Subduction initiation along a passive continental margin: Lessons learned from the Mesozoic arc north of the Neo-Tethys in Iran

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Background

Subduction is the major driver for plate movement, but how it initiates is poorly understood. Of these four "Wilson Cycle" processes, by far the least well understood is the birth of a convergent margin of Andean- or Japan-type, because there are no obvious on-going conversions of passive margins into active ones. Current understanding of the physics of subduction initiation is primarily based on numerical modeling of modern oceans, but the kinematics of how an intraoceanic system develops into a full-blown Andean-type margin are cryptic, unless the margin simply initiates along an old passive margin. In the Atlantic Ocean, despite sections of oceanic lithosphere older than 170 Ma, transformation of the passive continental margin into a subduction zone has yet to occur. There are two short segments of intraoceanic subduction zones, the Antilles and Scotia arcs, but they constitute less than 5% of the total length of the continental margin, and are unlikely to develop into Andean-type margins.

Calc-alkaline magmatic suites preserved in continents are reliable indicators of the presence of ancient subduction zones. One of the key questions that can be tackled is, what are the limits on the age of the oceanic lithosphere in earlier oceans where subduction began? Another question is, at what rates might subduction propagate from one or more inception points along a continental margin? Answering those questions requires well-constrained timing of both oceanic opening and subduction initiation, using arc magmas as a proxy. The extensive histories of subduction and arc magmatism along the Andean and Cordilleran margins span back to early Paleozoic time, but the record of events near the time of formation of these arcs is too fragmentary to address these questions at large scale. Within the greater Alpine-Himalyan collision belt, however, information is now emerging for the Mesozoic Neo-Tethyan continental margin, along a major segment of the belt in Iran known as the Sanandaj-Sirjan belt. The ancient arc is remarkably well preserved in the forearc region of the younger Urumeiah-Doktor arc of Cenozoic age, and is thus ideal for investigating the timing of subduction nucleation.

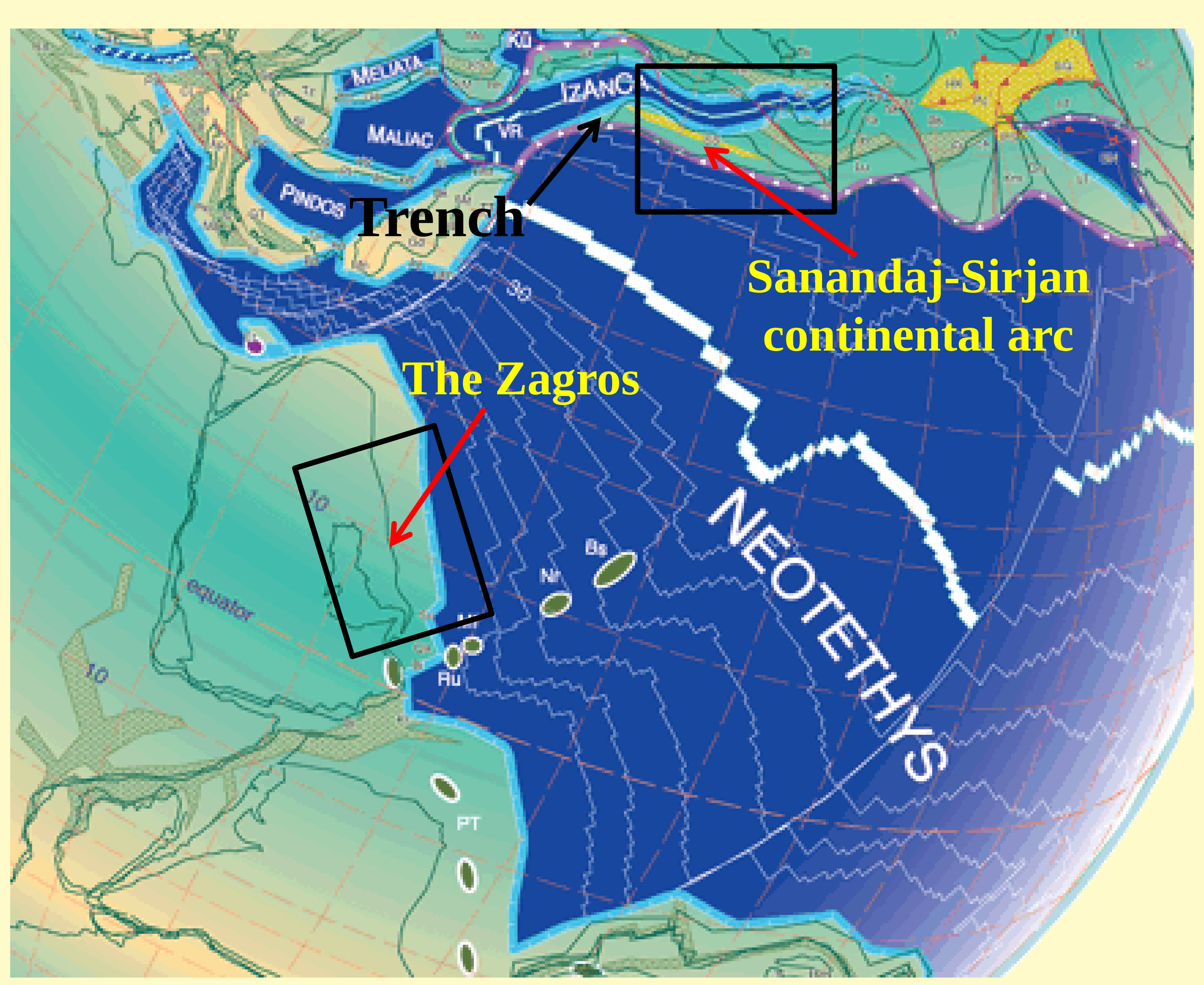

Fig. 1. Neo-Tethys Ocean dividing Iran (black boxes) around 180 Ma (Stampfli & Borel, 2002). Note that subduction north of the Neo-Tethys is generally assumed to be full-blown by this time.

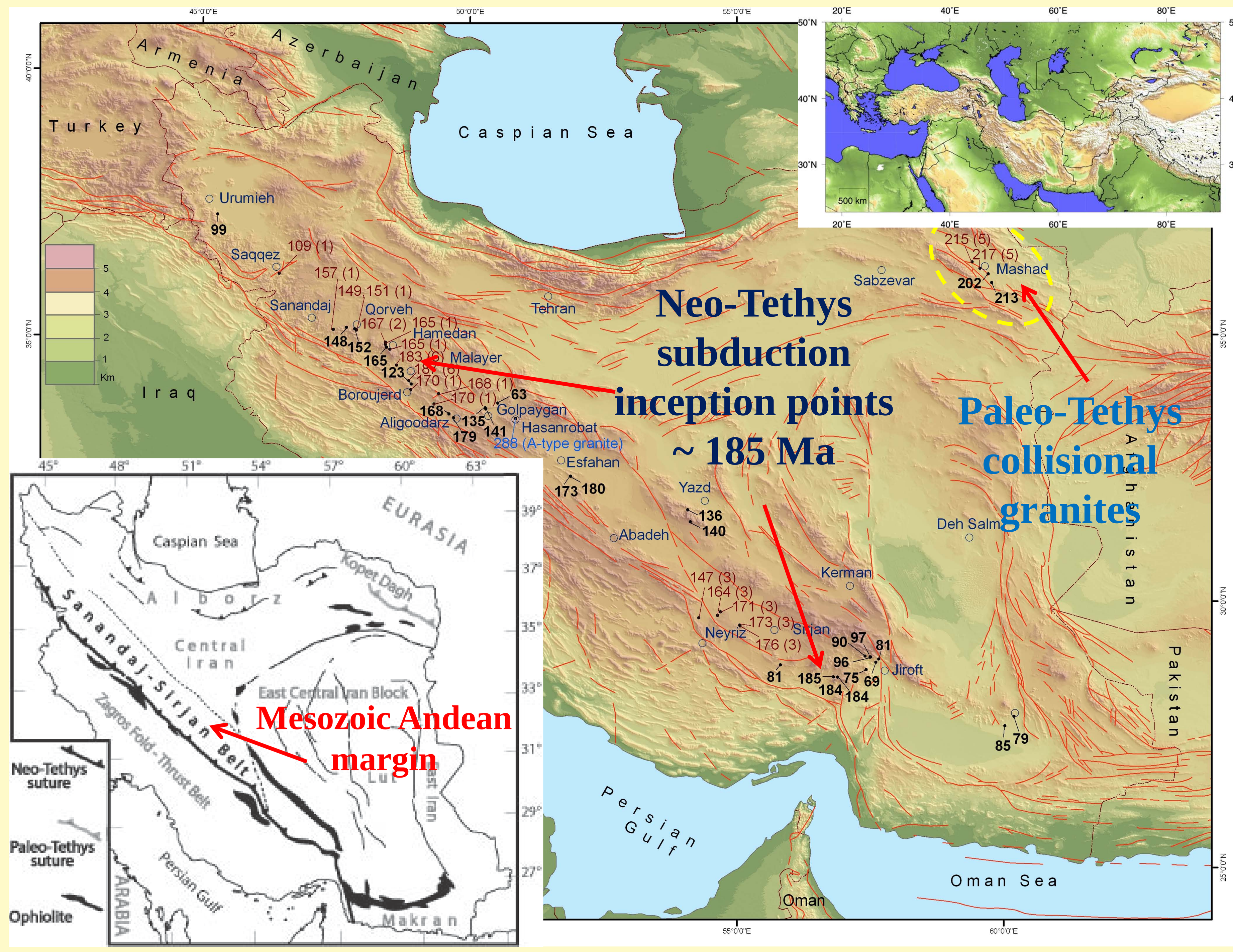

Fig. 2. U-Pb zircon ages of calc-alkaline granitoids of the Sanandaj-Sirjan belt showing two widely (1000 km) separated subduction inception points around 185 Ma. Data was obtained using the IMS-1270 ion microprobe at UCLA.

Timing of the Neo-Tethys opening and subduction initiation

Neo-Tethys sea-floor spreading began between what are now the Zagros Mountains and the Sanandaj-Sirjan belt in the Permian, based on the formation of a passive margin preserved in the stratigraphic and igneous record. A U-Pb zircon age of 288 Ma for a ferroan A-type granite at Hasan Robat in the Golpayegan region of the Sanandaj-Sirjan zone places the timing of continental rifting in the early Permian (Fig. 1).

Intra-oceanic subduction in this sector of the Jurassic Neo-Tethys probably did not occur because no record of such arcs has been preserved. If this is correct, then subduction initiation in Neo-Tethys was fundamentally different from known Cenozoic examples, where all cases are intra-oceanic (e.g. Stern, 2004).

For initiation of subduction in the Neo-Tethys, global plate reconstructions suggest that the northern continental margin had fully transformed into a trench by the beginning of Jurassic time (~200 Ma) (e.g., Stampfli and Borel, 2002) (Fig. 1). However, crystallization ages of the calc-alkaline granitoids from the SSB reveal that north-dipping subduction had locally nucleated at around 185 Ma, when the oldest oceanic lithosphere was no more than about 115 Myr old. The oldest Mesozoic arc granitoids of the SSB are 187 Ma and 185 Ma, near Malayer and southeast of Sirjan, respectively, and define two inception centers roughly 1000 km apart (Fig. 2). The dataset suggests relatively slow but consistent northwesterly migration for subduction initiation from those inception centers through Jurassic time (Fig. 3). For arc granitoids of northwest Iran there are no Jurassic ages yet, and Cretaceous ages are dominant.

Subduction propagation rate

The geochronologic data clearly illustrate trench-parallel migrtation of subduction nucleation (Fig. 3), and suggest some tentative propagation rates. For the 300 km long segment to the south of Sirjan, the 38 Ma age difference from one end to the other indicates a rate of about 8 mm/yr. The 200 km long segment from Malyer to Sanandaj with a 30 Ma time difference on both ends provides a slightly slower rate of about 7 mm/yr.

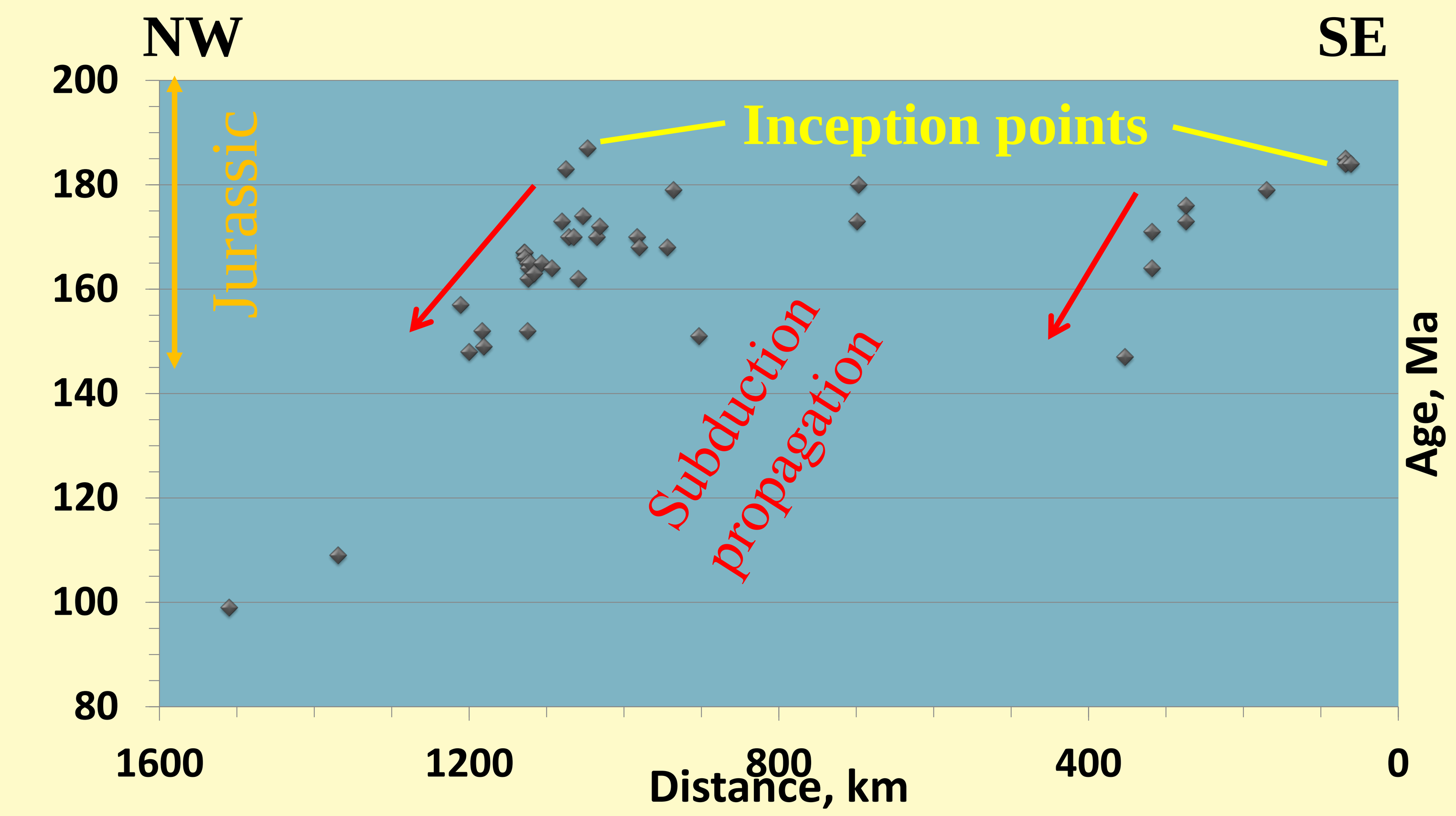

Fig. 3. Trench-parallel projection of the granite ages vs. distance from SE end of the Sanandaj-Sirjan belt. Subduction nucleation was clearly segmented and propagated in NW direction at rates of 7-8 mm/yr.

Spontaneous or induced?

From numerical modeling it appears that subduction initiation was induced in all Cenozoic examples (Gurnis et al., 2004). Induced subduction is suggested to succeed a strong compressional event (Stern, 2003). The closing of Paleo-Tethys obviously preceded initiation of subduction in the Neo-Tethys. We know that accretion of the Cimmerian part of Iran (i.e., the Alborz, Central Iran and Sanandaj-Sirjan) (Fig. 1 and 2) to Eurasia was completed by late Triassic. U-Pb zircon ages of collisional granitoids near Mashhad constrain the timing of Paleo-Tethys closure at 217 Ma to 202 Ma (Fig. 2). Whether the 15 Ma elapsed between Cimmeria-Eurasia collision and subduction initiation in the Neo-Tethys is geodynamically reasonable and supported by other evidence, the result contrasts strongly with the history of the Himalayan collision. Today, after 50 million years since the closure of the Neo-Tethys in the Himalayas, no subduction has initiated within the Indian plate.

Conclusions

Globally significant conclusions from this study include:

1) In contrast to the Cenozoic examples, a passive continental margin was a favorable tectonic setting for the nucleation of subduction, at least in the Neo-Tethys.

2) Subduction initiation and the development of arcs along most of the northern margin of the Neo-Tethys took at least 60 m.y. less time in comparison with the modern Atlantic.

3) Subduction initiation in the Neo-Tethys was segmented at a length scale of about 1000 km. This supports results from numerical modeling suggesting that spontaneous sinking of the whole oceanic lithosphere is very unlikely (Gurnis et al., 2004).

4) Subduction initiation in Neo-Tethys succeeded the Paleo-Tethys closure after only about 15 Ma, whereas 50 million years has elapsed since the closure of the Neo-Tethys in the Himalayas, and no subduction has initiated within the Indian plate.

References

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