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Reconstructing plate motion paths where plate tectonics doesn't strictly apply

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The classical approach to reconstructing plate motion invokes the assumption that plates are rigid and therefore that their motions can be described as Eulerian rotations on a spherical Earth. This essentially two-dimensional, map view of plate motion is generally valid for large-scale systems, but is not practicable for small-scale tectonic systems in which plates, or significant parts thereof, deform on time scales approaching the duration of their motion. Such "unplate-like" (non-rigid) behaviour is common in systems with a weak lithosphere, for example, in Mediterranean-type settings where (micro-)plates undergo distributed deformation several tens to hundreds of km away from their boundaries.

The motion vector of such anomalous plates can be quantified by combining and comparing information from two independent sources: (1) Balanced cross sections that are arrayed across deformed zones (orogens, basins) and provide estimates of crustal shortening and/or extension. Plate motion is then derived by retrodeforming the balanced sections in a stepwise fashion from external to internal parts of mountain belts, then applying these estimates as successive retrotranslations of points on stable parts of the upper plate with respect to a chosen reference frame on the lower plate. This approach is contingent on using structural markers with tight age constraints, for example, depth-sensitive metamorphic mineral parageneses and syn-orogenic sediments with known paleogeographic provenance; (2) Geophysical images of 3D subcrustal structure, especially of the MOHO and the lithospheric mantle in the vicinity of the deformed zones. In the latter case, travel-time seismic tomography of velocity anomalies can be used to identify subducted lithospheric slabs that extend downwards from the zones of crustal shortening to the mantle transitional zone and beyond.

Synthesizing information from these two sources yields plate motion paths whose validity can be tested by the degree of consistency between crustal shortening estimates and the amount of subducted lithosphere imaged at depth. This approach has several limitations: (1) shortening values in mountain belts are usually minimum estimates due to the erosion of deformational fronts and out-of-sequence thrusting that obscure or even eliminate zones of shortening. Also, subduction may occur without accretion of material to the upper plate; (2) sedimentary ages are often loosely bracketed and only high-retentivity isotopic systems yield ages near the age of mineral formation in metamorphic rocks; (3) images of seismic velocity anomalies are highly model-dependent and the anomalies themselves may have been partly lost to thermal erosion, especially in areas that have experienced heating, for example, beneath extensional basins. Thus, only a few orogens studied so far (e.g., the circum-Mediterreanean belts) have the density of geological and geophysical data needed to constrain the translation of a sufficient number of reference points to obtain a reliable plate-motion vector. Nevertheless, this approach complements established methods for determining plate motion (plate-circuits using paleomagnetic information, ocean-floor magnetic lineaments) and provides a viable alternative where such paleomagnetic information is sparse or lacking.