Sci. Bull. (2015) 60(18):1598–1616
DOI 10.1007/s11434-015-0891-z

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Earth Sciences

Exotic origin of the Chinese continental shelf: new insights into the tectonic evolution of the western Pacific and eastern China since the Mesozoic

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Received: 27 July 2015 / Accepted: 26 August 2015 / Published online: 11 September 2015

Abstract The effect of paleo-Pacific subduction on the geological evolution of the western Pacific and continental China is likely complex. Nevertheless, our analysis of the distribution of Mesozoic granitoids in the eastern continental China in space and time has led us to an interesting conclusion: The basement of the continental shelf beneath East and South China Seas may actually be of exotic origin geologically unrelated to the continental lithosphere of eastern China. By accepting the notion that the Jurassic–Cretaceous granitoids in the region are genetically associated with western Pacific subduction and the concept that subduction may cease to continue only if the trench is being jammed, then the termination of the granitoid magmatism throughout the vast region at $\sim 88 \pm 2$ Ma manifests the likelihood of "sudden", or shortly beforehand (~ 100 Ma), trench jam of the Mesozoic western Pacific subduction. Trench jam happens if the incoming "plate" or portion of the plate contains a sizeable mass that is too buoyant to subduct. The best candidate for such a buoyant and unsubductable mass is either an oceanic plateau or a micro-continent. We hypothesize that the basement of the Chinese continental shelf represents such an exotic, buoyant and unsubductable mass, rather than seaward extension of the continental lithosphere of eastern China. The locus of the jammed trench (i.e., the suture) is predictably located on the shelf in the vicinity of, and parallel to, the arc-curved coastal line of the southeast continental China. It is not straightforward to locate the locus in the northern section of the East China Sea shelf because of the more recent (<20 Ma) tectonic re-organization associated with the opening of the Sea of Japan. We predict that the trench jam at ~ 100 Ma led to the re-orientation of the Pacific plate motion in the course of NNW direction as inferred from the age-progressive Emperor Seamount Chain of Hawaiian hotspot origin (its oldest unsubdued Meiji and Detroit seamounts are ~ 82 Ma), making the boundary between the Pacific plate and the newly accreted plate of eastern Asia a transform fault at the location east of the continental shelf of exotic origin. This explains the apparent ~ 40 Myr magmatic gap from ~ 88 to ~ 50 Ma prior to present-day western Pacific subduction initiation. We propose that basement penetration drilling on well-chosen sites is needed to test the hypothesis in order to reveal the true nature of the Chinese continental shelf basement. This testing becomes critical and cannot longer be neglected in order to genuinely understand the tectonic evolution of the western Pacific and its effect on the geology of eastern China since the Mesozoic, including

Electronic supplementary material The online version of this article (doi:10.1007/s11434-015-0891-z) contains supplementary material, which is available to authorized users.

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the cratonic lithosphere thinning, related magmatism/mineralization, and the mechanism of the subsequent South China Sea opening, while also offering novel perspectives on aspects of the plate tectonics theory. We also suggest the importance of future plate tectonic reconstruction of the western Pacific to consider the nature and histories of the Chinese continental shelf of exotic origin as well as the probable transform plate boundary from ~100 to ~50 Ma. Effort is needed to reveal the true nature and origin of the ~88 ± 2 Ma granitic gneisses in Taiwan and the 110–88 Ma granitoids on the Hainan Island.

Keywords Mesozoic granitoids in eastern China · Exotic origin of Chinese continental shelf · Trench jam · Transform plate boundary · Basal hydration weakening · Lithosphere thinning · Craton destruction · Mantle hydrous melting · Crustal melting · Plate tectonics · South China Sea

"There are no facts, only interpretations."
[Friedrich Nietzsche (1844–1900)]

1 Introduction

It has been a common knowledge that the continental shelf is the offshore extension of the continent covered with land-derived sediments. That is, the basement of the shelf is geologically part of the same continental lithosphere. As a result, this common perception has been widely accepted as a fact without doubt in all relevant studies. While this notion may still hold true in places, our analysis of the distribution of Jurassic–Cretaceous granitoids in the eastern continental China in space and time led us to an interesting conclusion, which is in nature a testable hypothesis of both regional and global significance, i.e., the basement of the Chinese continental shelf (beneath East and South China Seas) may actually be of exotic origin geologically unrelated to the continental lithosphere of eastern China. We predict the shelf basement to represent a sizable mass with large compositional buoyancy, transported to and collided with the continental China at ~100 ± 10 Ma. This new view is an element of our ongoing research in evaluating the possible consequences of paleo-Pacific subduction on the tectonic evolution of the western Pacific and continental China since the Mesozoic. In this context, we acknowledge that much effort has been expended in the past decades, in particular over the past ~10 years, to understand the *why* (triggers), *how* (mechanisms), *when* (timing and time span) and *where* (spatial extent) of the lithosphere thinning in eastern China with highly commendable achievements as evidenced by abundant publications, but it is our view that the *bottleneck* for any further insight lies in a genuine understanding of the nature and histories of the continental shelf of China.

In this paper, we do not wish to review the mounting literature on regional geology, geophysical investigations and many detailed petrological and geochemical studies, but report our findings and inferences that have led to the hypothesis. We then discuss the geodynamic implications of global significance in the regional context and plausible ways of testing the hypothesis.

2 Motivation of this study

The Paleozoic diamondiferous kimberlite volcanism in eastern China convinced many that there existed a long-lived North China Craton (NCC) with the lithosphere thickness in excess of 200 km. There was also the view that the NCC may not be a typical craton because of its widespread tectonomagmatic activities since the Mesozoic [1, 2]. The current consensus is that the NCC was once indeed a type craton, but lost much of its deep ~120 km portion since the Mesozoic, leaving its present-day thickness of 60–80 km [3–17] by means of delamination [4, 8–13], thermal and chemical erosion [3–5, 7, 15] and basal hydration weakening [18, 19].

While the potential effect of the paleo-Pacific subduction on the Mesozoic geology of the eastern continental China has been mentioned in the literature, Niu [18, 19] was the first to specifically advocate the concept of *basal hydration weakening* as the primary mechanism to convert the basal portion of the mantle lithosphere into asthenosphere, hence having thinned the lithosphere, beneath eastern China. The water that did so came from dehydration of the paleo-Pacific slab that lies horizontally in the mantle transition zone beneath eastern China [20, 21]. Different opinions may still exist, but the role of paleo-Pacific subduction is now widely accepted as manifested by the thematic conference "*The connection of the North China Craton destruction with the Paleo-Pacific subduction*" that took place on March 26–27, 2015, in Beijing, organized and supported by the NSFC. In this context, it is necessary to better inform the readers again of the essence of the *basal hydration weakening* concept: (1) It is not limited to the NCC destruction, but applies to the lithosphere thinning throughout eastern China at least east of the GGL shown in Fig. 1 [18, 19, 22] because the surface elevation directly reflects the lithosphere thickness [18]; (2) the wisdom is that the strength (and thus the stability) of mantle lithosphere is largely controlled by how dry it is (see Fig. 13 of Ref. [22]). The lithospheric root can be strong and long lasting if it is dry (see Ref. [19, 22, 23]), but can be readily weakened with the addition of water (e.g., through the form of hydrous melt). In contrast, the effect of heating (e.g., by hot mantle plumes) is insignificant in weakening the lithosphere (see pp. 4155–4156 of Ref. [23]). This basic principle has inspired our insight into the concept of *basal hydration weakening*. On the other hand, the Mesozoic-Cenozoic geology of the eastern continental China in the greater context of the western Pacific further attests the above wisdom.

Despite the efficacies of the *basal hydration weakening* mechanism in causing lithosphere thinning, we recognize a potential problem that needs addressing [22]. The present-day paleo-Pacific slab stagnant in the mantle transition zone beneath eastern China is connected to the current western Pacific subduction zones, which began at ~50 Ma [24, 25], meaning that the transition-zone slab is of Cenozoic age. This is inconsistent with the documentation that the lithosphere thinning beneath eastern China occurred largely in the Mesozoic with the peak at ~120 Ma [14] and was probably completed before ~110 Ma inferred from the literature data [13, 22, 26, 27]. This means that the continued dehydration of the present-day transition-zone slab maintains the seismic low-velocity zone (LVZ) beneath the already thinned lithosphere in eastern China, but is not the very cause of the lithosphere thinning in the Mesozoic [22]. Therefore, two basic questions need addressing:

(1) Was there any subduction zone in the Mesozoic western Pacific with subducted slab lying in the mantle transition zone beneath continental China, a scenario as seen today, that may have developed *basal hydration weakening* to cause the lithosphere thinning, largely completed prior to 110 Ma?

(2) If (1) above is true, then *why* and *when* did this subduction terminate? Can we locate the locus of this Mesozoic subduction (i.e., equivalent to a suture)?

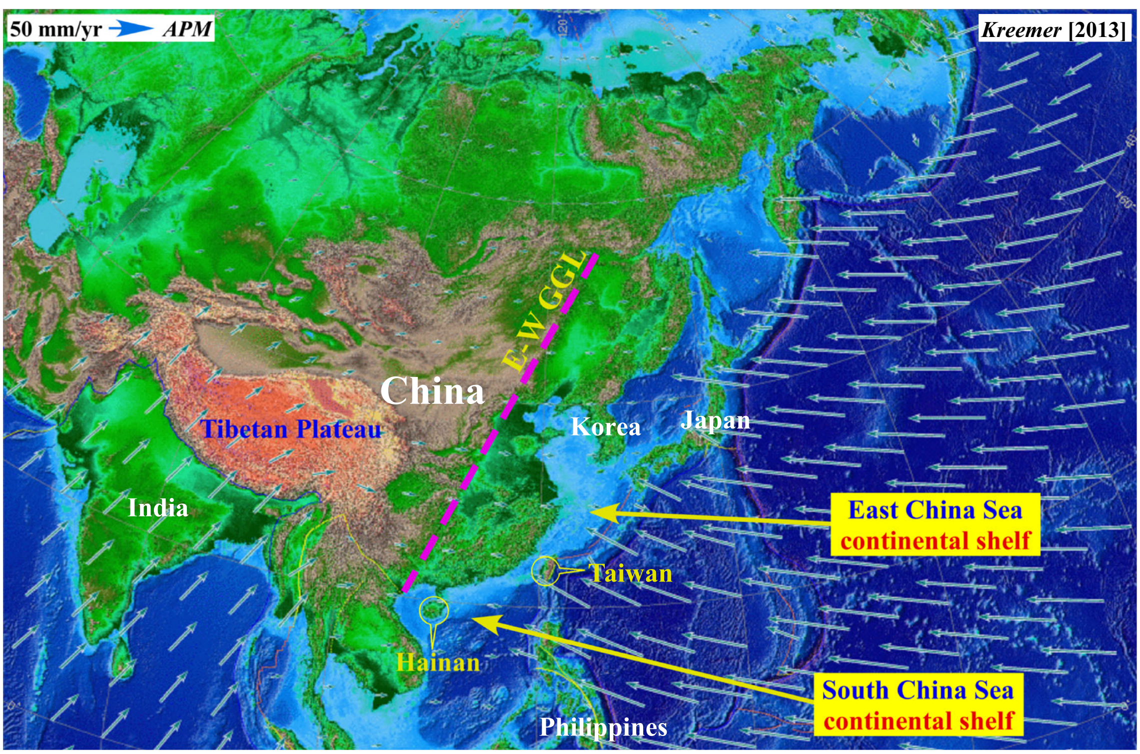


Fig. 1 Portion of the world topographic map, indicating the continental shelf of the East and South China Seas in the context of the eastern Asia continental tectonic framework and western Pacific trenches, arcs and back-arc basins. Also shown are the present-day plate motion vectors using the "sub-asthenosphere" reference frame (APM; from UNAVCO: http://jules.unavco.org/Voyager/GEM_GSRM). The pink dashed line approximates the great gradient line (GGL) marked by contrasting differences in elevation, gravity anomaly, crustal thickness, heat flow and mantle seismic velocity between high plateaus in the west and hilly plains to the east, which is interpreted as the expression of sharp variation in lithospheric thickness from ≥150 km thick beneath the plateaus to ≤80 km thick beneath eastern China, whose thinning histories/mechanisms and the coeval magmatism have been interpreted to be genetically associated with paleo-Pacific subduction in the Mesozoic and thereafter [18], leading to our testable prediction for the exotic nature of the continental shelf of East and South China Seas. Note that the Islands of Taiwan and Hainan are on the continental shelf of exotic origin

3 The presence of a Mesozoic Pacific subduction zone toward beneath continental China

The answer to question (1) above is definite. The widespread Jurassic–Cretaceous granitoids in the eastern continental China (from Northeast China to North China and to Southeast China as seen in Fig. 2) are indirect but convincing evidence for the presence of Pacific plate subduction beneath continental China in the Mesozoic [28, 29]. Hence, the eastern continental China in the Mesozoic was characterized by an active continental margin, similar to the present-day Andean-type margin with a continental magmatic "arc" [30, 31].

3.1 An active continental margin, but not an Andean-type margin

While we agree that the eastern continental China in the Jurassic–Cretaceous represented an active continental margin with underlain subduction and related crustal granitoid magmatism, we also agree with Zhang [32] that it was *NOT* an *Andean-type* margin because of lacking a well-defined narrow continental magmatic arc as does along the Andes at present. Indeed, the Jurassic–Cretaceous granitoids in eastern China span emplacement time for $\sim$100 Myrs from $\sim$190 to $\sim$88 Ma (Fig. 3) and spread diffusively in a wide zone in excess of 1000 km (see Figs. 2, 4, 5). Importantly, contrary to the arguments and ideal model expectations in the literature, these granitoids show no systematic NW-to-SE age variation of any sort as demonstrated by plotting the emplacement age as a function of longitude (Fig. 4) or as a function of the shortest distance (perpendicular) to the GGL (Figs. 1, 2, 5). That is, the granitoid magmatism could take place in the coastal region as well as anywhere in the continental interiors as far as >1000 km to the west at any latitude and at any given time as shown, for example, in panel D at $\sim$130 Ma (Figs. 4, 5). Obviously, an Andean-type continental margin model cannot explain the Mesozoic granitoid magmatism in the eastern continental China, but requires the presence of an areally vast mantle heat source in space and time echoed by the granitoids at the crustal level [22].

3.2 Evidence for the presence of Mesozoic Pacific slab in the mantle transition zone beneath eastern continental China (as the Cenozoic slab seen at present)

3.2.1 The Mesozoic granitoids in eastern China largely resulting from intra-crustal re-working

A brief conceptual review is useful here to better understand the random distribution of the Mesozoic granitoids in the eastern continental China in space and time. The century-old debate on the origin of granites and granitoids was settled by experimental demonstrations [33] that granitoids are of magmatic origin through partial melting of existing crustal rocks. Wyllie [34, 35] further synthesized experimental data on possible sources through anatexis to produce granitoid magmas. The continued studies accumulated over the past 40 years, especially with the aid of trace element and isotope geochemistry, have consolidated our understudying that with the exception of minor A-type granitoids that could be produced by protracted fractional crystallization of alkali basaltic melts, all other granitoids must be produced by crustal melting with the melt undergoing varying extent of fractional crystallization (see Ref. [18]). Partial melting of basaltic ocean crust or underplated mafic rocks produces I-type granitoids of dominantly dioritic-granodioritic compositions with inherited mantle isotopic signatures (e.g., high and more positive $\varepsilon_{Nd(t)}$ values). On the other hand, partial melting of old and mature continental crustal rocks produces S-type granitoids of more felsic compositions with Al_2O_3-rich phases and low and more negative $\varepsilon_{Nd(t)}$ values.

In terms of continental crust growth, I-type granitoids and the volcanic equivalent directly or indirectly derived from the mantle represent net contributions whereas S-type granitoids and the volcanic equivalent are products of crustal reworking with no net contributions to crustal growth. Our current and ongoing studies of the syncollisional granitoids from southern Tibet, Qilian, Qinling and Kunlun orogenic belts are exclusively I-type granitoids dominated by high $\varepsilon_{Nd(t)}$ (Fig. 6b), supporting the hypothesis of continental collisional zones as primary sites for net continental crustal growth (i.e., juvenile crust formation and preservation) because the immediate source rocks are interpreted to be last crustal fragments of the closing ocean basins with inherited mantle isotopic signatures [36]. By contrast, the Mesozoic granitoids from eastern China are dominated by S-type granitoids with volumetrically minor I- and A-types, possessing low $\varepsilon_{Nd(t)}$ isotopic signatures (Fig. 6a), which is consistent with these granitoids being largely crustal re-working with limited juvenile crustal contribution.

3.2.2 On the heat source for the intra-crustal re-working and the Mesozoic granitoid magmatism in eastern China

Compared with mantle peridotites, continental crustal rocks have significantly lower solidi ($\sim$600 to $\sim$900 °C; see Refs. [34, 35]) with the actual melting temperatures depending on water contents. Nevertheless, the geotherms are such that all the crustal rocks are in solid state under

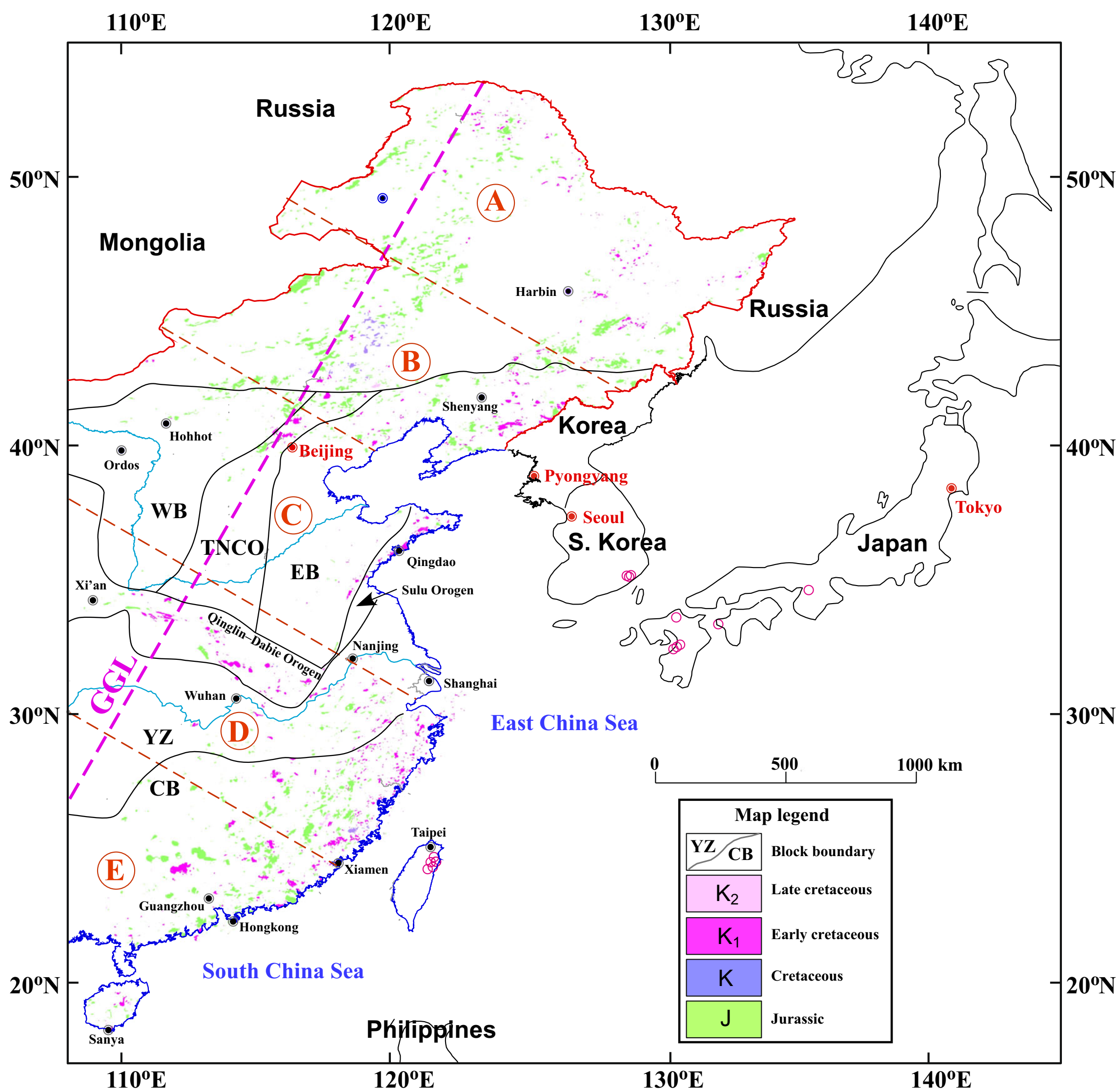


Fig. 2 Eastern portion of simplified geological map of continental China, emphasizing the distribution of Jurassic and Cretaceous granitoids (after 1:1,000,000 Geological Map and Data Base by the Chinese Geological Survey, 2005). Note that the emplacement ages of the granitoids in terms of geological time periods are taken from that map, but high-quality zircon crystallization U–Pb ages from the recent literature are used for discussion (see Figs. 3–5). The use of K (Cretaceous) follows what is given in that map when K_1 and K_2 were not distinguished in that map. Note that those Triassic or older granitoids interpreted to be associated with the CAOB (Central Asia Orogenic Belt) to the north and with the QDOB (Qinlian-Dabie Orogenic Belt) to the south are not considered here so as to focus on the influence of the paleo-Pacific subduction. Given the outstanding feature of the GGL (Great Gradient Line, see Fig. 1) reflecting the lithosphere thickness and thinning mechanisms as a consequence of paleo-Pacific subduction, and because the GGL (trending ~N29°E) is to a first order perpendicular to the northwestward (~N61°W) subduction of the paleo-Pacific plate, it is useful to examine the distribution of the granitoids in time and space with respect to the GGL (equivalent to possible correlation with the paleo-Pacific subduction). Given the large longitudinal and latitudinal span of these granitoids, we arbitrarily divide them into A, B, C, D and E five sections as indicated by the light-brown dashed lines (also see Figs. 3–5). The pink open circles are reported granitoids of Cretaceous age in the literature (not in the above-mentioned map) from Japan, South Korea and Island of Taiwan. The tectonic units indicated are West Block (WB), East Block (EB) and Trans-North China Orogen (TNCO) of the North China Craton (NCC), Yangtze Craton (YZ) and Cathaysia Block (CB). The international border of continental China is in red, and the coastal lines of China are in blue

subsolidus conditions. That is, crustal melting is unlikely without heating. Excess heat accumulation due to radioactive decay is theoretically possible if thermal insulation strata are present and effective, but this could be true only locally [18] and cannot be invoked as effective mechanism to explain the widespread Mesozoic granitoids in eastern China. The adequate heat source for crustal melting can only come from mantle-derived basaltic melts [18, 29, 37, 38]. This well-established concept leads us to reason and to depict an interesting picture:

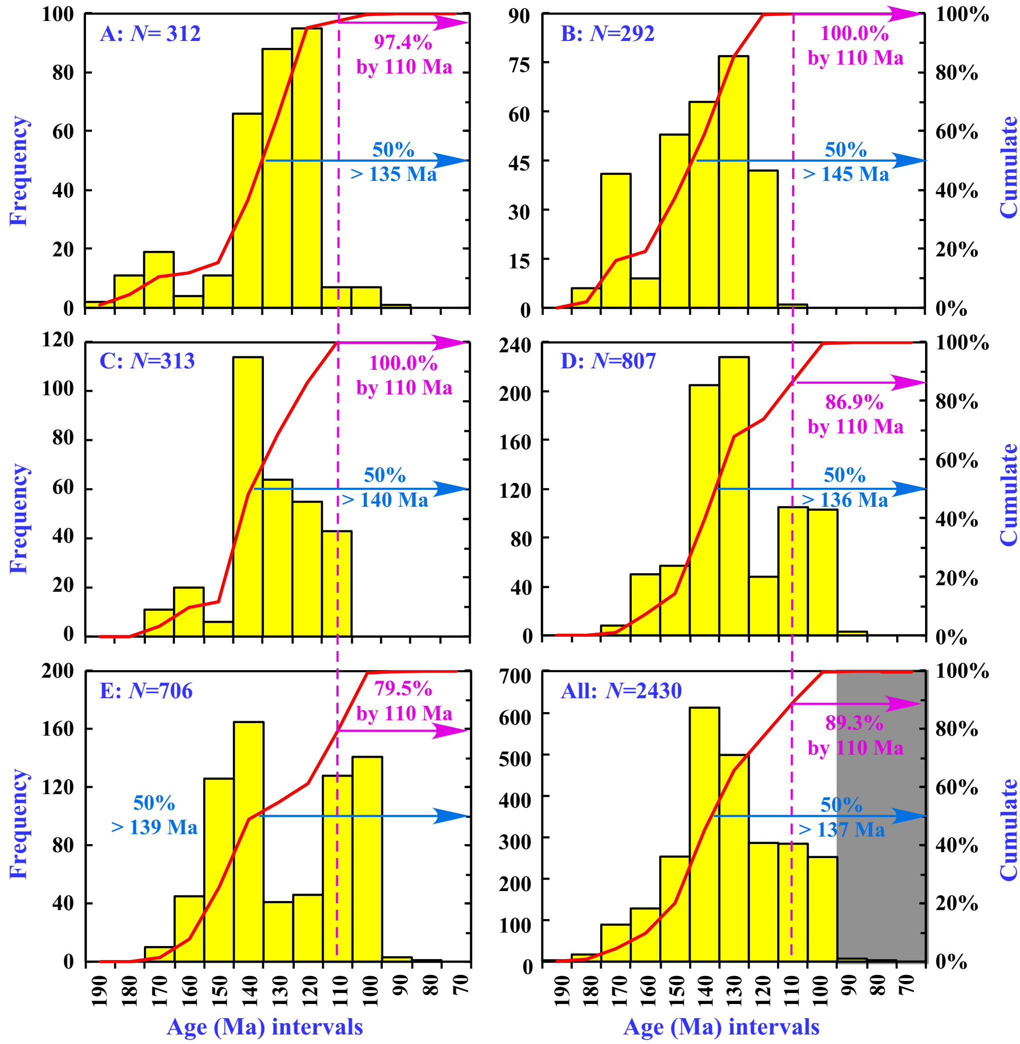


Fig. 3 Histograms with 10-Myr bin width to show the age distribution of Jurassic–Cretaceous granitoid abundances in the eastern continental China in sections A, B, C, D, E (see Fig. 2) and altogether as "All". There are 465 high-quality zircon U–Pb ages in total from the recent literature (see Appendix A for data and Appendix D for data sources). To be statistically more representative of the granitoid abundances in space and time, we have made a very painstaking effort to obtain the exposed area size of age-constrained plutons by the point-counting method using 3′-by-3′ (latitude-by-longitude) unit grids on the basis of the recently available 1:250,000 Geological Maps (Chinese Geological Survey, 2005) with details given in Appendix B. For example, in Section A, there are 88 unit grids with granitoid ages in the range of 135–125 Ma (the 130 Ma bin). The light blue arrowed lines show that ~50 % of the granitoids were emplaced prior to the time indicated (e.g., in the case of A, 50 % of the granitoids were emplaced prior to 135 Ma). For the entire data set, 50 % of the granitoids were emplaced prior to 137 Ma. The other points to note are: (1) most granitoids were emplaced prior to 110 Ma as indicated by the arrowed pink lines, and (2) the granitoid magmatism was essentially terminated by ~88 Ma (see text for significance)

(1) The granitoid distribution in the Mesozoic eastern continental China in time (emplacement age) and space (Figs. 2, 5) effectively echoes the mantle melt formation in the corresponding time and space. The key question is thus what may have actually caused mantle melting randomly in such time and space?
(2) Lithosphere stretching induced asthenosphere upwelling and decompression melting can be ruled out because this would produce coeval magmatism of linear distribution, which is not observed. Thermal mantle plume melting can also be ruled out because of lacking flood basalts, lacking expected space–time pattern of surface magmatism, and because plume melting residues would thicken, not thin, the lithosphere against geological record.
(3) Hence, the lithosphere thinning, lithospheric mantle melting and induced crustal melting manifested by the observed time–space distribution of the granitoids altogether must represent different effects of the same cause. We hypothesize that the common cause is our

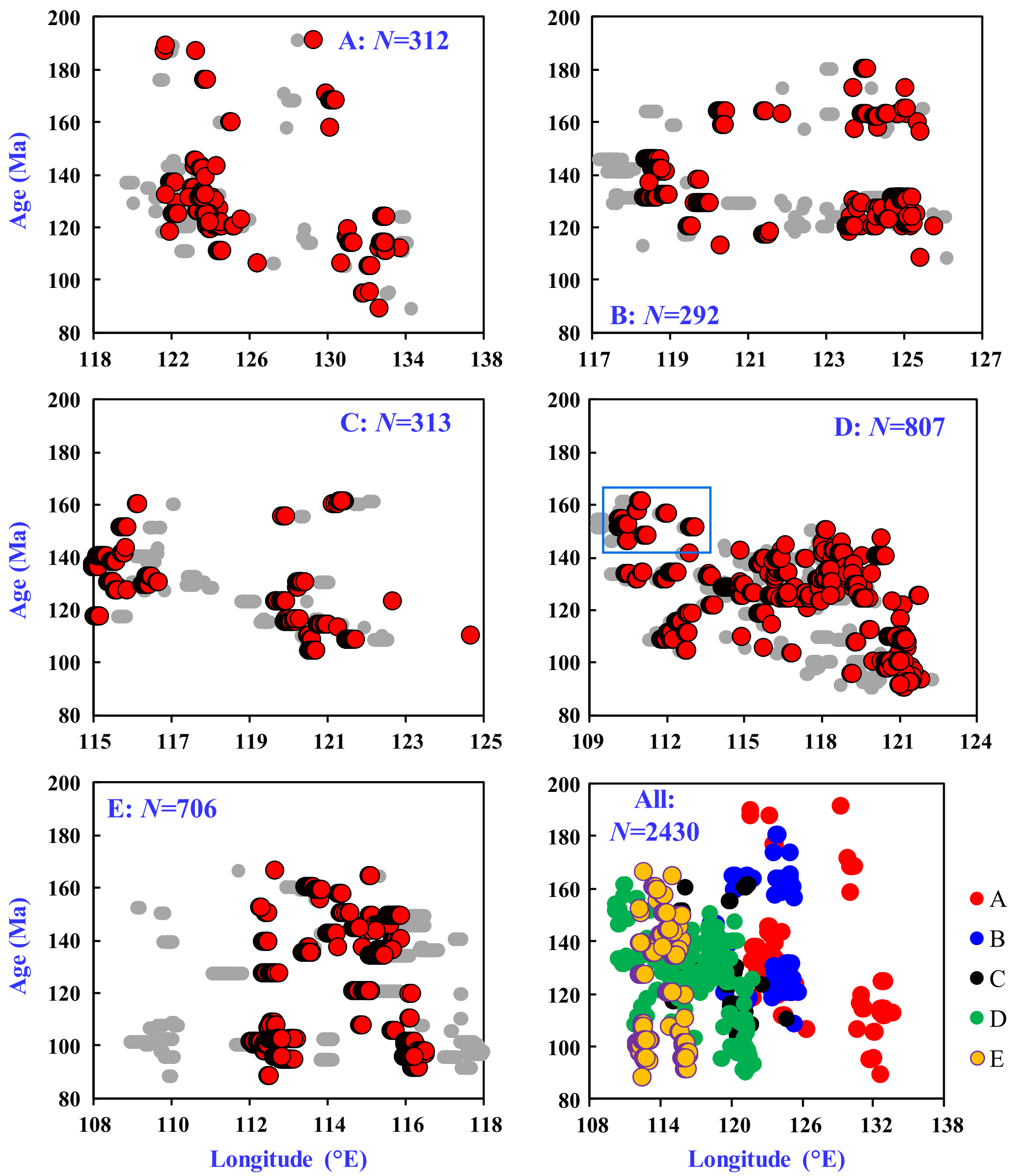


Fig. 4 Distribution of Jurassic–Cretaceous granitoids in eastern China in sections A, B, C, D, E (see Fig. 2) and altogether (Panel "All") plotted against longitude. The data are the same as in Fig. 3. The gray-filled circles are actual sample locations (longitude), and the solid circles filled in red are the same data points corrected for sample locations by projecting onto the central plane perpendicular to the GGL in each of the A–E sections. Clearly, there is no systematic age variation as a function of latitude (between panels A–E from north to south) and longitude (horizontal axis). We emphasize that there is no obvious NW-to-SE age decrease except for samples from Section D, but the apparent trend disappears if the samples from Huashan plutons (in the rectangle) could be excluded. Note: the massive granitoids in Section D apparently form a NWW trend (Figs. 2, 9 below) parallel to the Qinling-Dabie Orogen (QDO). These "Xiao Qinling" granitoids have been interpreted as post-collisional products of the ~230 Ma QDO in the literature, but we consider them as genetically associated with the Pacific subduction and the QDO-parallel trend simply results from enhanced erosion/outcropping due to continued uplift of the QDO because QDO-related deformation continued throughout the Mesozoic as evidenced by the ~400 km offset of the QDO with the Sulu Orogen (Fig. 2). The apparent rarity of the granitoids in Section C results from the poor exposure within the topographic plains of the North China Craton (NCC)

familiar concept and process of *basal hydration weakening* [18, 19] that weakens and converts the basal lithosphere into asthenosphere while producing basaltic melts from the being-converted mantle lithosphere. Such melts rise, underplate/intrude the crust *en route to* the surface (the Mesozoic basalts/minor andesites with "arc" signature) while causing crustal melting for the observed granitoids.

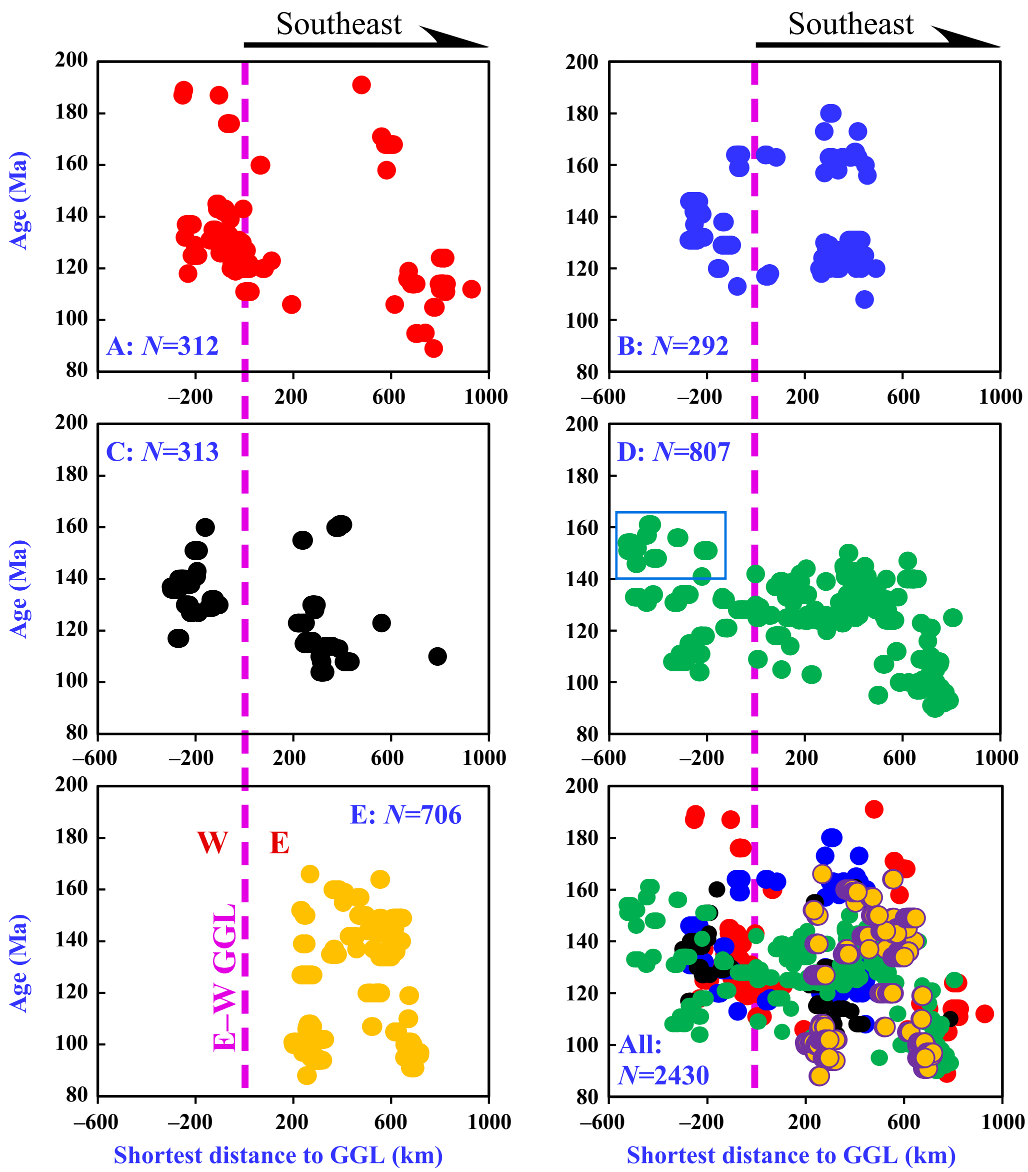


Fig. 5 Same as in Fig. 4, but the samples are plotted as a function of the shortest distance (perpendicular) to the GGL indicated by the pink dashed lines (see Fig. 2) in terms of actual kilometers. Important points to note: (1) The granitoids are not limited to the east of the GGL, but also exist in abundance west of the GGL from ~190 to 100 Ma; (2) there is no obvious age variation with respect to the GGL; and (3) in a long time period of ~100 Myrs (from ~190 to ~88 Ma) the granitoid magmatism occurred in a zone in excess of 1000 km wide in the eastern continental China. All other information is the same as in Fig. 4

(4) It follows that there must be a source of water in the mantle whose space-and-time distribution corresponded to the space-and-time distribution of the crustal granitoid magmatism in the Mesozoic eastern continental China (Figs. 2–5). We further hypothesize that in the Mesozoic, the source of water or "reservoir" was most probably the stagnant paleo-Pacific slab in the mantle transition zone that laterally extended far to the west in excess of 1000 km from the coast (Fig. 2) as is the case observed in the Cenozoic [20, 21]. Such areally widespread stagnant slab would differentially release water with time (depending on relative age and extent of thermal equilibrium with the ambience), causing lithosphere thinning by basal hydration weakening as elaborated in [18, 19] and illustrated in cross section in Fig. 7a, b with phase equilibria and detailed explanations given in Fig. 7c, d. Figure 7b also explains the time–space random distribution of the granitoids in the Mesozoic eastern continental China (Figs. 2–5).

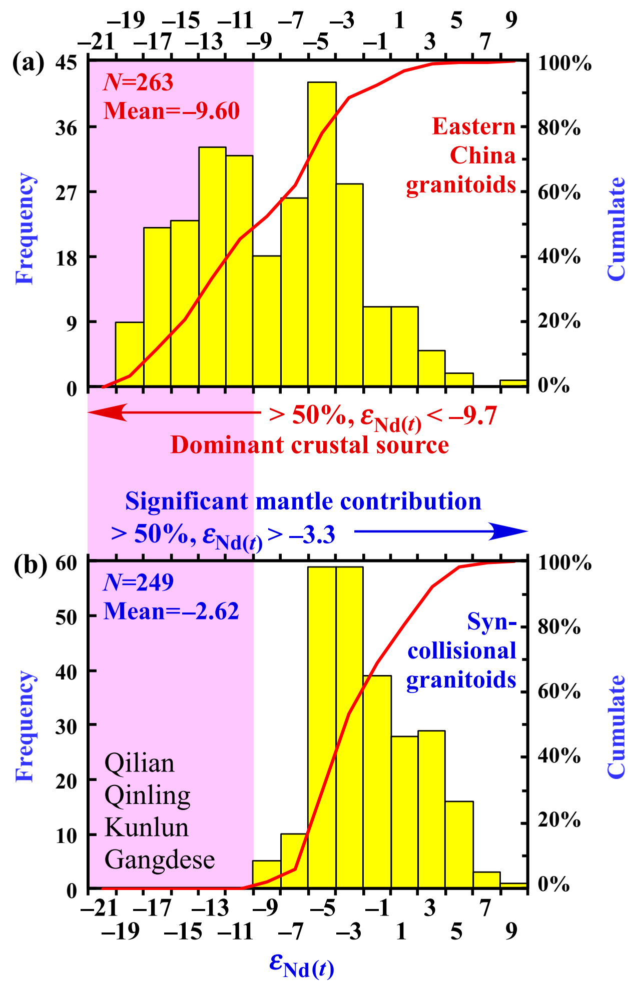


Fig. 6 Neodymium ($\varepsilon_{Nd(t)}$) isotope histograms to compare the Jurassic–Cretaceous granitoids in the eastern continental China (**a**) (see Appendix C for data and Appendix D for data sources) with orogenic (syncollisional in a broad sense) granitoids from Qilian, Qinling, Kunlun and Gangdese granitoids (**b**) (data are from [54–66] and our unpublished data on samples from these various orogenic belts). Clearly, the eastern China granitoids are dominated by mature crustal sources, whereas the syncollisional granitoids have sources with rather significant mantle input such as melting of the ocean crust during collision with minor continental crustal contributions [36]

With all the conceivable possibilities considered, the above interpretations constitute an important novel hypothesis to test.

4 Termination of the Mesozoic subduction at ~100 Ma

This section attempts to answer question (2) above. If we accept that there indeed existed a Pacific subduction zone toward beneath the eastern continental China in the Mesozoic as manifested by the widespread granitoids with their origin elaborated above, then we must address this question. This is because the present-day western Pacific subduction zones are young (≤ ~50 Ma) and have nothing to do with the Mesozoic lithosphere thinning and related granitoid magmatism, and because the prevailing models dedicated to discuss the tectonic evolution of the western Pacific since the Mesozoic have simply assumed the "typical Andean-type margin" and thus focused on how and when the Andean-type margin evolved to the present-day western Pacific type plate boundary [31].

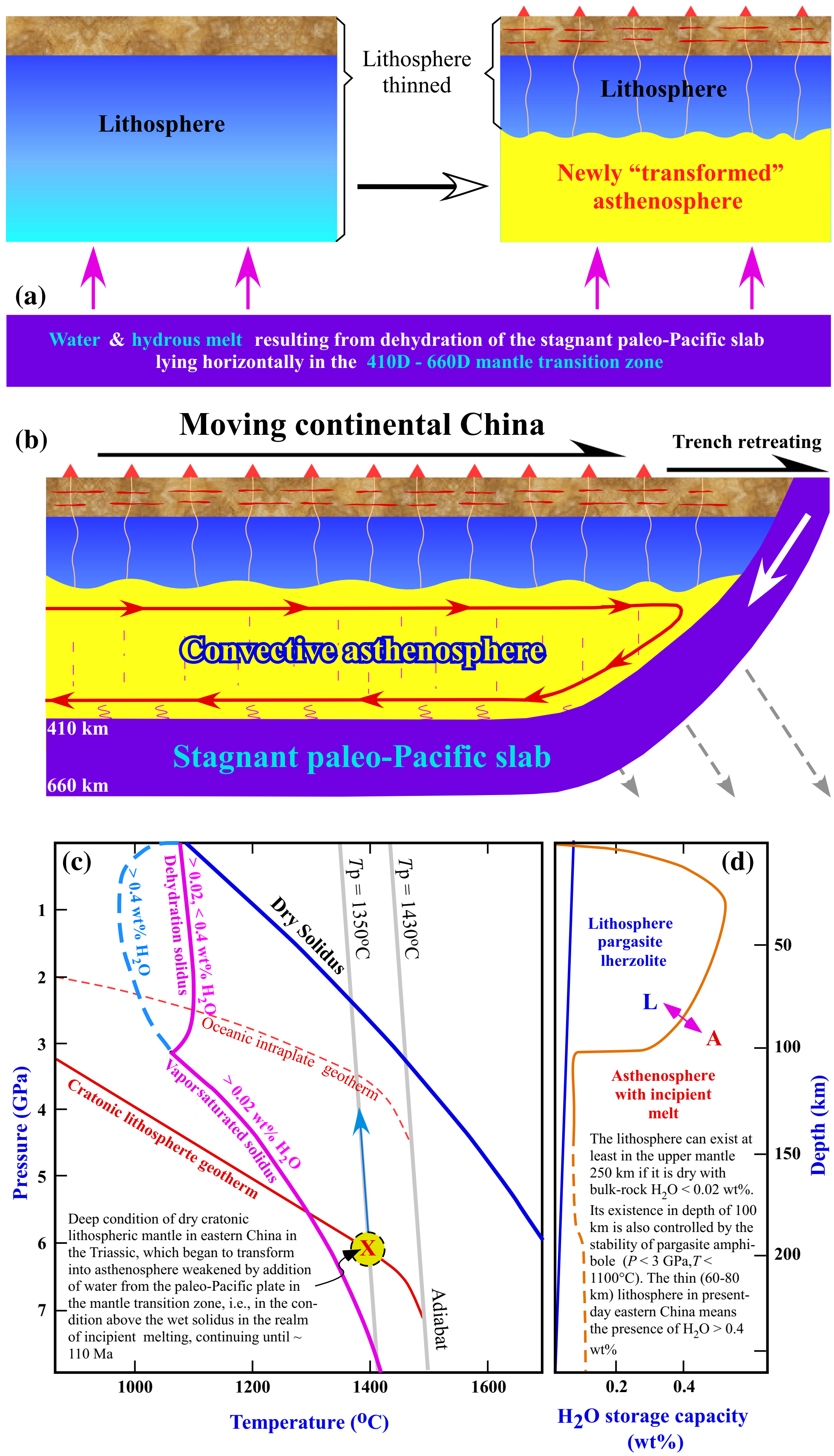
Figure 3 illustrates in the form of histograms to show the emplacement ages of the granitoids in the Mesozoic eastern continental China uninfluenced by the CAOB and QDOB magmatism. To see how the emplacement ages may vary with latitude, we divided from north to south into five sections A, B, C, D and E (see Fig. 2). Appendices referred to in caption to Fig. 3 give the data and data sources. If the granitoids are indeed associated with the lithosphere thinning and the intensity of granitoid magmatism approximates the intensity of the lithosphere thinning as we argue, then the thinning began at ~190 Ma and ended largely at ~110 Ma to the north. In the southern sections, the lithosphere would begin thinning more or less the same time at ~180 Ma, but ended at ~110–88 Ma. Taking all the age data together (in panel All, lower right), we can say the following with confidence:

(1) The Mesozoic lithosphere thinning began at ~190 Ma with gradual increase in intensity to reach an apparent peak at ~140 Ma. The thinning intensity decreases in a step function with time until ~88 Ma when the granitoid magmatism ended, implying the lithosphere thinning in discussion would have also ended at this time (see below).

(2) We must emphasize again (see Ref. [18]) that the lithosphere thinning was not limited to the NCC, but took place throughout the entire eastern continental China from Northeast to southeast beyond the NCC as indicated by the granitoid distribution (Figs. 2–5) as well as the topographic contrast on both sides of the GGL (Fig. 1).

(3) About 50 % of the dated granitoids are older than ~137 Ma, suggesting that, by inference, significant lithosphere thinning had already happened by this time.

(4) About 89 % of dated granitoids are older than 110 Ma, suggesting that, by inference, the lithosphere thinning was essentially completed by this time, a prediction [22] that is consistent with the inference from the basaltic geochemistry [13, 26, 27]. This is because the NCC basalts erupted before ~110 Ma have a typical "crustal" or "arc" signature, which is consistent with melting of a metasomatized mantle lithosphere source [22, 39, 40], whereas the NCC basalts erupted after ~110 Ma resembling the



Lithosphere
Lithosphere thinned
Lithosphere
Newly "transformed" asthenosphere
(a)
Water & hydrous melt resulting from dehydration of the stagnant paleo-Pacific slab lying horizontally in the 410D - 660D mantle transition zone
(b)
Moving continental China
Trench retreating
Convective asthenosphere
410 km
Stagnant paleo-Pacific slab
660 km
(c)
> 0.4 wt% H2O
Dehydration solidus
> 0.02, < 0.4 wt% H2O
Dry Solidus
Tp = 1350°C
Tp = 1430°C
Oceanic intraplate geotherm
Vaporsaturated solidus
> 0.02 wt% H2O
Cratonic lithospherte geotherm
X
Adiabat
Deep condition of dry cratonic lithospheric mantle in eastern China in the Triassic, which began to transform into asthenosphere weakened by addition of water from the paleo-Pacific plate in the mantle transition zone, i.e., in the condition above the wet solidus in the realm of incipient melting, continuing until ~ 110 Ma
Pressure (GPa)
1
2
3
4
5
6
7
1000
1200
1400
1600
Temperature (°C)
(d)
Lithosphere pargasite lherzolite
L
A
Asthenosphere with incipient melt
The lithosphere can exist at least in the upper mantle 250 km if it is dry with bulk-rock H2O < 0.02 wt%. Its existence in depth of 100 km is also controlled by the stability of pargasite amphibole (P < 3 GPa, T < 1100°C). The thin (60-80 km) lithosphere in present-day eastern China means the presence of H2O > 0.4 wt%
50
100
150
200
Depth (km)
0.2
0.4
H2O storage capacity (wt%)

◀**Fig. 7** **a** Modified from Ref. [18] to illustrate the concept of basal hydration weakening as the primary mechanism to cause lithosphere thinning by converting the basal "lithosphere" into "asthenosphere" with accompanying magmatism in the eastern continental China since the Mesozoic [18, 22]. Note that previous studies have focused on mantle melting and basaltic (basaltic–andesitic) magmatism, but we stress here that the mantle-derived melts with liquidus temperature in excess of 1100 °C will, on their way up, cause crustal melting and granitoid magmatism. In fact, the widespread Mesozoic granitoids in eastern China all resulted from crustal melting induced by mantle-derived melts (e.g., [29, 38]). **b** Modified from Ref. [22] to elaborate the crustal melting illustrated in (A) and to explain why the granitoids show no systematic variation in space and time (Figs. 2–5). Fast trench retreat under gravity resulted in the three-layered structure: the paleo-Pacific slab left behind stagnantly in the mantle transition zone, the continental China lithosphere passively drifting eastward (the origin of continental drift as described in Ref. [22]) and the wedge-suction [18] induced asthenosphere convection. The slab-derived water in the form of incipient hydrous melt percolates upwards, metasomatizes the upper mantle, and weakens/converts the basal lithosphere into asthenosphere accompanied by melting of the being-converted lithosphere/asthenosphere to produce basaltic melts. These melts rise and underplate/intrude the crust, causing crustal melting for the granitoids. That is, the crustal granitoid magmatism is ultimately determined by the transition-zone slab dehydration, i.e., where there is slab dehydration atop the transition zone there will be overlaying crustal melting. Because the slab is stagnant but the lithosphere with crust is moving, crustal melting occurs whenever and wherever it moves over the dehydrating slab in the transition zone. Hence, the age and location of a granitoid pluton is a surface/crustal expression of the dehydrating transition-zone slab at that time and in that location, thus giving no systematic granitoid distribution in time and space (Figs. 2–5). Note that because continental drift is passive response to trench retreat [22], the relative position of the "volcanic arc" immediately above the subduction zone will not change throughout of the life span of the subduction. **c**, **d** are modified from Green and co-authors [67, 68] to show the dry solidus (thick blue), water-saturated solidus with >0.02 wt% H_2O (thick pink) at $P > \sim 3$ GPa and with >0.4 wt% H_2O (thick dashed light blue) at $P < \sim 3$ GPa and amphibole dehydration solidus (think pink) with $\sim$0.02–0.4 wt% H_2O at $P < \sim 3$ GPa. The intraplate geotherms of mantle lithosphere beneath ocean basins (thin dashed orange line) and cratons (thick red line) are shown for reference relative to the adiabatic geotherm of the asthenosphere with a mantle potential temperature of $T_P = 1430$ °C [68] although others prefer $T_P = 1350$ °C to be more general (e.g., [69]). In *D* is the experimentally determined H_2O storage capacity of mantle peridotite rocks, largely controlled by the stability of the hydrous pargasitic amphibole ($P \leq \sim 3$ GPa, $T \leq 1100$ °C). This means that in the upper mantle depths of $\sim$100–250 km, the lithosphere can be stable so long as it is dry with bulk $H_2O < 0.02$ wt%, i.e., the condition for the lithospheric mantle or cratonic root stability. Note that at depths of 200–250 km, the temperature difference between the dry solidus and wet solidus is on the order of >300 K and it is thus physically difficult and practically unlikely to weaken and thin the lithosphere by excess temperature that is unavailable, but it is straightforward by addition of minute water [18, 22], say >0.02 wt% or 200 ppm, to bring the mantle rock onto the wet solidus, converting the basal lithosphere into the asthenosphere. For example, assuming "X" represents the stable deep part of the eastern China continental lithosphere prior to the thinning, addition of H_2O derived from the transition zone (see above) would make it well above the wet solidus, causing incipient melting and transforming the basal lithosphere into asthenosphere

present-day ocean island basalts (OIB) whose composition is consistent with melting of the metasomatized asthenosphere source, and most of which are in the category of alkali basalts [22, 39, 41].

(5) Importantly, the granitoid magmatism essentially terminated at $\sim$88 Ma ($\pm$ 2 Ma analytical error), suggesting that, by inference, the cause of crustal melting ceased to exist at this time. This indicates that mantle melting for basaltic melt as heat source for crustal melting and granitoid magmatism essentially stopped. This means that the trigger of mantle transition-zone slab dehydration likely diminished. The straightforward conclusion would be that the subduction suddenly stopped at $\sim$88 Ma. The fact that rarely or essentially little or no magmatism from $\sim$88 to $\sim$50 Ma in the greater region of the western Pacific is consistent with this inference that the subduction stopped for the eastern continental China granitoid magmatism. This is an important observation that must be considered concerning the tectonic evolution of eastern China. However, to determine the exact timing of subduction cessation is not straightforward because transition-zone slab dehydration would continue for some time until (a) it can no longer dehydrate constrained by the stability of the hydrous phases in the transition zone (e.g., wadsleyite $\sim$3 wt% H_2O; ringwoodite $\sim$3.2 wt% H_2O) and (b) even if dehydration continued, the amount of H_2O released may no longer be transported in the form of hydrous melt (i.e., under-saturated and absorbed by minerals) during its percolation through the asthenosphere (the convective yellow region in Fig. 7b). If the water (or hydrous melt) is entirely absorbed in the mantle (e.g., <0.2 wt% at depths of >100 km or <0.4 wt% at depths of <100 km; see Fig. 7c, d), there would be no water-facilitated lithosphere melting to produce basaltic melt as heat source available to cause crustal melting and the granitoid magmatism.

(6) The above analysis leads us to the conclusion and the subduction must have stopped at $\sim$88 Ma and is more likely some time prior to $\sim$88 Ma as certain amount of time is needed for last fragments of the subducted transition-zone slab to release adequate water for mantle melting and the resultant crustal granitoid magmatism. While experimental work is needed to quantify the amount of time required for complete transition-zone slab dehydration to lose the potential for causing mantle melting and corresponding crustal magmatism, we predict that the time may be short and is on the order of $\sim$10 Myrs. This would mean that the Mesozoic subduction may have stopped at $\sim$100 Ma.

5 Why did the Mesozoic subduction stop at ~100 Ma?

Niu et al. [42] demonstrate that subduction, once initiated and continued, cannot stop and the only cause of subduction cessation is trench jam. The arrival of a sizable mass of large compositional buoyancy at the trench will jam the trench because it is too buoyant to subduct, thus stopping subduction. This concept is well illustrated in a self-explanatory set of cartoons using the buoyant oceanic plateau of mantle plume origin as an example in Fig. 8. Among demonstrative arguments, the history of the giant Ontong Java Plateau in the Southwest Pacific provides a convincing case for its buoyant and unsubductable property [43–45] and for its effective cause to change the subduction polarity toward beneath it only a few million years after the trench jam in the Southwest Pacific [42]. The Caribbean Oceanic Plateau is another example of large buoyant and unsubductable mass with seafloor subduction beneath it from both Pacific and Atlantic sides [42]. It is important to note that the oceanic plateau model illustrates in its clarity the trench jam concept (Fig. 8), but micro-continents are more buoyant [43, 44], unsubductable, and can thus be more effective to cause trench jam and subduction cessation [42].

6 The continental shelf of East and South China Seas as an exotic and unsubductable terrane

All the above observations, data analysis and reasoning have inescapably led us to the conclusion, which is in nature a testable hypothesis: The basement of continental shelf of East and South China Seas is best understood as an exotic massive terrane of large compositional buoyancy, transported by the NW moving paleo-Pacific plate in the Mesozoic (we call it "paleo-Pacific plate" rather than using the possible yet unproven "Izanagi" plate [46]), and collided at $\sim$100 Ma with the eastern China continental margin. The collision jammed the trench, stopped subduction, and thus ended the transition-zone slab dehydration induced mantle melting for basaltic melt as the heat source for crustal melting, terminating the granitoid magmatism in the eastern continental China at $\sim$88 Ma. The $\sim$100 Ma collision time is unconstrained (see above), but is a reasonable estimate by assuming a $\sim$10 Myr time period is required to allow complete dehydration (constrained by the transition-zone mineral stability) of the last slab fragments for mantle melting, crustal melting and the eastern continental China granitoid magmatism to last until $\sim$88 Ma.

6.1 The nature of the East and South China Sea continental shelf of exotic origin and the locus of its collision with eastern continental China

The East China Sea (ECS) and South China Sea (SCS) are geographic divisions, but their shelf basement is geologically the same. Their geographic separation by the Island of Taiwan and Taiwan Strait has been a more recent geological event associated with the uplift of Taiwan in response to the complex compression and subduction in the region. Hence, we use continental shelf of China for the entirety since the collision at $\sim$100 Ma. Despite some published work in the old Chinese literature, we essentially know very little about the nature and history of this exotic terrane, but we do know predictably that it *must not* be the same as the Cathaysia basement of Southeast China, *must be* compositionally buoyant, and *must* have experienced continued basal lithosphere thinning in the Cenozoic. These "*must*" and "*must not*" represent our assertive request for hypothesis testing. We cannot rule out that the continental shelf basement of exotic origin could be an oceanic plateau, but equally we cannot refute the possibility that it may actually represent a micro-continental mass. To help address this issue, we need first to locate the locus (or the suture) of the collision taking place at $\sim$100 Ma between the exotic terrane and the Cathaysia Block in South and East China.

Figure 9 shows that the Southeast China costal line is an arc (dashed red line), which in length and curvature is similar to the India-Asia Collision Arc (solid red line). It should be noted that the "arc shape" is determined by the prior existing subduction zone/trench (hence the familiar Island "arcs") although the collision with the entering plate may modify the arc shape. Hence, the arc shape of the Southeast China coastal line is not coincidental, but is inherited from the prior subduction zone and trench. The arc shape with contrasting elevation is also not coincidental but indicative of collision with different intrinsic properties on both sides. The entering Indian plate is flat with low elevation relative to the receiving Tibetan Plateau "plate", where the convergence has continued to this day since the collision $\sim$55 Ma with thickened cratonic lithosphere ensuring the India plate above sea level. In the case of the Chinese continental shelf (CCS), the entering exotic plate is anticipated to be also flat at the time of collision (recently modified by back-arc opening, etc.) with low elevation relative to the receiving Cathaysia Block (CB) above sea level. Both CCS and CB are of low elevation because of the thin lithosphere and the lack of the Himalaya-like range is consistent with being no continued convergence since the collision at $\sim$100 Ma. To the north, the locus of the collision is hard to trace (dashed light blue line with question marks; Fig. 9) because of the recent (<20 Ma) tectonic reorganization associated with the opening of the Sea of Japan.

The above analysis shows unavoidably that both the Islands of Taiwan and Hainan are exposed constituents of the exotic terrane geologically unrelated to the Cathaysia Block in South China. Many researchers may disagree on this unconventional reasoning, but there is practically no convincing evidence at all that the geological record in Taiwan is comparable to that of South China. In fact, a recent study shows that the basement of the Hainan Island, in particular in the Sayan area in the southern end, closely resembles that of Western Australia rather than that of South China [47]. We do not wish to emphasize this study [47] supports our hypothesis (maybe not as yet), but stress that "*there are no facts, but interpretations*" as quoted above and that there are many more unknowns than knowns that require our objective and open-minded thinking to develop insights. Because our hypothesis has huge implications, we advocate interested members to work together to test the hypothesis.

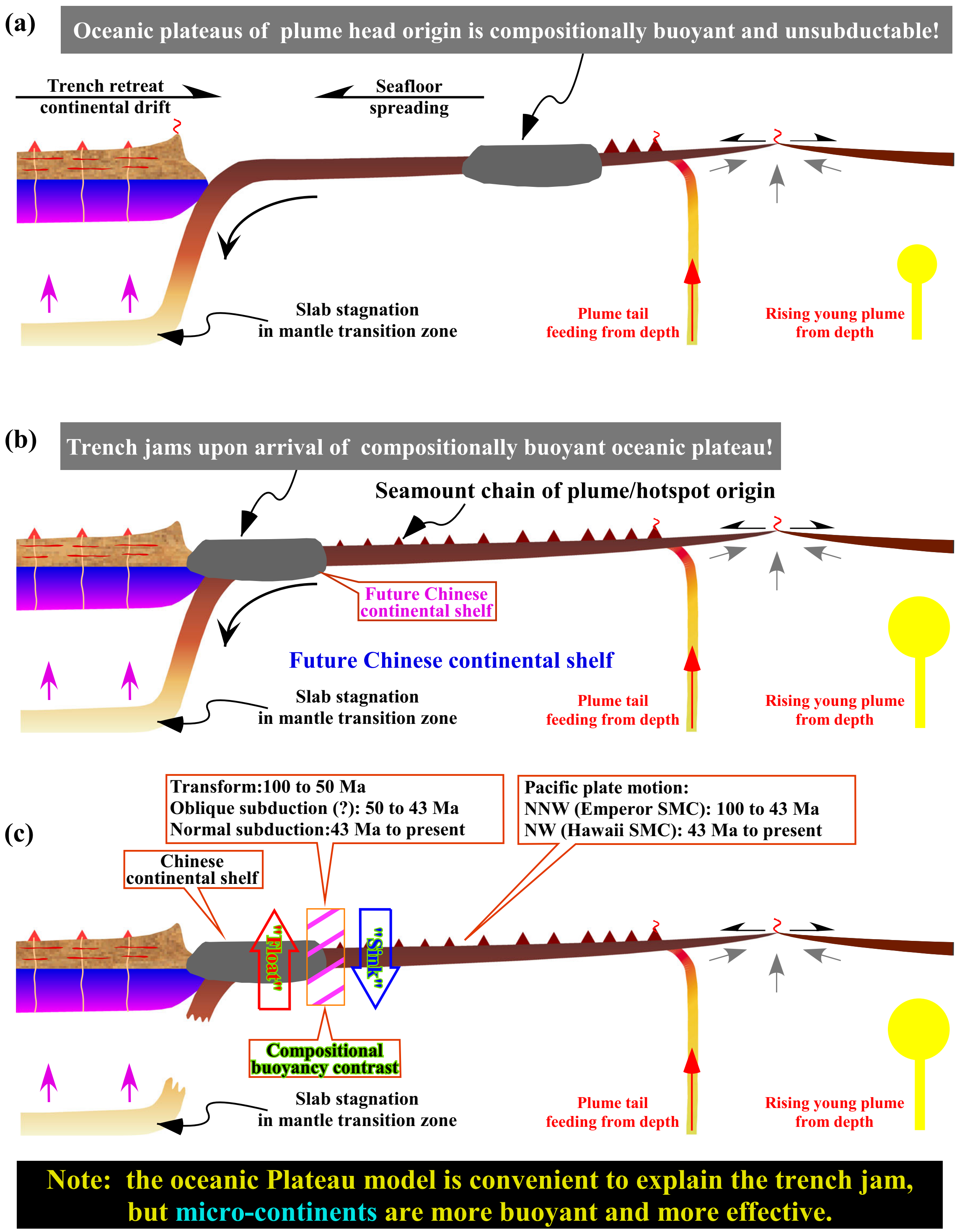
6.2 Testing the hypothesis

Some detailed and thorough work to compare the geological record from the Islands of Taiwan and Hainan with that of the Cathaysia Block will be useful. However, basement penetration drilling at selected sites on the shelf of South China Sea, East China Sea, and perhaps Yellow Sea will be essential (see Fig. 9). There are many industrial boreholes drilling into the cover sediments on these shelves, but we propose to work with the industries and IODP to select ideal sites for deep and basement penetration drilling so as to obtain the minimal information necessary to test the hypothesis concerning the nature and history of the Chinese continental shelf of exotic origin.

The hypothesis also means: (1) the basement of the young (<15 Ma) Ryukyu Island Arc as well as the Okinawa Trough are parts of the same exotic terrane, whose study, including sampling outcrops of the land-side Ryukyu Trench wall if possible will be useful; (2) South China Sea was opened as a back-arc basin spreading system from within the exotic terrane; thus, the basement of the several archipelagos in the South China Sea is also ideal targets for deep drilling.

7 Summary and broader implications

1. *The exotic origin* The basement of the continental shelf of China is of exotic origin. It could be a fossil oceanic plateau, but is more likely a sizable micro-continent with large compositional buoyancy transported by, or along with, the paleo-Pacific plate in the Mesozoic. It was too buoyant to subduct, thus collided with the eastern margin of continental China, jammed the trench and caused subduction cessation at $\sim$100 Ma (Fig. 8). The locus (or suture) of the collision is likely on the shelf in the vicinity of, and parallel to, the Southeast China coast, whose arc shape is inherited from that of the prior trench (Fig. 9).
2. *Testing the hypothesis* The above is an unescapable conclusion based on our analysis of the Jurassic–Cretaceous granitoid distribution in space and time in eastern China and insights gained from geological record and physical principles. This conclusion is in nature a hypothesis to test by basement penetration drilling on the shelf of the East China Sea, South China Sea and perhaps also the Yellow Sea (Fig. 9). The origin and history of the South China Sea is at present an international "hotspot" with concentrated studies, but predictably, its opening as a back-arc basin was initiated from the interior of the exotic terrane. Hence, the basement of several archipelagoes scattered in the South China Sea also needs selecting for basement drilling.
3. *The importance of testing the hypothesis* Testing the hypothesis (a) can provide insights into the plate tectonic reconstruction of the Mesozoic western Pacific in a global context, and (b) will also offer us a fresh and open-minded understanding of the continental geology of eastern China since the Mesozoic. At present, the practical hindrance for any further insight into the tectonomagmatic processes of eastern China since the Mesozoic lies in unraveling the nature and history of the basement of the Chinese continental shelf.
4. *Not an Andean-type margin* The eastern continental China in the Mesozoic may be considered as an active continental margin as done by many, but it is not an Andean-Type margin because the granitoids do not define "magmatic arcs" at any given time. Rather, the granitoids distribute randomly in space and time in a wide zone in excess of >1000 km (Figs. 2–5), which is most consistent with the presence of a stagnant paleo-Pacific slab in the mantle transition zone beneath the region. The stagnant slab dehydrated and released water in the form of hydrous melt that percolated through and metasomatized the upper mantle, weakened the base of the lithosphere while producing basaltic melt as the heat source (also material contribution; Fig. 6) for crustal melting and the granitoid magmatism (Fig. 7).


(a)
Oceanic plateaus of plume head origin is compositionally buoyant and unsubductable!
Trench retreat
continental drift
Seafloor
spreading
Slab stagnation
in mantle transition zone
Plume tail
feeding from depth
Rising young plume
from depth
(b)
Trench jams upon arrival of compositionally buoyant oceanic plateau!
Seamount chain of plume/hotspot origin
Future Chinese
continental shelf
Future Chinese continental shelf
Slab stagnation
in mantle transition zone
Plume tail
feeding from depth
Rising young plume
from depth
(c)
Transform:100 to 50 Ma
Oblique subduction (?): 50 to 43 Ma
Normal subduction:43 Ma to present
Pacific plate motion:
NNW (Emperor SMC): 100 to 43 Ma
NW (Hawaii SMC): 43 Ma to present
Chinese
continental shelf
"Float"
"Sink"
Compositional
buoyancy contrast
Slab stagnation
in mantle transition zone
Plume tail
feeding from depth
Rising young plume
from depth
Note: the oceanic Plateau model is convenient to explain the trench jam,
but micro-continents are more buoyant and more effective.

◀**Fig. 8** Cartoons significantly modified from Ref. [42] to use the oceanic plateau model to explain the concept of trench jam, i.e., the oceanic plateau of mantle plume head origin is massive, compositionally buoyant and is thus unsubductable (**a**), whose arrival at trenches will jam the trench and stop subduction (**b**). As a result, subduction-related magmatism ceases to continue although dehydration of the transition-zone stagnant slab subducted earlier can continue its role in causing H_2O-induced mantle melting [18, 22] and crustal anatexis for granitoid magmatism (left-hand side of the cartoons) for some time (up to 10 Myrs?). New subduction can thus begin in the back at the compositional buoyancy contrast indicated with stippled rectangle (**c**) [22, 42]. Note that the oceanic plateau model is convenient to explain the concept of trench jam, but micro-continents of sizable mass are compositionally more buoyant and more effective such as geological terrenes and blocks that constitute the Greater Tibetan Plateau [70–73]. The basement of the Chinese continental shelf is predicted to be such an exotic terrain in (**c**). Because of the trench jam, the Pacific plate changed its motion toward NNW direction at ~100 Ma, making the Pacific plate in transform contact with the eastern Asian plate (eastern China with the shelf of exotic origin) at the compositional buoyancy contrast (the stippled rectangle; in (**c**)) until ~50 Ma when the present-day western Pacific subduction began. Since ~50 Ma, the Pacific plate may continue to move in the NNW direction as manifested by the age-progressive Emperor Seamount Chain (SMC) of Hawaiian hotspot origin, but now the contact with the Asian plate changed from transform to oblique (low angle) subduction until ~43 Ma. At ~43 Ma, a hypothetical oceanic plateau ("Hawaiian plume head"?) jammed the trench, causing the Pacific plate to re-orientate its motion in the NW direction and to subduct beneath the present-day western Pacific subduction trenches as manifested by the age-progressive Hawaiian SMC of Hawaiian hotspot origin [42, 74]

5. *The lithosphere thinning not limited to the NCC* While destruction of the NCC is emphatically discussed by the Chinese community, it is unambiguous that the lithosphere thinning is not limited to the NCC, but rather extensive throughout the entire eastern continental China in the Mesozoic as previously pointed out and as indicated by the granitoid distribution (Figs. 2–5). A view going beyond the NCC in a larger context will open our mind with greater vision toward a genuine understanding of the tectonomagmatic evolution of the eastern continental China since the Mesozoic.
6. *Timing of the lithosphere thinning* If the granitoid magmatism was genetically associated with the lithosphere thinning as we argue and illustrate (Fig. 7), then, by inference, the intensity of the granitoid magmatism manifests the intensity of the lithosphere thinning. It follows that the lithosphere thinning began ~190 Ma until ~88 Ma, and largely completed by ~110 Ma with the peak at ~140 Ma (Fig. 3).
7. *Largely crustal reworking* As shown by the Nd isotope compositions, the Mesozoic granitoids of eastern China are dominated by a mature crustal source with >50 % samples having $\varepsilon_{Nd(t)} < -9.7$ and 95 % samples having $\varepsilon_{Nd(t)} < 0$ (Fig. 6), i.e., their petrogenesis is consistent with crustal melting (or crustal re-working) induced by heat, with some material contribution, of mantle-derived basaltic melts (Figs. 6, 7). This has implications for the thinner-than-normal mafic lower crust in the eastern continental China as recognized by Gao et al. [48] without having to invoke mafic lower crust foundering into the asthenospheric mantle [9], which is physically not straightforward given the presence and protecting effect of the mantle lithosphere [18, 19]. Nevertheless, the recognition by Ref. [48] is important, and the intriguing question put forward has been largely overlooked. This question should be adequately addressed as we suggest here by quantitative evaluation of the melting processes and physical contributions of mantle mafic melts to the crustal level in the Mesozoic.
8. *The ~40 Myr magmatic gap and the transform boundary* As we argue, the paleo-Pacific subduction offshore southeast coast of the continental China (Fig. 9) ceased at ~100 Ma with the magmatism continuing to ~88 ± 2 Ma, yet the present-day western Pacific subduction did not begin until ~50 Ma [24, 25] and the Ryukyu subduction began even later (<15 Ma). There is thus a ~40 Myr gap without subduction-related magmatism, which is unexpected from the simple model prediction that a new subduction should develop in the back of the buoyant exotic terrane (The stippled rectangle in Fig. 8c) whether it is an oceanic plateau or a micro-continent [42]. However, the absence of magmatism can also be understood if what is developed there is not a new subduction zone but a transform fault. We predict that from ~100 to ~50 Ma, the paleo-Pacific plate was in transform contact with the eastern Asian continental plate at the eastern margin of the newly accreted Chinese continental shelf of exotic origin (see below).
9. *Re-orientation of the Pacific plate motion from NW to NNW at ~110 Ma* Niu et al. [42] show that trench jam can cause the Pacific plate to change its motion toward where subduction was happening. We predict that the Pacific plate changed its course at ~100 Ma from toward NW to toward NNW where active subduction was occurring at the western Aleutian trench (or its predecessor) as inferred from the age-progressive Emperor Seamount Chain of the Hawaiian hotspot origin, whose oldest yet unsubducted seamounts are Meiji and Detroit of ~82 Ma. This would produce a transform plate boundary between the NNW moving Pacific plate and the eastern Asian continental plate (see above; also the stippled

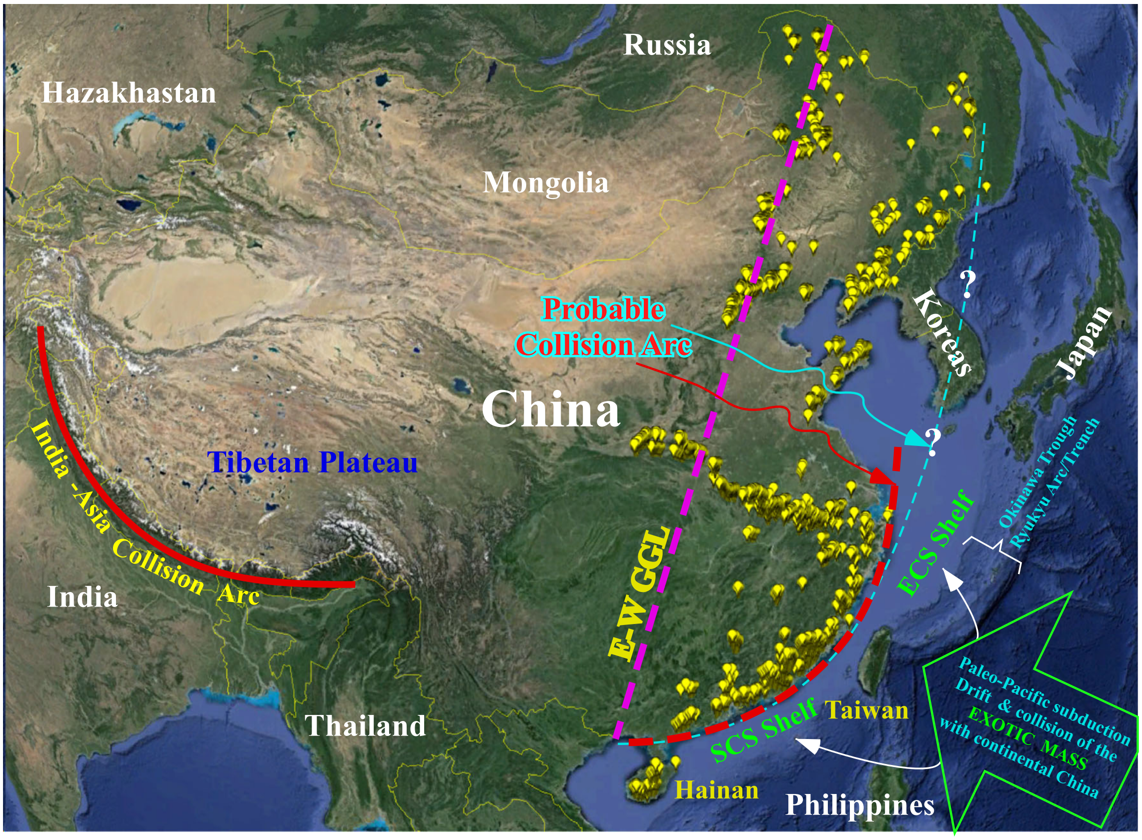


Fig. 9 Portion of the world topographic map, highlighting the continental China and its adjacent land and seas (Google Map, 2015) to illustrate several key points: (1) We emphasize the testable hypothesis that the Chinese continental shelf (shelf basement of East China Sea and South China Sea altogether) is of exotic origin, which as a large ocean plateau or more likely micro-continent transported with the northwestward moving paleo-Pacific plate that subducted in a paleo-Trench in the vicinity of continental China; (2) arrival of the buoyant and unsubductable oceanic plateau or micro-continent at the trench jammed the trench (see Fig. 8); (3) the exact trench location is unknown, but is likely parallel to and in the vicinity of the South-East China costal line indicated by the thick red dashed line, which is in length and arc similar to the India-Asia Collision Arc (the thick red line); (4) the collision arc in the northern section is hard to locate (see the light blue dashed line with question marks) because of the recent (<20 Ma) tectonic reorganization associated with the opening of the Sea of Japan. The yellow "drop" dots are granitoid sample locations with ages in the literature, and we have sampled many of them for testing the hypothesis by comparing intrinsic geochemical characteristics of these granitoid samples and the basement rocks of the SCS and ECS shelf. The latter can only be obtained by basement penetration drilling through working with industries and the IODP community

rectangle in Fig. 8c) until $\sim$50 Ma when the present-day western Pacific subduction began. At this time, the Pacific plate may continue its NNW course, but this transform boundary of compositional buoyancy contrast may have just turned into a trench with oblique subduction until $\sim$43 Ma.

10. *Re-orientation of the Pacific plate motion from NNW to NW at $\sim$43 Ma* Collision of the buoyant Hawaiian mantle plume head (oceanic plateau) at $\sim$43 Ma with the predecessor of the Aleutian–Kamchatka trench jammed that trench, resulting in the re-orientation of Pacific plate motion by 60° in the present NW course and its subduction into the western Pacific trench as manifested by the age-progressive Hawaiian Seamount Chain of the Hawaiian hotspot origin (see Ref. [42, 74] for details). This analysis needs considering in future plate tectonic reconstruction of the region in a global context.
11. *Some intriguing questions exist* We continue to consider these questions as important elements of our hypothesis testing and we also advocate that the community objectively discuss these issues. (a) The reported 88 ± 2 Ma and older granitoids from Japan and South Korea (Fig. 2) are expected because they are close to the eastern margin of the continental China at that time long before the opening of the Sea of Japan at $<\sim$20 Ma [49]. (b) The 88 ± 2 Ma old granitic gneisses exposed in the Central Range in Taiwan are coeval with the last episode of the granitoid magmatism on the eastern continental

China, but whether they share a similar origin remains to be investigated. (c) We also note that 110–88 Ma old granitoids on the Island of Hainan are common, which are also coeval with the last episodes of the granitoid magmatism on the eastern continental China, but more detailed petrology, geochronology and isotope geochemistry on these and many other samples are underway in our effort in testing aspects of the hypothesis (see Fig. 9 for sample locations). (d) Of particular interest is the recently reported ~73 Ma granitoid from Longlou at the NE corner of the Hainan Island [50], whose geological significance is under consideration. (e) We also note that a recent study [51] suggests on the basis of detrital zircon age spectrum analysis that some pre-Middle Jurassic sediments from Southwest Japan may have come from South China, in particular the Cathaysia Block (vs. anticipated North China). This is actually straightforward because Southwest Japan has the closest proximity (see Fig. 2) to the northern section of the Cathaysia Block before the separation of Japanese Islands from the continental Asia recently (<~20 Ma). (f) In addition, we consider the necessity of discovering the possible presence of remnant Mesozoic Pacific slab in the mantle transition zone or deeper somewhere. This is not straightforward because it may no longer be detected seismically because of adequate thermal equilibration with the ambience. However, if it existed at all, its fragments may lie in the mantle below or more likely far to the west of the western continental China because the slabs must be stagnant in the mantle transition zone (in geologically reasonable length of time) whereas the continental lithosphere must have drifted fast to the east since the Mesozoic in response to western Pacific trench retreat (see Ref. [22]). (g) Importantly, our prediction for the transform boundary from ~100 to ~50 Ma is conceivable with logical reasons and ability to explain the magmatic gap between ~88 and ~50 Ma. One possibility is that the predicted transform may be the predecessor of the present-day subduction boundaries of the Japanese Trench, the Ryukyu Trench (although it is younger) and the Philippines Trench, but all these must be verified through collecting data and data-based plate reconstruction with particular effort to understand the origin and histories of the Philippines Plate as attempted in the literature [49, 52, 53]. (h) The younger ages (as young as ~ 70 Ma?) of some volcanic rocks in southeast China [29], if verified to be correct, may reflect post-collisional "memory" without affecting the statistical significance of the ~ 88 ± 2 Ma magmatic termination (Fig. 3), but the collision timing of ~ 100 Ma can be refined with more reliable data becoming available.

12. We emphasize again that the *bottleneck* toward further insights into the plate tectonic reconstruction and geological evolution of the western Pacific and continental China since the Mesozoic lies in the genuine understanding of the nature and histories of the continental shelf of China (the same shelf basement beneath East and South of China Seas). The latter is also required in order to truly understand the origin and histories of the South China Sea.

Acknowledgments This work was supported by the National Natural Science Foundation of China (41130314, 91014003), Chinese Academy of Sciences Innovation (Y42217101L), grants from Regional and Local Authorities (Shandong Province and City of Qingdao) and supported by National Oceanography Laboratory in Qingdao. The principal ideas in this paper were previously presented by the senior author at the annual national symposia on Destruction of the North China Craton (December 2012 & 2014, Beijing), at a workshop in the First Institute of Oceanography (December 2013, Qingdao), at the Western Pacific land–ocean-geo-dynamics workshop (March 2015, Qingdao), and at the thematic conference. The connection of the North China Craton destruction with the Paleo-Pacific subduction (March 26–27, 2015, Beijing) organized and supported by the National Natural Science Foundation of China (NSFC), for which we thank Professors Jin Zhenmin, Zhang Guowei and Zhu Rixiang for invitation. We thank Professors Xiaolong Huang and Shuguang Song for constructive reviews and Professor Zhidan Zhao for suggestions.

Conflict of interest The authors declare that they have no conflict of interest.

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Abstracted/indexed in

Science Citation Index, Chemical Abstracts, SCOPUS, Google Scholar, Inspec, Academic Search Alumni Edition, Academic Search Complete, Academic Search Elite, Academic Search Premier, ASFA 1: Biological Sciences and Living Resources, ASFA 2: Ocean Technology, Policy and Non-Living Resources, Biological Sciences, Biological Abstracts, BIOSIS Previews, CAB Abstracts, Current Contents/Physical, Chemical and Earth Sciences, Current Mathematical Publications, Digital Mathematics Registry, EMBio, Environmental Engineering Abstracts, Environmental Sciences and Pollution Management, Mathematical Reviews, MathSciNet, Meteorological and Geoastrophysical Abstracts, Pollution Abstracts, Water Resources Abstracts, Zentralblatt MATH, Zoological Record.

Science Bulletin 科学通报 (英文版) Vol. 60 No. 18 September 30, 2015 (Semi-monthly)

Supervised by Chinese Academy of Sciences
Sponsored by Chinese Academy of Sciences and National Natural Science Foundation of China
Published by Science China Press and Springer-Verlag Berlin Heidelberg
Subscriptions
China Science China Press, 16 Donghuangchenggen North Street, Beijing 100717, China
Email: sales@scichina.org Fax: 86-10-64016350
The Americas (North, South, Central America and the Caribbean) Springer Journal Fulfillment, 233 Spring Street, New York, NY, 10013-1578, USA
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Tel.: +49-6221-345-4303 subscriptions@springer.com
Printed by Beijing Artownprinting Co., Ltd., Chuangyeyuan Road, Taihu Town, Tongzhou District, Beijing 101116, China
Edited by Editorial Board of Science Bulletin, 16 Donghuangchenggen North Street, Beijing 100717, China
Editor-in-Chief Xiao-Ya Chen

CN 10-1298/N ISSN (Print) 2095-9273 ISSN (Online) 2095-9281
广告经营许可证: 京东工商广字第0429号

邮发代号: 80-214 (英)
国内每期定价: 180元

ISSN 2095-9273

ISSN 2095-9273
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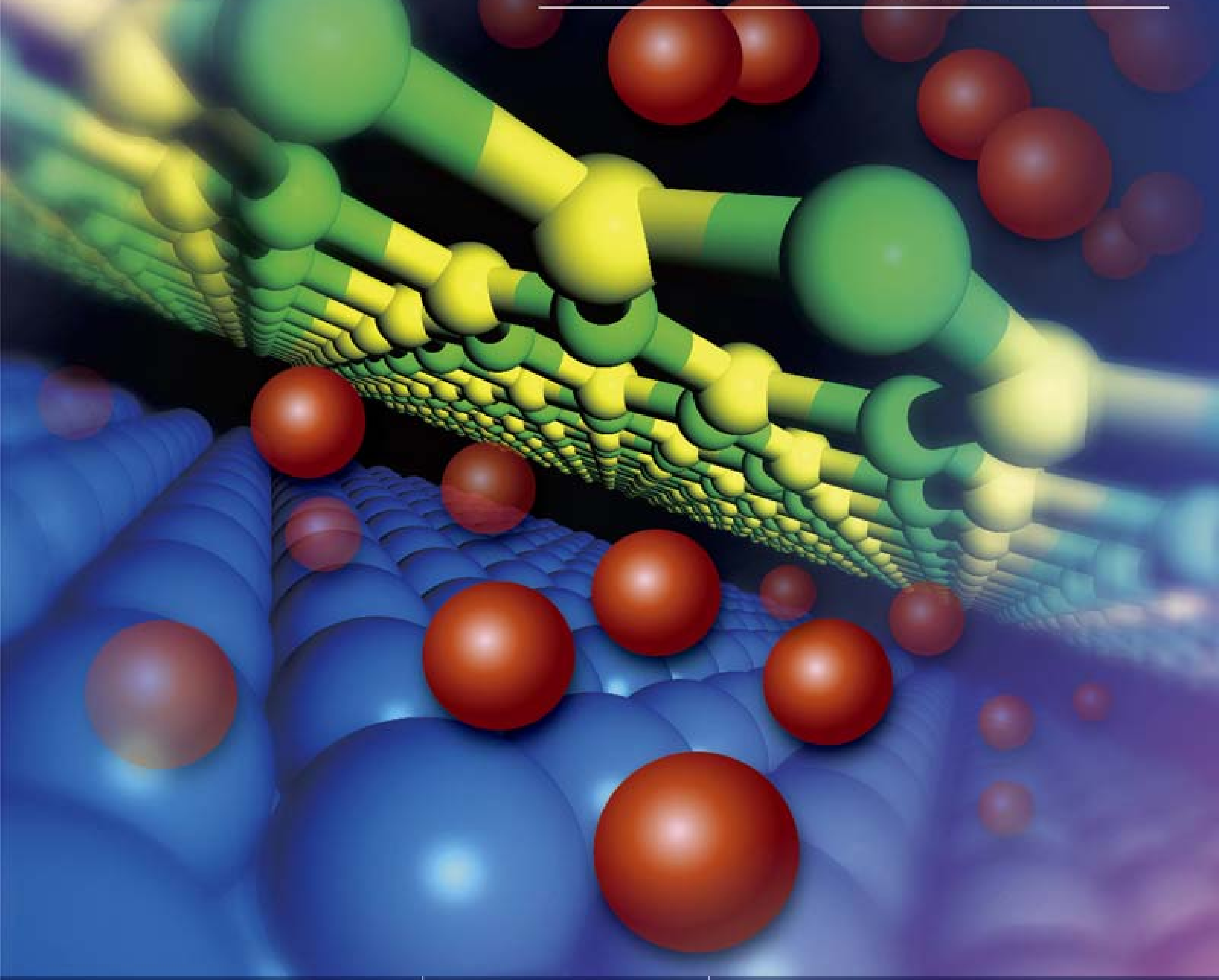
Science Bulletin

Volume 60 · Number 18 · September 2015



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COVER Two-dimensional (2D) atomic crystals such as graphene, hexagonal boron nitride (h-BN), and MoS interact weakly with solid surfaces through van der Waals interactions. Therefore, the interface between the 2D overlayer and substrate can be considered a nanoreactor, wherein molecule adsorption and catalytic reactions may occur. Recent surface science studies confirm that small molecules, including CO, O_2, H_2, and H_2O, can be readily intercalated under the graphene and h-BN overlayers. Moreover, catalytic reactions such as CO oxidation and water electrolysis also proceed at the interfaces. Since the distance between the 2D overlayers and the metal surfaces typically falls within the sub-nanometer range, it is expected that the 2D overlayers will have a strong confinement effect on the surface chemistry and catalysis over solid surfaces, and will promote reactions underneath the 2D overlayers. From conventional knowledge, surface graphitic overlayers on metal surfaces often poison the catalyst surfaces, resulting in deactivation. Our findings contrast the conventional knowledge but open up a new avenue to enhance catalytic performance through coating of metal catalysts with controlled graphitic overlayers. The cover illustrates the oxygen intercalation and CO oxidation occurring at the h-BN/Pt(111) interfaces, which was confirmed by in situ characterization using near ambient pressure X-ray photoelectron spectroscopy, photoemission electron microscopy, and low energy electron microscopy (see the article by Yanhong Zhang et al. on page 1572).

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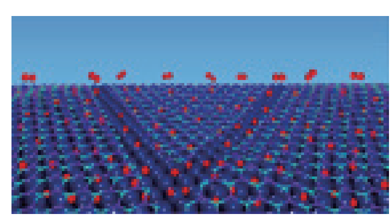

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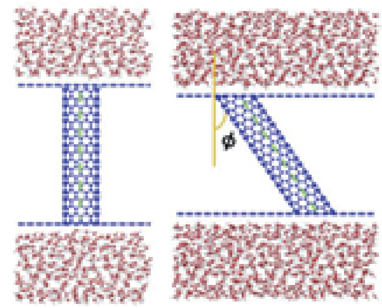

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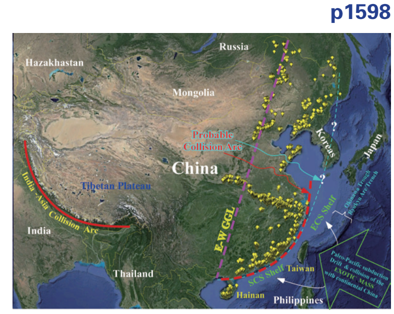
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