

## Mantle plumes: effect rather than cause of lithospheric breakup

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In 1971, Morgan suggested a concept of mantle plumes. The model is widely but not unequivocally accepted as the cause for flood basalt provinces. However, scientists familiar with volcanic activities or flood basalts, both time and regions, puzzled over how the mantle plume concept accorded with the observations. Many researchers argue that lithosphere breakup and associated volcanic or flood basaltic outbreaks and hotspots are controlled, top-down, by shallow processes, rather than by rising mantle plumes. Anderson has formalized this opposing view as the Plate paradigm. This paradigm includes concepts related to crack propagation, internal plate deformation, volcanic activities, recycled subducted slabs, and lithospheric breakup. Although both Plume hypothesis and Plate hypothesis relate to the thermal effect, few studies have been found to attempt to explain how the initial thermal instability forms or why the source of magma for volcanisms and LIPs might be maintained. In Plume hypothesis, they always assumed that such thermal instabilities are formed mostly at the core-mantle boundary and that the plume conduits remain for millions of years, as implied by the persistence of hotspots. White and McKenzie have developed a detailed formulation of the more passive and uniformitarian rifting model, providing an different explanation for the presence of huge basalt accumulations along rifted continental margins. However, they placed little emphasis on how mantle plumes begin and reach the base of the lithosphere.

In this paper, I combine the failure dynamic studies with inferences drawn from a three-dimensional modeling of surface cracking under thermal expansion induced extension and the results of geological observations to consider the dynamics of the putative link between mantle plume, flood basalts, and lithospheric breakup. I will show a numerical modeling result of a surface failure pattern occurred on a spherical shell loaded from inside with an internal pressure in a displacement control manner, resembling the behavior of thermal expansion, from which I derive an intuitive physical model of the process of surface cracking as a self-organized phenomena. It is shown that deep mantle plume is not required as the prerequisite for such a process. A new hypothesis for no-root mantle plume, starting from the top of the asthenosphere in a top-down pattern is then proposed, which implies that the mantle plumes should then be regarded as the effect rather than the cause of lithospheric breakup.

Based on the model, a LIP event can be considered as a positive feedback loop of a process that the response to its change amplifies the change. During a LIP event, heat accumulation in the mantle may cause continental uplift in the ways of thermal expansion and volume increase during the phase change. The lithospheric uplift may trigger rift in global scale with a pattern of polygonal fractures. This shallow-based lithospheric process can locally release stresses, thus promoting local de-compressive melting. Extra volume increase of the magma (during phase change from solid to liquid) may serve as the driving force for eruption, which in turn should result in new cracking and associated sudden pressure drop. The process will become unstable, providing the coupling between pressure and temperature within the mantle satisfy certain conditions for phase change. No deep mantle plume is needed to for such a LIP. This mechanism furthers our understanding of global cooling events: the gradual accumulation of heat within the earth may result in large igneous provinces, which may cause abrupt loss of heat during large volcano eruptions or huge flood basalts. This abrupt loss of Earth's heat makes the warming cycle to an end and a new start of the cooling cycle initiates, with glaciations as the extreme results.

Keywords: Mantle plume, rift, de-compressive melting, thermal expansion

# Subduction Zones and Mantle Plumes

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In its simplest form, the plate-tectonic hypothesis expects volcano chains to lie behind subduction zones, e.g., the circum-Pacific belt and the Alpine-Himalaya continent-continent collision zone. Nevertheless, volcanism associated with subduction is considerably more diverse than this. In this paper I argue that this diverse volcanism reflects the real, complex stress fields associated with subduction zones. Specifically, where the lithosphere is in extension, permissive volcanism occurs. Volcanism that is more diverse and widespread than predicted by the simple, textbook model of subduction zones is thus an expected feature of real geological cases.

Back-arc extension was not originally part of plate tectonic theory. Nevertheless, when it was discovered, it fit naturally into the model. It did not violate predictions of plate tectonics and radical revision of the theory was not required. Sinking slabs lie down in the mantle at their depth of neutral buoyancy and their surface hinges thus retreat. This process results in extension as the lithosphere ahead of hinges is pulled apart and volcanism occurs as a result. In some cases this deformation and volcanism takes the form of spreading and the development of oceanic crust. In other cases, distributed volcanism occurs, time-progressions may be observed, and small flood basalts may erupt. Examples include:

- \* spreading in the Sea of Japan;
- \* the Manus back-arc basin;
- \* volcanic activity in eastern China;
- \* the Columbia River flood basalt in the states of Washington and Oregon, U.S.A.;
- \* volcanism in the Basin-Range province in the western U.S.A.;
- \* volcanism in Italy, behind the Alpine subduction zone;
- \* distributed, time-progressive volcanism in eastern Anatolia, Turkey; and
- \* time-progressive volcanism in Mexico.

In addition, volcanism has been observed behind subduction hinges, for example as “petit spots” , attributed to permissive volcanism through cracks in the lithosphere as it approaches subduction zones and bends [Hirano *et al.*, 2006]. Volcanism at Samoa is likely also associated with cracking of the Pacific plate as it approaches the Tonga trench [Natland & Winterer, 2004].

Despite the obvious association of volcanism and lithospheric extension in the neighbourhood of subduction zones, in many cases this volcanism has been attributed to deep mantle plumes. In this paper I argue instead that the diverse volcanism that occurs in the wider neighbourhood of subduction zones can be explained naturally by expected lithospheric extension of various kinds. This provides a simpler explanation of volcanism in subduction environments than appealing to two separate and independent processes—plate tectonics and mantle plumes.

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<http://www.mantleplumes.org/>

Keywords: mantle plumes, subduction zones, plate hypothesis

# Geodynamic consequences of slab retreat: Implications for the orogenic development in the Circum-Pacific and Mediterranean-Carpathian regions

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Geodynamic reconstructions in both (south) western Pacific and the Mediterranean regions exemplify features of trench migration, back-arc extension, and transient pattern of surface subsidence-uplift those are characteristic for slab retreat/roll back tectonics. The development of these processes is usually followed by plate collision and tectonic displacements are mainly controlled by vertical forcings (e.g slab pull, mantle upwelling) rather than horizontal plate convergence. In this work, geodynamic modeling results of sub-crustal slab retreat (delamination) are used to infer the pattern and the amount of of surface uplift-subsidence, shortening-extension, trench migration. Model parameters are varied to test the influence lower crustal thickness/density, density of sinking slab, lithospheric thickness. Subsequently, a comparison between the model results are made against the; 1) last 12 Myrs tectonic evolution of the western North island in new Zealand, 2) Eocene-Oligocene evolution of New-Caledonia, Lord Howe regions 3) the last 10 Myrs post-orogenic lithospheric evolution of the Southeast Carpathians. Model results are in good agreement with the southward migration of the 1.2 km of uplift and 2 km of subsidence in the east of Taranaki basin in central island, 2 km of subsidence of the New Caledonia trough and 1-2 km of uplift of the Lord Howe rise, ~ 1 km of uplift in the southeast Carpathians-Transylvania and up to 6 km of subsidence in the Focsani basin. The retreating slab induces subsidence on the surface while pulling down the crust. The zone of slab removal results in the surface uplift and this is controlled by isostatic and dynamic response to the mantle uprising under the crust.

Keywords: Slab retreat, western Pacific, Mediterranean

## 東北アジア地域のプレート内部火山の深部構造と起源

### Mantle transition zone, stagnant slab and intraplate volcanism in Northeast Asia

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Three-dimensional P and S wave velocity structures of the mantle down to a depth of 800 km beneath NE Asia are investigated using ~981,000 high-quality arrival-time data of local earthquakes and teleseismic events recorded at 2388 stations of permanent and portable seismic networks deployed in NE China, Japan and South Korea. Our results do not support the existence of a gap (or a hole) in the stagnant slab under the Changbai volcano, which was proposed by a previous study of teleseismic tomography. In this work we conducted joint inversions of both local-earthquake arrival times and teleseismic relative travel-time residuals, leading to a robust tomography of the upper mantle and the mantle transition zone (MTZ) beneath NE Asia. Our joint inversion results reveal clearly the subducting Pacific slab beneath the Japan Islands and the Japan Sea, as well as the stagnant slab in the MTZ beneath the Korean Peninsula and NE China. A big mantle wedge (BMW) has formed in the upper mantle and the upper part of the MTZ above the stagnant slab. Localized low-velocity anomalies are revealed clearly in the crust and the BMW directly beneath the active Changbai and Ulleung volcanoes, indicating that the intraplate volcanism is caused by hot and wet upwelling in the BMW associated with corner flows in the BMW and deep slab dehydration as well.

#### Reference

Chen, C., D. Zhao, Y. Tian, S. Wu, A. Hasegawa, J. Lei, J. Park, I. Kang (2017) Mantle transition zone, stagnant slab and intraplate volcanism in Northeast Asia. *Geophys. J. Inter.* **209**, 68-85.

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Keywords: Northeast Asia, Intraplate volcanism, Mantle transition zone

## 新生代北東アジアテクトニクスはスタグナント太平洋プレートのマントル深部脱水作用を必要とするか？

### Does Cenozoic tectonics in NE Asia need the deep dehydration of the stagnant Pacific Plate?

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マントル遷移層のスタグナント太平洋プレート由来の流体成分が、北東アジアの新生代テクトニクスに重要な役割を果たしているというモデルが提案されている。しかし、鉱物学、岩石学、地質学的見地から、このマントル深部脱水モデルには多くの重大な見落としがある。

スラブ脱水反応によって放出された $H_2O$ によって蛇紋岩化マントルがマントルウェッジ最下部に形成されると考えられている。 $H_2O$ が深部マントルにもたらされるには、蛇紋岩化マントルが高密度含水ケイ酸塩鉱物が安定な6GPaまでスラブと共に沈み込む必要がある。しかし、蛇紋岩化マントルの主要構成鉱物である蛇紋石の物性は、蛇紋岩化マントル沈み込みが困難であることを示している。蛇紋石の密度はカンラン石の密度より著しく小さく、蛇紋岩化マントルは自らの浮力のため沈み込むことができない。蛇紋岩化マントルを沈み込ませるには、沈み込むスラブからの引きずりが必要である。しかし、蛇紋石の機械強度はカンラン石よりも小さいため、蛇紋岩化マントルはスラブ引きずりに対して滑り面として働くと考えられる。従って、スラブ引きずりは蛇紋岩化マントルに有効に働かないと考えられる。

太平洋プレートの最も古い部分と、若いフィリピン海プレートが二重沈み込みを行う中部日本は、蛇紋岩化マントルが6Gaまで沈み込める場所と考えられている。しかし、この場所で太平洋プレートの海溝系はNNE-SSW方向からNS方向に向きを変える。このようなスラブリジオメトリの転換点では、走行平行張力によってスラブウィンドが開くと考えられる。スラブウィンドを通じて、マントルウェッジはサブスラブマントルと相互作用を起こし、温度を上昇させると考えられる。中部日本における火山フロントの海溝側への移動は、伊豆一小笠原弧の衝突による地質構造の屈曲が原因であると考えられる。

西南日本山陰玄武岩のNb負異常は、マントル深部脱水作用の重要な証拠と見なされている。しかし、見積もられている含水量(1.5%)はハワイなどのOIBと同程度である。西南日本は付加体コンプレックスから形成されており、山陰玄武岩の地球化学的特徴は島弧リソスフェアの関与によって説明可能である。九州で観察される火山岩の地球化学的特徴と九州-パラオ海嶺の関係は、島弧火山岩類の地球学的特徴がスラブ由来流体ではなく、島弧リソスフェアの関与によって説明されることを示している。

深部脱水作用によって付加された $H_2O$ によるリソスフェア脆弱化が、北東アジアのリソスフェア薄化をもたらしたと考えられている。北東アジアにはタン・ルー断層など多数の横ずれ断層が発達する。横ずれ剪断による鉱物粒子の細粒化はリソスフェア脆弱化をもたらす。伸張テクトニクスを原因とする反応も鉱物粒子を細粒化させリソスフェアを脆弱化させる。剪断駆動溶融作用はマントル上昇流をリソスフェアの脆弱部に集中させ、さらなる脆弱化と薄化をもたらすと考えられる。

鉱物学、岩石学、地質学的見地から、上述のようにスタグナント太平洋プレートのマントル深部脱水作用を主張する研究には多数の重大な見落としがある。北東アジアから得られる証拠の束とそれらに基づく複眼的考察は、北東アジアで観察される地質事象は横ずれ伸張テクトニクスなどの浅所マントルの作用によって説明さ

れることを示している。

キーワード：リソスフィア加水脆弱化、スタグナントスラブ、蛇紋岩ダイアピル、H<sub>2</sub>Oチョークポイント、横ずれテクトニクス、鉱物粒子細粒化

Keywords: hydration weakening of lithosphere, stagnant slab, serpentine diapir, choke point of H<sub>2</sub>O, strike-slip tectonics, grain size reduction



## Remelting the Gondwanan Mantle - Older and Younger

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The SW Indian ridge Marion Rise and the Icelandic Rise are the two largest oceanic rises. Whereas Iceland is supported in large part by thickened crust, sampling shows SWIR crust is generally thin and discontinuous, even over the rise. Thus, in the absence of thickened crust, the Marion Swell at the top of the rise should be supported by previously melted buoyant depleted mantle. Though basalts and peridotites are more refractory up the rise, the degree of melting inferred from peridotite Cr spinel and basalt Na<sub>2</sub>O is only moderate. The peridotites, however, have substantially lower bulk alumina than those sampled to the east and west. Thus, the Marion platform mantle source must be garnet-poor and highly buoyant. This requires removal of high silica melts during the earlier melting, causing excess pyroxene depletion, consistent with a hydrous back-arc or arc environment.

Plate reconstructions shows the Marion Swell corresponds to mantle pulled from beneath the Pan-African Orogenic Belt, during breakup of Gondwana, while SWIR mantle to the east and west originated beneath Archean cratonic lithosphere. The Pan-African Orogenic belt is a 650 to 500 Ma ~1000-km wide terrain consisting of accreted micro-continental fragments and juvenile island arcs formed by subduction and closure of the Mozambique Ocean. Notably missing from the belt is any evidence of the old Mozambique Ocean Crust itself. The major suture zones bounding the belt are strike-slip zones due to southward-directed escape tectonics. These were re-occupied during Gondwana rifting, one of which now bounds the Marion Swell as the Andrew Bain Fracture Zones. Thus, the Marion Rise is likely the product of delamination of old arc-related lithosphere along with the Marion, Crozet, and Reunion Hotspots swept up in the radial mantle flow triggered by the emplacement of the Karoo Plume. The Karoo Plume itself is likely the product of the subduction of Mozambique Ocean crust, due to its greater density than old arc lithosphere, beneath the transition zone, up to ~560 Ma. This then eventually triggered the plume, initiating the breakup of Gondwana.

Keywords: Mantle Plumes, Ocean Ridge, Lithospheric Delamination

