SRK Consulting (US) Inc.
Suite F-40
4710 Business Park Blvd
Anchorage, Alaska 99503

T: 907 677 3520
F: 907 677 3620

anchorage@srk.com
www.srk.com

Memo

To:	Larry Cope, MSc	**Date:**	3/31/13
Company:	SRK Consulting (U.S.), Inc.	**From:**	Christopher W. Stevens, PhD
Copy to:	Vladimir Ugorets, PhD	**Project #:**	147900.020
Subject:	Pogo Mine - Review of Ground Temperature Data		

1 Introduction

1.1 Context

This memorandum presents a review of existing ground temperature data acquired at the Sumitomo Metal Mining Pogo, LLC mine site (Pogo Mine) located near Delta Junction, Alaska. SRK Consulting (U.S.), Inc. has been contracted to develop a site-wide hydrogeology model for the East Deep Expansion project. An important component of modeling ground water in northern latitudes is permafrost, due to its ability to limit ground water recharge. In support of the SRK ground water modeling, ground temperature data have been examined to determine the general characteristics of permafrost and its possible distribution across the mine site.

1.2 Permafrost

Permafrost is a thermal condition of earth's materials defined by temperatures at or below 0^{o}C for two or more consecutive years (van Everdingen, 1998). At a local scale, microclimatic influences alter the surface energy balance and heat transfer in the ground (Smith, 1975). Microclimatic factors impacting the presence and thermal condition of permafrost include ground surface aspect, vegetation, soil moisture and snow thickness.

In regions of high topographic relief, local ground temperatures and the presence of permafrost can be, in part, attributed to differences in solar radiation that contribute to heating of the ground (Dingman and Koutz, 1974). Incoming solar radiation received at the surface is known to be impacted by ground surface aspect, slope, vegetation cover and topographic shading. Vegetation also acts to moderate conductive heat flow between the surface and the ground. In the winter (freezing season), the local variability in snow represents the main influence on heat loss from the ground (Goodrich, 1982). Over time, these local effects and long-term changes in climate give rise to varying rates of permafrost aggradation and degradation (Williams and Smith, 1989).

2 Data Sources

SRK has performed a review of the existing ground temperature data to develop a conceptual understanding of permafrost at the Pogo Mine site. The available ground temperature data were reviewed to determine the following criteria.

- Permafrost presences or absence
- Permafrost temperatures below the approximate depth of annual variability
- Depth to the base of permafrost

Terrain conditions important to the general understanding of permafrost were assessed for each ground temperature sites using geographic data layers supplied to SRK by Sumitomo Metal Mining

Pogo, LLC. Several derivative data layers were calculated using ArcGIS v10, such as surface slope, aspect and radiation.

- Airphoto (1.5 ft spatial resolution)
- Digital elevation model (DEM)
- Surface slope determined as a function of degrees from horizontal
- Annual incoming surface radiation based on latitude, slope, aspect and local topographic shading

In addition, the following reports were reviewed for content relevant to this memorandum.

- Adrian Brown Consulting, Inc., 2009
- AMEC Earth & Environmental Ldt., 2001
- Golder Associates Ldt., 1998a
- Golder Associates Ldt., 1998b
- Golder Associates Ldt., 1998c
- Golder Associates Ldt., 1998d

3 Ground Temperature Sites

Ground temperature measurements were reviewed from 14 borehole sites located within the vicinity of the Pogo mine. Locally the sites are located within the Goodpaster floodplain, Liese Creek Valley, Liese Ridge and Pogo Ridge (Table 1, Figure 1). Elevations between these sites ranges from 1311 ft asl to 2751 ft asl. Vegetation cover varies from sparse black spruce trees on the north-facing slopes to dense birch and spruce forest on slopes south-facing slopes.

Ground temperature measurements provided to SRK were acquired between 10/13/1997 and 08/07/2000 using thermistor cables installed to a maximum depth of 293 ft bgs. At most sites, the ground temperature records are limited to a couple measurements recorded on a single date. These measurements are sufficient for determining deep permafrost conditions below the depth of annual variation. However, shallow annual fluctuations in ground temperatures are not effectively characterized with this dataset. At most sites the base of permafrost is greater than the thermistor cable and its exact depth cannot be determined.

Table 1. Location, site description, elevation and thermistor cable length for ground temperature sites.

Borehole ID	Description of site	X (NAD83 State Plane, AK 3)	Y (NAD83 State Plane, AK 3)	Elevation (ft asl)	Maximum depth, thermistor cable (ft bgs)
97-42	Liese Ridge, lower slope	1811388.73	3823717.32	1752.54	250
97-77	Pogo Ridge	1811424.77	3821703.83	2033.37	249
98-12	Goodpaster flood plain	1808362.36	3821135.58	1327.28	34
98-13	Goodpaster flood plain	1808247.00	3820775.00	1311.47	80
98-14	Goodpaster flood plain	1808299.99	3820311.22	1330.07	65
98-158*	Pogo Ridge, north side	1813061.22	3820135.02	2439.39	293
98-81	Pogo Ridge, south side	1809836.00	3819385.00	1842.29	100
LD4	Liese Ck Valley	1815041.30	3820551.40	2099.93	56
LD6	Liese Ck Valley	1815210.70	3821042.50	2089.49	82
LT2	Liese Ck Valley, lower slope	1817290.40	3818138.80	2620.00	49
LT4	Liese Ck Valley, lower slope	1818583.20	3818278.20	2721.46	46
LT5	Liese Creek Valley bottom	1817443.90	3818784.50	2453.64	101
LT6	Liese Ck Valley, lower slope	1818809.80	3818907.20	2630.27	47
PS-5	Pogo Ridge, north side	1814508.00	3819131.00	2751.46	50

* Location estimate from report

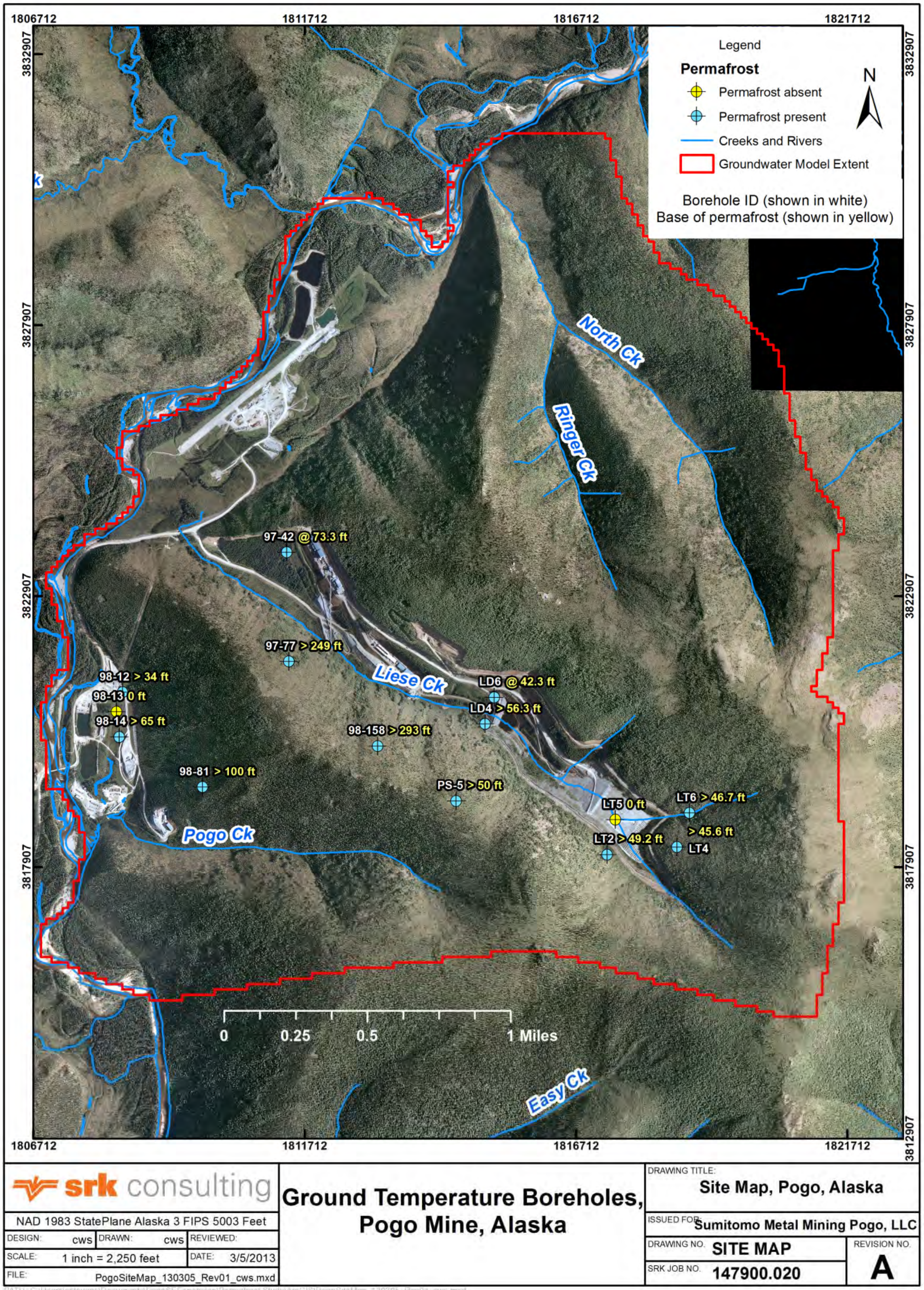


Figure 1. Site map showing the location of ground temperature sites at the Pogo Mine, Alaska.

4 Review of Ground Temperature Data

Ground temperature profiles from the 14 instrumented sites are presented in Appendix A. At some sites, progressive cooling of the ground below about 30 ft reflects the dissipation of heat introduced during drilling, such as site 98-185. Ground temperatures can be expected to cool until reaching thermal equilibrium with the surrounding ground. As a result, only the most recent temperature record was considered for each site.

Warm permafrost (>-2.1^{o}C) is present at 12 of the 14 sites (Table 2). Permafrost is absent at sites 98-13 and LT5. The coldest permafrost temperatures occur on the north and northeast-facing slope, which also represent locations where the lowest solar radiation has been calculated (Table 2). Slopes with a southern or westward aspect of the ground typically exhibit warmer permafrost temperatures or permafrost is absent.

The depth of permafrost (i.e. the base of permafrost) ranges from 42.3 ft bgs (site LD6) to greater than 293 ft bgs (site 98-158). Permafrost beneath sites LD6 and 97-42 with a southwest aspect are measured to be 42.3 ft bgs and 73.3 ft bgs, respectively. Permafrost is considerable deeper beneath slopes with a northern component of aspect, such as site 97-77 (>293 ft bgs) and 98-158 (>294 ft bgs).

Table 2. Summary of permafrost characteristics and relevant surface conditions (surface slope, aspect and calculated incoming solar radiation).

Borehole ID	Aspect	Slope (degrees)	Permafrost present (Y/N)	Permafrost temperature (^{o}C)	Base of permafrost (ft bgs)	Calculated Solar Radiation2 (WH/m2)
97-42	SW	16	Y	NA	73.3	702623
97-77	NE	28	Y	-0.92	>249.0	418135
98-12	W	8	Y	-0.97	>34.0	646607
98-13	W	4	N	1.45	0	615640
98-14	W	6	Y	-0.16	>65.0	614478
98-158	N	25	Y	-0.63	>293.0	426983
98-81	W	24	Y	-0.13	>100.0	638826
LD4	N	33	Y	-2.1	>56.3	325526
LD6	SW	13	Y	-0.1	42.3	704078
LT2	NE	28	Y	-1.8	>49.2	466968
LT4	W	17	Y	-1.2	>45.6	620940
LT5	-	4	N	0.3	0	654217
LT6	SW	19	Y	-0.7	>46.7	728288
PS-5	NE	5	Y	NA	>50.0	642409

4.1 Potential Incoming Solar Radiation

Figure 2 presents an estimation of annual incoming solar radiation for the Pogo Mine site. The potential radiation map indicates low radiation in cool colors (blue) and high radiation in warm colors (Yellow and red). These estimates do not account for shading effects of vegetation or complex diffusion in the atmosphere, among the other possible controls on the amount of solar radiation received at the ground surface.

Across the mine site, large changes in potential radiation occur in response to ground surface aspect, surface slope, and shading from local topography. Northern-facing slopes and the adjacent valley bottoms receive the lowest amount of annual radiation. These slopes are sparsely vegetated with black spruce. In contrast, southward-facing slopes receive the highest potential radiation and are densely vegetated with spruce and birch. These areas include the south-facing slope of Pogo and Liese Ridge. The increase in vegetation canopy is largely due to the greater availability of energy for plant growth on these slopes.

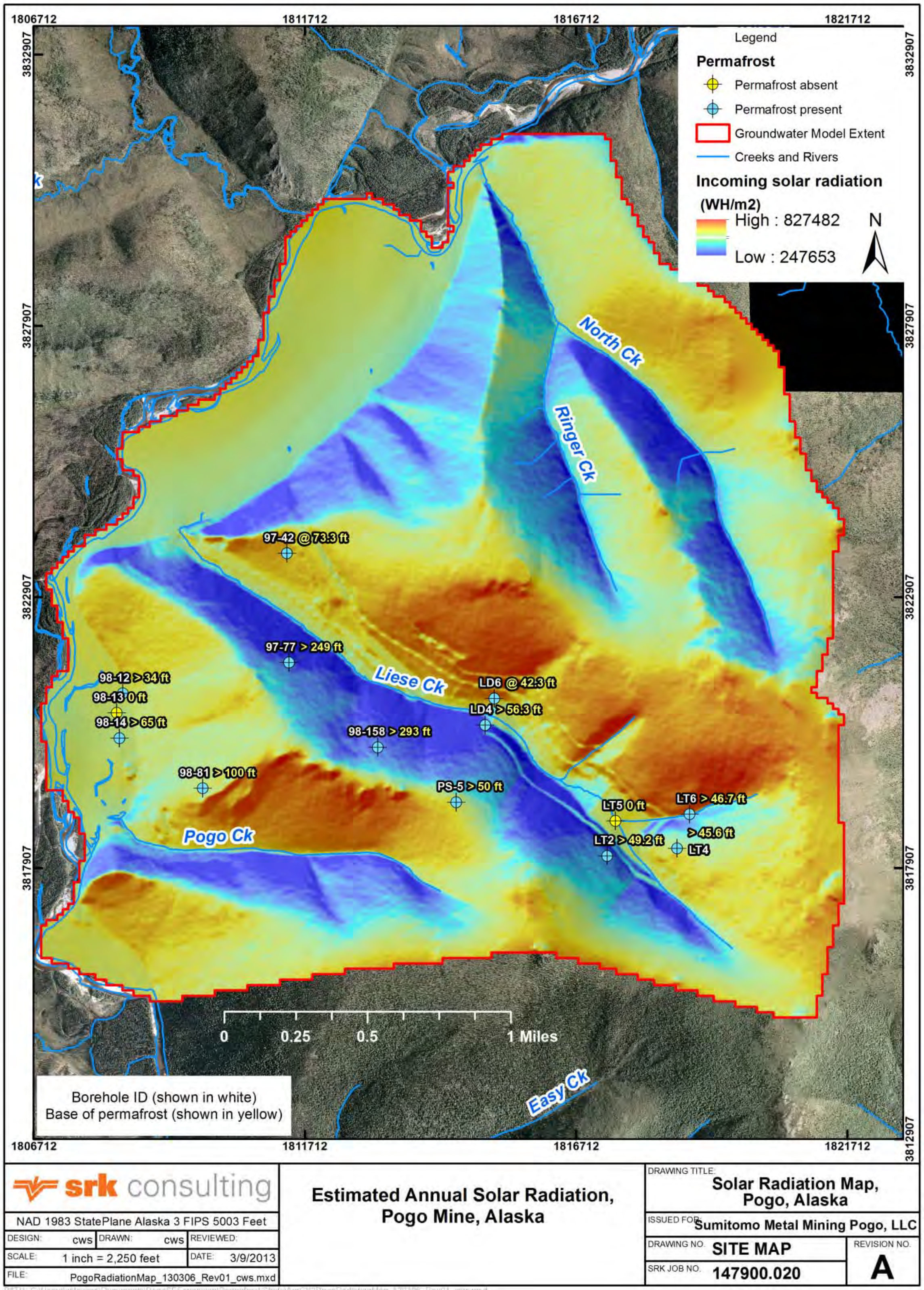


Figure 2. Estimated annual incoming solar radiation for the Pogo Mine site, Alaska.

Permafrost temperatures are generally colder on northern-facing slopes that receive a lower amount of solar radiation (Figure 3). Warmer permafrost temperatures are observed for southern-facing slopes (SW) characterized by higher solar radiation (Figure 3B). The estimated solar radiation for south-facing slopes may be reduced by increased shading from the vegetation canopy, thus reducing heating effects of the ground during the thawing season. As expected, west-facing slopes exhibit a slight decrease in radiation due to its exposure. Ground temperature data does not currently exist for south-facing slopes where the highest radiation is expected to occur.

The trends between permafrost temperature and potential solar radiation are based on a limited amount of data. It is reasonable to infer that permafrost temperatures may continue to warm and become absent beneath south-facing slopes that receive high solar radiation. During the winter, snow may also limit winter heat loss from the ground and impact permafrost distribution. Seasonal frost can be expected where permafrost is absent.

Permafrost-free zones on southward-facing slopes with high solar radiation have been identified elsewhere within Alaska's zone of discontinuous permafrost (Dingman and Koutz, 1974). At Bonanza Creek Experimental site southern-facing slopes free of permafrost have been inferred to contribute to groundwater recharge. Woo and Carey (1999) also describe the absence of permafrost on south-facing slopes for the Wolfe Creek Basin in the Yukon, Canada.

These locations may also receive greater snow accumulation that limits heat loss and contribute to a net gain of heat in the ground.

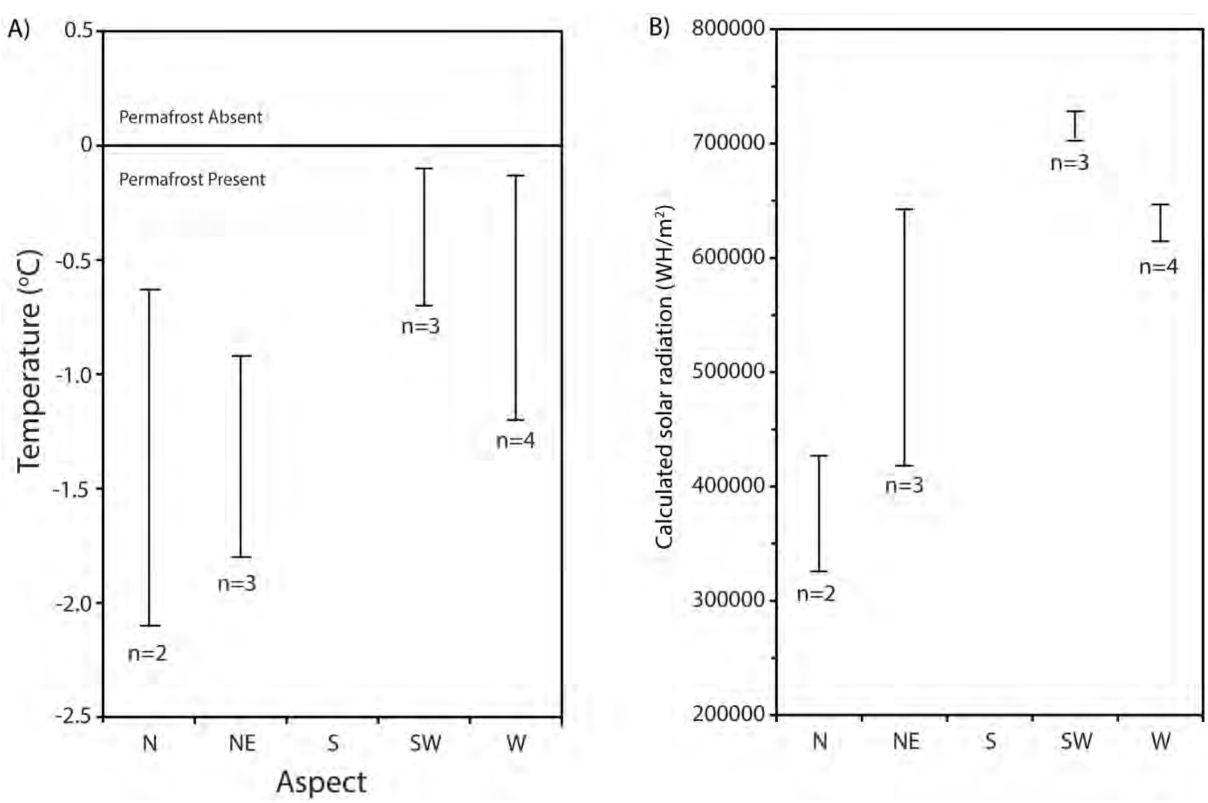


Figure 3. A) Permafrost temperature for instrumented sites with N, NE, SW and W surface aspect and B) calculated annual solar radiation.

5 Conclusions

SRK has performed a review of existing ground temperature data at the Pogo Mine site in support of site-wide hydrogeology modeling. The available ground temperature data indicates the presence of warm permafrost (>-2^{o}C) which is consistent with the zone of discontinuous permafrost (Karunaratne *et al.,* 2008). Permafrost is relatively thin and marginally below 0^{o}C on southwest-facing slopes vegetated with spruce and birch forests. In contrast, north-facing slopes are characterized by colder and deeper permafrost measured to be at least 293 ft bgs.

General trends in permafrost temperature suggest a relationship exists between solar radiation and vegetation in the vicinity of the Pogo Mine. However, the limited ground temperature data does not permit for evaluation of south-facing slopes with the highest incoming solar radiation (see Figure 2). It is inferred from the data that permafrost is absent beneath south-facing slopes with the greatest potential for solar radiation. This inference is supported by current geocryological understanding of permafrost variability across high relief terrain.

6 Recommendations

Pogo may wish to collect additional ground temperature measurements by taking advantage of opportunities during future investigations or exploration drilling programs. Such data can improve the current understanding of permafrost distribution and its thermal condition at the Pogo Mine site. This information may be used to further develop a predictive permafrost map based on landscape components.

7 References

Adrian Brown Consultants, Inc., 2009. Pogo Mine Inflow Evaluation and Control Review, April 2009.

AMEC Earth & Environmental Ldt, 2001. 2001 Geotechnical and Hydrological Characterization Program, December 2001.

Dingman, S.L., Koutz, F.R. 1974. Relations among vegetation, permafrost, and potential insolation in central Alaska. Arctic and Alpine Research, 6, 37-42.

Golder Associates Ltd, 1998a. Draft report on hydrogeological regime Goodpaster River Valley and proposed exploration adit Pogo Project, Alaska, June 1998.

Golder Associates Ltd, 1998b. Draft report on hydrogeological investigations Pogo Project, Alaska, February 1998.

Golder Associates Ltd, 1998c. Technical memorandum No. 1 field investigation and reults Pogo Project Alaska, October 1998.

Golder Associates Ldt, 1998d. Technical memorandum No. 2 characterization of hydrogeological regime, Pogo Project Alaska, October 1998.

Goodrich L.E. 1982. The influence of snow cover on the ground thermal regime. Canadian Geotechnical Journal, 19, 421-432.

Karunaratne, K.C., Kokelj, S.V., Burn C.R. 2008. Near-surface permafrost conditions near Yellowknife, Northwest Territories, Canada. In Proceedings of the Ninth International Conference of Permafrost, volume 2, Kane D.L., Hinkel K.M. (eds). Institute of Northern Engineering, University of Alaska: Fairbanks, AK; 1711-1716.

Smith M.W. 1975. Microclimatic influences on ground temperatures and permafrost distribution, Mackenzie Delta, Northwest Territories. Canadian Journal of Earth Sciences 12: 1421-1438.

Williams P.J., Burt T.P. 1974. Measurement of hydraulic conductivity of frozen soils. Canadian Geotechnical Journal, 11, 647-650.

Williams, P.J., Smith, M.W. 1989. The Frozen Earth Fundamentals of Geocryology. Cambridge University Press, 306 p.

Woo M, Carey, S.K. 1999. Permafrost, seasonal frost and slope hydrology, central Wolf Creek Basin, Yukon. In Wolf Creel Research Basin Hydrology, Ecology, Environment, Pomeroy, J.W., Granger, R.J. (eds)., Workshop proceedings, Whitehorse Yukon, Canada; 45-54.

van Everdingen, R.O., 1998. Revised May 2005. Multi-language glossary of permafrost and related ground-ice terms. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology.

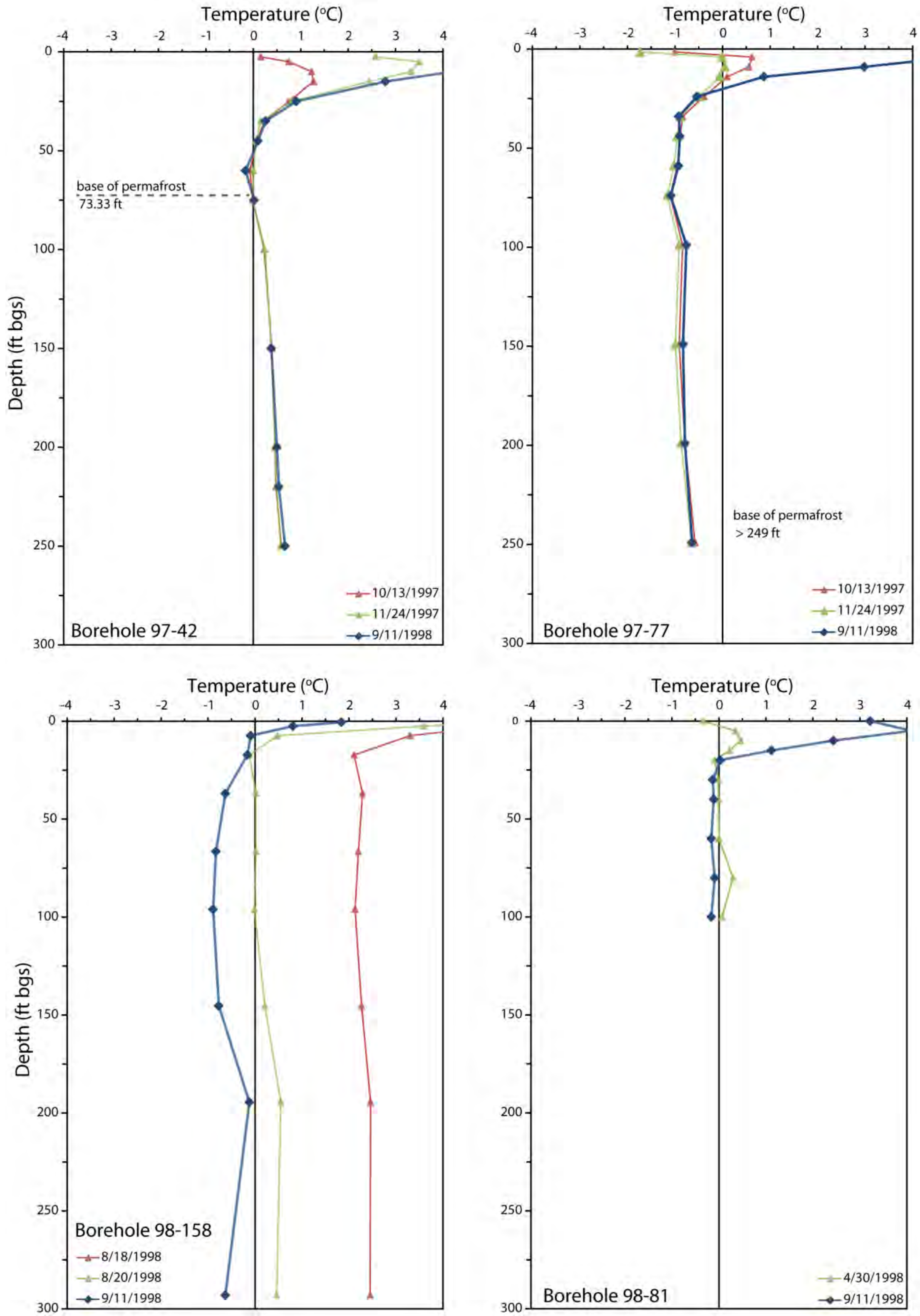
Regards

SRK Consulting (U.S.), Inc.

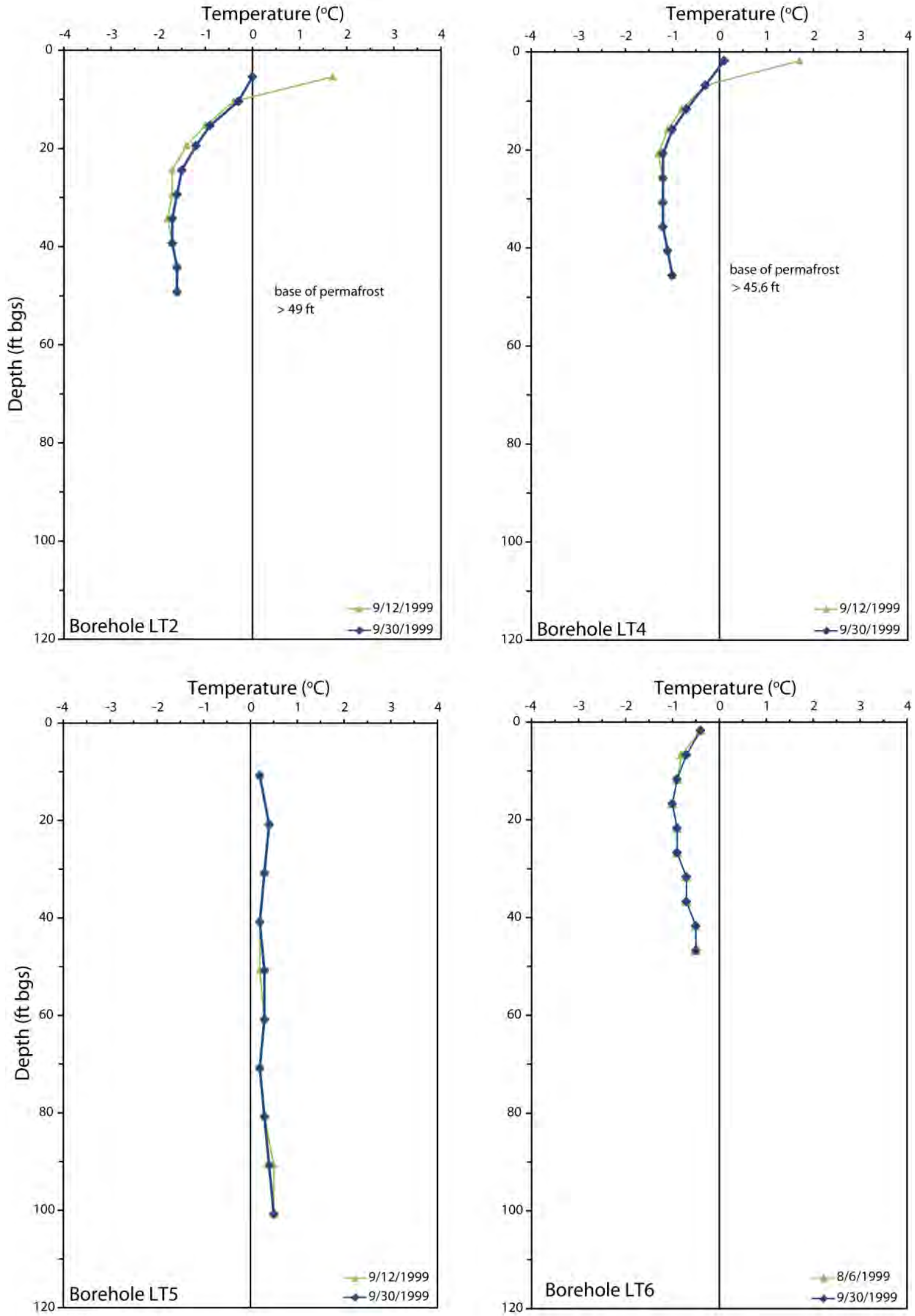
Christopher W. Stevens, PhD
Consultant, Geocryologist

Attachments:
Appendix A: Ground Temperature Profiles, Pogo Mine, Alaska

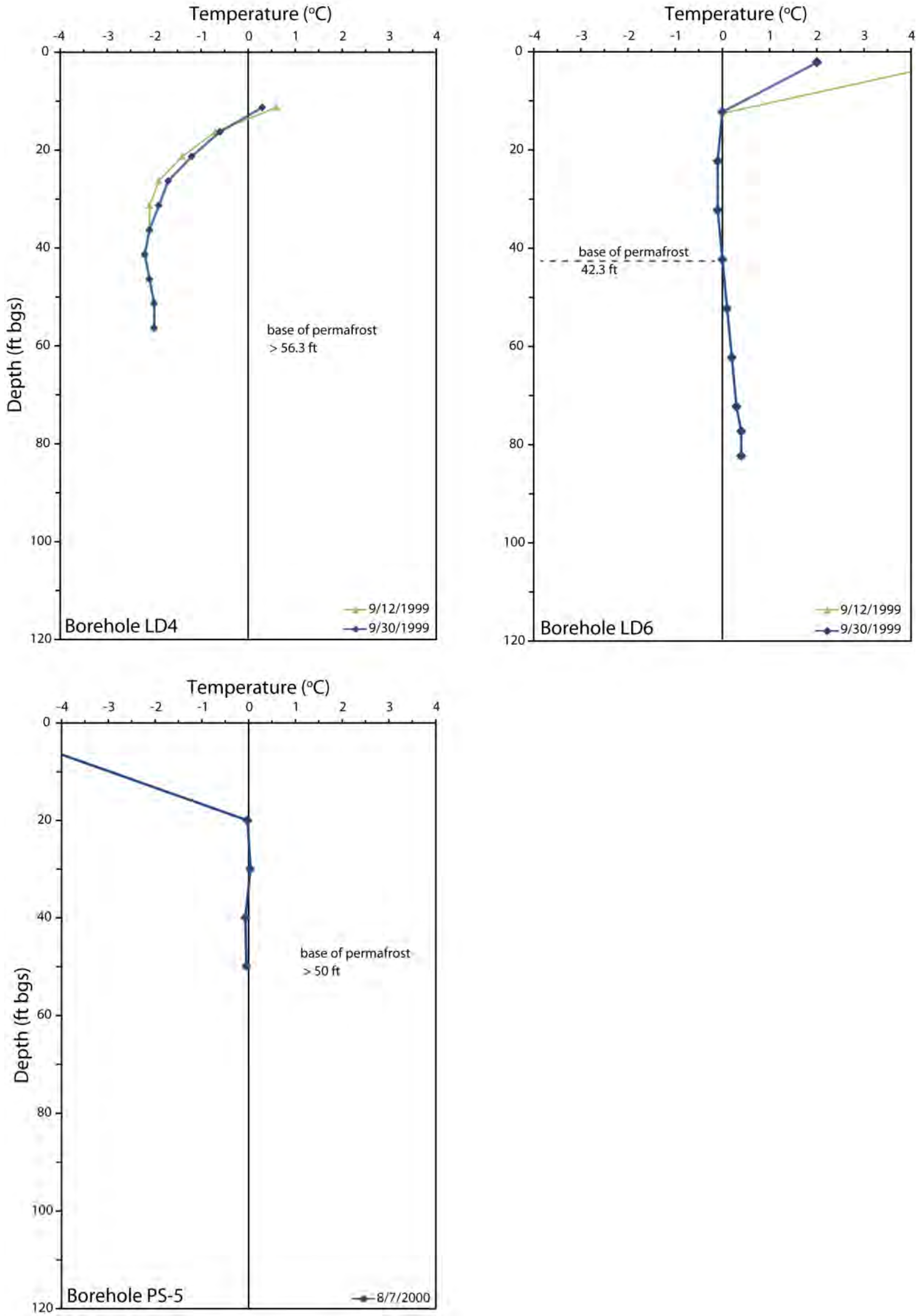
Appendix A: Ground Temperature Profiles, Pogo Mine, Alaska



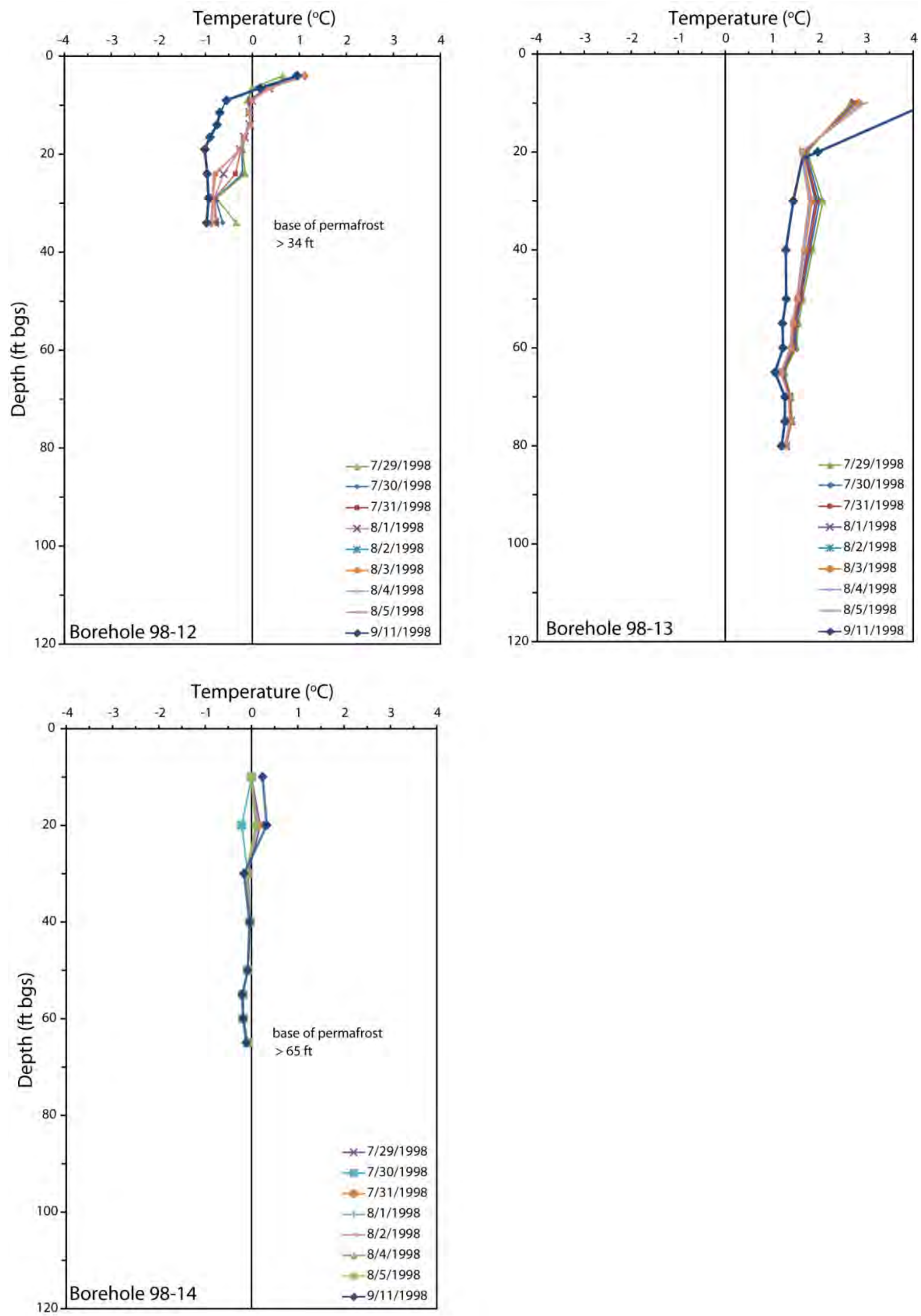
Ground temperature profiles for sites 97-42, 97-77, 98-158, 98-81, Pogo Mine, Alaska



Ground temperature profiles for sites LT2, LT4, LT5 and LT6, Pogo Mine, Alaska



Ground temperature profiles for sites LD4, LD6, PS-5, Pogo Mine, Alaska.



Ground temperature profiles for sites 98-12, 98-13, 98-14, Pogo Mine, Alaska