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Cyclicity, episodicity, and continuity in accretionary wedge evolution: insights from geophysical imaging and physical analogue experiments

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Geophysical profiles across active convergent margins reveal different styles and locations of sediment accretion, thrust slices dipping successively steeper towards the hinterland, splay faults, and blind thrusts as well as accumulation spaces e. g. thrust top basins and larger basins formed by regional subsidence, of very variable size and position. Morphologically, the continental slope at most margins can be sub-divided in a lower, middle, and upper slope, with often the middle slope being the most shallowly inclined, suggesting segmented wedges. Beneath the forearc, a subduction channel of a few hundred meters to a few km thickness marks a layer of material transport into greater depth that also hosts the plate interface and décollement zone. The petrographical composition of accretionary wedges and subduction channels as well as related pressures and temperatures are accessible through deep drilling or sampling fossil accretionary complexes now exhumed.

The structure, lithology, and tectonic history of forearcs as identified from geophysical and geology field observations hint to parameters possibly controlling material transfer at convergent margins. Among them, sediment supply, which itself is largely controlled by climate, width of the subduction channel, and interplate frictional properties, which also exhibit control on plate coupling and therefore the seismic potential of a forearc, are suggested to be of major importance. These parameters further may undergo temporal fluctuation, e.g. when climate changes or when different material is entering the trench and therefore potentially also the subduction channel.

High resolution monitoring of material flux and the evolution of fault zone kinematics of analogue experimental wedges made of granular materials exhibiting frictional behaviour equivalent to that of upper crustal rocks shows that accretionary cycles proceed as a chain of sub-processes, i.e. the development of a thrust slice from initial failure of the incoming layer and thrust initiation, growth of the thrust slice, underthrusting and accretion of the thrust slice to the initiation of the next thrust slice. Each of these sub-processes generates a characteristic uplift pattern. As accretionary cycles take place in characteristic time periods of some ten thousands to some hundred thousands of years, the related uplift pattern may provide a key to investigate the timing of wedge evolution in the field.

The spatio-temporal activity pattern of thrusts as observed in laboratory wedges suggests a mechanic segmentation of these wedges. Critical taper analysis shows that wedge segments may be sub-critical, critical, stable, or super-critical, depending on their geometry and physical properties. Similar segmentation also seems to be important in nature, as an inner, older wedge segment e.g. may act as a dynamic backstop for more recent accretion.

Besides testing the influence of specific parameters on wedge evolution, scaled sandbox experiments also offer to consider transient boundary conditions, e.g. of material input to the wedge. Structurally and kinematically, laboratory wedges generated through episodical material input differ from wedges which have formed as a result of continuous input. Therefore, wedge structures as observed in such experimental wedges may offer a possibility to detect episodical accretion and periods of subduction erosion in natural wedges, such as at the South-Central Chilean convergent margin.