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Discussion

Reply to "Break-up spots: Could the Pacific open as a consequence of plate kinematics?" Comment by R. Pilger

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1. Introduction

In our paper "Break-up spots: Could the Pacific open as a consequence of plate kinematics?" (Clouard and Gerbault, 2008), we show that the specific kinematical conditions of the Pacific plate since 8Myr create a wide east–west area of trans-tensional stress starting at the Kermadec–Tonga trench and ending in the South Central Pacific (SCP). We propose first that this transtensional kinematical context may be responsible for a tectonic plate reorganization where the Pacific plate would split between the Kermadec–Tonga trench and the Easter microplate, and second that the SCP recent volcanism consists in the first, preliminary step to this Pacific plate opening. In his comment, Pilger objects that some SCP hotspots exist since at least 70Ma. In the present reply, we will first present the complexity of the SCP volcanism, and then explain why we do not believe in a link with the old volcanism of the Northwestern Pacific.

2. The South Central Pacific volcanism

The SCP volcanism is composed of old and recent (<12Ma) volcanism. On Fig. 1, we reconstruct the apparent path followed by all the SCP hotspots, from 0Ma to their maximum age (according to age compilation from Clouard and Bonneville, 2005). We use the word "hotspot" for sake of simplicity, and refer here only to the generic meaning of a fixed source with regard to the moving lithosphere, excluding any source mechanism. Tracks are superimposed over the known radiometric age data of seamounts and islands. We think that the representation used in Fig. 1 is better than a simple distance/age graphic, as proposed by Pilger, which leads to mistakes such as that of associating the northern Austral islands (namely Raivavae Tubuai and Rurutu islands) with the Macdonald hotspot. Using a 100-km-wide track as representative of the zone of influence of a given hotspot source, Fig. 1 clearly shows that the northern Austral islands originated from a recent hotspot (Bonneville et al, 2006), named Tubuai on Fig. 1, which probably stopped producing magma at Raivavae ca. 6.5Ma. The track of the Macdonald hotspot is located more to the south (in red in Fig. 1), and is continuous until 9Ma. Before, there is an isolated 19Ma seamount relatively close to this track. And if the track is computed over 70Ma, it finally reaches the Tokelau chain hotspot (Fig. 2). But a huge gap of at least 50Myr exists. Thus, the Macdonald hotspot would have been active from 0 to 8 or 19Ma, and after a period of quiescence of ~50Myr, from 57 to 70Ma. This will be discussed in the next section.

For the other chains, unlike Pilger's comment, the Marquesas, Society and Pitcairn traces have been documented in Clouard and Bonneville (2001). The Society hotspot began at 4Ma, Pitcairn at 10Ma, and Marquesas at 5.5Ma. Rarotonga (1.6Ma) and Aitutaki (1Ma) islands are located at the beginning of a new volcanic track that we attribute to 2 hotspots even if data is missing to confirm this hypothesis. Arago and Tubuai initiated their activity at 12Ma, Pitcairn at 10 and Macdonald at 9Ma. We agree with Pilger's remark that they occur before 8Ma, the approximate time of the Pacific plate slab avalanche beneath the Solomon–Vitiaz trench (Pysklywec et al., 2003). This can be explained, or by locally favourable conditions (like an already weakened lithosphere by older structures as seen on Fig. 1 for Tubuai and suggested by several authors), or because of a change in the subduction zones force balance occurring slightly before the slab avalanche.

In the 1250km × 3000km area representative of the SCP, the Society, Pitcairn, Macdonald and Arago are the 4 active hotspots. Three more

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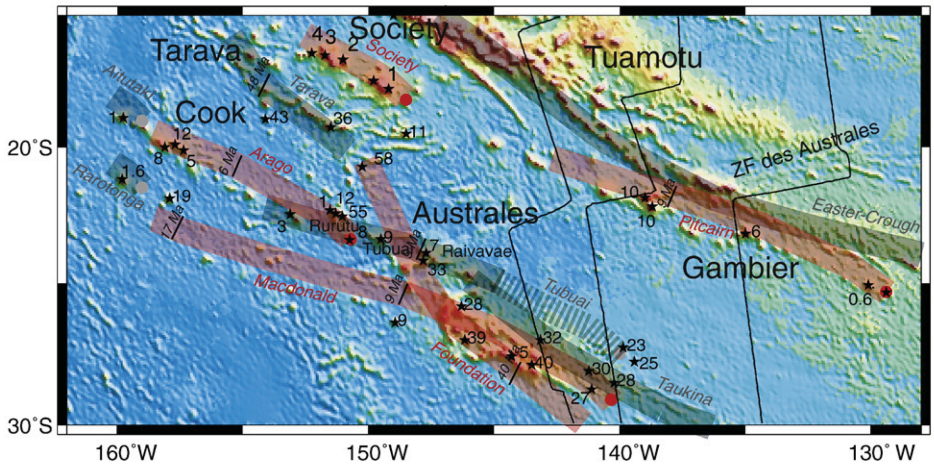

Fig. 1. Hotspots and hotspot tracks on the SCP seafloor. Active hotspots are the red points, hypothesized hotspots the grey points. Reconstructions are done with Wessel et al.'s (2006) stage poles. Each 100-km-wide track has the same colour as the hotspot that generates it. Theoretical track ages are in black italic numbers. Black stars locate radiometric ages of seamounts and islands (ages in black in Ma from the compilation of Clouard and Bonneville, 2005). The names of the hotspots are reported along the tracks. Volcanic chains are named in black.

hotspots complete the list of recent volcanism in this area: Rarotonga, Aitutaki and Tubuai. To summarize, there are 7 recent (<12Ma) linear chains covering the SCP region. This number is greater than any reasonable hotspot concentration on Earth, whatever the context.

In addition, 3 old asynchronous linear chains exist in the SCP: Taukina (McNutt et al., 1997), Tarava (Clouard et al., 2003) and Foundation (named Ngatemato by McNutt et al., 1997). Their ages, when they cross the SCP, range from 58 to 31Ma for Foundation, 47 to 35Ma for the Tarava and 25 to 22 for Taukina (see Fig. 1). The Tarava seamount chain appeared occasionally during the Emperor Hawaii bend, the Taukina chain is related to the Foundation seamount chain (McNutt et al., 1997). The present-day location of these hotspots (active or not) is far from the SCP region, and their presence simply indicates zones of weakened lithosphere.

3. Relation of the SCP present-day volcanism with older chains

a) Absolute Pacific plate motion

To relate older intraplate chains of the Northwestern Pacific with present-day hotspots, a reliable set of rotation poles of the Pacific plate is needed. The most recent one, which we used to produce Figs. 1 and 2 was proposed by Wessel et al. (2006). They determined rotation poles in the hotspot reference frame between 0 and 70Ma, from the tracks of Hawaii, Louisville, Foundation, Pitcairn and

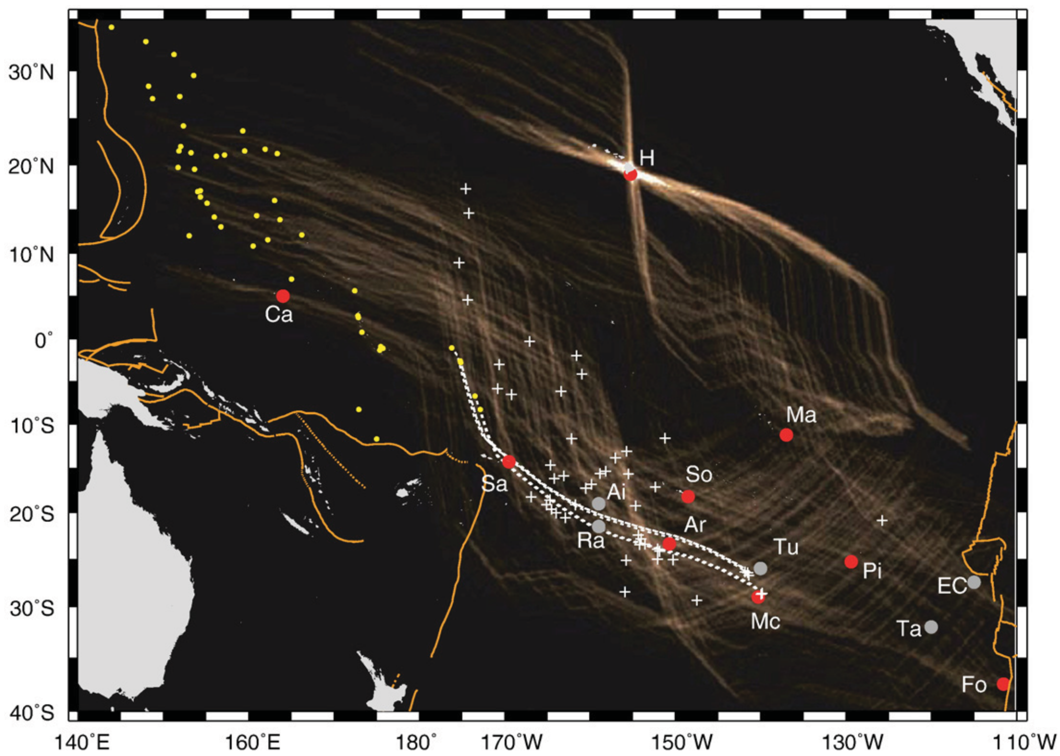

Fig. 2. Back-tracking of dated Northwestern Pacific seamounts (present-day location: yellow dots; back-track locations: white crosses) over a CVA image obtained from all the Pacific seamounts without age constrains (see text for explanation). The tracks of Tokelau seamounts are the white dotted lines. Bright spots in the CVA image result from flow line convergence over hotspots. Hotspots are displayed as red and grey dots (same colour convention as Fig. 1): Ha: Hawaii, Ca: Caroline, Sa: Samoa, Ra: Rarotonga, Ai: Aitutaki, So: Society, Ar: Arago, Mc: Macdonald, Pi: Pitcairn, Ta: Tarava, EC: Easter-Crough, Fo: Foundation.

Caroline hotspots. For older periods, Wessel et al. (2006) only reported previous poles from Kroenke et al. (2004), since these hotspot tracks have disappeared in subduction zones or vanished. Tracking back the origin of the 70–125Ma set of poles, they have been determined from the Musicians seamounts, Hess and Shatsky Ridges and some seamount chains of the Northwestern Pacific (Kroenke et al., 2004). These rotation poles can be correct but are more intuitive than totally reliable, as were those from Duncan and Clague (1985), the most commonly used. These poles were deduced from the orientation of the Line Islands for the 70–100Ma one and from the orientations of the Mid-Pacific Mountains for the 100–140Ma pole. Thus, at this point of our knowledge of the absolute Pacific plate motion before 70Ma, it is really hazardous to precisely track back intraplate volcanism older than 70Ma.

b) Link with the Northwestern Pacific volcanism

A lot has been speculated on the common origin of the SCP and the Northwestern Pacific volcanism. It is a logical reasoning since whatever the reconstruction (whatever the chosen Pacific rotation poles among all published poles) any old seamount of the Northwestern Pacific will very probably fall in the vicinity of one of the 7 present-day SCP hotspots. This is illustrated on Fig. 2, where we used Wessel et al.'s (2006) Pacific poles to track back all the dated Northwestern Pacific seamounts (age compilation from Clouard and Bonneville (2005), with in addition the ages of the Tokelau and Gilbert chains from Koppers and Staudigel (2005)). The tracks mainly end in the SCP region, but not over one specific hotspot. In particular, the backtracks of the Tokelau seamounts (5 dated seamounts) end partially near the Macdonald hotspot and partially near the Tubuai hotspot. Thus, the superposition of the possible hotspot at the origin of the Tokelau chain and the Macdonald hotspot is probably fortuitous. Koppers and Staudigel (2005) arrived at the same conclusion and proposed the existence of extinct hotspots with complementary mechanisms to explain the abnormal age progression of the Tokelau chain.

Another common argument to relate the Northwestern Pacific seamounts with the SCP hotspots is to say that the sampling of dated seamounts over the Pacific plate is sparse, and that, with more dating, results would be more convincing. In answer to this, we display on Fig. 2 the Cumulative Volcanic Amplitude (CVA) of all the seamounts of the Pacific plate (from Wessel's (2001) seamount compilation). The CVA surface is obtained by convolving seamount shapes with flow lines obtained by hotspotting (Wessel and Kroenke, 1997). The flow lines or tracks are only limited by the age of the seafloor underlying each seamount. With this representation, if a hotspot has been active for a long time, the tracks of the seamounts that it has generated will converge over its location, which results in a maximum in the CVA image. While the Hawaii hotspot presents a clear maximum (Fig. 2), indicating its present-day location and the production of numerous seamounts, there are no clearly localized maxima in the SCP region. As this technique uses all the seamounts, without a priori information on their age, it is another evidence that old (>50Ma) seamounts are not related to the present-day SCP hotspots.

Our last argument is that if someone wants to prove that a relation between the Northwestern Pacific volcanism and the SCP volcanism really exists, one would have to explain why a hotspot, now used in the sense of a fixed plume of diameter 100km, can have a 10Myr period of activity, an eruption rate of almost zero for 50 to 70Myr, and then a new activity. If the hotspot theory associated with deep mantle plumes did not exist, no one could be able to prove the existence of deep fixed plumes with such data. Conversely, we think that the Northwestern Pacific and the SCP volcanism evidence the same very fertile regional zone, which enable intraplate volcanism to occur each time that favourable conditions like lithospheric extension occur, as it is currently the case.

4. Conclusion

In reply to Pilger, we think that the Northwestern Pacific intraplate volcanism is not related to the recent SCP volcanism in the sense that it is not the same hotspots that generated it. Even if deep plumes exist, the intraplate Pacific volcanism cannot be explained solely by this mechanism, mainly because of gaps of more than 50Myr between activity periods of 10Myr, and because short-lived hotspots are too closely spaced. We made a link between recent Pacific intraplate volcanism and changes in kinematical conditions at the borders of the Pacific plate (Clouard and Gerbault, 2008): if this is occurring now, it may have occurred also in the past to a degree that may not have been sufficient to break the Pacific plate (permanency, direction and intensity of these boundary conditions). In fact, tensional stresses and strains generated by plate reorganisation have already been suggested as a cause for old intraplate volcanism (e.g., in the Tokelau/Gilbert chains by Koppers and Staudigel (2005), and in the Northwestern Pacific in general by Smith (2007)).

It is now admitted (see review in Foulger, 2007) that lithospheric extension associated with a fertile mantle source is necessary for the presence hotspots when these are not related to a deep mantle plume. In our paper (Clouard and Gerbault, 2008), we explained the SCP intraplate volcanism not only by lithospheric extension, but also because it is a part of a larger process of Pacific plate opening. In the same way that Pilger cites some important papers from the seventies to recall that the relation between lithospheric extension and intraplate volcanism is not so recent, we would like to cite directly the hotspot foundation paper from Morgan (1971). He said: “My claim that the hotspots provide the driving force for plate motions is based on the following observations to be discussed below. (1) Almost all of the hotspots are near rise crests and there is a hotspot near each of the ridge triple junctions, agreeing with the notion that asthenosphere currents are pushing the plates away from the rises. (2) There is evidence that hotspots become active before continents split apart. (3) The gravity pattern and regionally high topography around each hotspot suggest that more than just surface volcanism is involved at each hotspot. (4) Neither rises nor trenches seem capable of driving the plates.” All the characteristics of the hotspot volcanism he pointed out are present in our proposed mechanism, only our conclusion diverges. According to our model, kinematical and geometrical conditions of plates are responsible for plate re-organizations that induce intraplate volcanism. The important point of our paper is that we quantify the effect of present-day subduction zone forces on the Pacific plate stress field and subsequent internal deformation, which links ridges and hotspots.

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