

# Permafrost and Climate Change in the Colorado Front Range

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**Abstract:** Recent temperature observations along Trail Ridge Road indicate that there is no permafrost above treeline and the climate in that location has recently undergone a dramatic shift in the first decade of the 21st Century from a warming to cooling regime.

**Background:** The only known temperature based observation of permafrost in the Colorado Front Range was published by Ives(1973). The record [see Ives(1970), figure 3] shows that the thermal regime fits the definition of permafrost with two annual thermal cycles maintaining sub freezing temperatures at the base of the 3.8 m borehole on the North Slope of Niwot Ridge. A recent analysis of this temperature record used to document permafrost in the region indicates the permafrost is *Balch Ice* created and maintained by the infiltration of surface water and cold air into the borehole. The permafrost is the direct result of drilling the borehole. This suggests that at least some of the ice in the local rock glaciers have maintained subfreezing core temperatures and thus fit the definition of permafrost. *Balch Ice* is described in a fascinating book describing *ice caves* in Europe and elsewhere by Erwin Swift Balch {see Balch(1900)}. Goering and Kumar (1996) have determined that winter cold air advection in *open grade embankments* can lower the mean annual ground temperature by up to 5 C at Fairbanks, Alaska. An *ice cave* as described by Balch(1900) is similar to a deep well { *Balch Well* }, with no possibility for cold air escape, which is a more extreme case of *Balch Cooling* than the *ventilation of open grade embankments*, which are similar to talus slopes in the Colorado Front Range. *Balch Wells* may be present the at several sites in the rock cover of ablation moraines. Outcalt and Benedict (1965) indicated that the process of *Balch Ventilation*, which forms *Balch Ice*, protects glacier ice under ablation moraines belonging to the Temple Lake and Gannet Peak Stades of the *Little Ice Age*, which ended in the late 19<sup>th</sup> Century. They also noted that the same processes relieve interglacial pressure between bedrock and talus of *Little Ice Age* side valley rock glaciers producing downslope movement and surface flow morphology.

Early in the 21st Century, Jason Janke published a dissertation and a widely quoted paper (Janke(2005)) suggesting that permafrost is wide spread in the Colorado Front Range . He recently installed 30 shallow (less than 1 meter) instrumented boreholes with two temperature probes (at the surface and bottom in each hole) along Trail Ridge Road in Rocky Mountain National Park. A

two year record from these sites showed no Permafrost.

In July 2010 Janke installed three 6 m holes with thermal probes at 1 meter intervals. The temperature records from these installations has caused him to revise his previous estimate of the area underlain by permafrost downward to include only the are beneath surface flow lobes on the local rock glaciers (Janke(2011)). The mean annual temperature record form the three 6 m sites is worthy of detailed analysis.

The Mean Annual Ground Temperature Record at Three Six Meter Boreholes along Trail Ridge Road: The three sites all above treeline in tundra terrain with an elevation and ridge line orientation similar to Niwot Ridge, where permafrost was first discovered, are displayed as Figure 1.

**Mean Annual Ground Temperature Profiles at 3 Boreholes along Trail Ridge Road : 20 July 2010 - 19 July 2011**  
 If 6m BP2 inflection dates from 1976 then  $D=0.086 \text{ m}^2/\text{year}$  and the upper inflections are dated at 2.2, 0.3 and 9.3 years BP.

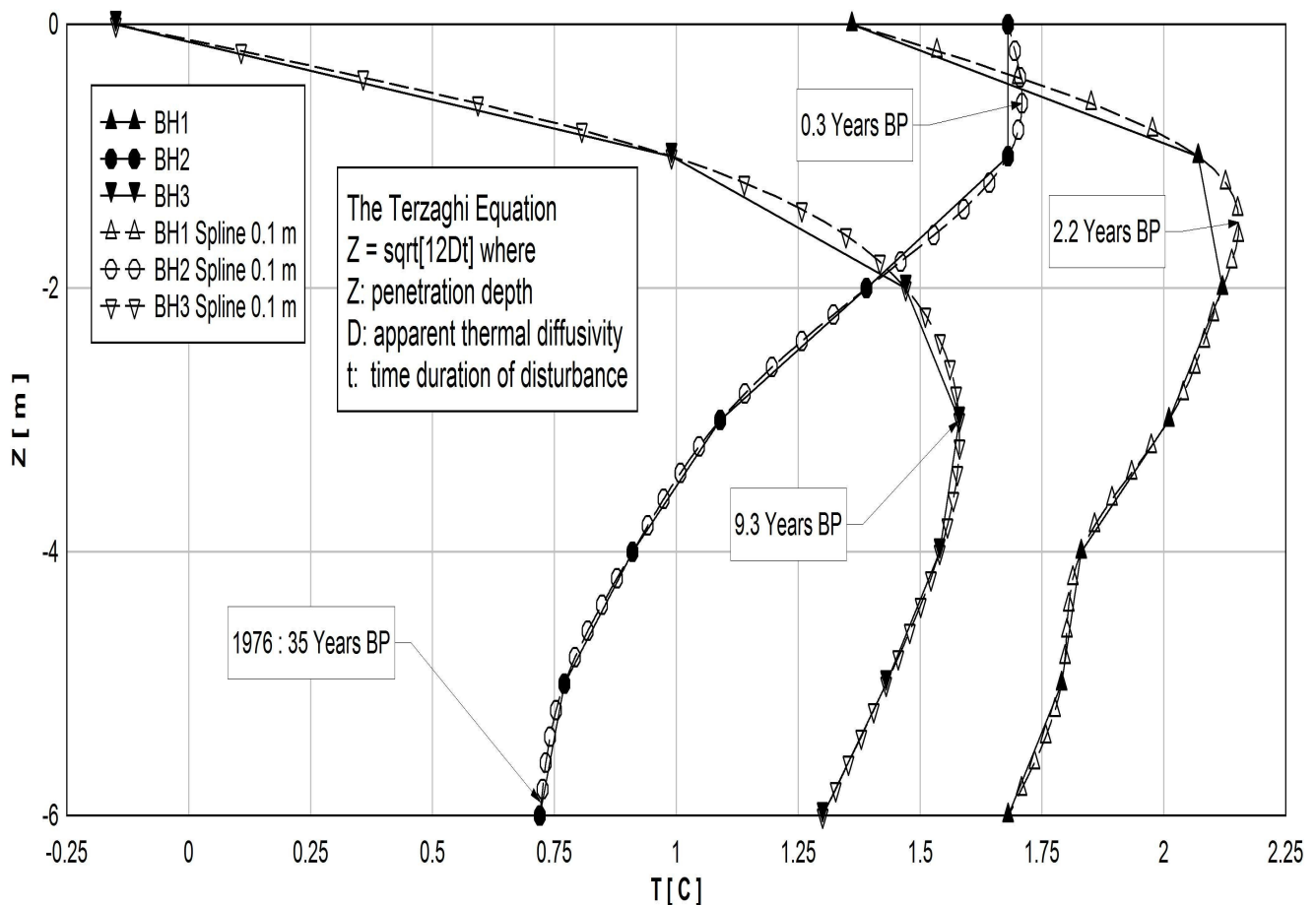


Figure 1. The mean annual ground temperature records from Trail Ridge Road.

If one assumes that the *inflection* at a depth near 6 m in the BH2 profile is the product of the dramatic global temperature warming regime transition that occurred in 1976 the equation developed by Terzaghi (1972) can be used to calculate the *apparent thermal diffusivity* and start times of the thermal disturbances indicated by other near surface *inflections*. It is important to note that the apparent *thermal diffusivity* is the product of both heat conduction and the effects of fusion, internal evaporation/condensation and vertical water migration. The upper inflections indicate that the ground temperature profiles on Trail Ridge are the product of a major climate regime change from warming to cooling early in the first decade of the 21st century. The time lag in between profiles is the likely product of complex local slope, exposure, substrate and surface conditions.

Conclusion: Near surface ground temperature data from remote locations may prove to be a more sensitive indicator of local climate change than air temperature, which is strongly modulated by land use changes and station relocation.

The deep borehole analysis validates the record from the shallow holes. All the available evidence indicates that there is no widespread modern permafrost beneath the ridge top tundra in the Colorado Front Range. However, it is probable that *Balch Ice* and *Little Ice Age Glacier Ice* that fits the definition of permafrost underlies flow lobes on the surface of some rock glaciers. It is apparent that there is a distinct state of *Balch Regional Geocryology*, which appears during the cooling that precedes regional permafrost development and follows permafrost ablation with warming.

There is a strong indication that the local climate in the Front Range experienced climate regime change from warming to cooling in the first decade of the 21st Century. In a recent article Haugen et.al.(2010) stated "If recent trends in area loss continue, the Arapaho Glacier may disappear in as few as 65 years." This prediction may need modification in light of the new temperature data from Trail Ridge. While the recent or *post modern* fascination with *infinite linear trends* has proven to have a demonic effect on the real estate market its potential for damage in application the realm of *climate science* may have an even greater potential for long term financial damage. An extreme example of this trend is a recent book by Pollack(2009) forecasting in dire terms the future impact of *anthropogenic global warming*. The damage to the stature and credibility of the natural sciences will probably exceed that produced by the Lysenko's *hybridization biology* in the former Soviet Union.

## References:

Balch, E.S. (1900) Glaciers or Freezing Caverns. Allen, Lane and Scott, Philadelphia: 332 pp. { can be read on line at Google Books }

Goering, D.J. and P. Kumar (1996) Winter-time in open grade embankments. Cold Regions Science and Engineering 24(1): 57-74

Haugen, B.D, T.S. Scambos, W.T. Pfeffer and R.S. Anderson (2010) Twentieth-century changes in the thickness and extent of the Arapaho Glacier, Front Range, Colorado. Arctic and Alpine Research 42(2): 189-209.

Ives, J.D. (1973) Permafrost and its relationship... : Front Range Colorado. Proceedings 2nd International Conference on Permafrost, Yakutsk, USSR : North American Contribution: 121-125.

Janke, J.R. (2005) Modeling the past and future permafrost distribution in the Colorado Front Range. Earth Surface Processes and Landforms (30): 1495-1508.

Janke, J.R. (2011) *personal communication*. Dr. Janke made his data from the deep Trail Ridge boreholes available for analysis when he was considering writing a paper to correct his earlier analysis of the area underlain by permafrost in the Colorado Front Range.

Kane, D.L, K.M. Hinkel, D.J. Goering, L.R. Hinzman and S.I. Outcalt (2001) Non-conductive heat transfer associated with frozen soils. Global and Planetary Change 29: 275-292.

Outcalt, S.I. and J.B. Benedict (1965) Photo-interpretation of two types of rock glacier in the Colorado Front Range, USA. Journal of Glaciology 5(42): 849-856

Pollack, H.N. (2009) A World Without Ice. {forward by Al Gore } Avery, New York: 284 pp.

Terzaghi, K (1970) Permafrost, J. Boston. Soc. Civil Eng. 39(1): 319-368