Can an Andean margin evolve directly from a passive margin? Possible example from the Northern Neotethys

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The final phase of the Wilson cycle requires transformation of continental passive margins to trenches; however, absence of the Cenozoic examples appears to be invalidating such possibility (Stern, 2004). The paradox continues as geodynamic modeling suggests that failure of passive margins is unlikely because by the time that the oceanic lithosphere becomes dense enough to sink it is too strong to collapse (Cloetingh et al., 1989). Current geophysical models limit the possibility of subduction initiation to weak zones in intra-oceanic domains (e.g., Gurnis et al., 2004), however a recent modeling invokes crustal extension at a continental margin as the trigger mechanism for inducing subduction (Levy and Jaupart, 2012), and another study predicts subduction nucleation along the Atlantic South American passive margin (Nikolaeva et al., 2011). Despite the plethora of work on the oceanic lithosphere rheology, the weakening mechanisms, and mechanically favorable sites to form a new trench and the amount of stress required for that, no study has been conducted on how subduction propagates from an inception point; and in particular, an investigation from a geological perspective is entirely missing. As an independent approach we are investigating the spatial and temporal details of subduction nucleation and rates of trench-parallel propagation by studying along-strike age variation of calcalkaline granitoids along the Neotethyan continental margin.

Within the greater Alpine-Himalayan collision belt (Fig. 1), relatively precise information is now emerging for the development of the Sanandaj-Sirjan zone of Iran, a major segment of the Mesozoic Neotethyan continental margin (Fig. 2). The Sanandaj-Sirjan zone (Fig. 2 & 4) is well suited for investigating the timing of subduction initiation because: 1) during Cenozoic closure of the Neotethys Ocean, it was juxtaposed against the relatively straight Arabian continental margin, and has thus undergone relatively modest post-collisional tectonic distortion, as compared with the syntaxial regions on either side of it; and 2) due to the northeastward migration of the arc near the end of the Mesozoic, magmatism ceased in the Sanandaj-Sirjan zone, and much of its volcanic cover was eroded away, exposing its plutonic roots in many areas. Because of the migration, the Mesozoic arc lies in the forearc region of the younger Urumieh-Dokhtar arc of Cenozoic age (Fig. 4), and is thus not complicated by widespread overprinting of younger magmatic events.

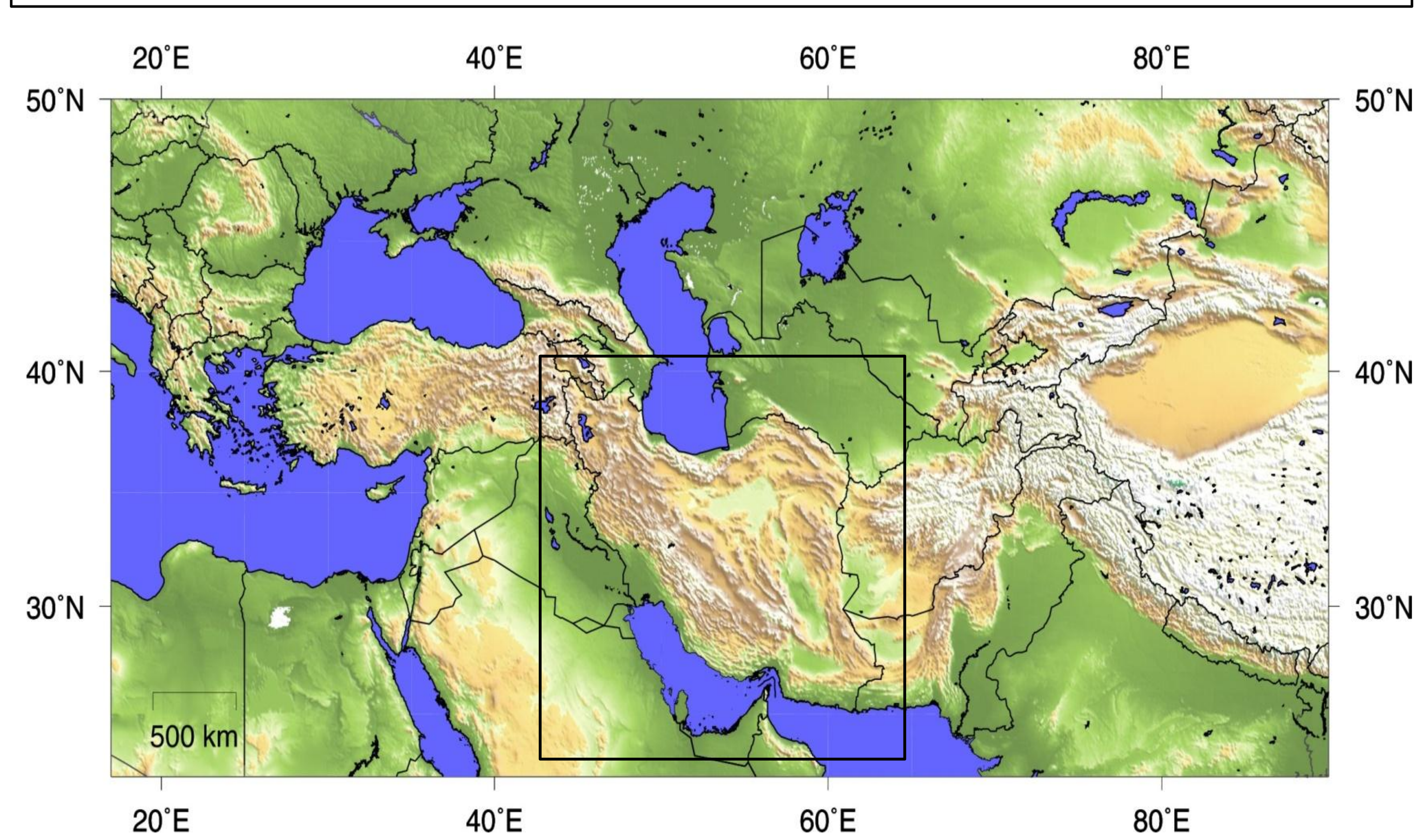

Fig. 1. The study area within the Alpine-Himalayan collision belt

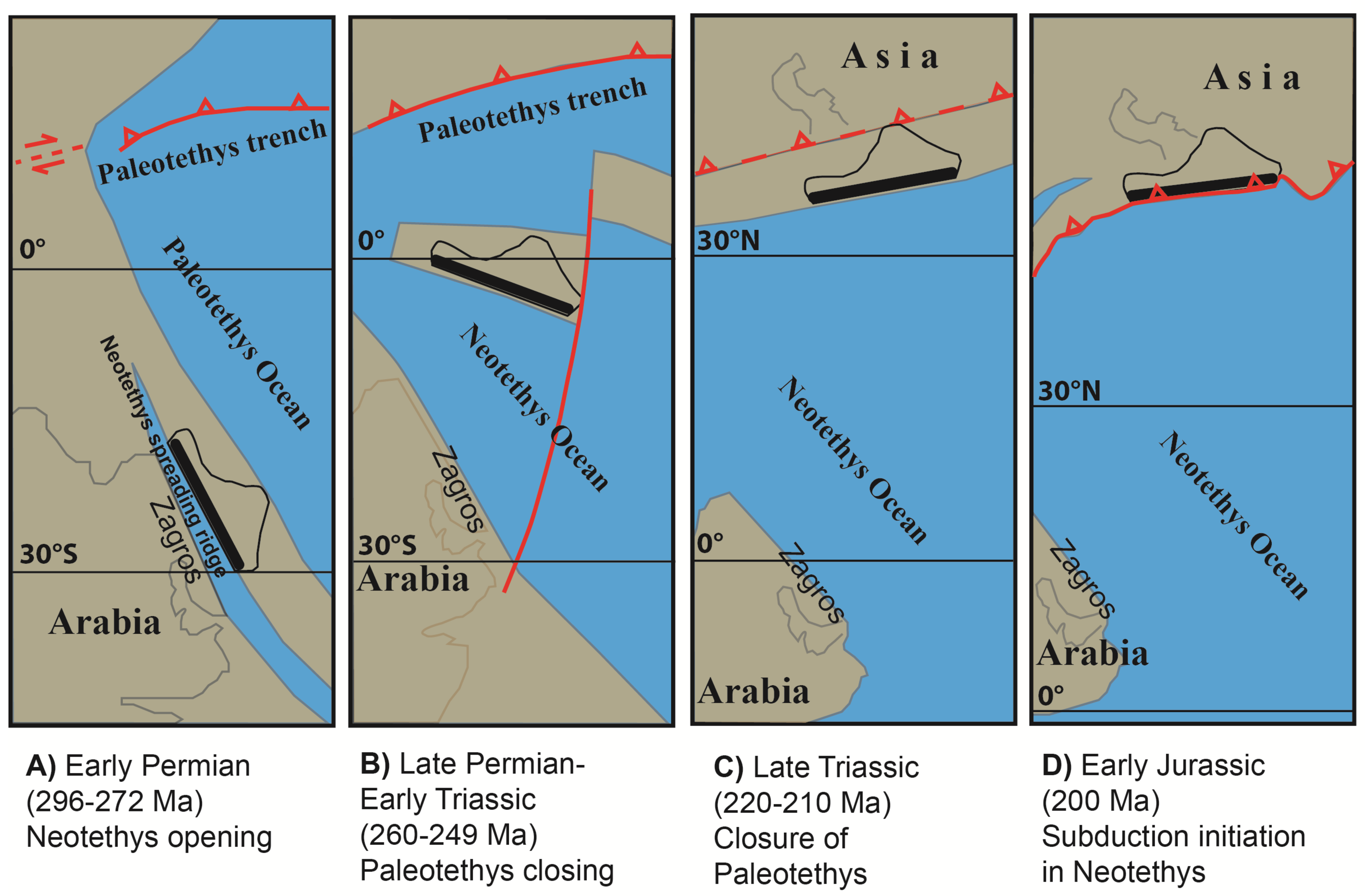

Fig. 2. Neotethys ocean evolution from opening to subduction initiation, based on paleomagnetic data from various crustal blocks (simplified after Stampfli and Borel, 2002; Muttoni et al., 2009). Position of Sanandaj-Sirjan zone indicated by heavy black line.

Neotethys sea-floor spreading began between what are now the Zagros Mountains and the Sanandaj-Sirjan zone in the Permian (Fig. 2 & 4). Paleoinclination data north of the Zagros suture record rapid northward movement of the Sanandaj-Sirjan zone and related areas from ca. 270 to 220 Ma, when it shifted from African to Eurasian paleolatitude. By the beginning of Jurassic the oceanic gap reached its maximum width of >3000 km at the meridian of Iran. Intra-oceanic subduction in this sector of the Jurassic Neotethys probably did not occur, because it would require wholesale subduction of these arcs with no trace preserved along the 1700 km length of the Zagros suture. Assuming this to be correct, then subduction initiation in the Neotethys Ocean was fundamentally different from known Cenozoic examples, which, as noted earlier, are intra-oceanic (e.g. Stern, 2004). For initiation of subduction in the Neotethys Ocean, tectonic reconstructions suggest that the northern continental margin had fully transformed into a trench by the beginning of Jurassic time (~200 Ma).

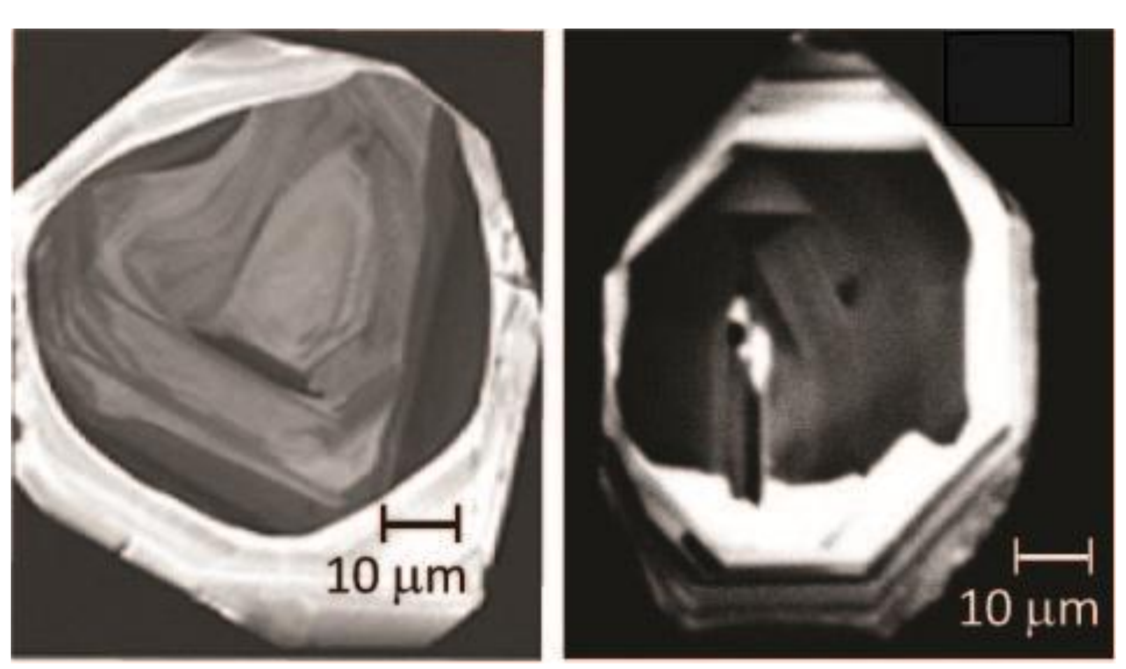

Figure 3. Two examples of zircons from the Sanandaj-Sirjan zone granitoids displaying xenocrystic cores with varying magmatic overgrowths in CL images, justifying the use of SIMS. U-Pb ages were obtained using the IMS-1270 ion microprobe at UCLA.

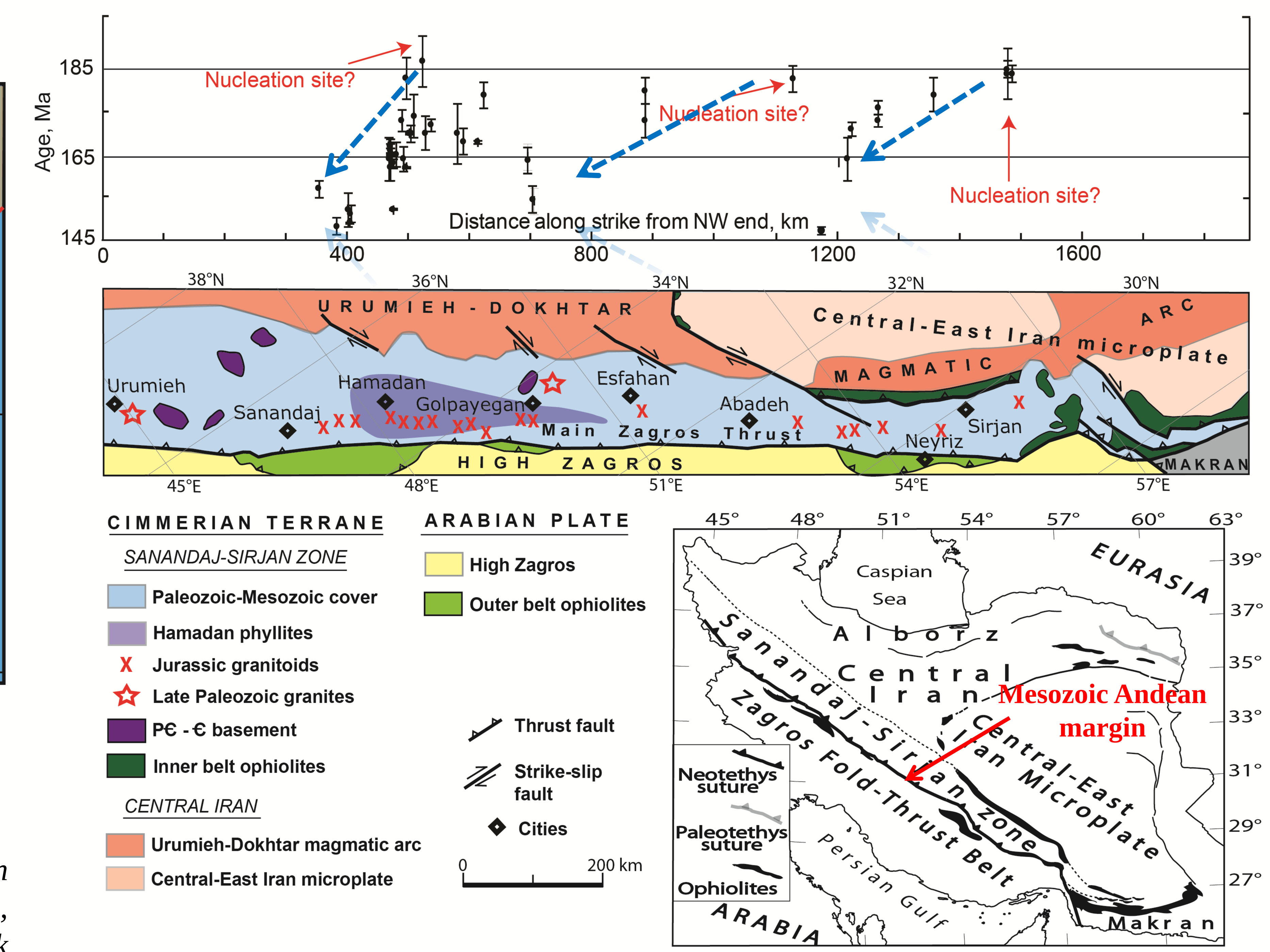

Fig. 4. The Sanandaj-Sirjan zone (heavy black line in Fig. 2) situated to the northeast of the Main Zagros Thrust (i.e., the Mesozoic-Cenozoic Andean margin) showing locations of the calcalkaline granitoids used in this study.
Top. Trench-parallel projection of the Sanandaj-Sirjan belt granitoid crystallization ages vs. distance from NW end. Subduction nucleation was clearly segmented with three inception points at ~500 km, 1000 km and ~1500 km (red arrows), and suggesting propagation in NW direction at rates of order 1 cm/yr (dashed blue arrows).

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 Neotethys.

2) Subduction initiation in the Neo-Tethys was segmented at a length scale of about 500 km and propagated in NW direction at rates of order 1 cm/yr, in contrary to the wholesale sinking of oceanic lithosphere suggested by the existing models for the Neotethyan evolution.

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

4) Valuable details about dynamics of subduction initiation can be deciphered from studying the granitoids at exposed roots of fossil arcs.