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Were the Ancestral Rocky Mountains Glaciated? Preliminary Evidence, and Tectonic Implications

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Introduction

The Late Paleozoic Ancestral Rocky Mountains (ARM) formed in western equatorial Pangea. Although this system has been the focus of significant research efforts, several basic aspects of its climatic and tectonic setting remain obscure. A key issue bearing on and linking both climatic and tectonic considerations is the topography of the system (cf. Chase et al., 1998). Specifically, how high were the mountains? Citing the thick, coarse clastics that mantle many of the classic ARM uplifts, Mallory (1972a) postulated elevations of 1500-3000 m, although paleoaltimetry is difficult to estimate owing to uncertainties regarding relative rates of uplift, denudation, and subsidence. Mack et al. (1979) first discussed the ARM in the context of its low-latitude position, and suggested geographically controlled climatic variations in the vicinity of the ARM, implying elevations significant to create orographic effects. More precise estimates of paleoaltimetry, however, have been elusive.

Here, we present preliminary evidence for alpine-type glaciation in parts of the equatorial ARM. Confirmation of our hypothesis implies at least locally high elevations for the ARM, assuming a climate system similar to the modern.

The Late Paleozoic Icehouse and Pangean Orogenesis

The Late Paleozoic is well known as a time of significant glaciation, marked at high (paleo)latitudes by widespread and unequivocal evidence for continental glaciers, and at low latitudes by pervasive and classic Pennsylvanian "cyclothems" representing the repeated waxing and waning of the Gondwanan ice sheets (Crowell, 1978; Veevers and Powell, 1987). The Late Paleozoic was also a time of widespread orogenesis related to final Pangean assembly. The Central Pangean Mountains (Appalachian-Mauretanide-Hercynian system) spanned low latitudes and may have reached significant elevations (> 3km; Otto-Bliesner, 1993). Given the temporal coincidence of both "icehouse" conditions and significant orogenesis in the Late Paleozoic, alpine glaciation at low latitudes –analogous to modern (and Pleistocene) tropical glaciers– is reasonable. Such systems, however, have exceedingly low preservation potential, and evidence for glacial ice beyond the limits of the classic Gondwanan ice centers has never been reported.

The Silt Problem: Hints of Ice?

Over the past decade, there has been growing recognition of the prevalence of eolian silt (loess) in the late Paleozoic record, especially in and around the ARM. Silt occurrences range from massive and locally pedogenically modified siltstone interpreted as loess deposits (e.g., Johnson, 1989; Kessler et al., 2001) to anomalously silt-rich fluvial and marine units that likely incorporate (reworked) silt of eolian origin (e.g. Soreghan, 1992; in press). Conditions in this part of western Pangea were apparently favorable for the generation of extensive silt, but the mechanism(s) for formation of this silt remain obscure.

Silt production requisite for significant loess accumulation is a consequence of energetic processes (Assallay et al., 1998). Pye (1995) noted that Quaternary loess occurs in periglacial, perimontane, and peridesert regions, apparently reflecting different modes of possible silt formation including, for example, salt weathering in hot deserts (Goudie et al., 1979) and tropical weathering (Nahon and Trompette, 1982). Most agree, however, that large-scale production sufficient to generate thick loess appears to reflect glacial grinding, and/or weathering in high, cold, tectonically active mountains (Smalley, 1995; Assallay et al. 1998).

Owing to the well-recognized low-latitude position of the ARM, and presumed aridity (western ARM), loessite deposits identified in this region have been inferred to be desert loess (e.g., Johnson, 1989; Soreghan, 1992; Kessler et al., 2001). The large volume of upper Paleozoic loess, however, is not consistent with the relative dearth of loess in modern deserts. We suggest that preliminary provenance and geochemical data are most consistent with a possible glacial and/or high mountain origin. Key data bearing on this interpretation include the following:

(1) Whole-rock (XRF-based) geochemistry indicates that Chemical Index of Alteration (CIA) values are very low, signifying minimal weathering involved in production of the silt.

(2) Detrital-zircon-based provenance analysis confirms that much of the silt was derived directly from Precambrian basement material (M.J. Soreghan et al., in press).

(3) Inferred peak Gondwanan ice (Crowell, 1995) coincides with apparent peak silt flux (as recorded in ARM strata), and a close spatial relationship exists between loess accumulations, and the Precambrian-cored Ancestral Rocky Mountains (Soreghan and Soreghan, in press).

If our inference of a periglacial and/or perimontane origin for the silt is correct, it implies significant elevations for at least parts of the tropical ARM.

Paleotopography and Periglacial Strata?

Confirmation of the glacial hypothesis requires direct evidence for mountain ice in the ARM, which is extremely difficult owing to poor preservation potential of alpine systems. Nevertheless, two lines of evidence bear on this possibility:

(1) Geomorphological evidence: If the ARM were glaciated, the possibility exists of preserved glacially carved features. Preserved paleotopography is rare, but has been documented for the late Paleozoic in regions of both glacial (e.g., Australia; Eyles and de Broekert, 2001). and non-glacial (e.g., U.S. mid-continent; Gilbert, 2002) origin. We recognize apparent buried late Paleozoic topography in the classic (Colorado) ARM on the basis of Permo-Triassic strata that drape paleodrainages displaying features of possible glacial origin.

(2) Sedimentological evidence: Preservation of periglacial strata is more likely than preservation of actual paleotopography, and we suggest that selected areas proximal to classic ARM uplifts (e.g., Uncompahgre) display features consistent with a possible glacial influence.

Alpine Glaciation in the ARM: Implications for Paleoaltimetry and Paleotectonics

On the basis of minimum elevations of terminal moraines, tropical glaciers of Equador, Kenya, and New Guinea extended to elevations of 3200-4000 m (average 3600 m) during the Last Glacial Maximum (Heine, 1995; Kaser and Osmaston, 2002). Modern analogy therefore implies that glaciation of the (tropical) ARM similarly records <u>minimum</u> elevations in this range. Significant structural relief adjacent to many ARM uplifts has long been recognized, but our reasoning suggests an additional 3-4 km (minimum) of topographic relief; yet using the zero isopach of the Pennsylvanian System (Mallory, 1972b) as a gauge, Precambrian-cored uplifts of the classic ARM were locally quite narrow (<25–100 km). Recognition of such significant structural AND topographic relief along such narrow uplifts bears on our understanding of tectonic styles of the ARM, and geodynamic mechanisms responsible for the uplifts.

Conclusions

We suggest the possibility of alpine glaciation of the ARM inferred on the basis of volume, provenance, and geochemistry of loess, in addition to provisional geomorphological and sedimentological evidence for ice within the classic ARM region. Our hypothesis implies very high elevations for the relatively narrow uplifts of the classic ARM, which bears on the geodynamic interpretation of the ARM system.

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