THE LEVEL OF NEUTRAL BUOYANCY EFFECT

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There are, I think, misconceptions about the meaning and significance of the level of neutral buoyancy (LNB) and how it affects magma ascent. Possibly the LNB plays a role in the Yucca Mountain area although I do not know of any positive evidence that it does so

specific

The concept is based simply on the relative densities of magma and lithospheric rocks. Mafic magmas have a density less than that of mantle peridotites and many deep-crustal crystalline rocks such as gneisses and granulites. They have a density higher than that of many granitic rocks, granitic magmas, and most upper-crustal sedimentary rocks and sediments.

Of course the densities of basaltic magmas vary according to their chemical composition, but they depend also on the content and density of any phenocryst phases or xenocrysts, compressibility effects, and the exsolution of gas bubbles.

Two effects may be distinguished. One is a broad effect involving the relationship between magma density and density of the entire lithosphere profile. The other is a local effect involving the relationship between magma and local countryrock density.

The broad effect.

Basaltic volcanoes are extraordinarily numerous, and probably many tens of thousands having youthful forms occur scattered over the continents and ocean floor. This fact is interpreted to mean that basaltic magmas are widely capable of reaching the earth's surface. From what is known of magmatic and lithospheric densities, the average lithosphere density is greater than magma density. Magma reaches the surface because of its positive buoyancy.

Among the many basaltic volcanoes are very large edifices. Examples are Fuji, Kliuchevskaya, Oshima, and Mauna Loa, standing 3.7, 3.0, 2.8, and more than 9 km respectively above their surroundings. These large volcanoes demonstrate that basaltic magmas have sufficient buoyancy to carry them well above the general surface of the lithosphere.

Of course basaltic magmas may in some cases rise because of tectonic pressure, but the fact that so many basaltic volcanoes occur in extensional settings suggests that buoyancy may be a more potent cause of magma ascent.

There are some tectonic settings, notably the thick young sedimentary prisms as in the Mississippi delta, where basaltic volcanoes are scarce or absent. It is not known if this reflects an inability of magma to reach the surface because it lacks sufficient buoyancy, a failure of magma to reach the surface because it forms intrusions instead, or a lack of magma in this tectonic environment.

The local effect.

The lithosphere is not uniform in density but is generally density-stratified. There are likely to be levels within it at which the lithosphere density is matched by the density of a given batch of basaltic magma. Those levels are levels of neutral buoyancy. Such levels may occur for instance at the Moho, at the boundary between young sedimentary prisms and crystalline basement rocks, at the base of a silicic magma body, and at the base of a volcano. Levels of neutral buoyancy are not necessarily horizontal, and for any given lithosphere profile and given magma density there may be several or there may be none.

A level of neutral buoyancy is one at which an ascending magma batch may form an intrusion instead of (or as well as) proceeding to the surface. In effect, at a LNB, magma is faced with a choice whether to proceed to the surface or intrude instead. The magma has ample buoyancy to proceed to the surface, but if the LNB is sufficiently favorable magma may intrude and pond there instead. The LNB can be sensed by magma because it is a level at which the difference between lithospheric pressure and hydrostatic pressure is greatest. Conditions are particularly favorable for intrusion if the LNB occurs where there is a great change in lithosphere strength (as where poorly lithified sediments rest on crystalline basement) or where a body of earlier-injected magma resides in the lithosphere.

or reside at the LNB

One can infer that magma chambers are situated in LNB positions. Longevity of a chamber is guaranteed because successive uprising magma batches are trapped therein.

Non-horizontal surfaces of neutral buoyancy also exists. They were inferred to exist along the margins of the Koolau dike complex (Oahu) to explain why the peak dike intensity in the complex is about 65%. It is inferred that at this intensity, dikes plus countryrock screens attain a bulk density equal to that of basaltic magma. Incoming magma batches therefore avoid the high-density complex and inject instead at the margins of the complex.

In the specific case of the Yucca Mountain Region, a LNB may well exist between Paleozoic sedimentary rocks and Cenozoic ignimbrites, (particularly where the latter are not densely welded), at the base of alluvial fills, and at the base of cinder cones. I do not know of any evidence for basaltic intrusions in the ignimbrites or at the base of alluvium, but the scoria mound field of Lathrop Wells volcano may be caused by basaltic magma coming out from the base of the cone instead of from the summit crater

Perhaps the first contribution to the concept of LNB was that by Gilbert (1877) who postulated that the emplacement level of laccoliths in the type-locality (Henry Mountains, Utah) was determined by the density contrast between countryrock and rising magma. Corry confirmed this relationship. He, however considered that the level of intrusion was a function of the density contrast between magmas and the "weighted mean density of the overburden". In this I think he was wrong.

The LNB concept is not new. The name was proposed by Ryan (1987), but the concept had previously been proposed for example to explain the "shadow zones" in silicic volcanoes, within which basaltic eruptions do not occur (Walker, 1974) and for the postulated formation of an intrusive-sheet swarm, identified as crustal layer 3, in Iceland (Walker, 1975).

REFERENCES

Corry, C.E. 1988. Laccoliths: mechanisms of emplacement and growth. Geol. Soc. Am. Spec. Pap., 220: 70 p.

Fiske, R.S. and Jackson, E.D. 1972. Orientation and growth of Hawaiian volcanic rifts — the effect of regional structure and gravitational stresses. Roy. Soc. Lond. Proc., A329: 299–326.

Gilbert, G.K. 1877. Report on the geology of the Henry Mountains. U.S. Geograph. Geol. Surv. of the Rocky Mountain Region. Washington, 160 p.

Ryan, M.P. 1987. Neutral buoyancy and the mechanical evolution of magmatic systems. In B.O. Mysen (edit.). Magmatic processes: physicochemical principles. Geochem. Soc. Spec. Publ., 1: 259–287.

Walker, G.P.L. 1974. Eruptive mechanisms in Iceland. In L. Kristjanssen (edit.). Geodynamics of Iceland and the North Atlantic area, 181–201. Reidel, Dordrecht.

Walker, G.P.L. 1975. Intrusive sheet swarm and the identity of crustal layer 3 in Iceland. Geol. Soc. Lond. J., 131: 143–161.

Walker, G.P.L. 1986. The Koolau dike complex: intensity and origin of a sheeted complex high in an Hawaiian volcanic edifice. Geology, 14: 310–313.

Walker, G.P.L. 1989. Gravitational (density) controls on volcanism, magma chambers, and intrusions. Austral. J. Earth Sci., 36: 149–165.

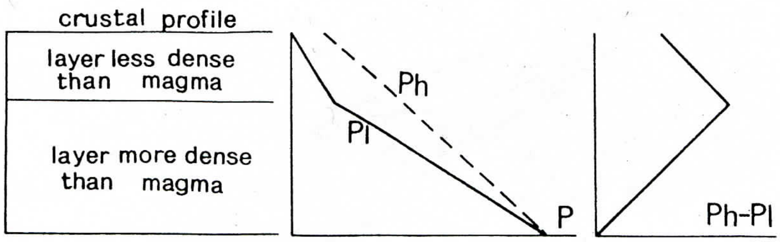

Fig. 1. Ascent of magma into a simple two-layer lithosphere. A level of neutral buoyancy exists between rocks more dense and less dense than mafic magma. Pl and Ph show lithostatic load, and hydrostatic pressure in the magma, respectively. Ph is sufficient to carry magma above the general surface of the lithosphere, but the LNB is a favorable level at which magma can intrude, because Ph − Pl reaches a maximum value there (After Walker, 1974).

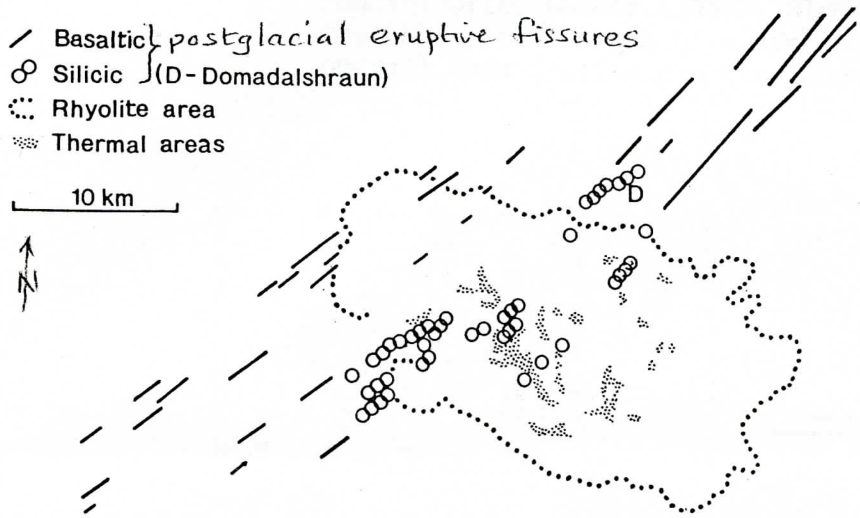

Fig. 2. A typical "shadow zone" — that of Torfajokull silicic volcano in Iceland — within which basaltic magmas fail to reach the surface because they are trapped by silicic magma. Mafic magma "stokes up" and may trigger eruptions of the silicic magma.

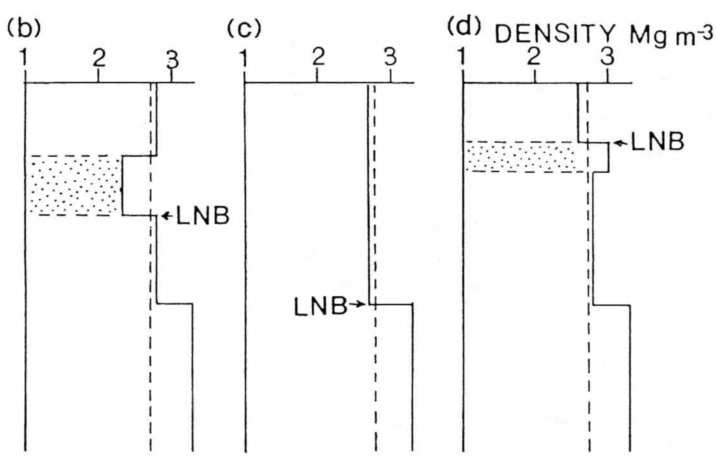

Fig. 3. Postulated density profile through crustal section (b) that includes a silicic intrusion (stippled), (d) that includes a large mafic intrusion (stippled) , and (c) where sedimentary rocks rest on crystalline basement, showing LNB which are favorable positions for magma to intrude. Magma densities shown by dashed lines.