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Short Communications

The synchronic Cenozoic subduction initiations in the west Pacific induced by the closure of the Neo-Tethys Ocean

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Subduction initiation is fundamental for the plate tectonics theory, which has drawn wide attentions [1–5]. Ocean-continent transition [1], emergence of plume head [5], age contrast, e.g., due to displacement of spreading ridges along transform fault [6], etc, have all been proposed as the main trigger of subduction initiation. Previous studies suggested two types of subduction initiations, namely spontaneous and induced [4]. Induced subduction initiation was resulted from pre-existing plate convergence, whereas spontaneous subduction initiation was triggered by large lateral density contrasts occurring across profound lithospheric weaknesses [4], or by emerging of mantle plume head within the plate [5].

The most important characteristics of Cenozoic subduction initiations in the west Pacific is their synchronicity (Fig. 1) [7]. For example, the oldest forearc volcanic rocks from Tonga-Kermadec Island was ~52 Ma [8], the gabbros from the ophiolitic sequence exposed in the Bonin and Mariana forearcs give the earliest crystallization age of 51.9 Ma [9], and magnetic anomaly shows that the Tasman Sea basin ceased spreading at ~52 Ma [10]. All these suggest that the Cenozoic northwestward subduction in the whole west Pacific initiated almost synchronously at ~52 Ma.

New dating results suggest that the steering of the Pacific plate commenced at ~53–52 Ma [11], which is supported by the reconstruction of the Australia and Antarctica [12]. Note that these occurred earlier than the subduction initiations along the west Pacific convergent margins [7].

Such a major steering of the giant Pacific plate requires huge driving forces. This was attributed to that the northward subduction of the Pacific Plate was blocked, e.g., likely by an oceanic plateau in the Bering Sea [7]. However, the two oceanic plateaus, the Shirshov and the Bowers Ridges, are too small. More importantly, no indication of major collision/deformation has been reported on them. Although, there might be other oceanic plateau, which has already been subducted or merged into the continent, responsible to the adjustment [7].

We argue that the steering of the Pacific plate and corresponding subduction initiations in the west Pacific may have been induced by the final closure of the Neo-Tethys Ocean. It has long been proposed that the Hawaiian-Emperor bending have been resulted from the reorganization of the Pacific plate due to the collision in the Tibetan Plateau based on old dating results, i.e., the collision occurred between 50 and 44 Ma, whereas the bending at ~42 Ma [13]. However, later studies suggest that the Indian continent collided with the Eurasian continent at ~60 Ma [14], and the post-collision convergence continues till now, i.e., the closure of the Neo-Tethys Ocean and consequently collision occurred ~15 Ma earlier than the old bending ages, and 5–7 Ma older than the refined bending ages of 53–52 Ma. Because of these reasons, the connection between collision in the Tibetan Plateau and bending in the west Pacific was discarded by the majority of the scientific community.

The detailed process of the collision between the Indian and the Eurasian continents may be better constrained by the drifting history of the Indian plate. Surprisingly, the drifting rate of the Indian plate did not decrease but rather increased to a peak values of ~200 mm/a at 60 Ma, which then dropped to 150 mm/a ~55 Ma (Fig. 2). Such acceleration of drifting may be attributed to the lubrication of subducted sediments during a soft collision [7]. Significantly, the drifting rate of the Indian plate dropped dramatically between ~55–52 Ma, indicating the commencement of hard collision [7], which fits well with the timing of the major adjustment of the Pacific Plate at ~53–52 Ma.

To the east of the Neo-Tethys convergent margin, in the Papua New Guinea islands, ophiolites were emplaced at ca. 58 Ma [15]. This implies that the closure of the Neo-Tethys Ocean and

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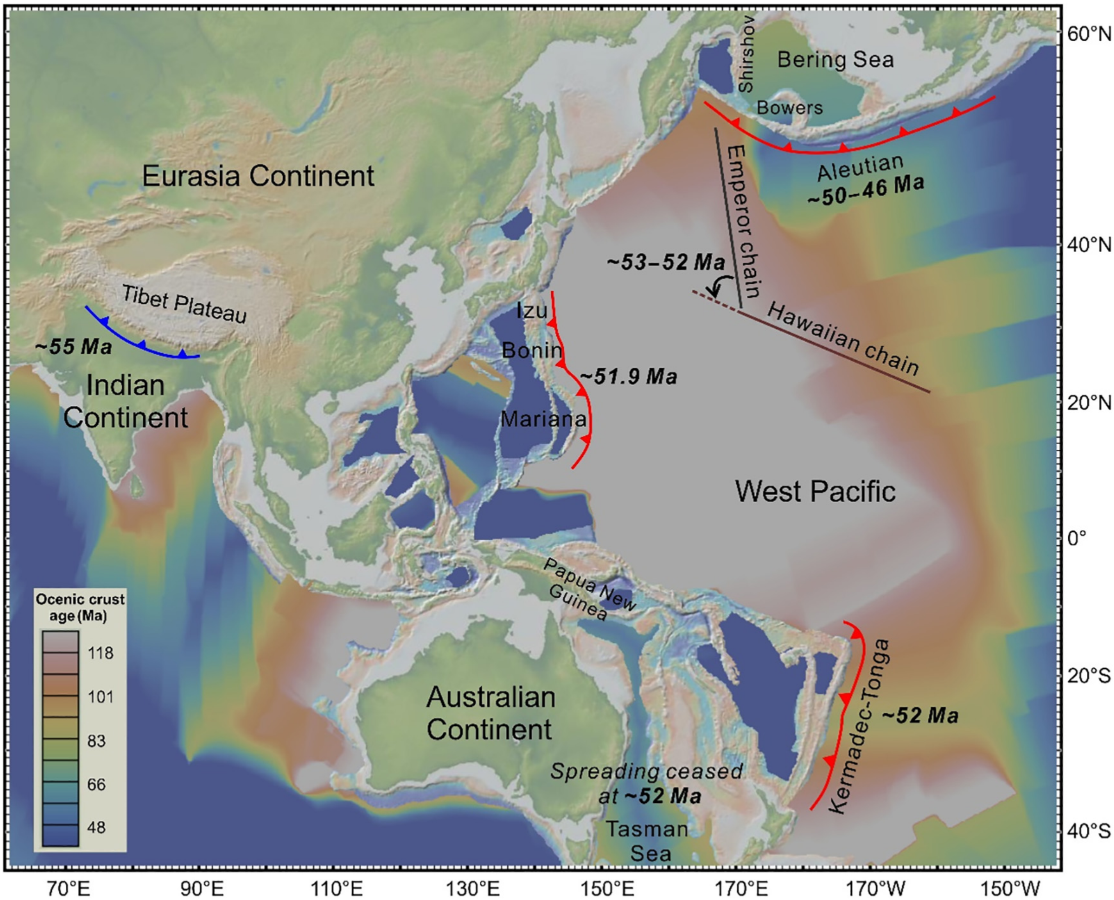

Fig. 1. The synchronicity of subduction initiation in the west Pacific. New dating results suggest that the famous Hawaiian-Emperor bending occurred at ~53–52 Ma, which is slightly older than the initiation of plate subductions in the west Pacific, and plausibly explains the induced subduction initiation in the whole west Pacific at ~52 Ma. Note, the Aleutian arc started slightly later than those in the west Pacific. As the steering of the Pacific plate continues, the old convergent margin to the north of the Aleutian retreated due to the declined northward drifting, forming the Aleutian arc (modified after Ref. [7]; base map is from GeoMapApp).

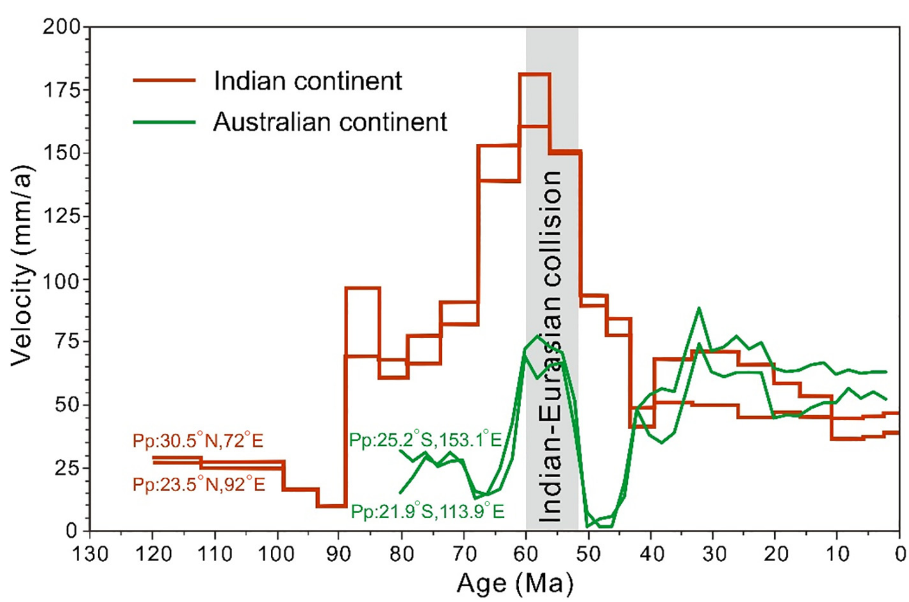

Fig. 2. The drifting rates of the Indian plate in the last 130 Ma (modified after Ref. [7]). It reached the peak value at ~60 Ma, and then decreased dramatically at ~55–52 Ma. Also shown are drifting rates the Australian plate calculated using GPlates in the last 80 Ma. Note, the drifting rate of the Australian plate also decreased dramatically between ~53–50 Ma, reaching nearly 0 at ~50 Ma. The major decrease in terms of drifting rate indicates hard collisions between the Indian and Eurasian continents. This is likely the main driving force that resulted in the northwestward subduction of the Pacific plate.

consequently collision occurred 5–7 Ma older than the refined bending ages of 53–52 Ma. These ages are K-Ar dating results obtained ~15 years ago, which usually have large errors. In addition, the high-pressure metamorphic rocks, especially those from the obducting plate, may be uplifted before the final collision through the subduction channel. The drifting rate of the Australian plate decreased since ~55 Ma, reached to its lowest value of ~0 at ~50 Ma (Fig. 2).

When hard collision started along the Neo-Tethys convergent margins, its northward movement was dramatically slowed down (Fig. 2). Meanwhile, there was not much resistance on the northward drifting of the Pacific plate. As a result of lever effect, the drifting direction of the Pacific plate changed to northwestward. Consequently, subduction initiation occurred roughly simultaneously in the whole west Pacific (Fig. 1). Therefore, these are induced but not spontaneous subduction initiations.

Overall, the hard collision at the Tibetan Plateau commenced before the steering of the Pacific plate (55–52 versus 53–52 Ma), which is compatible with their causal relationship. The very low drifting rate of the Australian plate (near 0 at ~50 Ma) is likely because it was close to the fulcrum point.

One characteristic of such induced subduction initiation is severe compressions and deformations at the early stage, which is followed by extensions once slab rollback starts. This is supported by the kilometer scale vertical movements in the northern Zealandia, which indicate severe compressions followed by extensions, roughly at the time of subduction initiation [2]. One may argue that no major vertical movement has been recognized in the Izu-Bonin-Mariana region before/during the subduction initiation. This is probably due to the age structure of oceanic crust there, which is much older than those at Zealandia (Fig. 1).

A recent paper in *Nature Communications* reports new dating results on samples obtained from International Ocean Discovery Program (IODP) Expeditions 352 at the Izu-Bonin-Mariana convergent margin in the West Pacific [3]. The results showed a rapid (0.6–1.2 million years) magmatic progression simultaneously along the Izu-Bonin-Mariana arc. Using numerical models, they further proposed that the self-sustained subduction was initiated by internal vertical forces, i.e., spontaneous subduction initiation controlled by density differences. According to their model, at some critical point, the old plate sinks into the hot asthenosphere mantle, forming the volatile-poor, mid-ocean-ridge-like forearc basalt, which is followed by boninite due to addition of fluids as subduction started [3].

This model, however, cannot explain the synchronous subduction initiations in the whole west Pacific. First of all, these subduction zones are associated with oceanic crusts of different ages, ranging from the Early Jurassic to the Late Cretaceous (Fig. 1), which should have very different density contrasts. It is hard for these places to reach the so called "critical point" [3] themselves all at the same time. Moreover, their modeling also requires a horizontal compression force of ~2 TN/m at the boundary, which was attributed to buoyancy differences [3]. However, buoyancy force is vertical. The model did not explain how to transform a vertical force into such a large horizontal one.

Our model suggests that the final closure of the Neo-Tethys Ocean blocked its northward drifting, which provides the horizontal push required by numerical models of subduction initiation [6] through lever effect and, plausibly explains synchronicity of Cenozoic subduction initiation in the west Pacific. It also explains the rapid magmatic progression recognized in the Izu-Bonin-Mariana convergent margin by previous authors [3]. The compression causes downward bending before subduction started at place with lithospheric weaknesses. This results in extensional fractures at the base of the lithospheric mantle. Consequently, asthenosphere matters intrude into these fractures and induces partial melting, forming forearc basalts. Once subduction initiated, the metasomatized portion of the lithospheric mantle that inserted into the asthenosphere dehydrates. At an average drifting rate of 70 mm/a, the oceanic slab reaches a depth of ~70 km within 1 million years, which is deep enough for dehydration melting and even slab rollback, forming boninite and then normal arc rocks.

In summary, the end of an old subduction, i.e., hard collision, induces new subductions [5]. This is a mechanism that keeps the plate tectonic system self sustained.

Conflict of interest

The authors declare that they have no conflict of interest.

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Author contributions

Weidong Sun conceived the work and wrote the manuscript. Lipeng Zhang plotted the figures. Lipeng Zhang, He Li and Xi Liu contributed to the discussion and writing of this paper.

Appendix A. Supplementary materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.scib.2020.09.001.

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