The Timing of Aleutian Arc Inception and Nascent Magmatic Evolution: Current Status and Future Prospects

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The Alaska/Aleutian subduction zone was chosen as the highest priority Primary site for Subduction Cycles and Deformation (SCD) research because it is the most seismically and volcanically active region in North America and opportunities for new discoveries abound. Moreover, several unique characteristics of the Aleutian Arc prompt the testing of fundamental hypotheses. For example, the origin of large, systematic variations in fault-slip behavior and magma composition can be investigated along-strike, and the lack of back-arc extension and longitudinal intra-arc rifting that produces remnant arcs means that the entire record of arc growth via magmatic additions is mostly preserved. The latter makes it possible to tightly link the composition and volume of plutonic, extrusive, and metamorphic rocks to seismic measurements of crustal structure (Holbrook et al., 1999; Shillington et al., 2004) and time scales of crustal growth (Kay and Kay, 1985; Jicha et al., 2006).

Among the key questions to be addressed through SCD research are: *What are the physical and chemical conditions that control the development of subduction zones, including subduction initiation and the evolution of mature arc systems?* and, *What are the geochemical products of subduction zones and how do these influence the formation of new continental crust?* Perhaps the best-studied oceanic case—the Izu Bonin-Marianas (IBM) system—reveals not only the timing (Ishizuka et al., 2011), but also the subsequent compositional evolution of magmatism (Reagan et al., 2008, 2010) associated with subduction initiation. These and other studies of the IBM system provide a model and hypotheses against which data from the Aleutian Arc can be compared. However, our understanding of how subduction initiated along the Aleutian Arc and how the initiation process influenced the course of mantle wedge evolution, magma generation, crust formation, and seismicity remains clouded, due in large part to the scarcity of data that bear on the ages and compositions of the earliest arc rocks.

Several advances of the past decade, including new geochronologic results, novel tectonic models, and forthcoming results from international expeditions to the adjacent fossil subduction zones of the Bowers and Shirshov Ridges (Fig. 1; Portnyagin et al., 2011; Kawabata et al., in press) make now the appropriate time to begin to answer the question: ***How did subduction initiate beneath the Aleutian arc, and how did this influence the evolution of its magmagenetic systems and seismogenic zones?*** First, recent $^{40}Ar/^{39}Ar$ dating and paleomagnetic studies have revealed that: between 81 and 47 Ma the Emperor seamount chain reflects southward motion of the Hawaiian mantle plume, the Hawaii-Emperor bend formed at 47 Ma, after which the Hawaiian seamounts reflect northwestward motion of the Pacific plate over a relatively fixed mantle plume (Fig. 1; Sharp and Clague, 2006; Tarduno, 2007). These findings do not exclude a change in plate motion associated with the bend itself, but are consistent with a several million year period between about 50 and 45 Ma for any change in plate motion to have occurred (Norton, 1995; Tarduno, 2007; Sharp and Clague, 2006). Second, $^{40}Ar/^{39}Ar$ and U-Pb dating of basaltic lava flows and underlying gabbro in

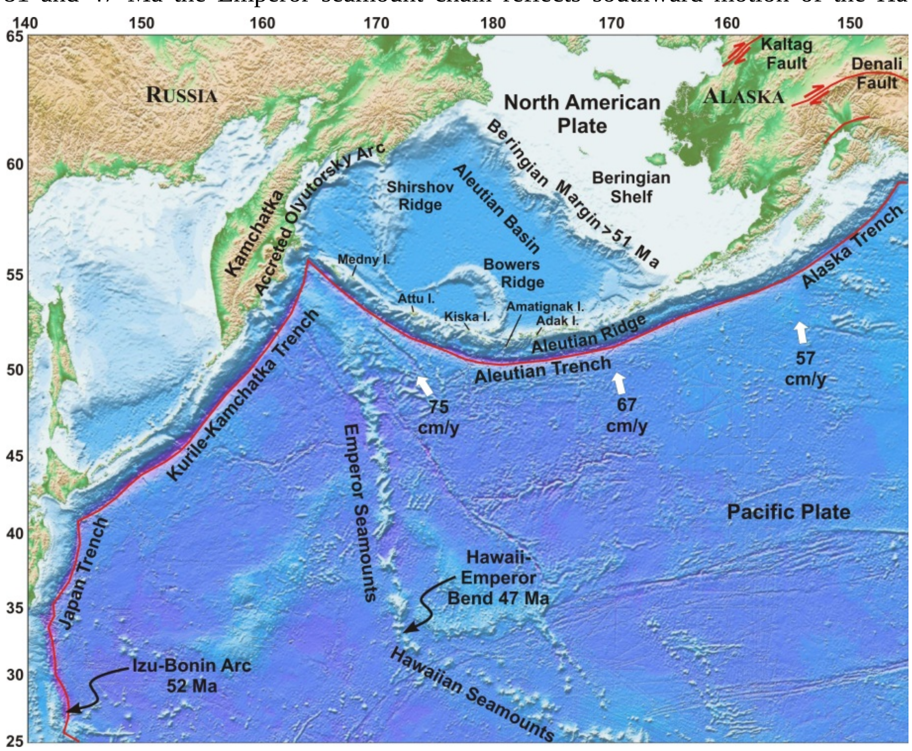

Figure 1. Physiographic and tectonic map of the Aleutian Arc relative to other major features of the north Pacific.

the IBM forearc indicate that the initiation of subduction in the western Pacific took place at 51-52 Ma (Ishizuka et al., 2011), about 4 myr before the Hawaii-Emperor bend formed (Fig. 1). Third, the inception and evolution of the Aleutian Arc may be understood in the framework of new tectonic models, including one that combines elements of subduction zone “obstruction” along the Olyutorsky (accreted) margin along the Kamchatka Peninsula, and continental margin “extrusion” of crustal blocks westward out of Alaska along major strike slip faults (Scholl, 2007; Fig. 1). Obtaining new geochronologic and geochemical information is crucial to linking the initiation of the Aleutian Arc temporally and dynamically to these discoveries and to testing current tectonic models.

Geochronologic data that constrain the inception and earliest evolution of the Aleutian Arc are few in number and several decades old. Only 32 $^{40}Ar/^{39}Ar$ ages have been obtained in the last decade from Aleutian rocks that are Miocene or older. The oldest reliably-dated rocks currently known to have formed in the Aleutian Arc are an andesitic lava dredged from 3000 m depth in Murray Canyon (Jicha et al., 2006) and a primitive basaltic lava that crops out on Medny Island in the Komandorsky Islands, both of which are 46 Ma (Layer et al., 2007; Minyuk and Stone, 2009; Figs. 1 & 2). The only U-Pb data in the Aleutian Arc is the ~30 Ma age of apatite in diorite on Umnak Island (McLean and Hein, 1984; Fig. 2).

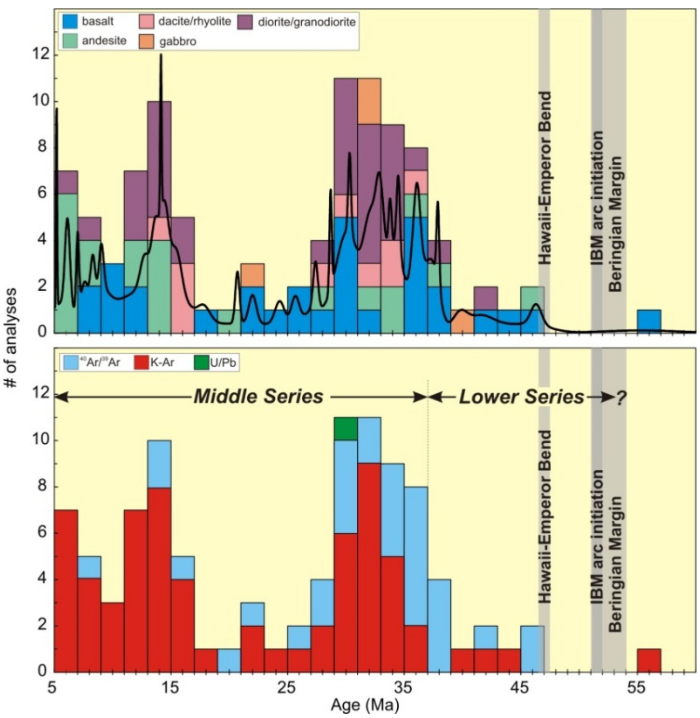

Figure 2. Histograms of published geochronologic data >5 Ma for Aleutian Arc west of 164° W. Each 2 Ma increment is subdivided by rock type (top) and method (bottom). Ages of Hawaii-Emperor Bend (47 Ma), IBM arc initiation (51-52 Ma), and Beringian margin magmatism (51-54 Ma) from Tarduno (2007), Ishizuka et al. (2011), and Davis et al. (1989), respectively. Solid black line is a probability density function that weights each age determination according to its uncertainty. Data sources available from authors.

The timing of Aleutian Arc inception and subsequent compositional evolution through the initial stages of arc growth are poorly known. Early estimates of Aleutian Arc inception varied from 70 to 40 Ma (Grow and Atwater, 1970; Cooper et al., 1976; Marlow et al., 1973), but were based on little or no geochronologic data. K-Ar, $^{40}Ar/^{39}Ar$ ages and one U-Pb age from subaerially exposed granodiorites and calc-alkaline arc lavas dredged from the Beringian margin (Davis et al., 1989; Fig. 1) range from 51-54 Ma. However, the relationship between Beringian arc magmatism and the Aleutian Arc remains unclear. $^{40}Ar/^{39}Ar$ ages of ~46 Ma from andesite in Murray Canyon (Jicha et al., 2006) and a basalt from Medny Island (Layer et al., 2007) provide a cursory minimum age for the initiation of subduction beneath the Aleutian Ridge. These ages closely match the oldest K-Ar dated lava reported by Tsvetkov (1991) from the Komandorsky Islands farther to the west. The tectonic model of Scholl (2007) proposes that initiation of the Aleutian Arc produced these middle Eocene magmatic rocks earlier than 46 Ma, but not before ~50 Ma. Because the start-up phase of arc growth is a voluminous outpouring across a broad front, it can be surmised that middle Eocene basement rock recovered from the crest of the Aleutian Ridge is not going to be significantly younger than the massif deeply buried beneath the ridge’s forearc slopes, or the missing seaward sector of the arc massif removed by subduction erosion and transcurrent faulting (Scholl, 2007).

Determining precisely how and when the Aleutian Arc began to form is one of the key pieces of the plate tectonic puzzle of the Bering Sea–Alaska–North Pacific region. The acquisition of a modest number of $^{40}Ar/^{39}Ar$ and U-Pb zircon ages from previously mapped subaerial and submarine plutonic and volcanic rocks – coupled with new trace element and Sr-Nd-Pb isotope data – could rapidly revolutionize our understanding of nascent Aleutian Arc processes and link them to other circum-Pacific phenomena. We draw attention to several islands in Figure 3 that are prime targets because they: (1) are situated in the forearc or extend significantly south of the modern volcanic axis, (2) have been partially mapped, and (3) have published geochronologic data indicating Eocene-Oligocene magmatism. Results from this type of study could fuel a more comprehensive effort by a wider group of GeoPRISMS investigators in the near future to understand Aleutian Arc initiation by delineating specific places along the forearc that hold the greatest potential for exploration using submersible ROVs, dredging, and geophysics.

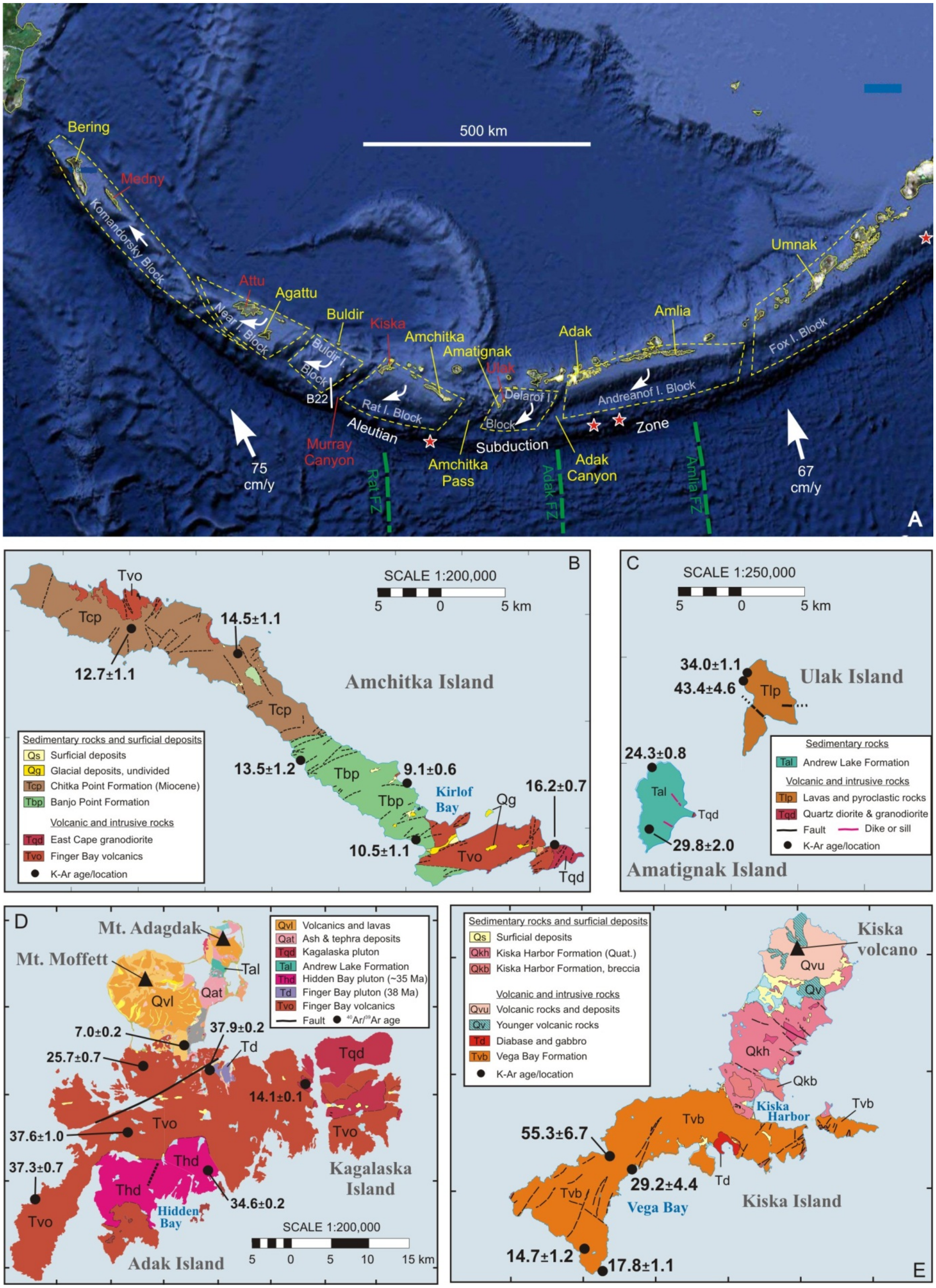

Figure 3. **A**) Google Earth map of the Aleutian Arc. Islands and dredge locations which contain lavas >40 Ma in red font. Dashed yellow lines outline clockwise-rotating crustal blocks. From west to east, the red stars correspond to the following great earthquakes of the last 65 years: 1. 1965 Mw=8.7 Rat Island; 2. 1957 Mw 8.7 Andreanof Islands; 1986 Mw 8.0 Andreanof; 1946 Mw 8.6 Unimak island. Geologic maps of: **B**) Amchitka, **C**) Amatignak and Ulak, **D**) Adak, and **E**) Kiska Islands, modified from Wilson et al. (2006). Sample locations for published K-Ar ages are shown as black dots.

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