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LETTER TO THE EDITOR

Comments on "Debris-Covered Glaciers in the Sierra Nevada, California, and Their Implications for Snowline Reconstruction," by D. H. Clark, M. M. Clark, and A. R. Gillespie

Clark *et al.* (1994) discuss rock glaciers and their implications for snowline reconstruction in the Sierra Nevada, California. In the first part of their paper the authors claim that the rock glaciers studied are actually debris-covered glaciers of the late Holocene age. In the second part of the paper they recalculate equilibrium-line altitudes (ELAS) according to their findings. In this letter I challenge both their interpretation of rock glaciers as debris-covered glaciers and, accordingly, their conclusion regarding snowline reconstruction. The evidence presented strongly suggests that the rock glaciers in question are indeed of periglacial origin and indicate the existence of at least discontinuous alpine permafrost in their area.

Clark *et al.* (1994, pp. 139–153) oppose the widely held view that rock glaciers are a morphological expression of mountain permafrost (e.g., Barsch 1987, 1988, 1992; Cui and Cheng, 1988; Giardino and Vitek, 1988; Gorbunov, 1983; Haeberli, 1985; Haeberli and Schmid, 1988; Haeberli *et al.*, 1988, 1992; Keller and Gubler, 1993; Vonder Mühll and Haeberli, 1990; Vonder Mühll and Schmid, 1993) and quote several authors who have ". . . demonstrated that some rock glaciers are cored by glacier ice mantled with a continuous and relatively thin debris cover" (p. 139). None of these authors has presented enough evidence to show unambiguously the existence of a continuous ice core of glacial origin. The periglacial model of rock glacier origin is based on a large number of ground temperature measurements, electrical resistivity, radio-echo, and seismic refraction soundings, as well as core drilling through an active rock glacier in the Swiss Alps (Haeberli *et al.*, 1988). These measurements were carried out not only in the Alps but also in the Argentine Andes (Ahumada, 1992; Happoldt and Schrott, 1992; Schrott, 1991), the Himalaya (Jakob, 1992; Barsch and Jakob, 1993; Fujii and Higuchi, 1976), and the mountains of mainland Norway and Svalbard (Sollid and Sørbel, 1992). These observations affirm that the elevations of many rock glacier termini coincide closely with the lower limits of discontinuous alpine permafrost in the representative areas.

The absence of contemporary permafrost features, as noted by the authors, cannot be used as an argument for the nonexistence of permafrost. Morphologic, textural, and hydrologic conditions in steep alpine terrain rarely allow the development of morphological expressions of permafrost other than rock glaciers themselves. Even if some of these forms are found they do not necessarily indicate permafrost conditions. For example, stone stripes or small stone circles can develop from diurnal freeze–thaw cycles (e.g., Williams and Smith, 1989). Since Clark *et al.* question rock glaciers as indicators of mountain permafrost, ground temperature measurements over a whole year would be helpful in clarifying this question.

On page 141, Clark *et al.* note that glacier ice on Southfork Pass rock glacier continues beneath the debris cover and does not end there. They present a photograph of a meltwater pond in the upper reaches of the rock glacier as proof (p. 143, Fig. 3). Without further evidence the claimed continuity of glacier ice must be placed in doubt. The meltwater depression is called a "thermokarst pond" by the authors. By definition, thermokarst requires the presence of degrading permafrost (Harris *et al.*, 1988; Williams and Smith, 1989). However, the pond is surrounded by overhanging ice. The ice is identified as glacial in origin from the presence of silt layers, which are separated by zones of clear ice thought to represent annual layering. Horizontal layering of ice-rich silt and sand is a common phenomenon in permafrost environments (e.g., Mackay and Dallimore, 1992, Fig. 4; Haeberli *et al.*, 1988, Fig. 5) and therefore cannot be used alone to determine the origin of an ice body. Ice fabrics, ice bubble patterns, and structural details could be examined to help understand the origin of the ice. In addition, water quality (i.e., ionic concentrations and oxygen isotopes) of the rock glacier ice could be compared with that of nearby glacier ice. Even if the observed ice is glacial in origin, this does not allow the conclusion to be drawn that the rock glaciers are indeed ice-cored throughout their entire length, since dead glacier ice can be incorporated into rock glaciers (Haeberli, 1989).

Several of the authors' own observations point to permafrost conditions and a periglacial origin for the rock glaciers in the study area. Clark *et al.* list extensive ablation drift upslope of the rock glacier termini, resid-

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longitudinal and transverse ridges in the drift, thermokarst features, and a concave deflated character of the debris mass as evidence for remnant debris-covered glaciers (p. 147). Debris-covered glaciers, however, typically do not display longitudinal or transverse ridges but lose their flow morphology as they downwaste. This and the other criteria point toward a typical rock glacier.

On page 140, the authors differentiate between lobate and tongue-shaped rock glaciers—a widely used morphological distinction. They write: ". . . (in contrast to valley wall [*lobate*] rock glaciers which may be periglacial in origin)." The morphological expression does not necessarily imply different internal structure and the presence or absence of permafrost. Clark *et al.* indicate a periglacial origin by mentioning internal shearing along ice lenses within the rock debris and the existence of local ice within the creeping talus rock mass [*lobate rock glaciers*]. The authors state on page 144 that ". . . valley wall rock glaciers reach altitudes more than 200 m below the lowest contemporary debris-covered glaciers. . . ", contradicting their conclusion that permafrost is absent from the area (p. 143). The conclusion seems to be that if those lobate rock glaciers are still active, permafrost does exist even below the lower limit of the tongue-shaped rock glaciers. If so, this would suggest a lower limit of discontinuous alpine permafrost about 3200 m in their study area.

A 1-m pit was excavated by the authors into the steep face of the rock glacier terminus. Saturated silty matrix was encountered at a temperature of ". . . only slightly above 0 degrees C" (p. 141). This observation, which was carried out in late summer, probably indicated the existence of a 1-m-thick active layer with permafrost below. In late summer and early fall, positive temperatures can prevail to a depth of several meters, below which permafrost is encountered, as demonstrated by Haeberli *et al.* (1988) on the rock glacier Murtèl I in the Swiss Alps.

On p. 143, the authors estimate rock glacier creep (flow) rates at 10–20 cm per year based on photogrammetric measurements of the movements of an individual large boulder. Linear extrapolation of these rates using the length of the Southfork Pass rock glacier of 1600 m would yield ages of 8000–16,000 yr. These ages are an indication that the rock glacier commenced its movement at the end of the last glaciation. Clark *et al.*, however, assume that the age of the rock glacier coincides with the end of the late-Holocene Recess Peak advance, without explaining the discrepancy between their assumption and the extrapolated age.

On pages 144–146, Clark *et al.* describe the insulating properties of debris covers on glaciers, citing Balch ventilation, and concur that the temperature within the debris cover is close to freezing even in summer. These low temperatures constitute another strong argument for the occurrence of permafrost in the region.

The second part of the paper is based on the assumption that the rock glaciers are remnants of debris-covered glaciers of Recess Peak age, contradicting the view of Burbank (1991) and Yount *et al.* (1982). Without presenting absolute dates or more conclusive evidence, this assumption and further implications regarding snowline elevations cannot be supported.

The periglacial model of rock glacier formation has been challenged and criticized many times in the past. However, the evidence presented fails to prove a glacial origin for the rock glaciers and in some cases even points toward a periglacial origin. Permafrost describes the thermal condition of the ground which is crucial for the long-term survival of underground ice. It cannot be assessed without the appropriate measuring techniques. The following additional observations would greatly clarify the origin of their rock glaciers.

—Year-round ground temperature measurements at different altitudes and different aspects to investigate possible permafrost conditions.

—Absolute ages of the rock glaciers and (other) Recess Peak deposits.

—Geophysical measurements on nearby glacier ice and rock glaciers to differentiate between different ice characteristics and to detect an active layer if present.

—Ice cystallography of several samples taken at various locations on, and at various depths within, the rock glacier to differentiate between glacier and nonglacier ice.

In summary, the evidence presented in the paper is insufficient to reject the periglacial origin of the tongue-shaped rock glaciers and also is insufficient to demonstrate a continuous ice core within the rock glaciers. Contrary to the authors' views, it seems likely that discontinuous permafrost, with a lower limit between 3200 and 3400 m, is common in their area. Finally, if the rock glaciers developed during and after Pleistocene deglaciation, as indicated by Burbank (1991) and Young *et al.* (1982), and not during the Recess Peak Neoglacial advance, as tentatively confirmed by linear extrapolation of present creep rates, the recomputation of equilibrium-line altitudes and their paleoclimatic implications must be questioned.

REFERENCES

Ahumada, A. L. (1992). Periglacial climatic conditions and vertical form associations in Quebrada Benjamin Matienzo, Mandoza, Argentina. *Permafrost and Periglacial Processes* 3, 221–224.

Barsch, D. (1987). The problem of the ice-cored rock glacier. *In* "Rock Glaciers" (J. R. Giardino, J. F. Shroder, and J. D. Vitek, Eds.), pp. 45–53. Allen and Unwin, Boston, MA.

Barsch, D. (1988). Rockglaciers. *In* "Advances in Periglacial Geomorphology" (M. J. Clark, Ed.), pp. 69–90. Wiley, New York.

Barsch, D. (1992). Permafrost creep and rockglaciers. *Permafrost and Periglacial Processes* 3, 175–188.

Barsch, D., and Jakob, M. (1993). Active rockglaciers and the lower limit of discontinuous alpine permafrost in the Khumbu Himalaya, Nepal. *In* "Proceedings VIth International Conference on Permafrost," Vol. 1, pp. 27–31.

Burbank, D. W. (1991). Late Quaternary snowline reconstructions for the southern and central Sierra Nevada, California and a reassessment of the "Recess Peak Glaciation." *Quaternary Research* **36**, 294–306.

Clark, D. H., Clark, M. M., and Gillespie, A. R. (1994). Debris-covered glaciers in the Sierra Nevada, California and their implications for snowline reconstructions. *Quaternary Research* **41**, 139–153.

Cui, Z., and Cheng, Z. (1988). Rock glaciers in the source region of Urumqui River, middle Tian Shan, China. *In* "Proceedings Vth International Conference on Permafrost in Trondheim, Norway," August 1988, Vol 1, pp. 724–727.

Fujii, Y., and Higuchi, K. (1976). Ground temperature and its relation to permafrost occurrence in the Khumbu Himal and Hidden Valley. *Seppyo* **38**, 125–141.

Giardino, J. R., and Vitek, J. D. (1988). Rock glacier rheology: A preliminary assessment. *In* "Proceedings Vth International Conference on Permafrost 1988," Vol 1, pp. 744–748.

Gorbunov, A. P. (1983). Rock glaciers of the mountains of middle Asia. *In* "Proceedings IVth International Conference on Permafrost 1983," pp. 359–362.

Haeberli, W. (1985). Creep of mountain permafrost: Internal structure and flow of Alpine rock glacier. *Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie and Glaziologie [Zürich]* **77**, 142.

Haeberli, W. (1989). Glacier ice-cored rock glaciers in the Yukon Territory, Canada? *Journal of Glaciology* **35**.

Haeberli, W., and Schmid, W. (1988). Aerophotogrammetrical monitoring of rock glaciers. *In* "Proceedings Vth International Conference on Permafrost in Trondheim, Norway," August 1988, Vol. 1, pp. 764–769.

Haeberli, W., Huder, J., Keusen, H. R., Pika, J., and Röthlisberger, H. (1988). Core drilling through rock glacier permafrost. *In* "Proceedings Vth International Conference on Permafrost in Trondheim, Norway." August 1988, Vol. 2, pp. 937–942.

Haeberli, W., Evin, M., Tenthorey, G., Kensen, R., Hoelzle, M., Keller, F., Vonder Mühll, D., Wagner, S., Pelfini, W., and Smiraglia, C. (1992). Permafrost research sites in the Alps: Excursions of the International Workshop on Permafrost and Periglacial Environments in Mountain Areas. *Permafrost and Periglacial Processes* **3**, 189–202.

Happoldt, H., and Schrott, L. (1992). A note on ground thermal regimes and global solar radiation at 4720 m a.s.l., High Andes of Argentina. *Permafrost and Periglacial Processes* **3**, 241–246.

Harris, S. A., French, H. M., Heginbottom, J. A., Johnston, B., Ladanyi, D., Sego, D. C., and van Everdingen, R. O. (1988). "Glossary of Permafrost and Related Ground-Ice Terms." National Research Council Canada, Technical Memorandum No. 142.

Jakob, M. (1992). Active rock glaciers and the lower limit of discontinuous alpine permafrost, Khumbu Himalaya, Nepal. Permafrost and Periglacial Processes **3**, 253–256.

Keller, F., and Gubler, H. (1993). Interaction between snow cover and high mountain permafrost Murtèl/Corvatsch, Swiss Alps. *In* "Proceedings VIth International Conference on Permafrost," Vol. 1, pp. 332–337.

Mackay, J. R., and Dallimore, S. R. (1992). Massive ice of the Tuktoyaktuk area, western Arctic coast, Canada. *Canadian Journal of Earth Sciences* **29**, 1235–1249.

Schrott, L. (1991). Global solar radiation, soil temperature and permafrost in the Central Andes, Argentina: A progress report. *Permafrost and Periglacial Processes* **2**, 59–66.

Sollid, J. L., and Sørbel, L. (1992). Rock glaciers in Svalbard and Norway. *Permafrost and Periglacial Processes* **3**, 215–220.

Vonder Mühll, D., and Haeberli, W. (1990). Thermal characteristics of the permafrost within an active rock glacier (Murtèl/Corvatsch, Grisons, Swiss Alps). *Journal of Glaciology* **36**, 151–158.

Vonder Mühll, D., and Schmid, W. (1993). Geophysical and photogrammetrical investigation of Rock Glacier Muragl I, Upper Engadin, Swiss Alps. *In* "Proceedings VIth International Conference on Permafrost, Vol. 1, pp. 654–659.

Williams, P. J., and Smith, M. W. (1989). "The Frozen Earth. Fundamentals of Geocryology." Cambridge Univ. Press, London/New York.

Yount, J. C., Birkeland, P. W., and Burke, R. M. (1982). Holocene glaciation, Mono Creek, central Sierra Nevada, California. *Geological Society of America Abstracts with Programs* **14**, 246.

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