Towards a better understanding of hot spot volcanism

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Most of the Earth's listed active volcanoes are located at the borders between two tectonic plates, where upsurge of magma from the mantle is facilitated. When these magmatic uprisings occur at a subduction zone, where one tectonic plate plunges under another, they give rise to volcanic massifs such as the Andes cordillera.

Other volcanic chains are formed along oceanic ridges, submarine regions of ocean-floor extension. However, some volcanoes are governed by a completely different mechanism: intraplate volcanism. As their name suggests, these volcanic constructions appear in the very centre of tectonic plates.

Scientists now know that some of them, such as the Hawaii-Emperor archipelago or Reunion Island, result from magmatic upsurges generated at the boundary between the Earth's core and mantle situated 2 900 km deep. Others, such as those of the central Pacific, display different characteristics. They are anomalous, in their simultaneously high number, unusually high concentration and short life-span and prompt scientists to look for hypotheses other than a deep-mantle plume to explain the causes of intraplate volcanism.

Researchers from the IRD and the University of Chile focused on a group of islands and archipelagos in the central Pacific Ocean (Samoa, Cook, Rurutu, Austral, Tahiti, Marquis, Pitcairn), each listed as resulting from hot-spot activity. These scientists aimed to find out if movements of the Pacific plate where these seven hot spots are located could be involved in their formation. They used numerical mechanical simulation models of the effect of the westward displacement of the Pacific plate on internal deformations during the past 10 million years.

This model incorporates a differential tension regime which acts on the Pacific plate, the northern part moving with greater velocity than the southern part, which undergoes a kind of braking effect exerted by the bloc of the Australian plate (see the 3D diagram). The model shows the region to be the site of an East-West shear band which superimposes on the geographical zone where the seven hot spots investigated in the study are grouped.

Another model was subsequently built up that takes into account the cooling of the tectonic plate with increased distance from the oceanic ridge that generated it. This second model also brought evidence of a shearing band, but this zone appeared more diffuse towards the east than in the first simulation. Moreover, this more diffuse shearing zone was superimposed on an anomaly of the Earth's surface classically attributed to an upswelling of the oceanic lithosphere. This anomaly, caused by the upward pressure of the underlying mantle, appears along with an unexplained variation in the ocean floor. This second numerical model therefore indirectly allows the geographical location of the hot spots on an East/West line of weakened lithosphere to be matched with a variation in its thickness.

The existence of a hot spot is usually considered to be linked to the occurrence of a mantle plume, a sort of giant bubble of magma generated by the thermal convection currents circulating in the mantle. This magmatic bubble exerts an upward pressure pushing on the base of the oceanic lithosphere. Then, once broken through, the latter allows the magma to erupt through the Earth's crust. Although this process effectively explains the origin of deep-seated hot spots, it does not provide satisfactory explanations for other forms of intraplate volcanism such as that which occurs in the African rift or certain more recent hot spots situated in the central part of the Pacific Ocean.

The results of this study suggest an alternative scenario which envisages the involvement of shearing strain within the tectonic plates during the formation of a certain type of hot spot volcanism. In the central Pacific, such deformation could therefore be a step towards the break-up of the Earth's largest tectonic plate into two in a timescale of around ten million years. Furthermore, if the movements of a tectonic plate were effectively to play a role in the formation of a hot spot, that would signify that such spots would not be so static as hitherto believed.

The characteristic time-scale for heat-transfer processes in the mantle is in the order of more than 100 million years whereas the movement of the plates occurs over shorter geological time-scales of around ten million years. Certain hot spots could thus change and develop in space relatively rapidly, in line with displacements undergone by the tectonic plates.

Source: Institut de Recherche Pour le Développement