TERRESTRIAL BASALTS REVISITED: THE IMPORTANCE OF PLANET SIZE

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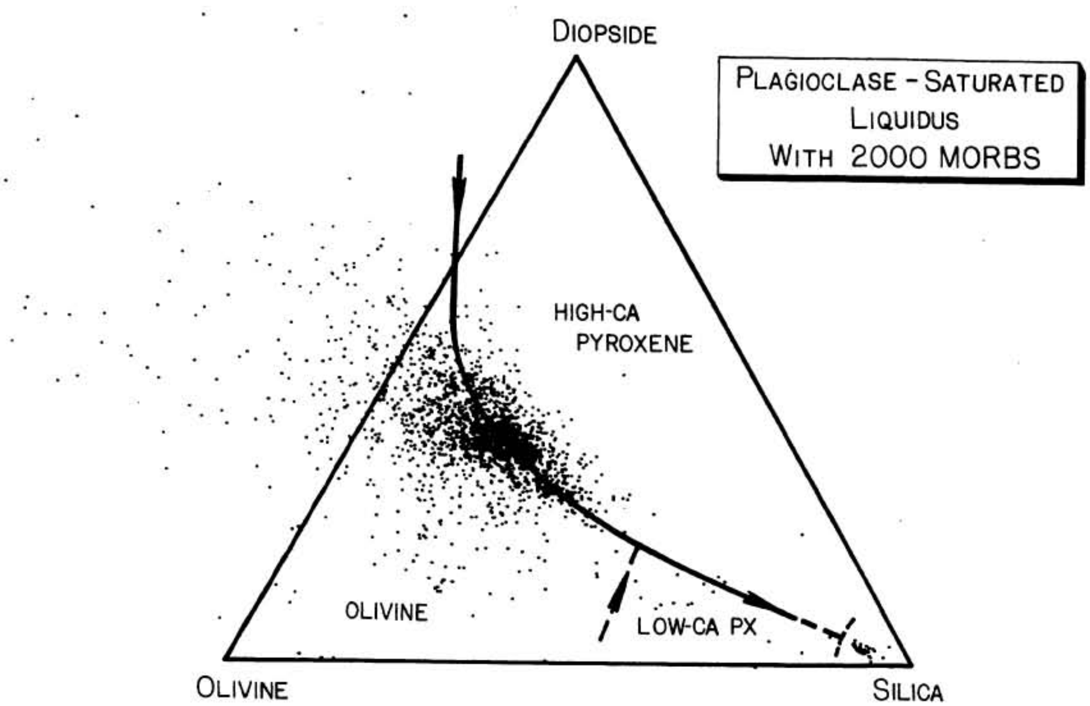
Previous investigations have presented simplified liquidus projections for typical basalt systems of the lunar highlands and the eucrite parent planet (1,2). A similar projection has now been prepared for terrestrial MORBS - by volume the most important basalt type on earth. The figure shows a plagioclase-saturated liquidus in the tetrahedron plagioclase-diopside-olivine-silica. Boundary curves were located by microprobe analysis of glasses coexisting with the various crystal species of the intersecting phase volumes at 1 atm., dry (3).

Also shown on this diagram are the compositions of 2000 MORBS from the literature (4). The densest cluster of MORBS is found on the boundary of the ol + cpx (+ plag) phase volumes. The scatter is considerably reduced when only fresh MORB glass compositions (5) are considered, presumably because the compositions of liquids are not obscured by alteration and phenocryst accumulation which may affect rock compositions. The implication of this figure is that the major control on MORB chemistry is crystal-liquid equilibration at low pressure - a conclusion already reached (6) but largely ignored (7,8,9,10). The operation of crystal-liquid equilibrium at low pressure was also found to be the major control on lunar Fra Mauro basalt and eucrite compositions. With this as background, it would be surprising if the majority of basalt samples from Mercury, Venus, and Mars did not also show a major chemical control by equilibration at low pressures.



BASALTS AND PLANET SIZE

Walker, D. et al.

On the moon and eucrite parent planet, partial melting was argued to be the crystal-liquid process operating at low pressure because of the peritectic nature of the ol + low-Ca px + plag equilibrium around which the basalt compositions cluster. The clustering is expected in a melting process but not in a fractional crystallization process at a peritectic. The cluster of earth's MORBS is not on a peritectic and low-pressure melting is not argued. Yet the clustering should not be encountered in a simple crystallization process; and so a combination of fractionation and magma mixing in a steady-state system at low pressure is argued as the control (3,11,12,13). The advocated process of periodic remixing of hot, fresh magma into a cooler, fractionating, crystal-charged magma chamber is equivalent to partial melting in terms of phase equilibrium constraints - even though the physical process is quite different. Either process can produce compositional clusters - and the complex process argued for the earth cannot be excluded for the moon and eucrites by phase equilibrium arguments. Still, the tectonic setting of steady-state MORB fractionation appears to be peculiar to an active object such as the earth at present. Perhaps the moon was capable of such activity early in its history, but was the eucrite parent planet?

Terrestrial, lunar highlands, and eucrite basalts have the common property of clustering on ol + plag + pyroxene saturation curves at low pressure, albeit through the operation of different mechanisms. It is the nature of the pyroxene and the type of equilibrium which separates the earth from the other two cases. The change in terrestrial MORBS to a crystallization sequence with high-Ca px before low-Ca px (and the attendant loss of the reaction relation between olivine, the liquid, and the primary pyroxene) is a result of the larger size of the earth and the pressure gradient it develops with depth. Primary melts which fractionate to eventually produce MORBS segregate as deep as $\sim$60 km or more (6,9). Lunar Fra Mauro basalt may also segregate at depths this great but the smaller moon only imposes a pressure of $\sim$3 kb at this depth as compared with $\sim$20 kb in the earth. Liquids generated by melting 2-pyroxene peridotite increase in normative cpx/opx ratio with increasing pressure (6,10) at the same time normative ol increases. Olivine fractionation then produces MORBS with augite as their primary pyroxene rather than pigeonite or opx. An auxiliary effect which enhances cpx importance at low pressure is produced by the greater abundance of alkalies in the earth. Qualitatively, alkalies couple with Al, making plagioclase less An-rich. Ca is thus liberated to px, increasing cpx. The spectrum of source regions required to make the observably different crystallization sequences and correlated chemical properties of several meteorite groups may also be explained in this way by combination of alkali-rich and alkali-poor material (14). Although the connection between planet size and volatile abundance is speculative, the more important pressure effect enhancing cpx/opx ratio has a very straight-forward dependence on planet size.

A number of other properties of eruptives appear to be related to planet size:

BASALTS AND PLANET SIZE

Walker, D. et al.

A) *Hotness* The larger energy/mass of a larger gravitational field allows basalts generated by pressure-release melting to follow steeper adiabats for longer distances on larger planets. Thus greater temperature contrasts can be generated and we might expect bigger planets to be able to generate hotter eruptives. The earth has generated komatiites ($\sim 1600^0C$); the moon, ultramafic glasses ($\sim 1400^0C$); and the eucrites erupted relatively cool ($<1200^0C$) although their heating must have been by some other mechanism.
B) *Endurance* Larger planets have better thermal insulation (in terms of surface/volume) so they may be expected to remain active longer. This expectation is confirmed by a survey of "closure ages" for basaltic volcanism in the size series eucrite ($\sim$4.6 by), moon ($\sim$2.5 by), earth (still active). Crater chronologies suggest (15) that Mercury and Mars fit this series according to their size.
C) *Variety* The larger pressure range within, the greater endurance of, and the possibly higher level of volatile enrichment in larger planets may lead to more variety of eruption products. Terrestrial volcanics show much variety reflecting depth of melting, previous depletions of the source regions, and variable volatile enrichment, among other factors. The moon produced a pedestrian series of rocks by comparison; while the eucrites are positively barren of variety.
D) *Pristinity* The feebler gravity field of a small planet is less effective in driving crystal fractionation once primary melts are segregated. As many as ¼ of the eucrites are unaffected by secondary crystallization differentiation. However the incidence of primary magmas on the moon is only measured in percent, while the proportion of primary magmas on earth is <1% - reflecting efficient secondary differentiation.

It is easy to imagine any number of circumstances which could upset these correlations. Yet the observation that properties A-D do correlate with planet size suggests that planet size is a useful index of eruption character. Exceptions to these general rules would be provided by the shergottite, nakhlite, and chassignite meteorites if they should prove to come from asteroid-sized objects. Their cpx-predominant, young, volatile-rich, and fractionated characters are consistent with larger parent bodies. The possible discrepancy would disappear if they came from a large body (e.g., Mars?).

References: (1) Walker et al.(1973) EPSL 20,325-336. (2) Stolper (1977) GCA 41,587-612. (3) Walker et al.(1979) Con.Min.Pet. (subm.). (4) Mutschler et al.(1976) Comp.Geosci. 2,51-57. (5) Melson et al.(1976) Smiths.Contrib.Earth Sci. 19,31-60. (6) O'Hara (1968) Nature 220,683-686. (7) Fuji and Kushiro (1977) CIWYB 76,461-465. (8) Bender et al.(1978) EPSL 41,277-302. (9) Green et al.(1979) Jaeger-Hales Vol., Acad. Press. (10) Presnall et al.(1979) J.Pet.,in press. (11) O'Hara (1977) Nature 266,503-507. (12) Rhodes et al.(1979) Tectonophys., in press. (13) Bryan et al.(1979) Tectonophys.,in press. (14)Stolper et al. (1979) GCA,in press. (15) BVSP (1980) Basaltic Volcanism on the Terrestrial Planets, Chap. 8.