Research Note

Decoupling as an alternate model for transpression during the initial opening of the Norwegian-Greenland Sea

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Transpressive plate motions during the opening of the Norwegian-Greenland Sea were in some manner responsible for the development of Spitsbergen's Tertiary fold-and-thrust belt. A flower model has been proposed for the large-scale structural architecture of Tertiary deformation (Lowell 1972). An alternate model of decoupling, where convergent and transcurrent motions were accommodated in totally or partially separated, subparallel belts is suggested.

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Folds and thrusts that disrupt both Hecla Hoek basement rocks and the overlying late Paleozoic through Mesozoic platform cover rocks also locally deform Tertiary clastic strata (Orvin, 1934; Birkenmajer 1981). These structures are concentrated in, but not restricted to (Andresen et al. 1988), a NW trending belt along and parallel to Spitsbergen's west coast. The realization that these 'compressive' structures were coeval with and adjacent to an intracontinental, dextral transform plate boundary that linked spreading in the Arctic and Norwegian-Greenland oceanic basins suggested a transpressive setting (Harland 1969; Lowell 1972). Some 400 km of dextral displacement of Greenland past the northern Barents Shelf (including Svalbard) in the period between 60 and 37 Ma (anomalies 24–13) is indicated by the magnetic data in the relevant oceanic basins (Pitman & Talwani 1972; Myhre et al. 1982).

Hanisch (1984) argues that some of these structures are related to Late Cretaceous rifting in the North Atlantic as convergence on the opposing side of a pole of rotation. However, sedimentologic studies of the Tertiary strata (Steel et al. 1985) indicate initiation of a western source terrane in the late Paleocene/early Eocene – probably representing emergence of the transpression related crustal welt. Also, seismic profiles indicate that Tertiary structures exist underneath the west limb of the central Tertiary basin (Nøttvedt & Rasmussen 1988). These structures are probably responsible for the formation of the western limb, and clearly postdate the Paleocene strata that are so tilted (up to 20 degrees). While several different kinematic phases occurred (Birkenmajer 1981; Lepvrier & Geyssant 1985), a point we wish to make here is that at least part of the folding and thrusting did take place during Tertiary dextral motion of Svalbard past Greenland; hence the proposal of a transpressive setting for a significant portion of that history is correct.

Lowell (1972) proposed a flower geometry for the transpression-induced crustal architecture. Vertical transcurrent faults at depth bend into en echelon, shallowly-dipping thrust faults at shallower crustal levels. This architecture was based on clay models, on experience in other zones with a similar tectonic setting and on an analysis of Svalbard's Tertiary structures to the extent they were known at that time. An important aspect of Lowell's model is that the transcurrent and compressive (convergent is perhaps a better word) components are 'coupled' – they are accommodated in the same zone on adjacent and connected structures, and fault slip would be expected to be oblique. This was one of the earlier formulations of the 'flower' model. In discussions on Svalbard's Tertiary tectonics some variant of Lowell's initial model often appears (e.g. Steel et al. 1985). With this background we would like to first describe some inconsistencies with a simple application of the flower model in the particular instance of Svalbard, and then to briefly propose an alternate model that might be considered in future work.

A hallmark trait of transcurrent mobile regimes is an en echelon pattern of structures (Wilcox et al. 1973), and such a pattern is an integral part of Lowell's flower model. However, Tertiary folds in the platform cover generally have subhorizontal axes trending N25-40W. Many are within a few degrees of being parallel to the trend of the present continental margin (N32W), and by inference, to the Spitsbergen fracture zone along which dextral transcurrent motion had occurred (Maher 1984). They also show no marked preference for being consistently clockwise or counterclockwise of this direction. Prominant folds in Oscar II Land have stepped axial surface traces consistent with dextral transcurrence (although along a more northerly trending zone). However, a slight, but consistent southerly plunge of several fault-propagation folds could also explain this pattern. Thrust faults in Wedel Jarlsberg Land overlap in a map pattern that could be consistent with sinistral and not dextral motion (Dallmann pers. comm. 1988). Again, other explanations, such as that of lateral ramps, do not require a sinistral transcurrent component of motion.

Several wrench faults of probably Tertiary age have orientations inconsistent with those of the standard Wilcox et al. (1973) model for transcurrent-related en echelon patterns. The Orvindalen fault in Wedel Jarlsberg Land (Flood et al. 1971) is dextral, but is also at a high oblique angle to the mobile zone overall (in a position expected of the antithetic, sinistral secondary wrench fault). It would perhaps be more consistent with sinistral transcurrence. Other highly oblique faults may be more easily explained as lateral ramps or tear faults. A further complicating factor is that many minor oblique wrench faults may be of younger transtension age and not coeval with folding and thrusting.

Two explanations for an altered en echelon pattern during transpression suffer difficulties in Spitsbergen's case. Continued strike-slip motion can rotate earlier formed folds and thrusts into sub-parallelism with the mobile zone (although consistently to one side). However, neither the penetrative simple shear, nor a system of well developed wrench faults necessary to accomplish such rotation is evident. A second explanation is that an additional convergent component should change the initial orientation of en echelon structures. Folds and thrusts would be expected at a smaller angle to the mobile zone boundaries. The larger the convergent-transcurrent plate motion ratio the smaller the angle between the two. In Spitsbergen's case the transcurrent component was by far the dominant one, possibly two orders of magnitude larger than the shortening component. A distinct angularity should therefore, arguably, still be in evidence.

Major Tertiary, synthetic, dextral wrench faults in Svalbard are not documented. One candidate is the Forlandsundet graben eastern border fault, but the age of movement on this fault may postdate transpression since the fault truncates fold structures in adjacent Carboniferous strata (Ohta pers. comm. 1988). In Wedel Jarlsberg Land careful mapping in basement rocks west of the zone of platform cover involvement (Hauser 1982; Bjørnerud 1987) shows a general continuity of structure. While Tertiary folds and thrusts may exist here, wrench faults with more than 1–2 km offset are unlikely in this area. Yet, in Lowell's model folds and related faults accommodate a predominate strike-slip component and a minor convergent component.

A thin-skinned contractional nature of Svalbard's Tertiary deformation has been made even more apparent by recent work (Nøttvedt & Rasmussen 1988). Andresen et al. (1988) show that structures along the Billefjorden and Lomfjorden fault zones are Tertiary in age and consistent with ENE–WSW stratal shortening. Classic concepts from other contractional foreland belts, such as fault-propagation and fault-bend folds, a ramp and flat geometry of an ascending basal thrust surface and forward propagation of thrusting, work very well in understanding the Tertiary structures.

While Lowell's (1972) discussion focuses attention on critical aspects of Tertiary deformation we believe the flower model should be either substantially revised or replaced. Structures that accommodated a significant amount of the required transcurrent motion are not demonstrated, while a minimum of some 6 km of stratal shortening perpendicular to the general trend of the mobile belt can be demonstrated (Gudlaugsson et al. 1987; Maher unpublished). The above discrepancies suggest an alternate model of decoupled transpression where the transcurrent and convergent (compressional) components develop coevally in parallel belts, the latter of which is preserved on Spitsbergen, and the former of which is either submerged along the continental margin and/or in NE Greenland (Maher & Craddock 1983). Taken together, Greenland and Svalbard Tertiary structures form a zone some 200+ km wide (ignoring subsequent extension associated with passive margin development). Decoupling would not have to be complete; i.e. a belt with predominantly transcurrent structures on one side and predominantly compressive structures on the other, with a mixed zone in between, can be envisioned. The mobile zone could then be thought of as a deforming 'microplate' or plate slivers between two more rigid continental masses. The Brøggerhalvøya area, at the N end of the exposed portion of the Tertiary fold-and-thrust belt, represents a distinct anomaly in structural trend and transport direction (Challinor 1967). It may represent the wedge shaped end of such a sliver; i.e. transpression was decoupled to the south and coupled to the north of this area.

Fitch (1972) initially proposed decoupling of oblique plate motion across the Indonesia trench-arc complex. The convergent component was accommodated along the Benioff zone and a large fault along the axis of arc volcanism accommodated the transcurrent component. Beck (1983, 1986) discusses a mechanical model for when decoupling might occur and concludes it may be fairly common. He applies the model to the U.S. western Cordillera and proposes that post-docking exotic terrane transport may be due to decoupling of oblique subduction.

In conclusion, the predominantly convergent, thin-skinned nature of Spitsbergen's Tertiary structures suggests decoupling of the transcurrent and convergent plate motions during early phases of the opening of the Norwegian-Greenland and Arctic oceanic basins. Decoupling has been proposed for other tectonic settings; it has a formulated mechanical-theoretical basis, and should be considered for Spitsbergen. Documentation of significant coeval transcurrent motion on specific structures will be crucial in testing whether decoupling occurred, and if so, to what degree the components were decoupled. The proposal of decoupling has significant implications for exploration, for detailed plate reconstructions and for understanding the relation between Svalbard's and Greenland's Tertiary structures.

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