Linking paleo-surface characteristics and deep crustal processes caused by mantle plumes

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Buoyant upwellings from the deep mantle (mantle plumes) can arrive at the base of the lithosphere and generate large igneous province (LIP) magmatism which is emplaced throughout the crustal profile, from a deep-crustal magmatic underplate to intra-crustal dykes, sills, and layered intrusions, and surface volcanism. The presence of mantle plumes, has a direct influence on deep crustal magmatism, metamorphism, and dynamics.

In this contribution we provide an overview of the links between mantle plumes and their surface expression and atmospheric influence. We consider three aspects: 1) the distribution of associated large igneous provinces (LIPs) and especially their volcanic expression; 2) topographic changes (domal and annular) associated with the flattening of the mantle plume head at the base of the lithosphere, and also development of triple junction rifting; and 3) dramatic climatic excursions in both atmosphere and oceans as recorded by compositional changes in sedimentary rocks and in weathering characteristics. The goal of this investigation is to address the inverse situation: using the characteristics observed at the Earth's surface and their timing to infer the existence and location of paleo-mantle plumes, and thus infer their deep crustal effects.

Presence of flood basalts and erosional exposure of LIP plumbing system

The most dramatic evidence for the presence of a mantle plume is their LIPs. LIPs have broad significance for a number of areas of geology. LIPs are important in constraining paleocontinental reconstructions (Ernst et al. 2013), are a tool in resource exploration targeting (e.g. Ernst and Jowitt, 2013), are analogues for planetary intraplate magmatism (e.g. Head and Coffin, 1997; Ernst, 2014), and have a causal role in dramatic climate change throughout Earth history (Ernst and Youbi, 2017).

The distribution of the flood basalt component of LIPs will be concentrated above the mantle plume centre region, but intrusive magmatism can be distributed out to >2000 km away from the plume centre. In older terranes, LIPs are typically recognized by their plumbing system (of mafic dykes, sills and layered intrusions) since the flood basalt component has typically been removed by erosion.

Topographic changes (domal and annular)

Domal uplift (up to 2000 km across, and up to a couple km in maximum elevation) is characteristically associated with the arrival of a mantle plume. Domal uplift is expected on the basis of modelling and is directly recognized through the bullseye pattern of sedimentary erosion or more indirectly through the presence of a giant radiating dyke swarm (Ernst, 2014). Triple junction rifting is often associated, but can be offset from the centre of domal uplift due to pre-existing zones of lithospheric weakness.

Recent discovery of giant circumferential dyke swarms (Buchan and Ernst, 2018a,b) suggests that an annular uplift can circumscribe the plume centre (by comparison with corona on Venue, which are inferred to be an analogue). A circumferential dyke swarm (and inferred annular topographic uplift) can circumscribe the plume centre at a radius of hundreds to >1000 km.

Dramatic climatic excursions

There is an increasing recognition of the role of LIPs and their silicic counterparts, Silicic LIPs (SLIPs), in rapid environmental and climate changes, including global warming (Hothouse events), global cooling (Icehouse events, i.e. Snowball Earth or regional glaciations), anoxia, stepwise oxygenation, acid rain/ocean acidification, enhanced hydrothermal and terrestrial nutrient fluxes, and mercury poisoning, leading, in many cases, to mass extinctions (e.g. Ernst and Youbi, 2017; Bond and Grasby, 2017).

Many short dramatic climatic excursions can be linked to a LIP (particularly those emplaced in less than 1 myr). However, some excursions are not linked with any known LIPs, but it can be speculated that some of these are caused by LIPs as yet unrecognized. While the majority of LIPs have probably been recognized, there remain cratonic regions with abundant currently-undated Precambrian mafic units that likely belong to LIPs (e.g. Ernst et al. 2013).

Influence of plumes on deep crust

This research summarizes characteristics observed at the Earth's surface for the recognition of paleo-mantle plumes. Recognition of mantle plumes is significant for deep continental crust for many reasons, including the following: 1) as a locus of lithospheric thinning and continental breakup (or attempted, but failed breakup); 2) for locating the central region (within about 500 km of the plume centre) that is the locus of a deep crustal intrusions including a magmatic underplate; 3) a thermal pulse from the plume can enhance lower crustal metamorphism, and 4) magmatic underplating at the crust-mantle boundary can increase seismic velocities of the lowermost crust and cause vertical growth of the crust (Thybo and Artemieva, 2013).

References

Bond, D.P.G. and Grasby, S.E., 2017. On the causes of mass extinctions. Palaeogeogr. Palaeoclimatol. Palaeoecol. 478, 3–29.

Buchan, K.L., and Ernst, R.E., 2018a, A giant circumferential dyke swarm associated with the High Arctic Large Igneous Province (HALIP): Gondwana Research, 58, 39–57.

Buchan, K.L. and Ernst, R.E., 2018b, Giant Circumferential Dyke Swarms: Catalogue and Characteristics, in Srivastava, R.K., Ernst, R.E., Peng, P. (eds.) Dyke Swarms of the World – A Modern Perspective. Springer (in press)

Ernst, R.E., 2014, Large Igneous Provinces. Cambridge University Press. 653 p.

Ernst R.E. and Jowitt S.M., 2013, Large igneous provinces (LIPs) and metallogeny. In: Colpron M. et al., eds. Tectonics, metallogeny, and discovery: The North American Cordillera and similar accretionary settings. Society of Economic Geologists Special Publication, 17, 17-51.

Ernst, R.E. and Youbi, N. 2017. How Large Igneous Provinces affect global climate, sometimes cause mass extinctions, and represent natural markers in the geological record: Palaeogeography, Palaeoclimatology, Palaeoecology, 478, 30-52.

Ernst, R.E., Bleeker, W., Söderlund, U., and Kerr, A.C., 2013. Large igneous provinces and supercontinents: toward completing the plate tectonic revolution. Lithos 174, 1–14.

Head, J.W. and Coffin, M.F., 1997, Large Igneous Provinces: a planetary perspective. In: Mahoney, J.J., and Coffin, M.F. (eds.) Large Igneous Provinces: Continental, Oceanic and Planetary Flood Volcanism. AGU Geophysical Monograph, 100, 411–438.

Thybo H. and Artemieva, I.M., 2013. Moho and magmatic underplating in continental lithosphere. Tectonophysics, 609, 605-619.