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REPLY TO COMMENT ON "AGE OF PRE-NEOGLACIAL CIRQUE MORAINES IN THE CENTRAL NORTH AMERICAN CORDILLERA"

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Begét's several criticisms of our paper deal with our treatment of the location and interpretation of his charcoal sites, tephrochronologic considerations in the North Cascades, theoretical considerations of climate-forcing mechanisms, considerations of the merits of or problems with use of pollen and lake sediment records, and ice-core isotope variations as proxy climate indicators. We will address each of these points in order.

Begét's two published maps of the White Chuck site (1981, Fig. 2, and 1984, Fig. 6) apparently are not drawn on topographic bases, and do not agree on the positions of the charcoal sites relative to Portal Peak, *or* the latitude of the charcoal sites, *or* the azimuthal relationship of the two charcoal sites, *or* the laboratory numbers of the 8380 ± 80 yr BP radiocarbon age. Since Begét's (1981) Figure 2 is labeled a sketch map, we take Figure 6 (1984) to be the more accurate map. But, this map also contains inaccuracies; 1) it shows the north rim of the cinder cone to extend westward across the major gully northeast of Portal Peak, whereas the cone lies entirely southeast of the gully; 2) it leaves off the highest, southwest rim of the cinder cone, and 3) when the (closely-spaced) charcoal localities in that figure are plotted on the best available topographic base (Fig. 1 in this reply) using Begét's mapped distance and azimuth from Portal Peak, the charcoal sites appear to be located on the east-side distal slope of the cinder cone. But, there is no till on that slope, as Begét himself (1984, Fig. 6) indicates. Moreover, if the "gully, pond, and other physical features described [by Davis and Osborn, 1987] lie as far as several hundred meters southwest from the charcoal locality" (Begét's comment), then the charcoal localities lie up to several hundred meters northeast of the physical features, or on the east side of the cinder cone where there is no till. Begét's admonition that his charcoal localities do not lie in the low flat area we (1987) described is unfairly directed, because given his crude maps there was little other choice in our interpretation. Moreover, our field examination of the cinder cone revealed no exposures like that described ("distal flank of low morainal ridges, near crest") in Begét's comment. Although Begét perhaps correctly criticizes our interpretation of his charcoal site localities, he still fails to provide a photograph or detailed and accurate geologic map to show where his site *is*. This confusion will be cleared up only when such data are forthcoming. A reasonable presumption is that a site and interpretation which serve as the cornerstone of a formally named event ("Mesoglaciation", Begét, 1983) should be easily locatable and subject to independent verification.

A further point regarding the glacier that Begét claims advanced to form the White Chuck moraines is obvious from the topographic map shown here as Figure 1: there is little likelihood that the small cirque glacier rode up and over the high, sharp, southwest rim in preference to flowing down the large, deep trough on the northwest edge of the cinder cone. This glaciological implausibility also has important connotations for interpretation of former equilibrium line altitudes (ELA's) of glaciers in the area of the White Chuck cinder cone. Begét's (1984) White Chuck moraines require a much greater ELA depression than the 85 m he suggests.

We do not find any conflict with Begét's tephra stratigraphy, which only provides a maximum age for the White Chuck

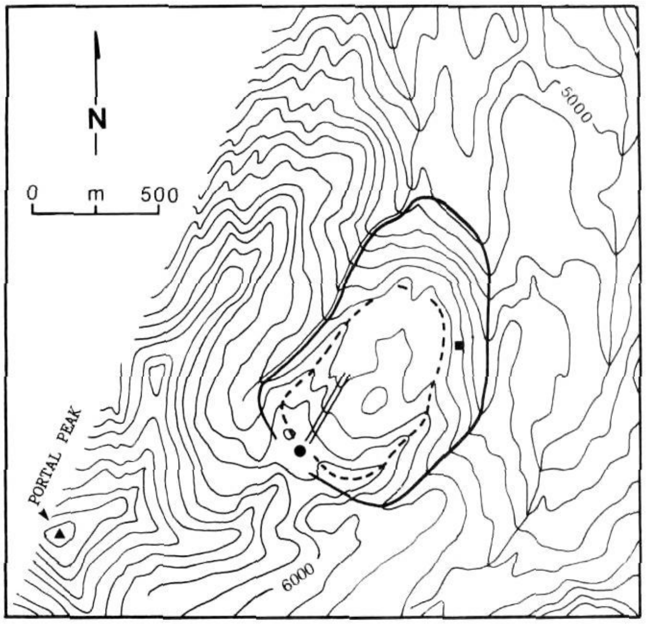

FIGURE 1. Topography of the White Chuck cinder cone and vicinity, with contours enlarged from the Glacier Peak Quadrangle (1:62,500). Bold line: cinder cone boundary; dashed line: cinder cone rim; solid square: calculated position of Begét's charcoal sites, based on the distance (1.78 km) and azimuth (65 E of N) from Portal Peak shown in Figure 6 of Begét (1984); solid circle and adjacent double line: pond and gully, respectively, described by Davis and Osborn (1987). Contour interval 30.5 m.

Topographie du cône de scories de White Chuck et des environs (à partir de la carte de Glacier Peak (1/62 500). Ligne grasse: limites du cône de scories; tirets: rebords du cône de scories; carré noir: position des sites à charbon de Begét calculée d'après la distance (1,78 km) et l'azimut (65 E du N) à partir de Portal Peak comme l'illustre la figure 6 de Begét (1984); cercle noir et ligne double adjacente: étang et ravin, décrits par Davis et Osborn (1987). Équidistance: 30,5 m.

moraines of 11.2 ka. Considering the statistical and other errors inherent in radiocarbon dating, the White Chuck moraines could be the same age as the Temple Lake moraine in Wyoming (minimum-limiting age of 11,400 ± 630 yr BP [GX-12719]; Zielinski and Davis, 1987) and the Triple Lakes moraines in Colorado (minimum-limiting age of 10,410 ± 520 yr BP [GX-11774]; Davis, 1987). It is also conceivable that Glacier Peak tephra occurs on the White Chuck till, but has not yet been found, or was mostly eroded off. Such tephrostratigraphic problems have been noted elsewhere in the North Cascade Range (Porter, 1978; Waitt *et al.*, 1982). In any event, Begét's tephra mapping does not preclude a pre-Holocene age of the till.

Begét goes on to state that we "maintain that oscillations of climate and concomitant glacier advances did not occur in the early Holocene because models of orbital climatic forcing do not retrodict (*sic*) such cooling." We never said this in our paper, nor did we "assume that astronomic effects... are solely responsible for and can be correlated with terrestrial climatic changes...". In fact, we made no claims at all as to the causes of short-term Holocene climatic oscillations. We merely pointed out that extraterrestrial climatic forcing provided 5 to 10% more solar radiation in the early Holocene Northern Hemisphere summer than it does today (Davis and Osborn, 1987, p. 369), and hence that the warm early Holocene would have been a relatively difficult time to maintain alpine glaciers. Begét plots net annual solar radiation at 45°N as curve F on his Figure 1, which supports our view that the early Holocene was much warmer than the late Holocene, therefore less conducive for alpine glacier growth. In all alpine areas of the world late Holocene (Neoglacial) moraines were built during the coldest time since late Pleistocene deglaciation, yet represent much less extensive glacier advances than do the White Chuck moraines. The White Chuck moraines represent snowline depressions at least 85 m greater than those during the late Holocene, an unlikely situation during the early Holocene, considering the much higher solar radiation values.

Begét also claims that our "discussion mixes vegetation records from both high and low elevation bogs and lakes, even though it is likely that vegetation at the diverse sites responded in different ways to short term climatic events". But we were not indiscriminate in our discussion of pollen records; rather we analyzed any and all records from the North American Cordillera that included radiocarbon dating control spanning the early Holocene. We recognized that adjacent high- and low-elevation pollen records might preferentially reflect different responses to climatic change; for example, low elevation sites are better for monitoring fluctuations of the lower treeline in response to changes in mean annual precipitation, rather than summer temperature. In all alpine areas forest vegetation reached maximum altitudes by the middle of the Holocene, and most pollen records *do* reflect a cooling trend during Neoglaciation, despite Begét's statement to the contrary. In some alpine areas forest vegetation was not completely established by the early Holocene, thus environmental stress should have been high. Yet, no pollen records suggest a reversal in either warming summer temperature or drying annual precipitation during the early Holocene. Sampling resolution on the order of a couple hundred years is certainly sufficient enough to reflect the climatic fluctuations necessary to explain glacier advances such as those represented by the White Chuck moraines. In their extensive review of vegetational history and paleoclimatic implications during deglaciation in the northwestern United States, Barnosky *et al.* (1987) reached conclusions similar to our own, that the early Holocene was the warmest and driest time following deglaciation throughout the area, without evident climatic reversals.

Begét suggests that we "do not consider proxy climatic data sets other than pollen curves, including some which may be especially sensitive to glacier fluctuations." He first cites Leonard's (1986) organic carbon record from lake sediment cores in the Canadian Cordillera as evidence for a glacier advance about 8 ka. But, Leonard's ages for early Holocene glacial activity are only estimates based on extrapolated sedimentation rates; the oldest dated horizon in Leonard's sediment cores is Mazama tephra, at 6.8 ka. Even if these ages are taken at face value, Leonard (1987) has revised his estimated age of early Holocene glacial activity to greater than 9 ka; it cannot be used to support Begét's proposed 8.4 ka climatic reversal. New information from the Canadian Rocky Mountains further confounds Begét's concept of alpine glacier advances at 8.5-7.5 ka due to climatic cooling. Luckman (1988) radiocarbon-dated wood fragments from the snout of Athabasca Glacier in Alberta to suggest that a mature tree cover existed for many kilometers upstream of the present glacier snout about 8.3 to 8.0 ka.

In regard to the Wind River Range of Wyoming, lake sediment cores do exhibit decreases in organic carbon during portions of the early Holocene. However, these carbon values are notably higher than those related to deposition of the outer type Temple Lake moraine in the latest Pleistocene (Zielinski and Davis, 1987). As for the San Juan Mountains in Colorado, the "lake records" (*sic*) (bog sediment cores) that Begét cites from Andrews *et al.* (1975) include thin micaceous sand lenses that could have resulted from short-term storm activity or any number of possible explanations other than cooling during the early Holocene (P. Carrara, 1988, oral communication). Neither of the lacustrine sediment records from the Wind River Range or San Juan Mountains supports an early Holocene glacial advance of the magnitude represented by the White Chuck moraines.

In a long discussion Begét claims that stable isotope studies of ice cores in Greenland and Antarctica support a global climatic cooling during the early Holocene. However, many ice core records do not support this view, but in contrast suggest that the early Holocene was part of the warmest period in the last 100 ka (Koerner, 1988). In any event, ice core records from the polar regions are poor choices for a discussion of Holocene climatic change in the mid-latitude North American Cordillera. For example, the effects of high summer insolation in high northern latitudes during the earliest Holocene may have been buffered by the lingering presence of the Laurentide icesheet (Kutzbach and Guetter, 1986; Kutzbach and Gallimore, 1988; Barnosky *et al.*, 1987; Bartlein, 1988).

In summary, we do not deny that periodic climatic oscillations may have caused alpine glacier advances during the Holocene. However, we contend that these advances were never greater than those of the late Holocene (Neoglaciation), and that more extensive glacier advances represented by moraines such as the Triple Lakes in Colorado, the type Temple Lake in Wyoming, and perhaps even those in the White Chuck cinder cone near Glacier Peak, represent climatic changes more likely during the late Pleistocene rather than during the warm early Holocene. If Begét's 8.4 ka age for the White Chuck moraines is correct, the implied cooling event is an anomaly amongst dozens of other well-dated climatic records in the North American Cordillera.

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