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Black Hills–Alberta carbonatite–kimberlite linear trend: Slab edge at depth?

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ABSTRACT

Carbonatites and kimberlites (~48 to ≤46 Ma) occur along a 700-km-long, N40°W linear trend of alkalic magmatism (~55 to ≤46 Ma) that extends from the Black Hills of South Dakota and Wyoming, across eastern Montana to southern Alberta. Isotopic and trace-element concentrations point to a genetic linkage among alkalic igneous rocks, carbonatites, and kimberlites along the trend (group 1), with Sr–Nd isotopic ratios flanking bulk silicate earth. In contrast, alkalic rocks southwest of the N40°W trend (groups 2 and 3) have significantly lower initial epsilon-Nd values and different trace-element contents (e.g. higher Ba, but lower REE, U, and Th).

A tectonomagmatic model is proposed here to account for placement of the genetically related group 1 magmas along the N40°W linear zone; the model suggests that the edge of the Kula plate was lodged in the mantle transition zone directly below the N40°W trend by ~50 Ma. Mantle material rising through the Kula–Farallon slab window may have been concentrated at the southwest edge of the Kula slab, focusing melts upward along the trend. Geochemical attributes of group 1 magmas along the trend can be explained by an extremely small partial melt of carbonated peridotitic mantle (0–1%). Initiation of extension at ~53–49 Ma is important because it may have stimulated mantle upwelling and decompressional melting, as well as facilitated intrusion of asthenospheric melts into the Wyoming Archean craton. Although groups 2 and 3 are thought to be largely lithospheric melts, their Sr–Nd isotopic compositions reflect a greater proportion of asthenospheric component after ~50 Ma, following onset of extension in the west.

1. Introduction

The Great Plains alkalic province of South Dakota, Montana, Wyoming, and southern Alberta, is part of the "Kamloops–Challis–Absaroka" volcanic belt of western North America (Armstrong and Ward, 1991) (Fig. 1). It represents Paleogene magmatic activity farthest inboard of the trench where the Kula, Resurrection, and Farallon plates subducted to the east/northeast beneath the North American plate (Atwater, 1970; Engebretson et al., 1985; Lonsdale, 1988; Haeussler et al., 2003; Bradley et al., 2003; Madsen et al., 2006). Different petrogenetic and tectonomagmatic models explain geochemically and isotopically diverse alkalic magmas of the Great Plains alkalic province (GPAP) with sources in asthenosphere and subcontinental lithospheric mantle, along with a Cretaceous–Tertiary subduction component from the Farallon and/or Kula plates. Asthenospherically-derived magmas (kimberlites and carbonatites; belonging to group 1, defined later) traverse the lithosphere of the Wyoming Archean craton, currently estimated to be at least 200 km thick (Dueker et al., 2001; Schutt and Humphreys, 2001; Karlstrom et al., 2002), and at least 170 km thick during Eocene time (Hearn, 1989; Carlson et al., 1999; Hearn, 2004). Kimberlites and carbonatites in the GPAP are likely derived entirely from asthenospheric mantle, the exception being the carbonatite in the Bearpaw Mountains, which may include a lithospheric component (Fig. 2)(Scambos and Farmer, 1988; Scambos, 1991; Duke and Frost, 2003). Kimberlites and carbonatites (and rocks of kimberlitic affinity) are frequently associated in space and time, and, although there is still much debate with respect to their generation and sources, many consider them to be genetically linked (e.g. Green and Wallace, 1988; Barker, 1989; Bailey, 1993; Dalton and Presnall, 1998; Harmer and Gittins, 1998; Gudfinnsson and Presnall, 2005). Kimberlite magmas (Type I; Smith, 1983) are relatively rare, rapidly emplaced, ultramafic, ultrapotassic, undersaturated with respect to silica, enriched in LILE and REE, and have high contents of CO_2 and H_2O. They are derived from the mantle, usually contain abundant mantle and crustal xenoliths, and are an important source of diamonds (Dawson, 1971; Mitchell, 1986, 1995; Wilson and Head, 2007; Richardson and Shirey, 2008). Carbonatite magmas are also rare, and by definition contain greater than 50% carbonate minerals, are undersaturated with respect to silica and highly enriched in LILE and REE. They have high contents of CO_2 as well as other volatiles such as H_2O and F, but they have a wide range of Sr–Nd–Pb isotope ratios, making their sources difficult to pinpoint (Woolley and Kempe, 1989; Bell and Blenkinsop, 1989; Bell, 1998). Origins and geneses of carbonatite magmas are debated, but the majority agree they are

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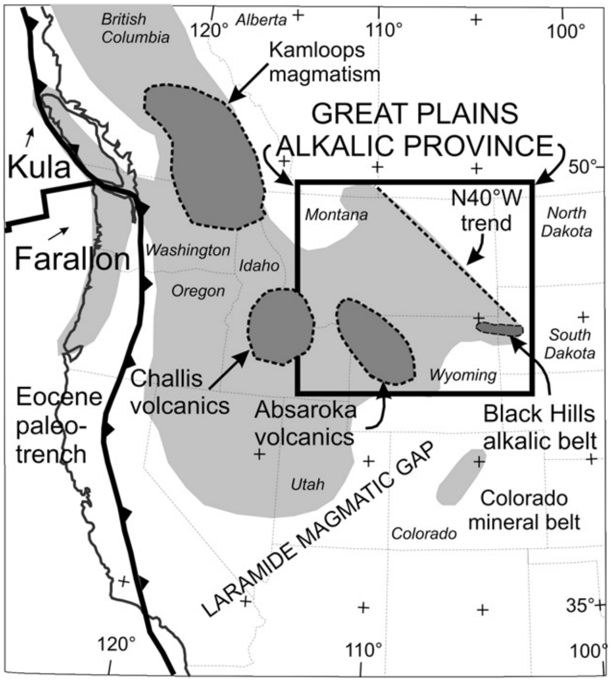

Fig. 1. Location map of Eocene magmatism from 40–55 Ma in North America (modified from Armstrong and Ward, 1991). Inset on this map is the Great Plains alkalic province (Fig. 2). Light grey areas are regions of Eocene magmatism, and dark grey areas are igneous centers. Eocene paleotrench is from Madsen et al. (2006) and Breitsprecher et al. (2003). Location of spreading ridge between Kula and Farallon plates is from Breitsprecher et al. (2003).

derived from within the mantle, whether from heterogeneities (e.g. subducted ocean crust) within a plume originating in the lower mantle or mantle transition zone (located at 410–670 km depth between upper and lower mantle), from metasomatically enriched mantle (lithospheric or asthenospheric), or from "normal" asthenospheric mantle (e.g. Eggler, 1989; Dalton and Wood, 1993; Barker, 1996; Dalton and Presnall, 1998; Harmer and Gittins, 1998; review by Bell, 2001; Bell and Tilton, 2001; Bizzarro et al., 2002; Hoernle et al., 2002; Bizimis et al., 2003; Chakhmouradian, 2006; Guzmics et al., 2008).

Subcontinental lithospheric mantle is proposed to be an important source component in alkalic magmas from groups 2 and 3 (groups defined later) of the GPAP, including those of the Crazy Mountains (Dudás et al., 1987; Dudás, 1991), Highwood Mountains (O'Brien et al., 1991, 1995), Absaroka volcanic province (Feeley, 2003), Bearpaw Mountains (MacDonald et al., 1992; Downes et al., 2004), Milk River minettes (Buhlmann et al., 2000), Sweetgrass Hills, and Eagle Buttes (Scambos and Farmer, 1988; Scambos, 1991). The Crazy Mountains magmas are proposed to be derived almost entirely from subcontinental lithospheric mantle (Dudás et al., 1987; Dudás, 1991), whereas other centers are thought to have their sources in both lithospheric mantle and asthenosphere (Eggler et al., 1988; Irving, 1988; O'Brien et al., 1991; MacDonald et al., 1992; O'Brien et al., 1995; Buhlmann et al., 2000; Feeley, 2003; Downes et al., 2004). The lithospheric mantle component is mid-Proterozoic in age, and may be the source of high concentrations of Ba and LREE, but lower concentrations of Th, U, and HFSE in melts; it has radiogenic $^{87}Sr/^{86}Sr$, unradiogenic $^{206}Pb/^{204}Pb$, and negative to strongly negative values of ε_{Nd} (Fraser et al., 1985; Dudás et al., 1987; Dudás, 1991; O'Brien et al., 1991; Carlson and Irving, 1994; O'Brien et al., 1995; Downes et al., 2004).

Various tectonomagmatic models seek to explain Eocene magmatism in the GPAP, the main question revolving around the presence or absence of a subducted slab beneath the region during this time. One model includes an intact, low-angle subducted slab beneath the region, with melts of a "metasomatized carapace" above the slab, triggering partial melting of the overlying mantle wedge, followed by

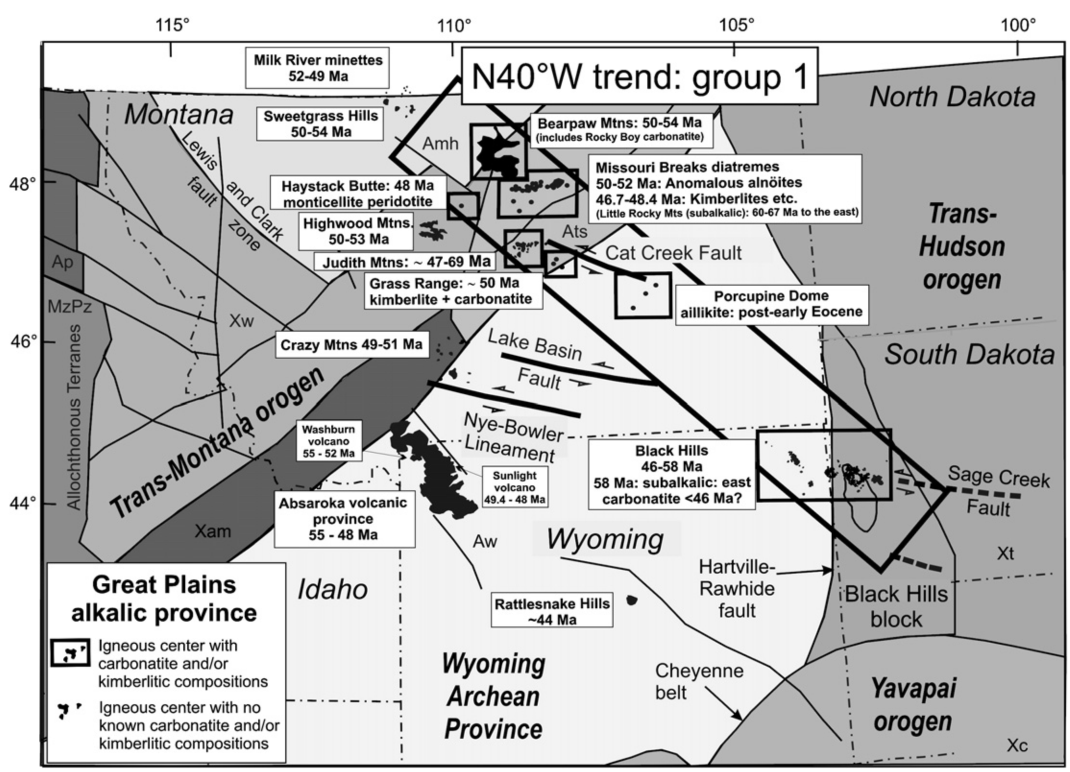

Fig. 2. Location of major Paleocene–Eocene alkalic igneous centers and associated WNW fault zones of the Great Plains alkalic province (GPAP), overlaid on Precambrian basement map (Sims et al., 2004) (Not all igneous centers are included on this map because of lack of space.) Note the N40°W zone with carbonatites, kimberlites, and rocks of kimberlitic affinity. The Rocky Boy stock (carbonatite) referred to in the text is located in the Bearpaw Mountains. Precambrian terranes are as labeled by Sims et al. (2004): MzPz (oceanic-arc rocks of Mesozoic–Paleozoic age), Xc (Colorado province), Xt (Trans-Hudson orogen), XAm (foreland fold-and-thrust belt), Xw (Wallace terrane), Ap (Pend Oreille domain), Amh (Medicine Hat block), Aw (Wyoming province), and Ats (tectonically shortened margin).