New geochemical and geochronological insights on forearc magmatism across the Sanak-Baranof belt, Southern Alaska: A tale of two belts

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ABSTRACT

The Sanak-Baranof belt (SBB) includes a series of near-trench plutons that intrude the outboard Chugach-Prince William (CPW) terrane over ~2200 km along the southern Alaskan (AK) margin. We present novel petrological, geochronological and geochemical data for co-magmatic microgranitoid enclaves and granitoid rocks from the Crawfish Inlet (~53-47 Ma) and Krestof Island (~52 Ma) plutons on Baranof and Krestof Islands, the Mt. Stamy (~51.4 Ma) and Mt. Draper (~54-53 Ma) plutons and associated mafic rocks intruding the Boundary block at Nunatak Fiord near Yakutat, AK, as well as select SBB intrusive bodies west of Yakutat. These data suggest that intrusion of the SBB plutons is actually a tale of two distinct belts – one pre- and another post-55 Ma – the latter of which corresponds to a dynamic period of plate reorganization along the Paleocene continental margin. Western SBB plutons young systematically from west to east (63 to 56 Ma) and Hf isotope analyses of magmatic zircon

change systematically with age, becoming increasingly evolved towards the east (i.e., ε_{Hf} = 9.3±0.7 for Sanak Island versus ε_{Hf} = 5.1±0.5 for Hive Island in Resurrection Bay). Eastern SBB plutons have crystallization ages ranging from 55 to 47 Ma, with no clear age progression along the margin. Furthermore, the Hf isotope ratios of eastern SBB rocks also vary systematically with age but in reverse: the oldest phases have ε_{Hf} = +4.7±0.7 (more evolved) and the youngest phases have ε_{Hf} = +13.7±0.7 (more primitive). We propose that these findings indicate distinct modes of origin and emplacement histories for the western and eastern SBB, and that the petrogenesis of eastern SBB suites post-55 Ma is most consistent with either: (1) an increasing mantle endmember component that may have been supplemented by interactions between the more southerly paleo-CPW terrane and ancestral Yellowstone hot spot; and/or (2) protracted transtensional activity in the ancient forearc during plate reorganization, which facilitated extensive decompressive melting and/or partial melting of mafic rocks interbedded with younger CPW sediments that collectively fed eastern SBB magmas.

INTRODUCTION

Over the past ~200 Ma, the southern Alaskan (AK) continental framework has been incrementally constructed and modified by a complex history of accretion, strike-slip faulting, metamorphism, and plutonism (Plafker et al., 1994; Garver and Davidson, 2015; Davidson and Garver, 2017). Accretion of the outboard Chugach-Prince William (CPW) terrane to the Wrangellia composite terrane (Wrangellia, Peninsular, and Alexander terranes) resulted in one of the largest accretionary complexes in the world (Fig. 1), with the majority of its growth occurring during Late Cretaceous and early Paleocene time (Plafker, 1990; Plafker et al., 1994). This intensive accretionary period was concomitant with major dextral strike-slip translational displacement of the outboard CPW and Yakutat terranes along the ~2000 km long Border

Ranges Fault system (MacKevett and Plafker, 1974; Pavlis et al., 1988, 2003; Little and Naeser, 1989; Pavlis and Roeske, 2007; Fig. 1), further complicating paleo-reconstructions. Resolving the dynamics of this accretionary episode, and constraining the paleo locations of the outboard CPW and Yakutat terranes in particular, remain outstanding questions in Cordilleran tectonics.

There are two competing hypotheses concerning the paleo-position and formation of the CPW terrane along the Cordilleran margin. The first, termed the 'Resurrection plate hypothesis,' posits that the CPW formed more or less *in situ* (Haeussler et al., 2003). In this scenario, the series of biotite tonalite, granodiorite, and granite plutons that intrude the CPW terrane over ~2200 km are reconciled by the eastward migration of the Kula-Resurrection spreading ridge, associated with the long-since subducted Resurrection plate (Haeussler et al., 2003). In the alternative 'Baranof-Leech River' hypothesis, the CPW terrane formed far to the south, making the schist and turbidites of the CPW (Davidson and Garver, 2017) terrane at Baranof Island contiguous with the nearly identical Leech River schist exposed on southern Vancouver Island (Fig. 1). Under this scenario, the anomalous near-trench plutons that intrude the CPW terrane were generated by the progressive northward transport of the CPW terrane above a fixed site of Kula-Farallon ridge subduction positioned at ~48 – 49 °N paleolatitude (Cowan, 1982, 2003).

Explaining the presence and emplacement history of this suite of unusual near-trench plutons (Figs. 1 and 2) is central to any tectonic reconstruction of the Cordilleran margin. Karig et al. (1976) were the first to suggest that this series of granitoid plutons may have been formed by heating of the wedge at the triple junction between the Kula-Farallon-North American plates (Marshak and Karig, 1977). The full ~2200 km extent of the belt was subsequently articulated by Hudson et al. (1977), who alternatively suggested that the melts were caused by anatexis of a thickened prism of accreted sediments. Hudson and colleagues at the USGS were the first to name this discontinuous series of plutons the Sanak-Baranof belt (SBB) (Hudson, 1979; Hudson et al., 1979). While the name coined by Hudson et al. (1979) stuck, most subsequent studies have instead supported the ridge subduction hypothesis of Karig et al. (1976) to explain the origin of the SBB (Hill et al., 1981; Moore et al., 1983; Barker et al., 1992; Bradley et al., 1993, 2000, 2003; Sisson and Pavlis, 1993; Haeussler et al., 1995; Pavlis and Sisson, 1995; Harris et al., 1996; Lytwyn et al., 2000; Sisson et al., 2003a, 2003b; Ayuso et al., 2009; Farris, 2010). Despite broad consensus for the ridge subduction and 'slab window' model (see Thorkelson and Taylor, 1989; Thorkelson, 1996) for the tectonic mechanism that formed the SBB, these petrogenetic studies disagree widely on the location of the CPW terrane at the time of SBB magmatism.

Two important and influential paleomagnetic data sets emerged that bore directly on the paleo-position of the CPW terrane and, by implication, the SBB plutons intruding it. Plumley et al. (1983) suggested that pillow basalts of the CPW on Kodiak Island experienced 25±7° poleward displacement, while Bol et al. (1992) suggested pillows and sheeted dikes of the Prince William terrane exposed on the Resurrection Peninsula (Kenai Peninsula) had experienced 13±9° poleward displacement. Thus, the ensuing ridge-trench intersection models that considered the paleomagnetic data suggested that SBB plutonism occurred well to the south of Alaska, followed by coastwise translation of the CPW and SBB following pluton emplacement (e.g., Bradley et al., 1993; Sisson and Pavlis, 1993; Haeussler et al., 1995; Pavlis and Sisson, 1995). This ridge-subduction and translation model was upended by Haeussler et al. (2003), who suggested more-or-less in situ SBB plutonism was driven by the hypothetical Resurrection plate – now completely subducted – but this hypothesis requires rejection of the paleomagnetic data (see appendix in Haeussler et al., 2003).

Regardless of which hypothesis is favored for the CPW terrane, there are several critical assumptions embedded within essentially all of the previous studies considering the SBB and its tectonic implications. These include that: (1) the SBB plutons are time-transgressive and young systematically (i.e., linearly, see Farris and Paterson, 2009) towards the east; (2) the same tectonic mechanism (e.g., crustal anatexis in a thickened accretionary wedge, and/or ridge-trench intersection and slab window development) was responsible for generating all SBB plutons; and (3) through these lines of reasoning, the SBB encompasses a coherent set of petrogenetically related rocks across the ~2200 km belt, but is distinct from other near-trench intrusive rocks farther to the south (e.g., on southern Vancouver Island). These assumptions persist despite the near-complete absence of geochronological and/or geochemical data available for SBB intrusive rocks spanning >400 km between the Boundary block at Nunatak Fiord near Yakutat, AK and Baranof Island at the purported easternmost periphery of the belt. Furthermore, several of the early geochemical studies of SBB rocks that form the basis for our petrogenetic understanding of the belt relied heavily on the modeling of bulk-rock trace elemental compositions – a technique that has recently been called into question. Thus, an effort to update and expand our petrogenetic understanding of the easternmost SBB intrusive rocks and re-assess these foundational assumptions about the entire SBB in light of a more comprehensive and robust belt-wide geochronological and geochemical analysis is warranted.

Here we present new petrological, geochemical and geochronological data for magmatic enclaves and their host granitoids from the Crawfish Inlet and Krestof Island plutons on Baranof and Krestof Islands near Sitka, Alaska. We present this detailed characterization of Crawfish Inlet and Krestof Island intrusive rocks alongside a comparable dataset for the Mt. Stamy and Mt. Draper plutons and affiliated mafic rocks intruding the Boundary block at Nunatak Fiord near Yakutat, Alaska. We also report new concordant U-Pb ages and ε_{Hf} analyses of magmatic zircons from select SBB intrusive rocks west of Yakutat, AK to facilitate comparisons on a belt-wide scale, as well as new ε_{Hf} measurements on detrital zircons collected from the CPW sedimentary materials that host the SBB plutons across the belt. Our findings suggest that the SBB records two distinct magmatic periods: one pre- and one post-55 Ma.

REGIONAL GEOLOGIC SETTING

The Chugach-Prince William terrane (CPW) and outboard Yakutat microplate make up the extensive and complexly deformed Mesozoic to early Cenozoic accreted terranes that are now situated along the southern margin of Alaska (Figs. 1 and 2; Plafker et al., 1989, 1994; Bradley et al., 2003; Garver and Davidson, 2015). The CPW composite terrane encompasses both the Chugach and Prince William terranes and is composed largely (~90%) of Campanian-Maastrichtian to Eocene turbidites and oceanic metabasalts (Plafker et al., 1989, 1994; Farmer et al., 1993; Garver and Davidson, 2015; Davidson and Garver, 2017). The turbidites[1] of the Chugach terrane (mainly Campanian-Maastrichtian in age) stretch roughly 2200 km from Sanak Island in the west to Baranof Island in the east (Fig. 1; Plafker et al., 1994; Bradley et al., 2003; Gasser et al., 2012). The Paleocene-Eocene Prince William terrane, mainly the Orca Group, has historically thought to have been primarily exposed in the Prince William Sound, but new U-Pb detrital zircon ages with Paleocene maximum depositional ages for metamorphosed turbidites extend the Prince William terrane farther east to southern Baranof Island (Fig. 1; Rick, 2014; Olson et al., 2017). Sandstone composition and zircon provenance is similar for turbidites of the Chugach and Orca Groups and they are thus treated as one common unit (see discussion in Garver and Davidson, 2015). However, a primary difference between the two is that the Orca

[1] Primarily includes the Shumangin Fm., Kodiak Fm., Valdez Group, and part of the Sitka Graywacke.

Group has large and significant packages of mafic volcanic rocks that appear to be locally associated with ophiolites (Davidson and Garver, 2017). East and south of Prince William Sound, amphibolites (± garnet) are common in the schists and gneisses of the Chugach Metamorphic Complex, which is the high-grade metamorphic equivalent of the CPW (Sisson et al., 1989; Bruand et al., 2011, 2014).

The thick package of imbricated turbidites (structural thickness >30 km) that dominates the CPW terrane is thought to have formed in an accretionary complex adjacent to an active volcanic arc built on or adjacent to early Mesozoic basement rocks (Plafker et al., 1994; Haeussler et al., 2006; Garver and Davidson, 2015). Petrographic and geochemical evidence suggests the source of detritus for the turbidites was a progressively eroded magmatic arc (i.e., the inboard Coast Plutonic Complex), and that erosion and deep exhumation resulted in sediment accumulation along the continental margin during the Late Cretaceous and early Paleogene (Hollister, 1979; Samson et al., 1991; Farmer et al., 1993; Plafker et al., 1994; Garver and Davidson, 2015). Analysis of sandstones from across the belt and ages of detrital zircon from those sandstones indicate broad homogeneity of the clastic materials (Zuffa et al., 1980; Dumoulin, 1988; Garver and Davidson, 2015). From a geochemical perspective, the turbidites of the CPW terrane are similar to the elemental and isotopic composition of its Coast Plutonic Complex granitic source (Samson et al., 1991; Farmer et al., 1993; Sample and Reid, 2003).

INTRUSIVE ROCKS OF THE EASTERN SBB

Our study focuses primarily on the Mt. Stamy, Mt. Draper, Krestof Island and Crawfish Inlet plutons situated in the easternmost portion of the SBB (Fig. 2). We sampled the Crawfish pluton in detail (Fig. 3; Tables 1 and 2; Supplement Table 1), with the goal of evaluating geochemical and geochronological characteristics within a single eastern SBB intrusive body on a local scale. We also conducted sampling and investigations of various plutons from across the remainder of the SBB (i.e., west of Yakutat, AK), including the Sanak, Nagai, Aialik, Hive Island, Sheep Bay and McKinley Peak plutons, as well as one sample from the Novatak Glacier pluton in the eastern SBB (Fig. 1; Lempert et al., 2015; Arntson et al., 2017).

The Crawfish Inlet pluton intrudes the Cretaceous to Paleocene Sitka Graywacke and its metamorphic equivalent schist of Baranof Island ("Baranof schist"; Rick, 2014), and is exposed over ~560 km^2 on southern Baranof Island (Fig. 3; Loney et al., 1975). The compositionally similar Redfish Bay pluton on the southern tip of Baranof Island is thought to be connected to the Crawfish at shallow depths, making this system one of the larger composite batholiths in the SBB (Loney et al., 1975). In addition, there are several small sills and plugs ("satellites") that occur southwest of the main body of the Crawfish pluton (e.g., locations 12 and 13 in Fig. 3; Loney et al., 1975). The Krestof Island pluton is located ~40 km northwest of the Crawfish pluton and is exposed over ~80 km^2 (Fig. 3). Although the exposed area of the Krestof Island pluton is relatively small, the pluton may be only partially exposed; its unexposed body is believed to be more expansive and may connect to other Eocene plutons on nearby Kruzof Island to the southwest (cf. Fig. 3, Loney et al., 1975). In comparison to the Crawford and Krestof pluton, smaller exposures of the Mt. Stamy and Mt. Draper plutons intrude the Schist of Nunatak Fiord (informal) of the Boundary Block (Fig. 4). Approximately 5 km east of the Mt. Draper pluton is a small (<10 km^2) exposure of mafic intrusions with complex crosscutting relationships, known colloquially as "the Nunatak" (Sisson et al., 2003b). The Schist of Nunatak Fiord (SNF) is comprised of CPW rocks that are compositionally similar to rocks elsewhere in the belt (Schartman et al., 2019), but here they are metamorphosed to greenschist and amphibolite grade (Sisson et al., 2003a, 2003b).

FIELD SAMPLING

Sampling sites were restricted to well-exposed and nearly continuous outcrops at sea level, with one exception. Due to difficulty accessing the pluton interior, large float blocks that are believed to have been derived from the nearby Mt. Stamy pluton were collected for that intrusive body. Figures 3 and 4 show approximate sample locations and Tables 1 and 2 (see Supplement Table 1 for a complete listing) provide specific lat-long coordinates for each sample. Samples collected from the Crawfish Inlet pluton were designed to capture a transect from the pluton periphery to its interior, which penetrates deepest into the pluton along the south arm of Whale Bay (Fig. 3).

Field relationships offer evidence of co-mingling between granitoid magmas of the eastern SBB with more mafic liquids. Magmatic enclaves are present in the Crawfish, Krestof, and Mt. Draper plutons. These magmatic enclaves generally occur in swarms of relatively smaller, roundish masses that possess aphanitic to fine-grained textures and exhibit crenulated to diffuse contacts (Figs. 5A-5D) with their host granitoids. A mafic dike that was sampled within the Mt. Draper pluton exhibits a cuspate-lobate contact, implicating a co-magmatic relationship between the dike and host granitoid (Fig. 5E-5F).

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Deleted: contrast to xenoliths that occur along the periphery of the Crawfish pluton (see Fig. 17 in Loney et al., 1975) – which are large (up to several tens of meters), exhibit metagraywacke lithology, and are characterized by sharp and angular contacts with host granitoids – t

PETROGRAPHY

Granitoids of the Krestof, Crawfish, Mt. Stamy and Mt. Draper plutons are all medium to coarse grained assemblages of plagioclase, K-feldspar, quartz and lesser biotite. Minor phases include muscovite, hornblende, garnet, and rare clinopyroxene (for more information, see Wackett, 2014; Arntson, 2018).

Enclaves emplaced within the Krestof, Crawfish, and Mt. Draper plutons are finer grained (aphanitic to fine-grained) and enriched in ferromagnesian minerals relative to the granitoids (e.g., Figs. 6C-6D vs. 6A-6B), and exhibit crenulate to diffuse contacts with their hosts (Figs. 6G-6H). The occurrence of acicular apatite (Fig. 6E) in some enclaves indicates rapid magmatic quenching (e.g., Wyllie et al., 1962; Didier, 1973; Vernon, 1984). Acicular hornblende occurs in enclaves (Fig. 6C), whereas accessory hornblende in the host granitoid exhibits equant and coarser grains (Fig. 6A). Zoned plagioclase and poikilitic textures (Fig. 6F) further support a magmatic origin for the enclaves (Vernon, 1984).

Gabbros from 'the Nunatak', the large mafic intrusive body associated with the Mt. Draper pluton (Fig. 4), exhibit subophitic textures with hornblende replacing clinopyroxene in grains surrounding plagioclase. The co-magmatic dike emplaced within the Mt. Draper granitoid contains fine-grained hornblende, plagioclase, and biotite.

WHOLE-ROCK MAJOR AND TRACE ELEMENT GEOCHEMISTRY

A total of 60 samples from across the SBB (Supplement Table 1) were selected for major and trace element analysis by x-ray fluorescence and inductively coupled plasma mass spectrometry methods at the Washington State University GeoAnalytical Laboratory in Pullman, WA. Details of sample preparation, analytical procedures, and precision/accuracy estimates are available at https://environment.wsu.edu/facilities/geoanalytical-lab/technical-notes/.

Whole-rock major element data are provided in Supplement Table 1 and illustrated in Figure 7. SBB intrusive rocks are calcalkaline in nature and include gabbro, gabbroic diorite, diorite, granodiorite and granite (Supplement Table 1) according to Middlemost's (1994) classification based on total alkalis versus wt % SiO_2. For rocks with >60 wt % SiO_2, Barker's (1979) classification identifies most SBB rocks as tonalite, granodiorite and granite. We further classify two samples of Crawfish satellitic bodies as leucogranites (Supplement Table 1) due to their low color indices (<1). To simplify discussion, we hereafter refer to all medium- and/or coarse-grained rocks that host magmatic enclaves and/or mafic dikes as “granitoids,” regardless of whether they classify as tonalites or granodiorites.

Among the plutons studied here, the Mt. Draper pluton (n = 11) exhibits the largest range in silica content, with values ranging between 47.8 and 74.0 wt % SiO_2. Samples from the Crawfish pluton (n = 22) exhibit SiO_2 contents ranging from 56.5 to 75.3 wt %. Excluding the high-silica Crawfish satellite leucogranites (~75 wt % SiO_2), eastern SBB granitoids (<55 Ma) generally exhibit higher CaO, higher Na_2O, and lower K_2O relative to granitoids from the western SBB (>55 Ma). The comagmatic mafic dike and mafic enclaves from the Mt. Draper pluton are metaluminous and broadly similar in elemental composition to Alaskan metabasalts and ophiolites of the Prince William terrane (i.e., Orca Group - cf. Fig. 7). Magmatic enclaves from the Krestof pluton (open squares) are distinct from their host granitoids (pink filled squares), with SiO_2 contents ranging between ~53 and 56 wt %, compared to ~62-63 wt % for their hosts (Fig. 7). Crawfish enclaves exhibit a much wider range in SiO_2 contents (~56 to ~72 wt %), overlapping with the host granitoids that contain between ~66-70 wt % SiO_2. Krestof (open squares) and Crawfish (open red triangles) least evolved enclaves (<63 wt % SiO_2) exhibit distinct TiO_2 and P_2O_5 signatures (Fig. 7). The least evolved (<63 wt % SiO_2) Crawfish enclaves (red open triangles) are noticeable outliers with respect to their P_2O_5 contents (Fig. 7).

Whole-rock trace element data are provided in Supplement Table 1 and illustrated in Figures 8-10. Geochemical distinctions between eastern and western SBB granitoids are more clearly defined using trace elements. Eastern SBB granitoids are generally lower in Sc, La Th, Zr, and especially Yb (as well as Y, not shown here), and are enriched in Sr relative to granitoids

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from the western SBB (Fig. 8). With respect to Sr, La, Th and Zr, the least evolved (<63 wt % SiO2) Crawfish enclaves (red open triangles) again plot as outliers (Fig. 8).

N-MORB normalized trace element patterns (Fig. 9) illustrate that both western (>55 Ma) and eastern (≤55 Ma) SBB granitoids generally exhibit Nb depletions and Pb enrichments. However, rocks from the western belt show flat REE and high field strength element (right half of spider diagram) patterns (Figs. 9A-9B), whereas granitoids of the Boundary block and Baranof Island, and the more evolved (i.e., ≥63 wt % SiO_2) enclaves are typically heavy REE depleted (Figs. 9C-9F). Ratios of Sr/Y in western SBB rocks are relatively low and overlap with typical values for N-MORB (Fig. 10A), whereas many of the more evolved (≥63 wt % SiO_2) rocks from the eastern SBB have high Sr/Y ratios approaching 230 (Fig. 10B). The vast majority of eastern SBB intrusive rocks – especially those with ≥63 wt % SiO_2 from the Mt. Stamy/Draper plutons and <52 Ma granitoids and enclaves from the Crawfish Inlet pluton – classify as adakites (Figs. 10B-10C; Martin, 1999; Drummond and Defant, 1990). Eastern SBB rocks that plot as outliers on Sr/Y diagrams are micaceous garnet-bearing leucogranites (one sample from Mt. Stamy/Draper and two samples near the Crawfish Inlet pluton) (Fig. 10).

SR AND ND ISOTOPE GEOCHEMISTRY

Fourteen samples (eight enclaves, six host granitoids; Table 1) from the Crawfish and Krestof plutons were selected for analysis by Thermal Ionization Mass Spectrometry for Sr and Nd isotopic compositions at the Jackson School of Geosciences Isotope Geochemistry laboratory, University of Texas-Austin. Details of the analytical procedures used at this lab can be found at: www.geo.utexas.edu/isochem/tech_notes/pdf/Sr-Nd-Pb-techniques.pdf. Details of decay constants, analytical errors, age and fractionation corrections, and general isotopic parameters are reported in Table 1.

Eastern SBB granitoid rocks and their co-magmatic enclaves or affiliated mafic rocks from the Crawfish Inlet, Krestof Island, and Nunatak Fiord all have ε_{Nd} and $^{87}Sr/^{86}Sr_{initial}$ compositions (Table 1) that plot along mixing curves between N-MORB and average CPW sediments (Figs. 11A and 11C; Boundary block data from Sisson et al., 2003b). The exceptions to this are two low-silica (one amphibolite, one gabbro) Boundary block samples from Sisson et al. (2003b) that were seemingly altered by seawater (Fig. 11C). The coherence of eastern SBB rocks to the MORB-sediment mixing curve differs substantially from Sr-Nd data for the more westerly Kodiak batholith, which largely departs from the curves (Fig. 11D). Rocks from the Crawfish Inlet pluton and Boundary block area are generally less isotopically evolved than most other SBB granitoids (specifically Kodiak main body and Cordova plutons), plotting outside of or at the lowermost (i.e., least-evolved) end of the compositional range observed for these other SBB suites (Fig. 11).

The least evolved Crawfish enclave is an outlier within the Baranof Island suite, but is isotopically similar to less evolved (<63 wt % SiO_2) amphibolites and mafic plutonic rocks that intrude the CPW terrane at Nunatak Fiord (Fig. 11C). Krestof Island enclaves and granitoids are more isotopically evolved than all Crawfish and most Yakutat-area granitoids, despite their lower silica content (Figs. 6-7). Krestof Island isotopic compositions broadly overlap with fields for the Kodiak batholith and western CMC intrusive suites, but are less isotopically evolved than the Cordova area plutons (Fig. 11). The Cordova and western CMC plutonic complexes also include late stage dikes (star symbols in Fig. 11B) that are isotopically more primitive than rocks from the main plutonic bodies (fields in Fig. 11B), whereas Kodiak satellite samples generally do not follow this trend. We note that this result could reflect the limited sampling of late-stage dikes within the Cordova and western CMC intrusive suites.

ZIRCON U-PB GEOCHRONOLOGY AND HF ISOTOPE GEOCHEMISTRY

U-Pb and Hf isotope data were collected by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at the Arizona Laserchron Center following the methods of Gehrels et al. (2008) and Gehrels and Pecha (2014). Details of the analytical methods are provided in Supplement Tables 2 and 3 for U-Pb and Hf isotopes, respectively.

This study presents new U-Pb zircon crystallization ages of 23 samples collected from 11 different plutons that span the entire length of the SBB (Table 2). The results for five of the samples were previously published in Davidson and Garver (2017). The complete geochronological data set is available in Supplement Table 2. Weighted mean Hf isotope compositions of zircon from 17 of these samples are also shown in Table 2, with the complete data set provided in Supplemental Table 3. We also report detrital zircon U-Pb ages and Hf isotope compositions from 24 graywacke samples collected from the Late Cretaceous to Paleocene turbidites of the Chugach-Prince William terrane in Supplement Table 3. Results from eight of these samples were previously published in Garver and Davidson (2015). For most samples, we collected 5 to 10 analyses from each of the major age peaks as shown on a probability density plot, for a total of 11 to 80 Hf analyses for each sample.

Pluton Crystallization Ages and Hf Isotope Compositions

One sample from the Sanak pluton at the westernmost edge of the SBB (Fig. 1) yields an age of 63.1 ± 0.9 Ma and a weighted mean ε_{Hf} composition of +9.3 ± 0.7 (Fig. 12). Two samples from the Nagai Island pluton record statistically indistinguishable ages of 62.6 ± 0.7 and 61.7 ± 0.7 Ma, respectively, and a weighted ε_{Hf} composition of +8.8 ± 0.7. The Aialik and Hive Island plutons near Seward, AK have nearly identical ages of 56.5 ± 1.0 Ma and 56.4 ± 1.5 Ma, respectively, and ε_{Hf} compositions of +5.9 ± 0.5 and +5.1 ± 0.5 (Fig. 12). Two samples from the

Sheep Bay pluton of eastern Prince William Sound northwest of Cordova, AK yield overlapping ages of 54.8 ± 0.7 and 54.3 ± 0.7 Ma, and identical ε_{Hf} of +4.8 ± 0.5. One sample from the McKinley Peak pluton east of Cordova records an age of 54.5 ± 1.7 Ma, and an ε_{Hf} composition of +7.4 ± 0.5 (Fig. 12).

More extensive U-Pb age and ε_{Hf} compositional data are available for several plutonic bodies between Yakutat, AK and Baranof Island in the far eastern SBB. Four samples from the Mt. Draper pluton at Nunatak Fiord near Yakutat yield closely clustered ages of 54.0 ± 0.6, 53.9 ± 0.8, 53.1 ± 0.7, and 52.8 ± 0.6 Ma with ε_{Hf} compositions ranging from +5.1 ± 0.6 to +7.6 ± 0.3 (Table 2; locations 1, 5, 30 and 32 on Fig. 4). These crystallization ages overlap with each other as well as with those obtained for the Sheep Bay and McKinley Peak plutons located ~400 km away (Fig. 12A; Fig. 2). One sample obtained from float blocks derived from the Mt. Stamy pluton north of Nunatak Fiord records a younger age of 51.4 ± 0.7 Ma, and an ε_{Hf} composition of +6.8 ± 0.5 (Fig. 4, location 19). We also dated a sample (HL19-20) collected from the Novatak pluton that intrudes the Chugach Metamorphic Complex in the Fairweather Range southeast of Nunatak Fiord, which yields a crystallization age of 52.0 ± 0.5 Ma, updating the 49 ± 7.3 Ma lower-intercept discordant date reported by Sisson et al. (2003b).

One sample from the Krestof Island pluton north of Sitka records an age of 52.5 ± 1.0 Ma and has an ε_{Hf} composition of +10.5 ± 0.5 (Fig. 3). Magmatic zircon for seven samples from across the Crawfish Inlet pluton yield crystallization ages spanning ~6 Ma, from 53.1 ± 0.8 to 47.3 ± 1.2 Ma (Table 2). These Crawfish samples also display a broad range of ε_{Hf} compositions ranging from +4.7 ± 0.7 to +13.7 ± 0.7 (Fig. 12, Table 2). A muscovite + garnet-bearing leucogranite (CP13-08D) satellite pluton that intrudes the CPW schist adjacent to the composite Crawfish Inlet pluton yields an age of 52.7 ± 0.8 Ma (Figs. 1C and 3). Our data also indicate that the Crawfish Inlet pluton becomes progressively younger towards its interior. Samples adjacent to intrusive contacts with surrounding country rock record ages of 53.1 ± 0.8 (CP13-13) and 52.2 ± 0.9 Ma (CP13-01), respectively. Alternatively, samples collected from the innermost portions of the pluton accessible along the arms of Whale Bay yield ages of 48.6 ± 1.2 (CP13-03), 48.0 ± 1.0 (CP13-04), and 47.3 ± 1.2 Ma (CP13-09), respectively (Table 2, Fig. 3).

Detrital Zircon Hf Isotope Compositions

Hf isotope data for detrital zircons in CPW turbidites (Supplement Table 3) were collected from across the CPW terrane at localities near the Shumagin Islands (4 samples), Seward area (4 samples), Prince William Sound (7 samples), Yakutat area (6 samples), and Baranof Island (3 samples) (Fig. 1). In the Shumagin Islands, sedimentary ε_{Hf} values range from +13.4 to –11.9 (n=88), with a single prominent peak at +9 on a probability density plot (Fig. 12A and 12C). In the Seward area, sediment ε_{Hf} ranges from +15.6 to –12.0 (n=101) with a broad peak centered at +6 on a probability density plot. In the Prince William Sound, ε_{Hf} spans a broad range from +13.5 to –24.4 (n=215), with two broad probability density peaks with maxima at +8 and +4 (Fig. 12A and 12C). In the Boundary Block, sedimentary ε_{Hf} values span the largest range from +15.0 to –31.3 (n=356), with a broad two-humped peak with maxima at +9 and +4 and a long tail driven by 22 analysis with $\varepsilon_{Hf} \leq -10$ (tail data not shown). On Baranof Island, CPW ε_{Hf} values range from +13.0 to –21.4 (n=164) with a broad peak centered at ε_{Hf} of –2 on a probability density plot (Fig. 12A and 12C).

STATISTICAL METHODS

All data inspection, visualization, and statistical modeling was conducted using R version 4.2.2 within the R statistical computing environment (R Core Team, 2022). Prior to model selection and fitting, we inspected our dataset for outliers, assessed assumptions of homogeneity and normality, and explored the relationship(s) between variables of interest following the general protocol outlined by Zuur et al. (2010). When necessary, we log_{10}- or square root-transformed variables to achieve normal distributions prior to model testing, and back-transformed the regressions afterwards for visualization and plotting purposes.

We used simple linear regression models within the R base package (R Core Team, 2022) to test whether elemental and isotopic variations in Crawfish Inlet and Krestof Island granitoid rocks change systematically through time. Simple linear regression was suitable for these tests due to the non-hierarchical structure of the data. For all other regression analyses, we used the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages to construct and compare best-fit linear mixed effects models (LMMs) in order to test several hypotheses regarding compositional and temporal variations across the entire SBB (and/or within individual belt segments). For all LMMs, we included a random intercept and/or random slope term for pluton/sedimentary formation and/or geochronological dating method (e.g., U-Pb), which helped account for the hierarchical data structure and different number of sites (*N*) or rock samples (*n*) sourcing from closely related rocks within distinct plutonic suites. In other words, including these random factor(s) helped balance the data structure to ensure that compositional results/relationships for densely sampled plutons (which would otherwise be disproportionately represented in the model) and/or more frequently utilized dating methods did not bias or skew the belt-wide inferences of interest.

We used LMMs to constrain the relationship between magmatic zircon ε_{Hf} composition and U-Pb crystallization age for SBB intrusive rocks across the entire belt, and then compared this LMM (for ε_{Hf} of SBB plutons through time) against the best-fit LMM for the ε_{Hf} composition of the CPW sediments these plutons intrude. We generally followed the LMM selection and validation protocol outlined by Zuur et al. (2010). Briefly, we initially tested different fixed effects structures using the maximum likelihood estimation and ranked models hierarchically using the Akaike Information Criterion (AIC). We retained the model that maintained the lowest AIC score ($\Delta_{AIC} > 2$) while preserving the maximum degrees of freedom. We then used the lmerTest package (Kuznetsova et al., 2017) to systematically test different random effects structures. Finally, we used anova in the R base package to statistically compare the best-fit LMMs obtained for belt-wide ε_{Hf} from magmatic (SBB plutons) and sedimentary (CPW sediments) zircons to test the null hypothesis that the compositional trend in magmatic zircon ε_{Hf} from SBB plutons mirrors the ε_{Hf} composition of the CPW sediments these plutons intrude.

We followed the same general procedure of model fitting, selection, and optimization to scrutinize the nature of the relationship between the U-Pb crystallization age of SBB intrusive rocks and their distance from Sanak Island at the western edge of the belt. We also used a locally weighted least squares (LOESS) regression model (R Core Team, 2022) to visualize changes in the median Sr/Y ratios of SBB intrusive rocks through time and space (i.e., as a function of modern distance from Sanak Island) across the length of the belt. For all models, we inspected residuals for both the global model and individual predictor variables to check for patterns and validate model performance, following the model validation protocols outlined in Zuur et al. (2010) and Zuur and Ieno (2016). We then used the MuMIn package (Bartoń, 2022) to estimate global and partial coefficients of determination (R^2) values for all fixed effects, although we note that these R^2 values should be considered relative due to the challenges associated with obtaining a singular goodness-of-fit metric for LMMs (see Jaeger et al., 2017; Harrison et al., 2018 and references therein for further discussion). For all statistical analyses, we assumed significance (i.e., significant correlation between variables and/or significant differences between two model structures) when $P < 0.05$.

GEOCHEMICAL TRENDS THROUGH TIME

At the local-scale, trace elemental and isotopic compositions within the Crawfish Inlet and Krestof Island plutons in the far eastern SBB change systematically with crystallization age (Fig. 13, Tables 1 and 2, Supplement Table 1). Samples from the Krestof and Crawfish plutons that are older than 52 Ma have lower Sr/Y ratios and are not adakitic (Fig. 10C). With one exception, younger (<52 Ma) Crawfish samples have Sr/Y characteristics resembling adakites (Fig. 10C). This trend is primarily driven by consistent time-transgressive variations in Y contents (Fig. 13D), which decrease linearly through time ($F_{1,14} = 7.568$; $R^2 = 0.351$; $P = 0.016$). Whole-rock isotopic compositions of Krestof and Crawfish granitoids also vary through time, becoming more “primitive” in nature with decreasing $^{87}Sr/^{86}Sr_{initial}$ ($F_{1,5} = 14.575$; $R^2 = 0.745$; $P = 0.012$; Fig. 13C) and increasing ε_{Nd} ($F_{1,5} = 24.618$; $R^2 = 0.831$; $P = 0.004$; Fig. 13B) values as crystallization age decreases. The time-transgressive variations in bulk-rock elemental and isotopic compositions mirror changes in the average ε_{Hf} values of Crawfish and Krestof magmatic zircon ($F_{1,5} = 21.054$; $R^2 = 0.808$; $P = 0.006$), which increase linearly with decreasing age (Fig. 13A; Table 2).

Time-transgressive compositional trends are also present at the regional scale across the SBB. Whereas differences in analytical methodologies preclude any direct assessment of the relationship between whole-rock geochemical metrics and U-Pb age using previously published data, our systematic collection and analysis of magmatic zircons for both U-Pb age and ε_{Hf} collected from the same sample permit a robust belt-wide comparative analysis of composition as a function of age across the belt ($N = 17$; $n = 241$); where N represents the number of whole-rock samples from across the SBB and *n* denotes the number of magmatic zircons analyzed for U-Pb and ε_{Hf} from *N* rock samples (Fig. 12). During the first ~8 Ma of magmatism, from ~63-55 Ma, ε_{Hf} values for western SBB igneous rocks decrease steadily with decreasing age, mirroring the decline in ε_{Hf} values for the CPW sediments that they intrude (Fig. 12A). During the ensuing ~55-47 Ma period, this trend reverses and broadens (Fig. 12B), resulting in a 'U-shaped' quadratic relationship between ε_{Hf} and U-Pb crystallization age for intrusive rocks across the SBB (Fig. 12B). This U-shaped trend that reflects a systematic increase in ε_{Hf} values for SBB igneous rocks younger than 55 Ma deviates sharply from the negative linear trend in detrital zircon ε_{Hf} values from CPW sediments (Fig. 12C), which are most evolved in the sedimentary packages exposed on Baranof Island (Figs. 12C-12D). The significant difference ($P < 0.001$) between εHf versus age models obtained for magmatic vs. detrital zircon is driven by the divergence towards more positive (i.e., primitive) εHf values for magmatic zircon in SBB rocks <55 Ma (Fig. 12).

The same 'U-shaped' trend and timing of the abrupt compositional reversal towards more positive or 'primitive' ε_{Hf} values for SBB rocks at ~55 Ma emerges whether one considers the U-Pb age and ε_{Hf} values obtained from individual magmatic zircons ($n = 241$; Fig. 12B) and/or the weighted U-Pb ages and ε_{Hf} averages for each aggregated whole-rock sample ($N = 17$; Fig. 12D). Granitoids from the Crawfish Inlet pluton show a particularly strong increase in ε_{Hf} with decreasing age (Figs. 12A and 13A), spanning a broader compositional range ($\varepsilon_{Hf} = 4.7–13.7$) than all intrusive rocks from across the belt (Fig. 12B). Isotopic compositions of other <55 Ma plutons from the eastern SBB (i.e., McKinley Peak, Mt. Draper, and Krestof Island) also exhibit a similar compositional trend through time (Fig. 12), but contain more positive (primitive) ε_{Hf} values relative to the coeval Crawfish samples.

DISCUSSION

Geochronological evidence for the 'tale of two belts'

Early workers recognized that near-trench igneous rocks of the SBB record a general time-transgression from west to east, which they ascribed to the migration of a trench-ridge-trench (T-R-T) triple junction being subducted obliquely beneath the continental framework (Karig et al., 1976; Marshak and Karig, 1977). Others later refined this trend by expanding the number of age dates available for near-trench intrusive rocks across the entire ~2200 km belt, which were found to range from ~61 Ma on Sanak Island in the west to ~50 Ma on Baranof Island at the belt's eastern edge (Bradley et al., 1993, 2000, 2003; Farris and Paterson, 2009). On the basis of variably reliable ages for SBB intrusive bodies obtained through K/Ar dating of muscovite or biotite (low reliability), $^{40}Ar/^{39}Ar$ dating of muscovite, hornblende, and biotite (intermediate reliability), and U-Pb dating of monazite and magmatic zircon (high reliability), these studies strengthened the case for systematic younging of SBB igneous rocks towards the east (Bradley et al., 1993, 2000, 2003). The repeatedly referenced ~61-50 Ma age range and systematic younging of SBB intrusive suites towards the east has featured prominently in most tectonic reconstructions of the Cordilleran margin - even when the hypothesized frameworks have been at odds. Specific examples of competing tectonic reconstructions that invoke this same systematic temporal trend for SBB plutons include the Resurrection Plate hypothesis of Haeussler et al. (2003) and the Baranof-Leech River hypothesis of Cowan (Cowan, 1982, 2003).

Farris and Paterson (2009) expanded on previous approaches by using a linear regression analysis of age as a function of distance from Sanak Island to derive an average estimate for the T-R-T triple junction migration rate along the margin, which they placed at ~19.6 cm yr^{-1} and leveraged in support of the Resurrection Plate hypothesis (Haeussler et al., 2003). However, this presumed linear relationship between SBB intrusive age and position along the margin has until now been based on only 12 concordant U-Pb monazite and zircon dates that span the entire ~2200 km of the belt (Bradley et al., 2003; Farris and Paterson, 2009), with half of those available ages sourcing from the 59-58 Ma Kodiak batholith in the western SBB (Farris and Paterson, 2009). Of the remaining six concordant U-Pb ages, only two robust ages had been obtained from the entire eastern half of the belt – a distance of >800 km stretching from the eastern PWS to Baranof Island (Figs. 1 and 2).

Our new belt-wide geochronological dataset nearly triples the number of available concordant U-Pb ages from across the SBB. Integrating our new U-Pb crystallization ages (n = 23) with existing U-Pb ages from across the belt (n = 12, Farris and Paterson, 2009) highlights divergent behavior in eastern SBB rocks that deviates from the systematic linear belt-wide relationship reported previously. Upon first inspection it is difficult to discern whether these age data are best represented by a linear or quadratic function, although the two models converge across most of the belt (Fig. 14). If all available ages from across the SBB are considered, then there is clear statistical evidence for a quadratic – rather than linear – relationship between crystallization age and position along the margin (Fig. 14A). If only the 35 concordant U/Pb ages are considered, then the linear and quadratic models become indistinguishable. However, modeling only the concordant U/Pb ages versus distance from Sanak Island using either approach (i.e., whether linear or quadratic) violates several basic assumptions of regression models, as post-model validation suggests that any continuous belt-wide regression generates a heavy-tailed and non-normal distribution of residuals, precluding robust assessment of age versus distance relations with this modeling approach.

The easiest alternative approach that generates a more random distribution of residuals involves using the ~55 Ma gap near Prince William Sound as the divide between the western and eastern SBB and running separate regression models for the two belts (Fig. 14B). This more clearly illuminates the discrepancies between the western and eastern belts, and in particular highlights the substantially weaker space-for-time relationship in the far eastern SBB. Running separate linear models for the two belt sections highlights that distance from Sanak Island can effectively explain > 97% of the variability in U-Pb crystallization ages for >55 Ma rocks in the western SBB, but only ~52% of the variability in observed U-Pb ages for <55 Ma eastern SBB intrusive rocks (Fig. 14B). Even when splitting the samples out by belt segment (i.e., pre- and post-55 Ma), the residual variance within the eastern SBB remains non-normal, further cautioning against the utility of modeling age-distance relations in the eastern portions of the belt. These data collectively suggest that a strong relationship between crystallization age and position along the margin is maintained prior to 55 Ma, but this relationship unravels as ages dip below <55 Ma.

In short, our expansion of the available U-Pb age data on igneous rocks across the entire near-trench plutonic belt – and especially within the eastern SBB – reveals several key points. First, our new U-Pb zircon age ranges expand the duration of SBB magmatism by almost ~5 Ma (63-47 Ma) relative to the most commonly cited 61-50 Ma age range. This would suggest many previous studies have underestimated the full duration of SBB magmatism by almost ~50%, although we do note that some studies have alternatively referenced a ~61-48 Ma age range for the belt (e.g., Madsen et al., 2006). More importantly, our expanded dataset dispels the longstanding assumption that the age of SBB plutons decreases systematically and consistently from west to east in relation to position along the modern margin. Our results portray a more nuanced picture of the timing of early Tertiary near-trench magmatism along the Cordilleran margin, and support the notion that the SBB is better represented as two distinct (i.e., western and eastern) belts (Fig. 14B). Under this scenario, near-trench intrusive rocks emplaced during the first ~8 Ma years of magmatism (from ~63-55 Ma) record a systematic spatial and temporal relationship, wherein position along the modern-day southern Alaska margin remains a strong predictor of intrusive age. However, during the second ~8 Ma of forearc magmatic activity (from ~55-47 Ma), widespread and long-lived magmatism generated coeval and compositionally heterogeneous near-trench intrusive rocks that are now separated by ~800 km (stretching from Prince William Sound to Baranof Island) along the modern-day margin.

Geochemical evidence for the 'tale of two belts'

Trace element geochemistry and the role of adakites

Most previous studies have interpreted forearc plutonism to be the result of subduction of a spreading ridge that generates unusually high thermal anomalies in the forearc, which stimulates partial melting of the accretionary wedge (e.g., Dickinson and Snyder, 1979; DeLong et al., 1979; Forsythe and Nelson, 1985; Sisson and Pavlis, 1993; Thorkelson, 1996; Sisson et al., 2003a). Informed primarily by whole-rock trace element and isotope geochemistry, previous geochemical studies of SBB near-trench intrusive rocks have supported this model and concluded that SBB magmas are the products of melts derived from N- and/or E-MORB mantle that combined (via assimilation and/or magma mixing processes) with accretionary wedge materials (Hill et al., 1981; Moore et al., 1983; Barker et al., 1992; Harris et al., 1996; Lytwyn et al., 2000; Bradley et al., 2003; Sisson et al., 2003b; Farris et al., 2006; Ayuso et al., 2009). Others have also highlighted that ridge subduction events and the ensuing generation of a 'slab window' (Defant et al., 1992; Thorkelson, 1996; Thorkelson and Breitsprecher, 2005) and/or potential for tearing around the edge of the down-going slab (Yogodzinski et al., 2001; Thorkelson and Breitsprecher, 2005) constitute tectonic settings commonly associated with the formation of adakites. Adakites are the term broadly applied to a class of sodium-rich intrusive and/or extrusive igneous rocks with high Sr/Y ratios, which mark them as clearly compositionally distinct from 'normal' wedge-derived arc rocks (Drummond and Defant, 1990; Martin, 1999; Martin et al., 2005; Hastie, 2021).

Despite broad general agreement regarding the endmember sources (i.e., mantle-derived and sedimentary melts) contributing to SBB magmas as mentioned above, there is an open debate regarding the role (or lack thereof) of slab melting in generating the SBB adakitic suites. Farris and Patterson (2009) proposed that higher Sr/Y ratios in the eastern SBB were due to the onset of slab melting in this portion of the belt, and used this line of reasoning to support the Resurrection plate hypothesis of Hauessler et al. (2003). In contrast, Harris et al. (1996) rejected slab melting as a plausible explanation for the origin of adakitic rocks of the western CMC (Fig. 1), while Sisson et al. (2003b) also favored a model involving partial melting of recently underplated amphibolite and/or metabasalt.

The aforementioned ambiguity regarding the processes responsible for the derivation of the same SBB adakite suites mirrors a broader debate amongst petrologists at-large. Most early studies on adakites linked their origin to slab melting (Kay, 1978; Drummond and Defant, 1990), but in the years since various classes of adakites (e.g., Martin et al., 2005; Hastie et al., 2010) and alternative petrogenetic models for adakite formation have been proposed (see Hastie, 2021 and references therein). It is now generally recognized that any tectonic environment catalyzing partial melting of basalt and/or amphibolite at sufficient crustal thicknesses to stabilize garnet and/or amphibole in the residuum can generate adakitic melts (e.g., Smith and Leeman, 1987;

Beard and Lofgren, 1991; Atherton and Petford, 1993), regardless of whether or not it involves direct melting of young (<25 Ma) and hot oceanic lithosphere. For example, adakitic melts have been found in intraplate environments stemming from partial melting of delaminated mafic lower crust (Xu et al., 2002). In igneous provinces where Sr/Y ratios in igneous rocks increase with time, crustal thickening and melting at greater crustal depths have also been suggested to play a role (e.g., Chapman et al., 2015).

Although both the term itself and the tectonic significance of ‘adakites’ remain contested, the conversation regarding SBB adakites is critical because their presence has repeatedly been cited as additional evidence for the ‘slab window’ mechanism of SBB pluton genesis (e.g., Haeussler et al., 2003; Madsen et al., 2006; Farris and Paterson, 2009). Furthermore, a consensus has emerged suggesting that systematic differences in Sr/Y ratios are recorded across the SBB, with lower Sr/Y (non-adakitic) melts in the western belt that grade towards systematically higher Sr/Y ratios in the eastern SBB (e.g., Haeussler et al., 2003; Farris and Paterson, 2009), which has been subsequently wielded to support particular tectonic reconstructions.

Combining our extensive compilation of previously published data with our newly available geochemical dataset from across the SBB unravels this long-standing assumption, as our synthesis demonstrates that Sr/Y ratios exhibit no clear and consistent trends across the SBB (Fig. 15). For example, compositionally heterogeneous near-trench dikes that intrude the CPW terrane near Seldovia (Kenai Peninsula) (Lytwyn et al., 2000; Bradley et al., 2003; Fig. 10A) have been dated to 57.0 ± 0.2 Ma by ^{39}Ar/^{40}Ar methods (Bradley et al., 2000), consistent with previous interpretations that they form part of the SBB (Lytwyn et al., 2000; Bradley et al., 2003). Many of these Seldovia dikes have high Sr/Y ratios (Lytwyn et al., 2000; Bradley et al., 2003; Figs. 10A and 15), despite lying ~300-400 km west of the definitively non-adakitic ~55

Ma Sheep Bay, Rude River, and McKinley Peak plutons exposed near Cordova, AK (Barker et al., 1992; this study; Fig. 15).

Within the far eastern SBB, the Crawfish Inlet and Krestof Island plutons illustrate that Sr/Y ratios within individual plutonic suites can vary substantially through time. Older (~53-52 Ma) magmas emplaced within the Crawfish and Krestof plutons are consistently non-adakitic and compositionally indistinguishable (with respect to their Sr/Y character) from most western SBB rocks (Fig. 10). In contrast, younger (<52 Ma) magmas emplaced within the Crawfish pluton exhibit high Sr/Y ratios and classify as adakites (Fig. 10C). In the case of the Crawfish pluton, the transition from low to high Sr/Y ratios is driven by a systematic decrease in Y contents through time (Fig. 13D), rather than temporal variations in Sr contents (data not shown). Rocks in the Boundary block (including one sample from the Novatak Glacier pluton emplaced within the Fairweather block) display an even broader Sr/Y range, further supporting our interpretations from Baranof Island and highlighting the broad variability in adakitic signatures within individual eastern SBB suites (Figs. 10B and 15).

In addition to dispelling the pre-existing notion that systematic variations in Sr/Y ratios are recorded across the SBB, we propose an alternative model for adakite genesis that reconciles both the petrogenetic process(es) responsible for generating SBB adakites and helps to explain their puzzling distribution (Fig. 15) and apparent time-transgressive nature at local scales (Fig. 10). Whereas previous models invoked adakite genesis via either slab melting (e.g., Haeussler et al., 2003; Farris and Paterson, 2009) and/or partial melting of underplated mafic lower crust (e.g., Harris et al., 1996; Sisson et al., 2003b), we propose instead that the timing, location, and local heterogeneity in adakitic signatures through time within individual intrusive suites may be more appropriately explained by increased partial melting of basalt-bearing CPW sediments at depth.

The locations of adakitic melts across the SBB support a broad association between the presence of mafic materials within the CPW terrane. We interpret the presence of adakites across the SBB as largely reflecting the locations where basaltic material was entrained within the accretionary wedge, rather than reflecting any systematic difference in the proportion of slab melting across the belt. For example, the increase in Sr/Y ratios of Crawfish Inlet magmas through time may suggest an increasing proportion of partially melting Orca Group metabasalts, which are now known to be exposed on Baranof Island (Rick, 2014). In Nunatak Fiord, the concomitant increase in Sr/Y ratios could involve incorporation of partial melts of amphibolite and other metabasalts (like 'the Nunatak'; Sisson et al., 2003b; this study) exposed within the Boundary Block accretionary wedge. We also emphasize that in addition to changing proportions of partially melted mafic (and associated sedimentary) inputs, other petrogenetic factors like crustal thinning/thickening (e.g., Chapman et al., 2015) and/or changes in the Sr/Y character of the mantle-derived magmatic source could also contribute to the variability in adakitic compositions within individual SBB suites.

Another alternative is that the local-scale time-transgressive variation in Sr/Y ratios signals some other regime shift. Could the youngest melts entrained within the easternmost SBB plutons record the first traces of ancestral Yellowstone hotspot volcanism prior to margin-parallel translation of the CPW terrane north to Alaska? One intriguing possibility is that the initiation of increased partial melting of metabasalts during the later emplacement stages of eastern SBB plutons was associated with the emergence of and subsequent interactions between the ancestral Yellowstone hotspot and outboard CPW terrane (e.g., Wells et al., 2014). It remains possible that the CPW terrane could have been located adjacent to the modern day coast of Washington at the time of intrusion by these younger SBB units (e.g., Cowan, 2003; Wells et al., 2014), and has since (post ~47 Ma) been subsequently transported northward to its current position along dextral strike-slip faults. We note that several of the least-evolved Crawfish enclaves record trace element and isotopic compositions broadly consistent with OIB-like mantle (outlier compositions in Figs. 6-9), although there are too few samples to draw robust conclusions. Nevertheless, the onset of widespread hotspot-associated magmatism would also provide a valid mechanism to both rapidly thicken the lower crust (Wells et al., 2014) and supply an additional mafic protolith for partial melting, thereby potentially contributing to the emergence of a strong adakitic signature within the youngest eastern SBB suites (i.e., youngest Crawfish Inlet and Boundary Block samples).

Pb, Sr, and Nd isotopic constraints

Our extensive dataset from the Crawfish Inlet pluton is, to our knowledge, one of the clearest documentations of systematic, time-transgressive compositional Sr-Nd isotopic variations recorded through time within an individual plutonic suite. We note that there are many other well-studied examples of systematic age progressions and relations within individual intrusive suites – the Tuolumne and Yosemite Valley Intrusive Suites constituting two examples (e.g., Bateman, 1992; Ratajeski et al., 2001; Coleman et al., 2004; Putnam et al., 2015; Bartley et al., 2018) – and acknowledge that some of these systems also record compositional variations through time. However, such clear and well-defined compositional and temporal progressions like those documented here for the Crawfish pluton (Fig. 13) may often be obfuscated in classical arc environments.

We tentatively suggest that this local signature of increasing mantle-derived proportions through time may comprise a characteristic signature of the eastern SBB intrusive belt, and that this time-transgressive signature may be used to distinguish between the western and eastern belts. Future studies may aim to better constrain the temporal and compositional relations at local levels within the Cordova, western CMC, and Yakutat area (i.e., Nunatak Fiord) intrusive suites to further test this assumption. Furthermore, higher resolution sampling and detailed characterization of near-trench igneous activity at local scales (i.e., within individual plutons and/or plutonic suites) across other tectonic environments that have recorded ancient ridge-trench encounters such as in Japan (Maeda and Kagami, 1996; Shinjoe et al., 2021) and/or Patagonia (e.g., Forsythe et al., 1986; D'Orazio et al., 2000; Lagabrielle et al., 2000) may help illuminate whether this trend is a recurring pattern associated with forearc slab window magmatism more generally, or is unique to the eastern portions of the SBB.

Hf isotopic constraints

Arguably the clearest case for partitioning the SBB into two separate belts is illustrated by our extensive belt-wide compilation of ε_{Hf} values versus U/Pb age (Ma) for both SBB units and the sedimentary rocks they intrude (Fig. 12). Here, magmatic zircon from the SBB are plotted as a continuous function of their crystallization age, whereas probability density fields for detrital zircon are positioned approximately at the ages of the plutons that intrude these sedimentary formations. As noted previously, the average ε_{Hf} values of detrital zircon from CPW accretionary sediments decreases systematically from +9 to –2 moving from west (i.e., Shumagin Formation) to east (i.e., Sitka Graywacke on Baranof Island).

Thus, detrital zircon in sedimentary rocks of the Shumagin Formation exhibit primitive (positive) ε_{Hf} compositions that broadly overlap with the ε_{Hf} values of magmatic zircon from the western SBB rocks (Sanak and Shumagin) that intrude them (Fig. 12A). This finding supports a petrogenetic model involving depleted mantle and accretionary sediment contributions to those magmas, and broadly implicates a substantial sedimentary component within western SBB melts. In contrast, substantially more evolved (negative) ε_{Hf} values from the Sitka Graywacke on Baranof Island diverges significantly ($P < 0.001$) from the ε_{Hf} regression trends for adjacent SBB rocks (i.e., Crawfish Inlet and Krestof Island plutons) that intrude them. Whereas the ε_{Hf} values for the oldest Crawfish intrusions broadly overlap with the detrital zircon mean, the ε_{Hf} signature of Krestof and Crawfish magmatic zircon becomes progressively more primitive (i.e., positive) with decreasing age. When average ε_{Hf} values are considered for each SBB igneous suite, a clear 'U-shaped' compositional trend emerges as function of age across the belt (Fig. 12B and 12D).

The consistent lowering of ε_{Hf} values in western SBB rocks >55 Ma (i.e., from Sanak Island to Prince William Sound) spanning the left-half of the 'U-shaped' trend could reflect lower proportions of MORB mantle (and a concomitant increase in the sedimentary component) towards the east, but it could alternatively (and/or collaboratively) reflect a compositional shift towards lower ε_{Hf} values driven by the changing ε_{Hf} signature of CPW sediments (Fig. 12A). A significant shift in detrital zircon ε_{Hf} values is apparent in the far eastern portions of the belt, though, where the average ε_{Hf} value for the Cretaceous to Paleocene Sitka Graywacke and Baranof schist drops to –2. The isotopically more evolved nature of the host sediments here contrasts sharply with the progressively more primitive ε_{Hf} composition of Crawfish Inlet pluton samples through time, the youngest (~49-47 Ma) of which approach depleted mantle values (Fig. 12B). Therefore, the U-shaped reversal towards more primitive ε_{Hf} values for magmatic zircon in Crawfish Inlet (and other eastern SBB) rocks through time likely reflects greater proportions of mantle-derived contributions to Crawfish/eastern SBB magmas, consistent with the time-transgressive trends in Sr-Nd isotopic and trace elemental compositions (see Fig. 13) discussed above.

Collectively considering the trace element (i.e., Sr/Y), Sr-Nd, and Hf isotopic evidence suggests that mantle-derived contributions to Crawfish Inlet magmas increased significantly and systematically during the ~6 Ma of sustained magmatism recorded within this composite pluton. One possible explanation for the larger mantle component recorded here is that there was a "clearing out" of the magmatic plumbing system during this long-lived magmatic episode, with a concomitant decrease in sediment assimilation through time. Within this framework, shorter lived magmatism (~1-2 Ma; see Farris and Paterson, 2009) within the western SBB may not have allowed for the establishment of a well-developed plumbing system, causing the ε_{Hf} isotopic signatures of the western SBB plutons to track more closely with those of the sediments they intrude. Other alternatives that more explicitly link the increasing mantle contributions in eastern SBB rocks to potential tectonic frameworks include: (1) an increasing mantle endmember component that was supplemented by interactions between the more southerly paleo-CPW terrane and ancestral Yellowstone hot spot (Wells et al., 2014); and/or (2) protracted transtensional activity in the ancient forearc during plate reorganization (Clennett et al., 2020), which in turn facilitated extensive decompressive and/or partial melting of mafic rocks interbedded with younger CPW sediments (Sisson and Pavlis, 1993; Pavlis and Sisson, 2003; Gasser et al., 2011).

SUMMARY AND CONCLUSIONS

The time-transgressive Sanak Baranof belt (SBB) exposed over ~2200 km along the southern margin of Alaska is really a tale of two belts: (1) a western belt (~1000 km long) with crystallization ages that young systematically from 63 Ma in the west (Sanak Island) to 56 Ma in the east (Resurrection Bay), and (2) an eastern belt with broadly coeval crystallization ages from 55 to 47 Ma that spans >800 km from eastern Prince William Sound to Baranof Island (Table 2,

Fig. 1). In the western belt, ε_{Hf} of magmatic zircon from the SBB plutons varies from +9.3 ± 0.7 on Sanak Island to +5.1 ± 0.5 at Resurrection Bay, and closely tracks the ε_{Hf} signature of detrital zircons from the CPW turbidites they intrude (Fig. 12A). In the eastern belt, there is a distinct and systematic departure of ε_{Hf} values for the plutons compared to the ε_{Hf} values recorded by the surrounding CPW turbidites (Fig. 12). This is especially apparent on Baranof Island, where the CPW turbidites have a distinct ε_{Hf} peak at –2, while the oldest phases of the Crawfish Inlet pluton (~53 Ma) have ε_{Hf} = +4.7 ± 0.7 and the youngest phases (47 Ma) have ε_{Hf} = +13.7 ± 0.7, which approaches the average ε_{Hf} value for depleted mantle (Fig. 12).

Major and trace element geochemistry and petrography of the SBB intrusive rocks show that they vary widely from gabbros to garnet+muscovite-bearing leucogranites. Whole-rock elemental and isotopic observations fail to clearly elucidate systematic differences between the western and eastern belts, including the widely referenced Sr/Y ratios and Sr-Nd isotopic values (Figs. 7-11, Fig. 15). Indeed, Sr/Y ratios from the same pluton (e.g., Crawfish Inlet) are shown to record both high Sr/Y (adakitic) and low Sr/Y signatures (Fig. 10C, Fig. 15). However, the distribution of adakites across the SBB broadly corresponds with the presence of metabasalts across the CPW terrane. Furthermore, there appear to be temporal differences in Sr/Y (and other isotopic proxies) at local scales within some eastern SBB suites. Older phases of the Crawfish inlet pluton (>52 Ma) have low Sr/Y and younger phases have high Sr/Y, perhaps indicating a change in the composition of the source region concomitant with systematic changes in ε_{Hf} and other geochemical proxies.

These new observations and syntheses suggest the SBB is a tale of two belts composed of a wide variety of granitoid rocks, which precludes a simple time-transgressive emplacement of plutons along the Paleocene-Eocene Alaskan margin due to the subduction of a migrating ridge.

Most plate reconstructions for the NE Pacific Basin indicate that emplacement of the SBB plutons occurred in a strike-slip environment that resulted in northward translation along the Cordilleran margin following intrusion, but the relationship to offshore plate geometries remains unclear because offshore marine magnetic anomalies of that age have long since been subducted (Engebretson et al., 1985; Shephard et al., 2013; Müller et al., 2019; Clennett et al., 2020). Several observations highlight the tectonic complexity and unique attributes of the eastern SBB, which distinguishes this portion of the belt from those >55 Ma SBB plutons to the west.

First, intrusion occurred in a dextral strike-slip environment that was in part manifested by significant slip on the Border Ranges fault system (BRFS). For example, the Tarr Inlet Suture of the BRFS appears to have hundreds of kilometers of dextral slip (postulated to be up to 700 km) that occurred between 58 and 42 Ma (Smart et al., 1996; Sisson et al., 2003b). Strike-slip faults are also common within rocks of the Chugach-Prince William terranes and are especially apparent across the eastern SBB, where several structures appear to have accommodated significant movement between the late Paleocene and early to middle Eocene (Bol and Roeske, 1993).

Second, wholesale crustal stretching and thinning very likely accompanied eastern SBB plutonism. The Chugach Metamorphic Complex (CMC) in the eastern Chugach Range has a remarkable record of synchronous plutonism and transtension at 55 and 50 Ma (see Sisson and Pavlis, 1993; Pavlis and Sisson, 2003; Gasser et al., 2011). The 57 Ma Resurrection ophiolite and allied fragments may have resulted from extreme transtension of the upper plate (Davidson and Garver, 2017).

Third, although the offshore plate setting is poorly understood, many models call upon interactions with an offshore ridge at a triple junction. To explain the geologic complexity of the eastern SBB, Sisson and Pavlis proposed that the subduction of transform offsets of a spreading ridge allowed certain areas along the margin to have prolonged heating or reheating (see Sisson and Pavlis, 1993; Pavlis and Sisson, 2003). Ridge segments and transforms may have therefore been juxtaposed at a high angle relative to the margin, with some segments subducted obliquely or nearly parallel to the margin (Sisson et al., 2003b). Thus, eastern SBB magmas were likely affected by complexities in the nature of the offshore spreading ridge, which may have assumed enigmatic orientations or behavior during the dynamic period of plate reconfiguration between 56 and 52 Ma (Sisson and Pavlis, 1993).

Fourth, paleomagnetic results from rocks of the CPW terrane – host to the SBB – raise the possibility that intrusion occurred far to the south, and that the CPW and SBB were subsequently translated north to Alaska. The available paleomagnetic data indicate ~1400 to 2500 km of margin parallel translation of the 57 Ma Resurrection Peninsula ophiolite and slightly older rocks on Kodiak (see discussion in Garver and Davidson, 2015). Published models suggest the age distribution of SBB plutons is related to either movement of offshore plate geometries (see Clennett et al., 2020) and/or movement of the CPW terrane as a strike-slip bound forearc sliver (or both). In any case, the enigmatic nature of the eastern SBB is almost certainly related to the complexity of the dynamic Pacific plate reorganizations that occurred around Chron 24 to 23 (~56 to 52 Ma) (Pavlis and Sisson, 1995; Wells et al., 2014; Clennett et al., 2020).

Parsing between potential mechanisms that comprehensively address all of the available geochemical, geochronological, and paleomagnetic data are beyond the scope of this study. However, some viable possibilities include a combination of oblique ridge subduction interacting with a dynamic transpressional to transtensional margin, which was simultaneously undergoing rapid sedimentation and tectonic thickening in the forearc stemming from exhumation and erosion of the Coast Plutonic Complex (e.g., Davidson and Garver, 2017). In the easternmost SBB, these events may have also been facilitated and/or followed by interactions with the ancestral Yellowstone hotspot (e.g., Wells et al., 2014) and ensuing dextral strike slip transport along the margin, which carried the CPW and Yakutat terranes northward to their modern-day position in Alaska. Regardless of what tectonic mechanism(s) are invoked, our findings clarify (at local scales) and complicate (at regional scales) the current picture of geochemical and geochronological relations across the SBB and must be accounted for in future tectonic reconstructions of the Paleocene-Eocene Cordilleran margin.

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FIGURE CAPTIONS

Figure 1. Schematic tectonic map of the modern-day Cordilleran margin stretching from the southwestern Alaskan margin at Sanak Island to northern Washington state (modified after Cowan, 2003) showing approximate locations and U-Pb crystallization ages of select Sanak-Baranof Belt (SBB) intrusive suites for which new geochronological and geochemical data are reported as part of this study. The exception to this is Kodiak Island, where the Kodiak batholith and associated intrusive rocks are displayed and the ages listed are after Farris et al. (2006). Symbols designated for each pluton/intrusive suite are shown on the left and used in all ensuing

figures. Additional abbreviations from the base map are as follows: BRF = Border Ranges Fault; PE = Peninsular terrane; AX = Alexander terrane; WR = Wrangellia terrane; QCF = Queen Charlotte Fault.

Figure 2. Larger-scale geologic map of the southern Alaskan margin (modified after Gasser et al., 2011) between the Kenai Peninsula and Baranof Island highlighting the major tectonic terranes, faults, and positions of the Aialik (AP) and Hive Island (HI) plutons, as well as the relative locations of all eastern SBB plutons studied in detail here. Symbols for all SBB plutons are as defined in Figure 1. Additional abbreviations for the plutons/intrusive suites are as follows: AP = Aialik Pluton; HI = Hive Island; SB = Sheep Bay; MP = McKinley Peak; MS = Mt. Stamy; MD = Mt. Draper; KI = Krestof Island; CI = Crawfish Inlet.

Figure 3. Detailed geologic map of Baranof Island near Sitka, Alaska. Sample locations are shown as small labeled dots with the adjacent numbers corresponding to the sample names listed in Supplemental Table 1. Samples K1 and K2 (KP13-01 and -02) were collected from the Krestof Island pluton located to the north of Sitka. The base map is modified after Wilson et al. (2015).

Figure 4. Detailed geologic map of the Nunatak Fiord region near the town of Yakutat, Alaska. The Boundary Block is a fault-bounded block comprising the schist of Nunatak Fiord and the Mt. Stamy (MS) and Mt. Draper (MD) plutons. The Mt. Draper Nunatak (MDN) is a mafic and highly heterogeneous portion of the Mt. Draper pluton. Sample locations are shown as labeled dots with the numbers corresponding to samples listed in Supplemental Table 1. Note that sample 19 (RF16-19) was collected from a large debris flow sourcing from the Mt. Stamy pluton, which was inaccessible for direct sampling. Areas in gray (unlabeled geologic units) are ice-covered. Base map modified from Wilson et al. (2015).

Figure 5. Field photos of select SBB plutons and their field associations with mafic intrusive assemblages across the far eastern SBB (Boundary Block and Baranof Island area). (A) Magmatic enclave swarm emplaced in the Crawfish pluton; note the quarter (~2.4 cm diameter) image center for scale and cuspate-lobate mingling fabric at the enclave-granitoid interface. (B) Magmatic enclave swarm emplaced in the Krestof pluton; note the rock hammer (~0.4 m in length) shown for scale. (C) Typical Krestof Island magmatic enclave exhibiting roundish shape, higher color index and aphanitic texture relative to its host. (D) Mafic enclave emplaced in the Mt. Draper host granite. (E) Mafic dike (sample RF 16-30B) that cross-cuts the Mt. Draper pluton and exhibits complex comagmatic contacts with Mt. Draper granitoid rocks. (F) Zoomed image of panel E inset, highlighting the cuspate-lobate texture (lower red arrow) between the dike and host granite, which indicates a comagmatic relationship. A mafic xenolith that displays sharp and angular contacts with the surrounding host rock (upper red arrow) is also shown for comparison.

Figure 6. Photomicrographs of selected samples from this study. All yellow scale bars are equal to 1 mm with the exception of panels (E) and (F), where the scale bars represent 0.1 mm and 0.2 mm, respectively. Abbreviations are defined as follows: hb = hornblende; bi = biotite; qz = quartz; pl = plagioclase. Crawfish host granitoid (CP13-07A; 67.3 wt % SiO_2) under (A) uncrossed and (B) crossed polars and an associated magmatic enclave (CP13-07D; 62.2 wt % SiO_2) under (C) uncrossed and (D) crossed polars. (E) Enclave CP13-07D shown under high magnification to highlight the presence of acicular apatite (select grains are circled in red), which indicates rapid magmatic quenching of the mafic enclave melt (e.g., Wyllie, 1962; Vernon, 1984). (F) Crawfish tonalitic enclave (sample CP13-06B) with evident poikilitic textures; note the difference in scale for the yellow scale bar. Krestof enclave sample KP13-02B (53.6 wt %

SiO_2) shown under (G) uncrossed and (H) crossed polars, highlighting the crenulate contact (indicated by black and white dashed lines) between the host granitoid (KP13-02A; 62.2 wt % SiO_2, shown on lower right) and aphanitic enclave dominated by finer grained plagioclase and clinopyroxene (upper left).

Figure 7. Major and minor element Harker diagrams for SBB intrusive rocks from this study and one sample (S69a) from Hill et al. (1981), which is geographically proximal to our Sanak Island sample (i.e., SI12-02, see Supplemental Table 1 for details) that was collected for zircon analyses, but which lacks whole-rock elemental geochemistry. All symbols are as shown in Figure 1. The shaded fields outline the compositional range of Paleocene-Eocene Alaskan metabasalts and ophiolites (gray fields; Lull and Plafker, 1990; Lytwyn et al., 1997; Sisson et al., 2003b) for comparison with the SBB intrusive suites of interest. Mg# is defined as 100*(MgO/40.31)/((MgO/40.31) + (FeO*/71.85)) where FeO* = (FeO + 0.9Fe_2O_3). ASI (Aluminum Saturation Index) is the molecular ratio of Al_2O_3/[CaO + Na_2O + K_2O] (Shand, 1951). The peraluminous-metaluminous boundary (solid line) at ASI = 1.0 is after Shand (1951) and the I-type/S-type boundary (dashed line) at ASI = 1.1 (with S-type > 1.1) is after White et al. (1986).

Figure 8. Trace element (in ppm) Harker diagrams for all new SBB intrusive rock samples from this study, with shaded fields for Alaskan metabasalts and ophiolites (references as in Figure 7) again shown for comparison. Symbols and fields are as denoted in Figures 1 and 7, respectively.

Figure 9. NMORB-normalized (after Sun and McDonough, 1989) spider diagrams for new SBB intrusive rock samples reported from this study. Symbols are as in Figure 1, although note the new symbol (black filled triangle) used to distinguish Crawfish leucogranite satellite bodies with > 75 wt % SiO_2 in panel (F). (A) NMORB-normalized spider diagram for ~63-56 Ma Western

SBB rocks stretching from Sanak to Hive Island in Resurrection Bay. (B) One sample (with ~57 wt % SiO_2) from the Novatak Glacier pluton in the Fairweather block plotted alongside mafic (i.e., < 53 wt % SiO_2) compositions from the Nunatak mafic body at Nunatak Fiord. (C) The least evolved enclave samples from the Crawfish Inlet and Krestof Island plutons. Note the relative SiO_2 contents for enclaves from the two plutons in the inset legend. (D) Granitoids from the 55-54 Ma Sheep Bay and McKinley Peak plutons near Cordova. Lines are missing where elemental analyses were not available (see Supplemental Table 1 for details). (E) More evolved enclaves and host granitoids (all with > 63 wt % SiO_2) from the Mt. Stamy and Mt. Draper plutons in the Boundary Block. (F) More evolved (i.e., > 63 wt % SiO_2) enclaves and host granitoids from the Krestof Island and Crawfish Inlet plutons at the easternmost edge of the SBB. Again, note the new symbol (black triangles) introduced for the Crawfish satellite leucogranites with > 75 wt % SiO_2.

Figure 10. Sr/Y vs. Y (ppm) diagrams for samples with > 54 wt % SiO_2 spanning across the SBB. Symbols for new data presented as part of this study are as in Figures 1, 7 and 9. The gray fields repeated in panels A-C represent adakites (Drummond and Defant, 1990). (A) Sr/Y vs. Y diagram for intrusive rocks of the western SBB, with new data from this study depicted as symbols and shaded fields representing previously reported datasets for > 55 Ma rocks from the western SBB. Data sources for the fields are as follows: Kodiak, Ayuso et al. (2009); Sanak-Shumagin, Hill et al. (1981); Seldovia, Lytwyn et al. (2000) and Bradley et al. (2003). Also illustrated are eclogite and garnet amphibolite partial melting curves labeled 1 and 2, respectively, after Drummond and Defant (1990), which assume an NMORB source (264 ppm Sr, 38 ppm Y). Tick marks with numbers adjacent indicate degrees of partial melting. (B) The same Sr/Y vs. Y diagram with data from this study shown as symbols while previous datasets for

≤ 55 Ma SBB rocks from across the eastern SBB are depicted as fields. The aqua field represents Cordova samples from the Sheep Bay, McKinley, and Rude River plutons; the aqua star symbol represents a late stage dacitic dike established by cross-cutting relations (Barker et al., 1992). The yellow field denotes early-stage intrusions from the Chugach Metamorphic Complex (CMC); yellow stars represent late-stage intrusive (Ti_4) dikes established by cross-cutting relations (see Harris et al., 1996; Sisson et al., 2003b for details). The green field represents samples from the Yakutat area, including the Mt. Draper and Mt. Stamy plutons as well as the Nunatak mafic intrusive body; the green hexagon represents a leucogranite outlier that plots substantially off-field (Sisson et al., 2003b). (C) Sr/Y vs. Y diagram for Baranof Island (i.e., Krestof Island and Crawfish Inlet pluton) samples plotted at an expanded scale relative to panels A and B (note the difference in y-axes). Symbols for Crawfish and Krestof samples are enlarged for samples for which U-Pb ages are available (this study). Enclaves are assumed to be the same age as the dated host rock they intrude, based on petrographic evidence of rapid magmatic quenching in most enclaves. U-Pb age data are lacking for samples illustrated by smaller symbols. The red triangle with the inset white asterisk represents a sample that was dated at ~51.2 Ma (see text for discussion), which plots far afield of the other younger (i.e. < 51.2 Ma) Crawfish Inlet samples, which otherwise cluster within the adakitic field.

Figure 11. ε_{Nd} versus $^{87}Sr/^{86}Sr_{initial}$ diagrams for new samples from this study and other available Sr-Nd isotopic datasets compiled from across the SBB. Mixing curves between NMORB and an average CPW sedimentary composition in each panel are after Harris et al. (1996). (A) Crawfish Inlet and Krestof Island samples (from this study) plotted in Sr-Nd isotopic space. Also shown are fields for N-MORB (light blue) and ocean island basalts (i.e., OIB, pink field) after Zindler and Hart (1986), Hofmann (1988; 1997), and Sun and McDonough (1989), as well as Salters and

Stracke (2004) and a range of average compositions compiled from the EarthChem PETDB database (<http://petdb.ldeo.columbia.edu/petdb/query.asp>). Purple hexagon symbols display the range of CPW sedimentary (Farmer et al., 1993, whole-rock compositions only; as well as one sample from Harris et al., 1996) compositions (also see legend inset). (B) Cordova area plutons (aqua field and aqua star, from Barker et al., 1992) and SBB units intruded into the Chugach Metamorphic Complex (yellow field and yellow stars; data from Harris et al., 1996 and Sisson et al., 2003b). As noted in the inset figure legend, the stars denote late-stage intrusions, while the fields depict the full range of earlier intrusive compositions observed within each respective suite. (C) Nunatak Fjord samples (data after Sisson et al., 2003b) plotted in Sr-Nd isotopic space. The blue dashed arrow shows the trend associated with seawater contamination and/or crustal assimilation (after Sisson et al., 2003b), which may explain two anomalous compositions. (D) Kodiak batholith samples (data from Ayuso et al., 2009; leucogranite sample 01PH107B that plots as an outlier has been excluded). Samples from the main body of the batholith are in gray, with mafic and felsic satellite compositions depicted as ovals (see legend inset).

Figure 12. (A) ε_{Hf} from magmatic zircon isolated from the SBB plutons (plotted as symbols) compared with ε_{Hf} values for detrital zircon from various CPW turbidite groups (plotted as color shaded areas). Color shaded fields represent bubble plots that were constructed from probability density plots of the detrital zircon ε_{Hf} data (see Methods) and are centered around the U/Pb defined ages of the plutons that intrude them. Vertical error bars shown for each SBB pluton data point represent $\pm 1\sigma$. (B) Individual ε_{Hf} samples from magmatic zircon isolated from the SBB plutons replotted with the optimized mixed effects regression model (equation: $\varepsilon_{Hf} = 4168 - 4753(\text{age}) + 1357(\text{age}^2)$; model $R^2 = 0.505$, $P < 0.0001$), where age represents the $\log_{10}$-

transformed U/Pb age of magmatic zircon in Ma (years). The ‘U-shaped’ quadratic relationship with age clearly highlights the compositional inflection point at ~55 Ma. (C) Probability density plots of the detrital zircon ε_{Hf} data (see Methods) plotted alongside the optimized linear mixed effects regression (equation: $\varepsilon_{Hf,\ CPW\ seds} = 268 - 152(age)$; model $R^2 = 0.363$, $P = 0.004$), where age represents the $\log_{10}$-transformed U/Pb age (in Ma years) of the plutons that intrude each CPW sedimentary unit. The negative linear function suggests the ε_{Hf} of CPW sediments becomes more evolved (i.e., lower ε_{Hf} values) through time. (D) Weighted means of the ε_{Hf} isotope data from the SBB plutons (symbols as in Figure 1 and previous panels) plotted alongside the optimized mixed effects regressions obtained for SBB igneous rocks (in black) and CPW sediments (in light gray). Vertical error bars for SBB pluton means are shown as $\pm 2\sigma$. The ε_{Hf} compositional trend through time for SBB plutons and CPW sediments diverges at ~55 Ma, and the best-fit regressions for plutons and sediments are significantly different in the eastern portions of the belt ($P < 0.001$).

Figure 13. Geochemical trends through time within the Crawfish Inlet and Krestof Island intrusive suites in the far eastern SBB. Linear regression fits are shown in black and the 95% confidence intervals are depicted with light gray dashed lines. Model goodness-of-fit metrics (i.e., R^2 values) and levels of significance ($P < 0.05$) are shown inset of each panel. (A) Weighted means of the ε_{Hf} data from magmatic zircon plotted versus U/Pb age (in Ma) of magmatic zircon. The vertical error bars represent $\pm 2\sigma$. Error bars for some symbols are within the symbol range. The line for the chondritic uniform reservoir (CHUR) is after Bouvier et al. (2008) (B) Whole-rock ε_{Nd} isotopic compositions versus U/Pb age (Ma) for Crawfish and Krestof samples where both of these metrics were available. The line for CHUR is after Jacobsen and Wasserburg (1980). (C) $^{87}Sr/^{86}Sr_{initial}$ whole-rock compositions versus U/Pb age (Ma) for Crawfish Inlet and

Krestof Island samples. The line for bulk silicate earth (BSE) at $^{87}Sr/^{86}Sr_{initial}$ = 0.7045 is after Salters and Stracke (2004) (D) Chondrite-normalized (using chondrite elemental composition from Sun and McDonough, 1989) Y concentrations (Y_{CN}) for Crawfish and Krestof granitoids as well as more evolved (i.e., > 63 wt % SiO_2) enclave compositions plotted against U/Pb age (Ma). Figure 14. (A) All U/Pb, Ar/Ar, and Ar/Ar biotite and white mica ages from across the SBB including data from Bradley et al. (1993, 2000, 2003), Haeussler et al. (1995), Sisson et al. (2003b), and Farris et al. (2006) plotted alongside new concordant U/Pb ages reported here (n = 23). White crosses denote previously obtained ages (n = 54) from across the belt while other symbols represent new U/Pb analyses (n = 23) with symbols as shown in Figure 1. The thin black line represents the optimized mixed effects quadratic regression (equation: U/Pb age = 63 – 0.9998(distance) + 1.00(distance^2); model R^2 = 0.834; P < 0.0001), where age is the weighted mean of the sample age ($\log_{10}$-transformed) and distance represents the distance from Sanak Island (in kms). The quadratic form derives from a weakening (i.e., less steep) relationship between U/Pb age vs. distance from Sanak Island in the eastern portions of the belt. Vertical error bars on symbols denote standard errors (± 2σ) around the weighted mean. (B) Concordant U/Pb ages for SBB intrusive rocks versus distance (in km) from Sanak Island. White crosses represent previously obtained ages (n = 12, data from Farris and Paterson, 2009). Other symbols represent new analyses (n = 23) reported in this study, with symbols as in Figure 1. Vertical error bars denote standard errors (± 2σ) around the U/Pb weighted mean ages. A strong linear correlation between U/Pb age and distance from Sanak Island remains evident for the first ~1100 km along strike (in rocks up to ~56 Ma) within the western SBB, with the modeled random slope regression (equation: U/Pb age = 63 – 0.0066(distance); model R^2 = 0.971; P < 0.0001) explaining >97 % of the variance in the data. However, in the eastern portions of the belt (i.e., for samples ≤55 Ma and >1100 km from Sanak Island) there is a relatively weak correlation. In this half of the SBB, the optimized random slope regression (equation of the form U/Pb age = 61.2 – 0.0049(distance); model $R^2 = 0.525$; $P = 0.0003$) explains only ~52% of the variance in the data. The substantially different slopes (0.0066 vs. 0.0049) also point towards disparate spatiotemporal relationships within the two portions of the belt.

Figure 15. Boxplots showing the complete range in Sr/Y values for all intrusive rocks with ≥ 54 wt % SiO_2 from across the SBB. Datasets containing new data from this study are designated by color-coded boxes and those compiled from other studies are shown as white boxes. The number of samples (n) from each location is denoted above or below each respective box. The bar in the middle of the boxes denotes the median, the edges of the box representing the 25% and 75% quartiles, and the vertical error bars denote the full range of the data (with statistical outliers plotted as individual symbols). The black line fit behind the boxplot represents a locally weighted least squares regression (LOESS) model implemented in the R base package (R Core Team, 2022). The 95% confidence interval for the LOESS model is depicted with a shaded gray field. Note the log scale on the y axis. Data for the fields compiled from other studies are as follows (from left to right): Sanak and Shumagin Islands, Hill et al. (1981); Kodiak, Ayuso et al. (2009); Seldovia, Lytwyn et al. (2000) and Bradley et al. (2003); Cordova area plutons (i.e., Sheep Bay, Rude River, McKinley Peak), Barker et al. (1992); Western Chugach Metamorphic Complex (CMC), Harris et al. (1996) and Sisson et al. (2003b); Boundary Block (Mt. Stamy and Draper) and Novatak Glacier plutons, Sisson et al. (2003b).

SUPPLEMENTAL MATERIAL

Supplemental Table 1. Major and trace element compositions for SBB samples (from west to east).

Supplemental Table 2. U-Pb geochronologic analyses from the Sanak-Baranof Belt, Alaska.

Supplemental Table 3. Hf isotope data from the Sanak-Baranof Belt, Alaska.

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