to involve several clock-controlled genes. It is worth noting that basic molecular components at this point seem evolutionarily conserved. Still, little is known about the clock mechanisms that control clock-controlled genes, and about the circadian transcriptional cascades from clock genes to enzymes and proteins. The second component is the input that allows the clock to interact with the surroundings, and still not much is known about the cellular and molecular bases of this component. This 'interface' component will remain important since the environment itself can change dramatically. The third is the output component that uses time information for controlling molecular clock works of the clock. We have just begun understanding about this component. In the years to come, the study of circadian humoral, neural, cellular and transcriptional cascades will help us understand how gene expression, physiology and behaviour are influenced by the geophysical environment we experience on the earth.

The uniqueness of this programme was the learning of chronobiology through an intensive mode of interaction. Both the students and faculty seem to be benefited by close academic interactions, since they stayed together for more than ten days. We have to begin intensive research programmes addressing specific questions in all three aspects of the clock (core element, inputs and outputs). An integrated research programme involving experts from different institutions may also be a good idea to keep up with the pace of development in this field at the global level. Additionally, the PAC may like to take up such meaningful schools in carefully identified and more specialized areas of life sciences in future.

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RESEARCH NEWS

In search of the enigmatic plumes beneath hotspots

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Most of the 500 to 600 volcanoes on the earth are major outlets for molten magma from the earth's interior, and these volcanoes are distributed along the earth's plate margins. A few are located away from such margins and are known as mid-plate or intraplate volcanoes, or hotspots. They occur both on the continents and oceans (Table 1). Actually, they represent sites of melting anomaly in the mantle beneath them and this melt ascends through narrow conduits or plumes. These plumes may rise from the top of the mantle or the asthenosphere as in the case of the plate boundary type of volcanoes but, for the intraplate hotspots, they rise directly from the depths of the lower mantle. Not all hotspots are plume-fed. For example, some known as swells and superswells occurring as oceanic plateaus and positive geoid anomalies (Table 1) are thought to be mere buoyant upwellings of the mantle[1]. However, several researchers doubt if these indeed could be devoid of plumes since such sites are observed to be located over partially molten zones present close to the core–mantle boundary (CMB)[2–4] suggesting a connection with this zone[5–10].

Plumes are supposed to begin at a thermal boundary layer, either at the interface region between the upper and lower mantle at a depth of 660 km or from a boundary close to the core–mantle junction (the so-called D″ layer) deeper down at about 2900 km (refs 6 and 7). The movement of the earth's plates over such stationary plumes is one of the widely accepted explanations given for the occurrence of a string of volcanic islands stretching away from the hotspot sites[11] (Table 1). Experiments in fluid dynamics have shown that the hot, less dense, less viscous mantle layer becomes gravitationally unstable and buoyant, and moves upwards as a diapir or a voluminous plume head. A column of magma trails the latter and finally assumes a variety of shapes – domes, waves, mushrooms, teardrops or dikes[1,7,8,12]. The mushroom-headed plume, quite voluminous in size, is known to give rise to flood basalts over the continents (e.g. Deccan basalts in India) and over the oceanic crusts (e.g. Ontong–Java Plateau in the western Pacific Ocean) through rapid eruption (often < 1 m.y.), and this is supposed to mark the initiation of hotspot eruption.

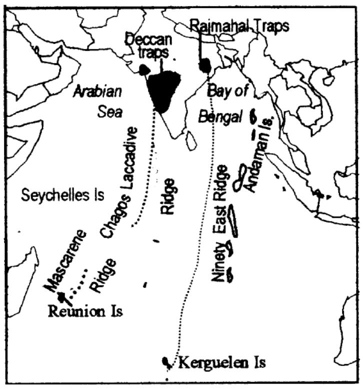
In recent years, considerable rethinking has been going on, in particular, among the geophysicists, about the supposed deep, lower mantle source for the hotpots. Many reject the ability of plumes to rise from depths of more than a few hundred kilometres and deliver the melt to the surface of the earth. The physico–chemical properties of the mantle, the expected phase transition of minerals at 660 km discontinuity, changes in chemistry, thermal structure and geometry of the plumes, all work against the buoyancy of the mantle melt and impede its upward movement. Alternate non-plume routes to hotspot volcanism, like eruptions through rifted or stressed plates, spreading-cracks in plates, or through upwelling of mantle melt have also been suggested for some of the well-known hotspots such as Hawaii[13], South Austral Islands[9], Yellowstone[14] and the Deccan basalts[15,16], all of which were always considered to be plume-fed. In fact, in a global assessment, a mere 8 out of 37 major hotspots around the world are found to have plumes beneath them (hotspots with asterisk in Table 1), and only in the Iceland hotspot there are indications for plume arising from the core–mantle boundary[4,17,18].

Table 1. Some major hotspots, flood basalts, large igneous provinces, swells and superswells around the world. Hotspots indicated with an asterisk have, in recent seismic studies, revealed presence of plumes beneath them (refs 1, 17, 29)

Intraplate volcanism	
Hotspot	Location
Hawaii* (Hawaii–Emperor Seamount Chain)	Pacific Plate
Bowie*, Samoa*, Louisville*	Pacific Plate
Easter* (Tuomoto–Line Island Chain)	Pacific Plate
MacDonald* Seamount (Austral–Gilbert Marshall Island Chain)	Pacific Plate
Yellowstone	North American Plate
Kerguelen (Ninety East Ridge)	South Indian Ocean
Reunion (Laccadive–Chagos–Mascarene Ridge)	SW Indian Ocean
Galapagos	Nazca Plate
Iceland*	North American–Eurasian Plate
Azores	Eurasian Plate
Afar*, Cape Verde, St. Helena and Canary	African Plate
Tristan, Ascension	South American–African Plate
Flood basalts/large igneous provinces	
Deccan basalts	Western India
Rajmahal traps	Eastern India
Tertiary North Atlantic basalts	Iceland
Parana basalts	Brazil–Paraguay
Karoo dykes	South Africa
Ontong–Java	Western Pacific
Siberian	Siberia
MacKenzie dyke swarm	NW Canada
Columbia River Basalt	North America
Swells/superswells	
South Pacific Rise (French Polynesia)	South Pacific
Eastern and Southern portions of Africa	African Plate

Box 1. Indian Ocean hotspots

The break-up of Gondwanaland between 170 and 100 Ma is believed to be intimately associated with several major hotspots present then and this led to gradual closure of the Tethys Ocean. The parting of Australia, India and Antarctica from Africa took place between 100 and 50 Ma leading to the formation of the Indian Ocean around 50 Ma. Today, Reunion and Kerguelen are the two hotspots located in the far southern regions of this ocean. Established views consider that their volcanism resulted in the line of islands marking the drift of India northwards in space-time. One of them stretches from the Reunion Island along the Mascarene Ridge–Chagos–Laccadive to SW India; the other extends N–S along the Ninety East Ridge up to the Andaman group of islands. Around 35 Ma, when India lay at 28°S palaeolatitude, the Reunion track was offset by the spreading ridge and the hotspot had since moved beneath the African Plate. The Kerguelen hotspot got covered by South East Indian Ridge and was cut-off from the Ninety East Ridge. The Rajmahal Traps in Eastern India are linked to Kerguelen plume flooding during mid-Cretaceous[23,32]. The Reunion hotspot has remained active for the last 65 million years[30]. Gravity and magnetic studies in the area around Saurashtra in western India have found volcanic plugs related to Reunion hotspot[31]. This hotspot volcanism, which resulted in the extensive Deccan basalts preceded by alkaline magmas, is believed to have opened up the North West Indian Ocean[26,30]. Non-plume models reject these views that the Deccan basalts are products of the Reunion hotspot volcanism. Instead, these basalts are now considered to be mantle upwellings through rifts that developed in the Indian Plate weakened by the heat build-up due to long-term insulation under the supercontinent, and also by several older (Jurassic?) rifts that underlie the Deccan basalts[15,16]. Seismic studies of the Reunion hotspot indicated predominant low seismic-velocity anomalies in the sub-lithospheric mantle (> 200 km) which are unlike hotspot distribution[18].



Scientists now believe that many of the plumes go undetected because of inadequate resolution achieved in present seismic methods, a problem more acute where these plumes happen to be narrow or located deep in the lower mantle[17]. This shortcoming is attributed to poor distribution of plate-boundary earthquakes as well as to relatively scanty seismic stations located mostly on lands[18]. Scientists propose to overcome these by employing more closely-spaced seismometers both on land and on the ocean floor, and also gather data for longer periods. Such seismic set-ups, it is expected, would provide much higher resolution than has been achieved so far and thus be able to image the elusive plumes. Encouraged by the results from several undersea and land seismic experiments (like MELT, SWELL, OSNPE, TRACK, DEFOR) undertaken during the last ten years, incorporating some of these modifications to interpret hotspots, mantle upwellings and associated geodynamics at several sites in Europe, Middle East, Iceland, East Pacific Rise, East African Rift, Yellowstone and Hawaii[4,18–20], a new Project named PLUME (Plume–Lithosphere Undersea Experiment) is being launched shortly. A team of geophysicists, geochemists and oceanographers from USA will gather data in two phases lasting 30 months in the Hawaiian region. They will be deploying an array of 64 wide-band seismometers on the ocean floor and 10 broadband stations on land. In the first phase, an inner network of 35 seismometers placed 75 km apart and an outer set of 39 seismometers will image the lithosphere and asthenosphere across the entire width (~ 1000 km) of this mantle upwelling for 15 months. In the next phase, more seismometers, 200 km apart, around the entire chain of Hawaiian Islands will record data for another 15 months. The team expects that the integration of the seismic wave arrival times, that slowed down while passing through the plume or swell, will be able to image the roots of the hotspot conduit. Thus they expect to track the plume roots up to 700 km depth or the bottom of the upper mantle.

While deployment of dense array of seismometers and cross-correlation of data gathered for long periods (5–10 years) can indeed provide better tomograms, a possible reason why the present seismic techniques fail to detect some of the plumes was postulated recently by seismologists from Princeton University, USA[21,22]. In their view, the travel times cross-correlation methods currently practised, use the 'ray concept' of seismic-wave propagation through the earth, as an approximation to the 'wave' concept. The seismic waves do get slowed down while passing through the hot plumes, but when these plumes happen to be narrow, the retarded travel times of their wave-fronts get 'healed' or corrected over a short distance after the waves emerge from the plume. They therefore, arrive at the seismic stations at 'truth travel times', as if they never transited a hot plume and had slowed down. As this 'wave-front' healing is not accounted for in the final picture using the ray concept, the plumes go undetected. On the other hand, the 'wave' theory of propagation recognizes the wave-front 'healing' *en route* and interprets the arrival times on a truer fashion. The Princeton group recently re-evaluated several thousand seismic recordings from the archives and found that the classic hotspots in the Pacific plate such as Hawaii, Tahiti and Easter Islands have indeed deep plumes.

Current global efforts through improved detection methods, incorporating suitable corrections, should be able to image features of the different types of hotspots and mantle plumes such as those involved in the continental flood basalts or large igneous provinces, volcanically rifted continental margins and small-scale upwellings. These are expected to provide answers to issues about mantle convection, hotspot magmatism, and plume–lithosphere interaction. They may also offer explanations about propagation of cracks in plates, development of ridges, the role of plumes in triggering flood basalts[23], continental break-up and formation of ocean basins[24–26], and even mass extinctions[27]. Hopefully, they may resolve the ongoing debate – whether these volcanism-related geological events are plume-based as believed hitherto, or in the light of new and supportive geophysical, geochemical and other data, they are non-plume in origin[15,16,28].

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