RESEARCH FOCUS

Cenozoic tectonic processes along the southern Alaska convergent margin

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The southern margin of Alaska is arguably the most tectonically complex part of the plate boundary that defines western North America. The tectonic configuration of this plate boundary is defined by an active subduction zone, two active volcanic arcs (the Aleutian and Wrangell arcs), some of the largest strike-slip fault systems on Earth (the Denali and Tintina faults), and an allochthonous crustal block, the Yakutat microplate, that is currently colliding in southeastern Alaska (Fig. 1; Plafker and Berg, 1994). In addition, large-magnitude earthquakes and extremely high topography mark this area as a dynamic, actively deforming continental margin.

The most accepted model for the tectonic development of southern Alaska is based on the "terrane tectonics" paradigm. The generalized framework of this model is that distinct crustal blocks (i.e., oceanic plateaus, volcanic arcs, rifted continental margins) are passively transported with subducting oceanic crust. As the terrane follows the oceanic crust into the subduction zone, the more buoyant terrane jams the subduction zone and forces the subduction zone to step outboard of the "jammed" segment, and thus the terrane becomes accreted or welded to the continental margin (i.e., the upper plate of the subduction zone). The final products of this process are crustal-scale blocks (i.e., terranes) that are fault bounded and that have no "geologic" affinity to adjacent crustal blocks along the continental margin. In the case of the northern Cordillera, the now "accreted" terranes are tectonically transported northward as rigid blocks by margin-parallel strike-slip faults. An important point for this model is that the major strike-slip faults along the continental margin are the driving force for northward translation of terranes. The terrane conceptual framework has been applied to tectonic settings around the globe, but southern Alaska was the centerpiece in the formation of this model (Jones et al., 1977; Coney et al., 1980; Jones et al., 1982; Coney and Jones, 1985).

In contrast to the terrane model, Redfield et al. (2007; p. 1039 in this issue) present an "extrusion" model to explain the tectonic processes along the southern margin of Alaska. In this new model, crustal blocks or terranes do not as much collide with the continental margin as they are "swept" northward by crustal flow along the continental margin, and are eventually extruded into the free face defined by the Aleutian subduction zone. This flux of crustal material flowing between "continental" North America and the Pacific plate is referred to as the North Pacific Rim orogenic stream (NPRS) by Redfield et al. In this extrusion model, margin-parallel strike-slip faults are not the primary driving mechanism for northward transport; rather, the major strike-slip faults more or less serve as the channel margins of the crustal flow, possibly analogous to levees along a fluvial channel.

Redfield et al.'s provocative model for the tectonic development of the northern Cordillera needs to be tested by future geophysical and geological studies. There are several testable aspects to the new model, and we explore here tests of the model as well as strong and weak aspects of the model based on the limited available data.

(1) The extrusion model is plausible based on recent global positioning system (GPS) observations (Fig. 1; Fletcher et al., 2001; Mazzotti et al., 2003; Fletcher and Freymueller, 2003; Freymueller et al., 2000; Avé Lallemant and Oldow, 2000; Sauber et al., 2006; Fournier and Freymueller, 2007) and kinematic studies that utilize GPS and Quaternary fault-slip data (Fig. 1; Flesch et al., 2007). The initial results from these studies are suggestive of extrusion of southern Alaska westward into the

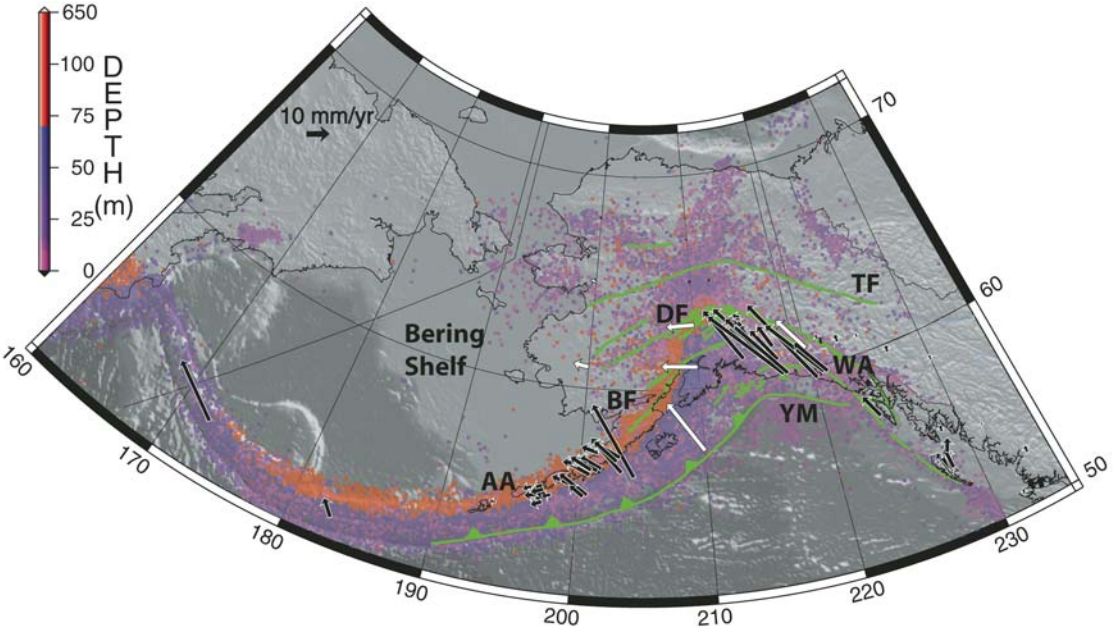

Figure 1. Southern Alaskan convergent margin. Green line segments denote major faults. Colored dots show locations of earthquakes $>M_w = 3$ from the Alaska Earthquake Information Center. Black vectors represent GPS observations from Sauber et al. (1997), Mazzotti et al. (2003), Fournier and Freymueller (2007), Fletcher and Freymueller (2003), and Avé Lallemant and Oldow (2000); white vectors show kinematic model velocities from Flesch et al. (2007). AA—Aleutian Arc; BF—Bruin Bay fault; TF—Tintina fault; DF—Denali fault; WR—Wrangell Arc; YM—Yakutat microplate.

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Aleutian subduction zone and Bering Sea area. An obvious weak link in these types of studies is the lack of GPS data from interior southwestern Alaska (Fig. 1).

(2) An important test of the extrusion model is the record of seismicity in western Alaska and the Bering Sea. If this process is occurring, there should be a clear record in the seismicity data. To our knowledge, the available data do not provide an unambiguous answer to this question. The available data (Fig. 1) do not clearly define zones of seismicity that might delineate areas of crustal flow. In fact, as shown in Figure 1, much of interior southwestern Alaska and the Bering Sea lack seismicity. Note, however, that Figure 1 shows some zones of focused seismicity in northwestern Alaska. Several workers have argued that northwestern Alaska is being extruded westward by a series of strike-slip faults (e.g., Dumitru et al., 1995) and/or by clockwise block rotation (Mackey et al., 1997). Future studies of the seismicity of all of western Alaska will be critical for evaluating tectonic models. The interpretation that the northern part of the Bering Sea is undergoing northeast-southwest extension (Dumitru et al., 1995; Mackey et al., 1997) will be a critical piece in the puzzle.

(3) Another important test of the extrusion model is the acquisition of geologic data to evaluate crustal flow in the Bering Sea area. From our perspective, a major question is why is the Beringian margin (the western boundary of the Bering Shelf shown in Figure 1) relatively undeformed? If crustal flow and related strike-slip faults required by the extrusion model are important in the tectonic framework of the Bering Sea, one would expect this older, mainly Mesozoic feature to be displaced by Cenozoic southwestward extrusion. Carefully collected marine geophysical and geological data sets will be needed to examine this apparent discrepancy in the extrusion model. Following the same line of reasoning, an important study would be to determine if the Cenozoic strata in the subsurface of the Bering Sea contain a record of active extrusion.

(4) An additional required component needed to understand the role of extrusion is the Neogene displacement record of the onshore parts of the Denali, Bruin Bay, and Tintina fault systems in western Alaska (Fig. 1). The extrusion model would predict that these are active fault systems. Unfortunately, due to their remote setting, very few studies have carefully evaluated Neogene displacement and paleoseismicity for these fault systems.

(5) Most of the previous points discuss issues pertaining to the northern termination of the NPRS (i.e., extrusion in the Bering Sea). An equally important question is what are the implications of the NPRS of Redfield et al. for the southern termination of this proposed feature? Does the NPRS, for example, link to Basin and Range extension in the southwestern U.S.? It has been shown that the opening of the Basin and Range province is partially driven by the northwestward motion of the Pacific plate, and that this boundary condition is important along the entire length of western North America (Flesch et al., 2007; Humphreys and Coblentz, 2007). Therefore, the proposed Alaska extrusion could be the end product of a Pacific plate "conveyer belt" system that guides North American lithosphere northward along the plate boundary, depositing it in southwestern Alaska.

(6) It is also important to consider the effect of flow beneath the Alaskan lithosphere, either from deeper mantle density buoyancies or from small-scale convection cells associated with the subduction of the Pacific plate. A global study of mantle convection and lithospheric stress (Lithgow-Bertelloni and Guynn, 2004) produces tractions and deviatoric stress consistent with the extrusion hypothesis of Redfield et al.

A useful outcome of re-evaluating the tectonic processes that are responsible for forming the convergent margin of southern Alaska will be to consider the northern Cordillera as a system of diffusively deforming crust. Traditionally, most studies of orogenic zones tend to separate discrete crustal elements such as subduction zones, forearc basins, strike-slip faults, batholiths, foreland basins, etc., and to treat these separate entities as rigid blocks. This type of approach has proven useful, but tends to de-emphasize the role of non-rigid behavior in an internally deforming orogenic belt, as well as the role of flow in the lower crust and upper mantle. From our perspective, future studies that integrate geological, geophysical, and modeling tools will be required for a better understanding of tectonic processes along convergent plate boundaries.

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