Yellowstone in Yukon: The Late Cretaceous Carmacks Group

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ABSTRACT

The Late Cretaceous Carmacks Group, a thick subaerial volcanic succession that once covered much of southwest Yukon, was deposited on an uplifted terrane and is divisible into a lower fragmental unit and an upper flood basalt unit. Coeval hydrothermal activity resulted in widespread alteration and gold mineralization. The lavas are shoshonites, enriched in large ion lithophile and light rare earth elements, but depleted in high field strength elements. Ankaramitic absarokite flows in the upper Carmacks Group range up to 15 wt% MgO, requiring a high liquidus temperature (1400 °C at 1 bar, dry). High K_2O contents (>3%) of these magnesian lavas indicate that the potassic character of the volcanic suite was established in the mantle. Although previously interpreted as subduction related, the Carmacks Group was erupted during a Cordilleran-wide magmatic lull and lacks coeval calc-alkalic batholiths. The lavas are petrologically similar to plume-related Eocene to Pliocene potassic lavas of the western United States.

New paleomagnetic collections, combined with previous work, place the Carmacks Group 17.2° ± 6.5° (1900 ± 700 km) south of its present position relative to the craton during deposition, near the paleolocation of the Yellowstone hotspot. The spatial coincidence, similarity of tectonic setting, and lithologic similarity of the Carmacks Group and Yellowstone volcanic successions suggest that the Carmacks Group is the 70 Ma effusion of the Yellowstone hotspot. Subsequent northward displacement of the Carmacks Group is attributed to coupling with the Kula plate. Correlation of the Carmacks Group and the Yellowstone hotspot fixes the paleolatitude and the paleolongitude of the terranes of the northern Intermontane belt at 70 Ma.

INTRODUCTION

Relative northward translation of terranes of the outboard Intermontane and Insular belts of the North American Cordillera is implied by both plate-motion and paleomagnetic studies. Plate-motion studies indicate a large (>2000 km) post–middle Cretaceous northward motion for the Pacific oceanic plates relative to the North American continent (Engebretson et al., 1985). Coupling between outboard portions of North America and the oceanic plates resulted in their northward translation (Debiche et al., 1987). Paleomagnetically determined paleopoles for mid- and Late Cretaceous formations are discordant with respect to cratonic North America (e.g., Irving and Wynne, 1991; Beck, 1992). These results have been interpreted to indicate large (>1000 km) postmagnetization northward translation. Cessation of northward relative displacement (at about 50 Ma) coincided with the transfer of the displaced crustal blocks back to the North America plate (Irving and Brandon, 1990).

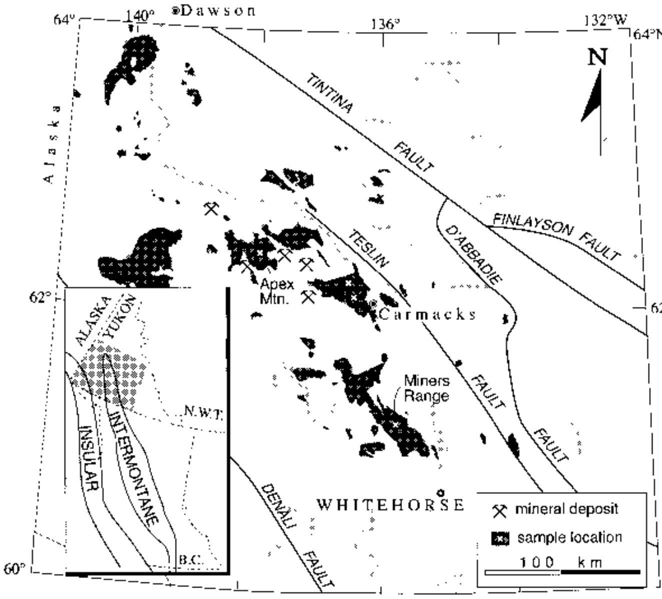

Figure 1. Distribution of Carmacks Group (dark areas), southwest-central Yukon, after Wheeler and McFeely (1991). Figure location and physiographic belts indicated on inset map.

Geologic support for large northward translation of portions of the Cordillera has, however, been ambiguous or contradictory (Cowan, 1994). Regional mapping of geologic structures across major strike-slip faults results in estimates of post–middle Cretaceous dextral displacement of 500 to 1000 km (Gabrielse, 1985; Price and Carmichael, 1986). Furthermore, geologic relationships have been used to argue that discordant paleopoles from plutons resulted from postmagnetization tilting and not northward translation (Butler et al., 1989, 1991).

This paper brings together the results of mapping, geochemical, and paleomagnetic studies of the Late Cretaceous Carmacks Group, a voluminous subaerial volcanic succession in southwest-central Yukon (Fig. 1), to show that it may represent the expression of the Yellowstone hotspot at 70 Ma. Implications of this correlation are discussed.

CARMACKS GROUP

The Carmacks Group comprises a number of thick volcanic exposures exposed between Whitehorse and Dawson (Fig. 1). These appear to be erosional remnants of a widespread sheetlike succes-

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sion that probably covered much of southwest-central Yukon (Tempelman-Kluit, 1974) between 72 and 69 Ma (Grond et al., 1984; Lowey et al., 1986; Hart, 1995). The volcanic succession generally includes a lower fragmental unit and an upper flood-basalt unit. The lower Carmacks Group consists predominantly of coarse volcaniclastic rocks and sandy tuffs interbedded with subordinate andesite and basaltic flows. The thickest and coarsest volcaniclastic sections define a number of central complexes that are commonly cored by small granitic intrusions. A small ($<10°$) angular unconformity underlies the areally more extensive flows of the upper Carmacks Group. The upper flat-lying, olivine- and clinopyroxene-phyric flows grade upward from basalt or andesite to primitive ankaramites with 15% MgO. Rhyolite and dacite flows are rare. The Carmacks Group commonly overlies a coarse Late Cretaceous cobble conglomerate that grades downward into an autochthonous basement breccia. It was deposited on an uplifted terrane with significant topographic relief (Tempelman-Kluit, 1974). Underlying basement rocks consist largely of middle Paleozoic and older quartzofeldspathic assemblages of continental affinity (Wheeler and McFeely, 1991).

Coeval plutonic rocks are rare; they are restricted to small high-level potassic plugs that intrude the lower fragmental volcanic unit. Small zoned intrusions, grading from olivine peridotite cores to felsite rims, also intrude basement rocks along arcuate faults that are concentric about the pluton-cored volcaniclastic piles. The volcaniclastic piles and arcuate faults define caldera complexes with diameters of >60 km.

Related hydrothermal activity resulted in widespread alteration, the resetting of K-Ar systematics, and epithermal and porphyry-style gold mineralization. Fragmental volcanic rocks of the lower Carmacks Group are commonly bleached and sausseritized, and contain quartz-chalcedony veins, amygdules, and agates. Gold deposits of Carmacks age hosted in highly altered rocks are shown in Figure 1. Older volcanic sequences in west- and south-central Yukon are commonly altered and yield K-Ar ages reset to Late Cretaceous (Hart, 1995).

GEOCHEMISTRY[1]

All the lavas of the Carmacks Group are highly potassic. The olivine- and clinopyroxene-phyric lavas of the upper Carmacks flows are similar in composition to the type absarokites of Wyoming (Gest and McBirney, 1979) but are slightly more siliceous and grade to shoshonites, which are less potassic than those associated with the Wyoming absarokites. Most of the lower Carmacks lavas have plagioclase phenocrysts and are petrographically and chemically classified as shoshonites. All the Carmacks lavas have a strong shoshonitic trace element signature, including enrichment in large ion lithophile elements (LILEs, e.g., K, Rb, Ba) and light rare earth elements (LREEs), but are relatively depleted in high field strength (HFS) elements (e.g., Nb, Zr, Ti).

The ankaramitic absarokite flows of the uppermost Carmacks range up to 15 wt% MgO and contain olivine phenocrysts whose compositions are as Mg rich as Fo_{93}. The K_2O contents (>3 wt%) of these lavas are too high to reflect contamination by any known lower-crustal lithology, and their primitive compositions suggest that their potassic character was established in the mantle. The low Fe and Al contents of these primitive lavas indicate derivation from a mantle source that was depleted in fusible major elements (c.f. Francis, 1995). Low Ca contents combined with high Ca/Al ratios and flat chondrite-normalized heavy rare earth element profiles indicate that neither clinopyroxene nor garnet was a residual phase in this mantle source. Systematic variation in LILE ratios (e.g., Rb/Ba, K/Na) in these primitive lavas suggest, however, that phlogopite was either a fractionating phase during ascent to the surface or a residual phase in their mantle source. The most likely source for the Carmacks magmas was a refractory harzburgite that had been enriched in trace LILEs and LREEs by a metasomatic event that precipitated phlogopite. The Si contents of the primitive Carmacks lavas are among the highest of any primitive terrestrial magma, suggesting that they reflect melting at relatively shallow mantle depths or in the presence of significant water pressures (Francis, 1995).

PALEOMAGNETISM[2]

The results of Marquis and Globerman (1988) from 18 sites in the Carmacks Group (declination (D) = 166.7°, inclination (I) = $-71.4°$, $k = 53$, $\alpha_{95} = 4.8°$) first indicated that it was displaced northward by 13.4° ± 8.5° (1500 ± 950 km) relative to cratonic North America since the Late Cretaceous. However, five of the sites from Table Mountain in northern British Columbia have since been shown to predate the Carmacks Group by 10 m.y. (Mihalynuk et al., 1992) and hence are excluded from this discussion. Concerns raised by Butler (1990) regarding sampling redundancy in the Marquis and Globerman (1988) study were addressed by Marquis et al. (1990), and their original site designations are used in our analysis below. In the present study, we have doubled the number of Carmacks Group sites from localities near Carmacks and on Apex Mountain (Fig. 1).

The Carmacks Group rocks are excellent paleomagnetic recorders of the paleofield. The magnetizations are single component with magnetite as the carrier. Sites with both polarities are present (five normal, eight reversed). Results from the new collection are not significantly ($p = 0.05$) different from the Carmacks Group sites from Marquis and Globerman (1988). When results from both studies are combined, they yield a mean direction ($D = 166.3°$, $I = -69.3°$, $k = 34.8$, $\alpha_{95} = 4.9°$, $N = 26$) that passes the fold test (maximum precision at 98% unfolding) and a corresponding paleopole at lat 78.4°N, long 88.6°E ($A_{95} = 7.8°$). The ancient north pole determined from the Carmacks Group is far-sided with respect to the expected north pole of North America at 70 Ma (average of five studies from Montana and Arizona selected by Wynne et al., 1992). The paleoposition of Carmacks, attained by placing the Carmacks pole on the North American pole, had to be 17.2° ± 6.5° (1900 ± 700 km) south of its present position (Fig. 2). Although our results have confirmed those of Marquis and Globerman (1988), the small difference in mean inclination (2.1°) between their study and ours translates into a larger apparent displacement.

DISCUSSION

Our data indicate a major igneous event in western North America, around the present-day latitude of Oregon, 70 m.y. ago. The Yellowstone hotspot at 70 Ma, determined by kinematically linking the hotspot reference frame to North America via Africa (method of Engebretson et al., 1985), was positioned at lat 41°N, long 231°E. The spatial and temporal coincidence of the Carmacks Group rocks with the Yellowstone hotspot (Fig. 2) leads us to propose that the Carmacks Group represents the 70 Ma effusion of the Yellowstone hotspot that has since been tectonically displaced 1900 km northward.

The Carmacks Group has previously been correlated with other post–80 Ma, pre-Tertiary volcanic successions and interpreted as a record of subduction-related arc- and transtensional-igneous activity (Souther, 1991). The potassic character of the Carmacks Group led to inferences of an arc-distal or back-arc tectonic setting (Grond

[1]GSA Data Repository item 9652, geochemical and paleomagnetic data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301. E-mail: editing@geosociety.org.

[2]See footnote 1.

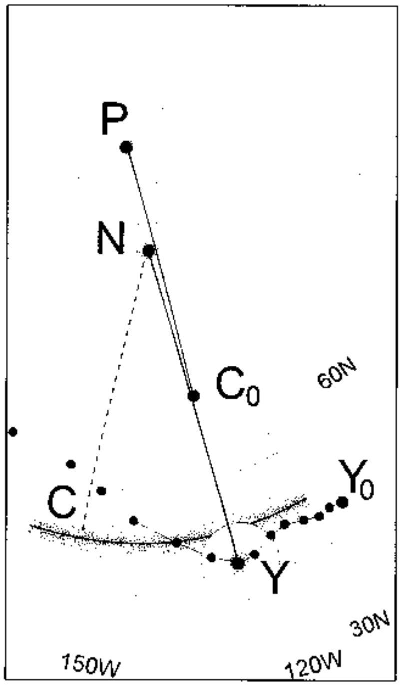

Figure 2. Ancient north pole (P) determined from Carmacks Group, currently at C_0 (lat 62.0°N, long 136.4°W), and of North America (N) at 70 Ma. Placing line P-C_0 to begin at N (dashed line), paleoposition of Carmacks had to be along arc marked C. Y is Yellowstone hotspot at 70 Ma. Uncertainty of 530 km in hotspot location was qualitatively estimated by assuming three independently and circularly distributed sources of error: possible motion between Pacific and African hotspots (3 km/m.y.); uncertainty in hotspot-Africa reconstructions (400 km); and uncertainty in Africa–North America reconstructions (280 km). Also indicated are reconstructed paleopositions of Yellowstone hotspot at 10 m.y. intervals, back to 130 Ma.

et al., 1984; deRosen-Spence and Sinclair, 1987). However, an increased number of age determinations from Late Cretaceous and younger volcanic rocks indicate that the 72–69 Ma Carmacks Group was an isolated volcanic occurrence (Armstrong, 1988). An arc association is inconsistent with the rarity of coeval plutonic rocks and lack of large calc-alkaline batholiths such as are commonly associated with continental volcanic arcs. The extensive flat-lying flows of the upper Carmacks Group are suggestive of a flood-basalt sequence.

Although shoshonitic volcanic suites are commonly assumed to be subduction related, this is not always the case. A number of authors (Fitton et al., 1991; Thompson et al., 1989; Müller et al., 1992) have interpreted Eocene to Pliocene potassic lavas of the western United States to represent the melting of the thermal boundary layer of the lower lithospheric mantle due to lithospheric thinning (Anderson, 1994) and the arrival of the Yellowstone plume (Fitton et al., 1991). The thermal boundary layer (or perisphere of Anderson, 1994) of the continental lithospheric mantle, a harzburgite residue from a previous melting event, is consistent with the expected mantle source of the Carmacks lavas. Fluids rising from the underlying asthenosphere may result in metasomatic formation of phlogopite, enriching the thermal boundary layer in relatively mobile LILEs and LREEs but not in HFS elements (McKenzie, 1989). The high liquidus temperatures required by the primitive Carmacks lavas (1400 °C at 1 bar, dry) and the coincidence of its estimated paleoposition with that of the Yellowstone hotspot are compatible with melting of such an enriched lower lithospheric mantle due to the impingement of the Yellowstone plume head in the Late Cretaceous.

Lithosphere-plume interaction is reflected in the stratigraphy of the Carmacks Group. The basal cobble conglomerate and basement breccia, the large relief on the sub-Carmacks unconformity, and the explosive volcanism and caldera formation that characterize the lower Carmacks Group imply pre- to synmagmatic extension, perhaps above the plume head. Upper flood basalts are primary mantle melts and may reflect subsequent breaching of the lithosphere. The extrusion of this voluminous succession during a brief 3 m.y. interval is also consistent with a plume origin.

Gold mineralization may be a character of the Yellowstone hotspot. Rich "bonanza-type" gold deposits in northern Nevada are interpreted to be genetically associated with the Yellowstone hotspot (Wilson, 1993). In Yukon, gold mineralization is related to the Carmacks volcanic units and coeval hydrothermal alteration (Fig. 1). A genetic model linking gold mineralization to hotspot-related hydrothermal activity is suggested. New exploration models, based on this linkage, may assist in the identification of additional gold mineralization in Yukon.

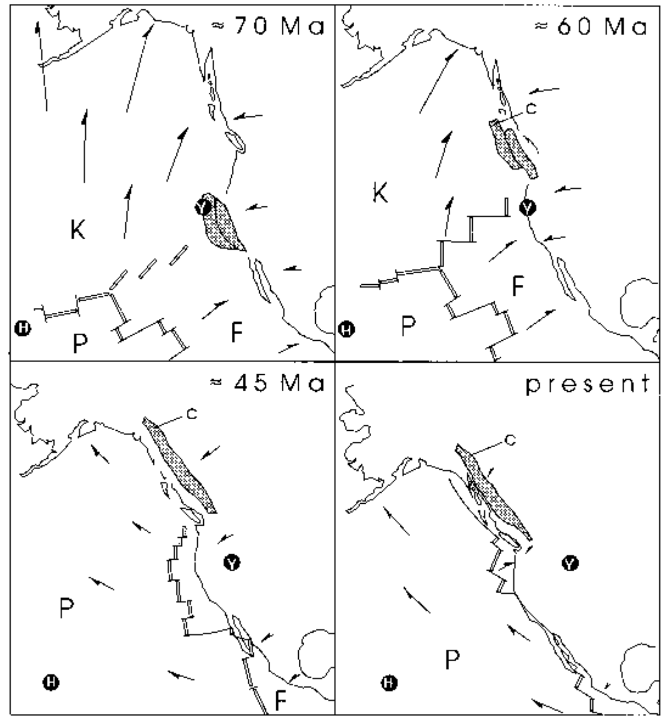

Figure 3. Paleogeographic reconstructions, in a fixed-hotspot reference frame, of North American Cordillera from 70 Ma to present (modified from Engebretson et al., 1985). Hawaii (H) and Yellowstone (Y) hotspots are indicated by black dots. Arrows are vectors indicating direction and distance traveled by each of Kula (K), Farallon (F), Pacific (P), and North American plates in 10 m.y. Syndisplacement attenuation of the displaced portion of the Intermontane belt (patterned area) is schematically accommodated by one fault. Passage of northern (outboard) Intermontane belt over Yellowstone hotspot at 70 Ma generated Carmacks Group (c).

Northward displacement of the Carmacks Group was facilitated by partial coupling with an adjacent, north-moving oceanic plate (Fig. 3). Table 1 summarizes tangential velocities, measured parallel to a great circle passing though the 70 Ma Yellowstone position and the present Carmacks location, for Kula–North America relative motion. Assuming 100% coupling (using all available margin-parallel component) and a total displacement of 2000 km, a 53 Ma arrival time is possible. If a 45 Ma arrival time is allowed, 70% of the margin-parallel component is needed.

Orogen-parallel displacement of the Carmacks Group by 1900 km is in conflict with estimates based on systematic mapping (Price and Carmichael, 1986). Terranes within and adjacent to the north-

TABLE 1. TANGENTIAL VELOCITIES FOR KULA-NORTH AMERICA RELATIVE MOTIONS FROM 70 TO 45 MA.

Time Interval		Margin-parallel	Margin-parallel	Total
From (Ma)	To (Ma)	component (km/m.y.)	displacement (km)	displacement from 70 Ma
70	65	133	685	685
65	55	107	1070	1735
55	45	124	1240	2975

ern Intermontane belt are juxtaposed with autochthonous North American strata along the Finlayson Lake and D'Abbadie fault zones. These originally contiguous structures are dextrally offset by the Tintina fault by almost 500 km (Fig. 1; Roddick, 1967; Price and Carmichael, 1986). A Paleocene plutonic belt that intersects the fault is similarly offset (J. K. Mortensen, 1995, personal commun.), indicating that motion is younger. Gabrielse (1985) suggested that linear faults lying between the Tintina and Teslin faults (Fig. 1) accommodated an additional 500 km of dextral translation. However, some of these faults appear to be truncated by undeformed mid-Cretaceous granites and may predate the Carmacks Group. Thus a maximum of 1000 km of northward translation of the northern Intermontane belt can be accommodated along known structures that were active until the Eocene.

Because of the axial symmetry of the geocentric axial dipole, paleolongitude, and therefore paleolongitudinal displacements, cannot be determined from a single paleopole. However, the Yellowstone hotspot correlation fixes the paleolongitude of rocks of the northern Intermontane belt at 70 Ma, providing an important new constraint for Cordilleran tectonic reconstructions. Assuming that orogen-parallel offset of Carmacks Group is approximated by the paleomagnetically determined displacement (1900 km), we estimate 1000 km of post–70 Ma cross-orogen shortening.

Hotspots with lifespans of around or greater than 100 m.y. are common (e.g., Clague and Dalrymple, 1989; Lawver and Müller, 1994). Thus the Yellowstone hotspot may have been initiated prior to the Late Cretaceous. The Cretaceous and Tertiary trajectory of the hotspot track was dominantly west-to-east and was close to the western North American margin (Fig. 2; Engebretson et al., 1985). Because oceanic plates within the northern Pacific Basin since 180 Ma generally exhibit northward, eastward, or southeastward displacements relative to North America (Engebretson et al., 1985), Yellowstone hotspot volcanic rocks emplaced onto these oceanic plates would have soon entered nearby subduction zones. These young, buoyant and "hard-to-subduct" edifices may have accreted and, like the Carmacks Group, been displaced along the margin.

CONCLUSIONS

The paleomagnetic latitude of the Carmacks Group places it in the vicinity of the Yellowstone hotspot at 70 Ma. We propose that the Carmacks Group represents the Late Cretaceous expression of the Yellowstone hotspot, and that these rocks have since been carried 1900 km to the north by coast-parallel transport. This correlation fixes the paleolatitude and the paleolongitude of the northern Intermontane belt at 70 Ma.

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