suggest an antipathy between aphyric ophitic basalts and olivine phyric basalts. Obviously, more data are needed to test this hypothesis.

Ophitic textures are best explained by contemporaneous crystallization of pyroxene and plagioclase from a liquid of equivalent bulk composition at a unique eutectic point or cotectic line determined by the composition and temperature of the melt (Philpotts and Ague 2009, pp. 199–200). At a eutectic point, crystal growth faces must accommodate the relative growth habits of each phase. As shown here, pyroxene within the large ophitic crystals appears to be anhedral, against elongate plagioclase laths, but the exteriors of the large pyroxene crystals are relatively euhedral, against the residual liquid (plagioclase-rich groundmass). Eutectic or cotectic crystallization of basaltic magma occurs between about 1,280° and 1,200°C and produces large ophitic or subophitic pyroxene crystals that contain subequal proportions of plagioclase and pyroxene (Philpotts and Ague 2009, pp. 200–226).

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