MINTO WASTE ROCK
STABILITY EVALUATION

SEPTEMBER, 1996

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EBA Engineering Consultants Ltd.

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Minto Explorations Ltd.
6411 Imperial Avenue
West Vancouver, B.C.
V7W 2J5

Attention: Mr. Lutz Klingmann, P.Eng.

Dear Lutz:

Subject: Minto Waste Rock Stability Evaluation

A stability evaluation has been completed for proposed construction of the South Waste Dump. This brief report presents and discusses the approach taken for the evaluation, the analyses carried out, and the conclusions and recommendations made from the study.

INTRODUCTION

Minto is currently proposing to construct a waste dump southwest of the designated tailings containment area. The proposed location is over gently sloping (about 3° to 10°) terrain, which is underlain by warm permafrost soils. Depths to bedrock are indicated to range up to 45 m based on exploration borings drilled nearby. Six geotechnical boreholes (Nos. 96-G07 through 96-G12) were drilled in the vicinity of the proposed waste dump, penetrating to depths of 4.8 to 10.7 m. A thermistor cable was installed to a depth of 10 m in Borehole 96-G08. The observed overburden soils consisted predominantly of silts and sands and were noted to contain varying amounts of excess ice. Two of the boreholes that were drilled slightly east of the dump area (Nos. 96-G09 and 96-G12) showed massive ice intervals of 1.5 and 4.0 m thick within the upper 10 m. The other four boreholes generally showed 0 to 20% excess ice contents.

Recent thermistor cable readings indicate a relatively uniform ground temperature of close to -0.8°C after equilibration with slight seasonal warming over the top 2 or 3 m. The active layer depth is close to 1 m. The collected temperature data is presented in Figure 1.

The nature of the overburden conditions (soil type, permafrost presence, ice content, and ground temperature) beneath the depths of observation and measurement are not known. Fine-grained, warm permafrost conditions have therefore been considered to extend through the full thickness of overburden soils to the bedrock contact.

APPROACH TO EVALUATION

Stability evaluations that involve ice-rich permafrost soils must address the selection of appropriate shear strength parameters that account for long-term creep deformation. However, creep theory for permafrost soils is normally considered valid for temperatures below -1°C. An extrapolation of creep theory to temperatures warmer than -1°C is beyond normal practice and would be viewed as questionable, particularly for long time applications and without supporting test measurements. Therefore, the present stability evaluation has examined back-analysis information from an existing slope in similar permafrost soils to provide, in a sense, demonstrated long-term strength data.

Boreholes 94-21 and 94-G11 were drilled on a cross-section of the existing north-facing valley slope at a location about 650 m downstream (northeast) from the waste dump area. The surficial soils comprise fine-grained, warm permafrost conditions similar to the proposed south waste dump area. A profile of the slope cross-section is presented in Figure 2. The stability of the slope was back-analyzed to determine the minimum strength parameters required to have maintained a factor of safety of at least 1.0 throughout the slope's long-term existence. This approach provides a large-scale, very long-term field test of representative fine-grained permafrost to demonstrate the very long-term strength of these soils against both rupture failure and limited creep deformation.

The back-analyses provide the minimum strengths that can be associated with different permafrost temperatures by evaluating critical failure planes through different depths of the soil profile. Critical failure surfaces passing along imaginary planes at soil depths of 5, 10, and 20 m were identified using the commercial program SLOPE-W. These soil plane depths correspond to relatively stable annual ground temperatures of -0.2, -0.5 and -0.8°C, respectively, as can be observed from Figure 3. The corresponding minimum computed long-term soil strengths were 20, 33 and 50 kPa.

It should be recognized that, since the back-analyzed slope has not failed throughout its long-term existence, these back-calculated strengths are minimum demonstrated values. As the actual factor of safety of the slope is some margin above 1.0, the long-term soil strengths may be somewhat greater. However, since greater long-term strengths cannot be demonstrated as ostensibly as those obtained from the back-analyzed long-term slope "field test", the back-calculated values have been carried forward (with their unknown degree of conservatism) for use in evaluating the stability of the proposed waste dump.

GEOTHERMAL ANALYSES

The waste rock stability evaluation has included consideration for the effect of dump construction on the ground thermal regime and, thus, possible changes to the long-term strength profile of the native foundation soils.

A geothermal calibration analysis was carried out to obtain a reasonable numerical simulation of the present equilibrated thermal regime for the south waste dump vicinity (refer to Figure 1). The predicted annual ground temperature profile variation is presented in Figure 4. The soil index and thermal properties used in the geothermal analysis are presented in Table 1.

The impact of waste dump construction was then evaluated by continuing the thermal simulation with monthly lift placements of waste rock. Each lift was simulated as 3 m thick with an initial placement temperature of 3°C. This placement temperature is considered to be conservative given the in situ rock is anticipated to be close to 0°C. The first lift was placed at the end of December after the active layer had finished freeze-back. Figures 5 through 9 present predicted ground temperature changes during the monthly periods associated with each sequential lift placement.

Figure 10 shows the predicted long-term (30th-year) annual ground temperature profile variation after waste dump construction. Although the analysis predicts permafrost conditions will remain, the top of permafrost has lowered to a depth of about 5 m below original ground and the ground temperature profile is shown to have warmed slightly from current conditions. The effect of these warmer ground temperatures on the long-term permafrost strength profile is discussed in the "Stability Analyses" section.

An additional thermal analysis was carried out for initial lift placement in August (when the active layer is fully thawed) to investigate whether the predicted permafrost temperature changes are sensitive to the time of year when waste rock material is initially placed on the ground. The results showed that the short- and long-term temperature profiles of the permafrost interval remain similar to those shown in Figures 5 through 10.

STABILITY ANALYSES

Stability analyses were carried out on trial waste dump lift configurations to determine minimum factors of safety against slope failure. Figure 11 presents the interpreted cross-section of the natural terrain through the proposed south waste dump area. The desired toe location for the waste rock material is also indicated. The depth of the bedrock contact was obtained from the earlier exploration boring locations shown in the figure.

As discussed above, the full thickness of the overburden soils has been conservatively assumed to consist of fine-grained, warm permafrost soils. Based on the equilibrated ground temperature profile shown in Figure 1 and the back-calculated minimum temperature-dependent soil strengths, the following strength profile was developed for the overburden soils:

Depth Interval	Soil Condition	Strength Parameter
0 to 1 m	Active layer	32°
1 to 2 m	-0.2°C	20 kPa
2 to 4 m	-0.5°C	33 kPa
Below 4 m	-0.8°C	50 kPa

This strength parameter profile was used only for short-term stability evaluations since the geothermal analyses discussed above predict ground warming over the long-term. To evaluate minimum factors of safety for long-term stability, the strength profile was adjusted as follows:

Depth Interval	Soil Condition	Strength Parameter
0 to 5 m	Thawed	32°
5 to 20 m	-0.2°C	20 kPa
20 to 40 m	-0.5°C	33 kPa
Below 40 m	-0.8°C	50 kPa

The rate of thaw front penetration into the overburden permafrost soils was also examined to consider potential for excess porewater pressure generation upon thaw. The maximum penetration rate (about 60 mm/year) occurs at the top of the permafrost. Based on this rate and a conservatively low estimate for the coefficient of consolidation (3.2 m^2/year), the maximum excess pore pressure generated on thaw is less than 3 percent of the vertical effective stress. Such pore pressures are not significant to the waste dump stability analyses. Furthermore, since the waste rock gradation will be very coarse (0.6 m minus), the dump will be free-draining and resistant to pore pressure development from precipitation infiltration.

Since the demonstrated back-analysis strengths for the overburden permafrost soils are relatively low, the results of stability analyses are unable to support significant waste rock placement in the proposed dump area. The results do show however that it is reasonable to consider the placement of one or two lifts of 3 to 5 m in thickness, provided that the face of each lift is groomed to a maximum slope of 2H:1V. Figures 12 and 13 present the computed minimum safety factors (1.77 and 1.41) associated with critical slip surfaces for 3 m and 5 m thick lift placements, respectively, under the initial ground temperature conditions. The actual short-term safety factors are likely higher since the short-term overburden strengths should be higher than the back-calculated long-term values.

Figures 14 and 15 show the case where a 3 m thick overlying lift is placed above the initial 3 or 5 m thick lift. The second lift has been set back to provide an overall maximum slope of 7H:1V. The minimum safety factors shown (2.56 and 2.19) are for the case of a critical slip surface that involves both lifts. These values, being higher than those for the single lift cases, indicate that the overall critical slip surface still passes through just the front extension of the bottom lift and that the second lift has been placed sufficiently back so as not to impact the short-term stability of the waste dump.

The computed minimum safety factors against short-term slope instability for either one or two lifts (of the dimensions described) are considered to be acceptable for waste dump design.

Figures 16 and 17 present the computed minimum safety factors (1.29 and 1.11) associated with critical slip surfaces for the 3 m and 5 m thick lift placements, respectively, under the predicted long-term ground temperature conditions. Figures 18 and 19 present the long-term case where a 3 m thick overlying lift has been placed. The corresponding computed minimum safety factors are 1.12 and 0.99.

The long-term safety factors are certainly lower than conventionally desired. However, these factors are comparable with the implied safety factor of 1.00 for the back-analyzed long-term stable slope, from which the strength parameters used in these analyses were derived.

CONCLUSIONS AND RECOMMENDATIONS

We conclude from the results of this study that it is reasonable to plan for the placement of one or two lifts of waste rock (of the dimensions described) in the proposed waste dump area for the following reasons.

- The predicted factors of safety against slope instability are acceptable in the short-term and are comparable to that for an existing stable slope in the long-term.
- The risk of failure is not large since the overall heights presently being recommended for the waste dump are not excessive.
- If long-term instability were to occur, deformation would be expected to be gradual and self-stabilizing due to the relatively gentle macro-profiles presented by the waste dump materials and overburden soils encompassed by the critical slip surfaces. The risk or, more specifically, consequence of the amount of deformation (toe heave and head slumping) required to re-stabilize the failure mass profile is not large.
- An unknown safety margin is inherent in the presented stability analyses due to the unknown safety factor for the back-analyzed long-term stable slope that was used for benchmarking with an assumed safety factor of 1.00.
- The placement of at least some waste rock in the proposed south dump area will also enable two other project needs to be served: road access to the proposed airstrip location can be accommodated across the waste dump surface and runoff water can be diverted into targeted streams by strategic positioning of the dump's perimeter slopes.

Due to the long-term nature of the stability issue and the potential for better long-term performance data to be gained, which might prove useful in demonstrating that additional lift construction is acceptable, we recommend the following:

- The proposed south dump area should be used for waste rock placement in one or two lifts (to the dimensions described). It might be beneficial to segment the dump into a few of the different configurations described to gain comparative performance information.
- Thermistor cable and slope inclinometer instrumentation should be installed and monitored to gain performance data measurements. An instrumentation layout and monitoring program should be prepared once a final waste dump design configuration is developed.
- An observational approach should be followed to implement any necessary changes in a timely manner.

CLOSURE

We trust that the results of this waste rock stability evaluation will serve the best interests of the Minto project.

We are available at your convenience if you have any questions or require additional information.

Yours truly,
EBA Engineering Consultants Ltd.

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TABLE 1 SOIL INDEX AND THERMAL PROPERTIES

Elevation Relative to Ground (m)	Soil Description	Average Water Content (%)	Dry Density (Mg/m^3)	Total Density (Mg/m3)	Frozen Thermal Conductivity (W/m°C)	Unfrozen Thermal Conductivity (W/m°C)	Frozen Specific Heat (kJ/kg-°C)	Unfrozen Specific Heat (kJ/kg-°C)	Latent Heat (MJ/m^3)
15.00									
0.00	waste dumps rock fill	3.0	2.20	2.27	1.980	1.927	0.770	0.830	-22
-0.30	moss/organic silt	75.0	0.50	0.88	0.500	0.340	1.860	2.760	-125
-4.80	silt and sand; trace of gracel and organics; frozen (ice-rich)	54.7	1.07	1.66	2.351	1.047	1.210	1.950	-195
-6.60	sand and gravel; some silt; fine to coarse sand; rounded to subrounded gravel	13.0	1.94	2.20	2.385	1.714	0.890	1.130	-84
-45.00	silt and sand - gravelly; coarse and fine angular gravel; trace of clay; fine to coarse sand; (ice-rich)	36.0	1.34	1.83	2.383	1.231	1.090	1.650	-161
-100.00	bedrock	0.0	2.60	2.60	1.770	2.639	0.730	0.730	0

Thermistor No.: 1064
Date Installed: Jul. 7, 1996

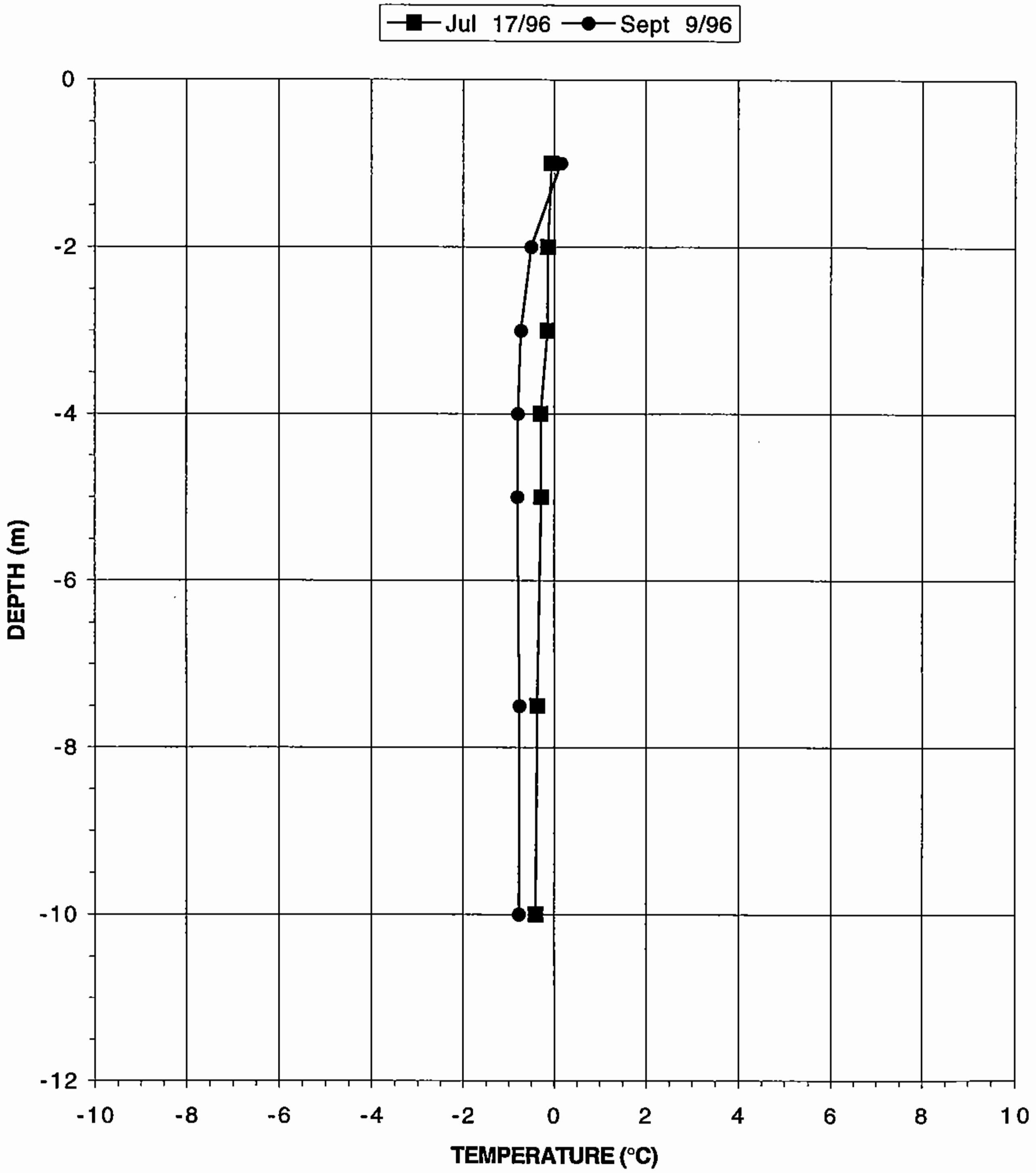

FIGURE 1: GROUND TEMPERATURE PROFILE
MINTO PROJECT - SOUTH WASTE DUMP
(BH 96-G08)

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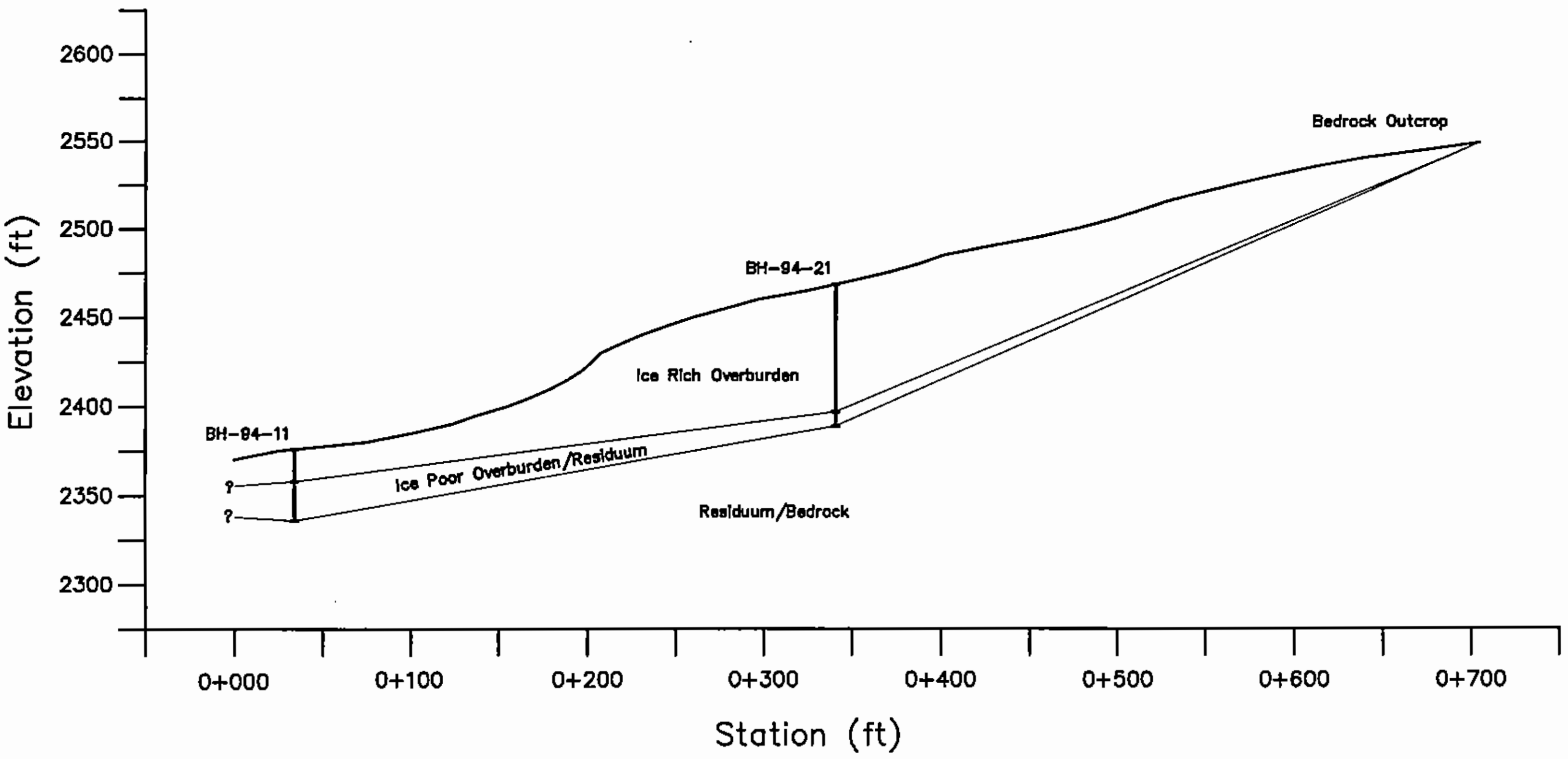

FIGURE 2: CROSS SECTION OF BACK-ANALYZED EXISTING SLOPE

Thermistor No.: 945
Date Installed: Aug.22/94

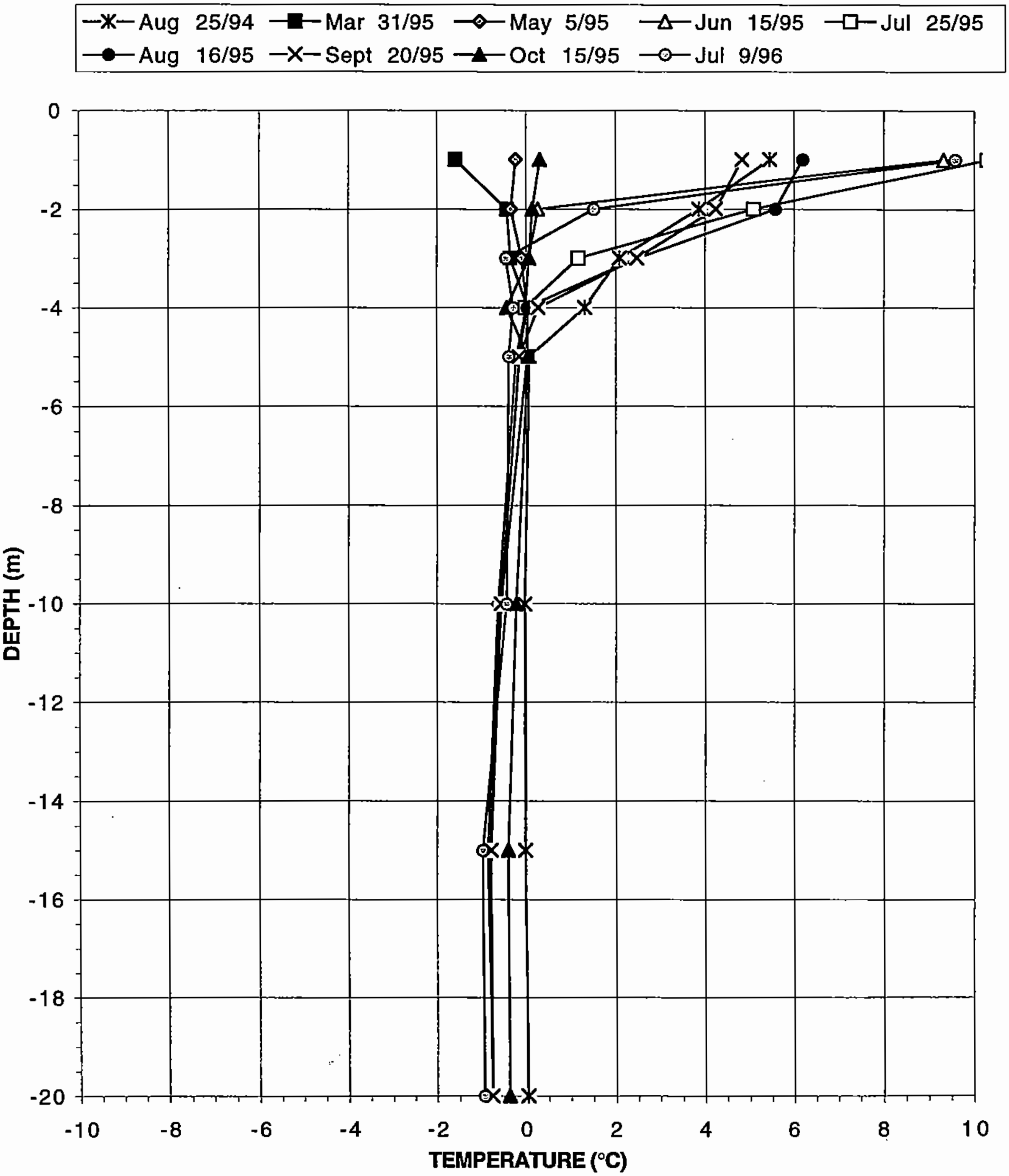

FIGURE 3: GROUND TEMPERATURE PROFILE
MINTO PROJECT - TAILINGS POND
UPPER SITE (BH 94-21, El.=752.43 m)

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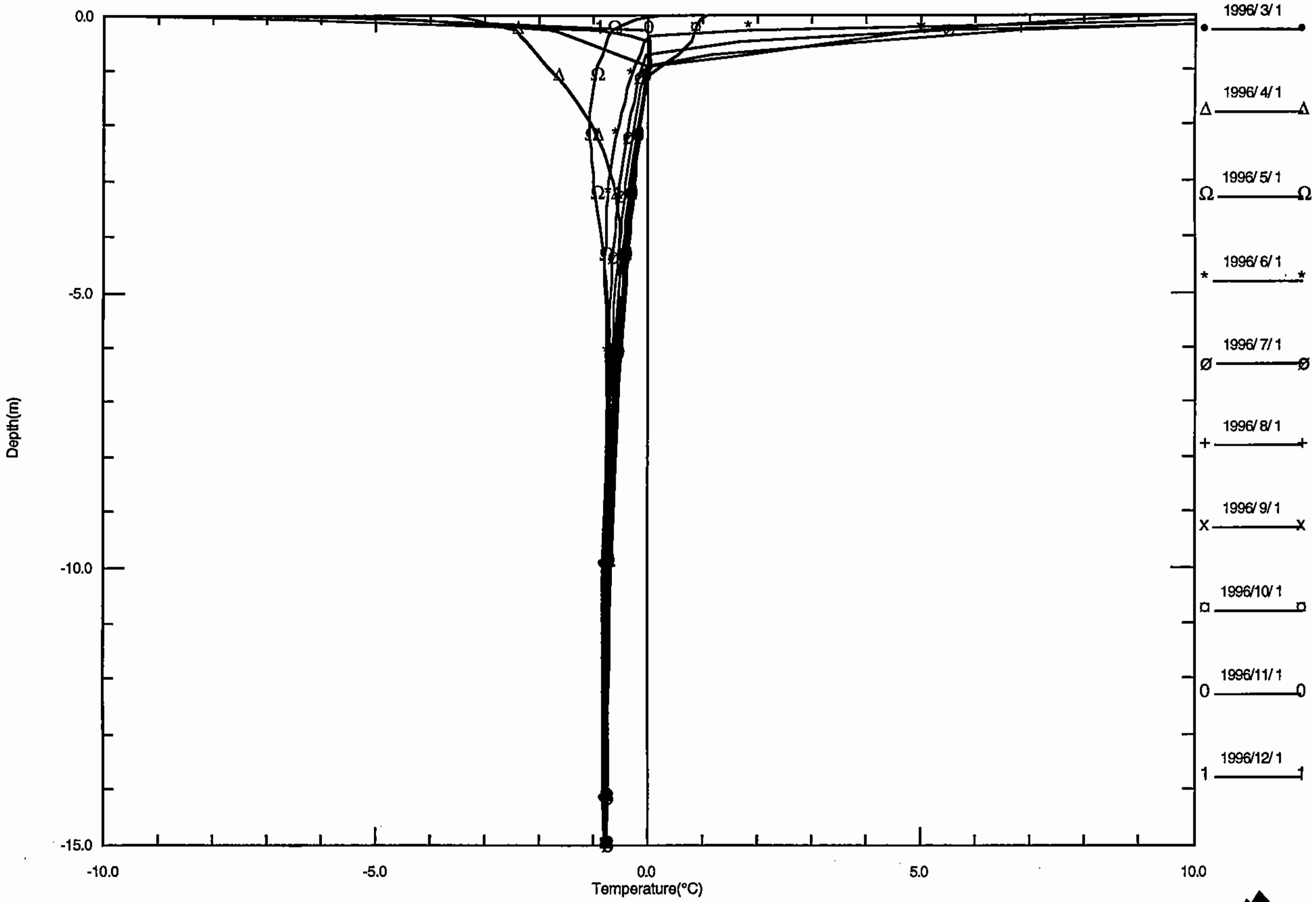

FIGURE 4: PREDICTED INITIAL ANNUAL GROUND TEMPERATURE PROFILE VARIATION FROM CALIBRATION ANALYSIS

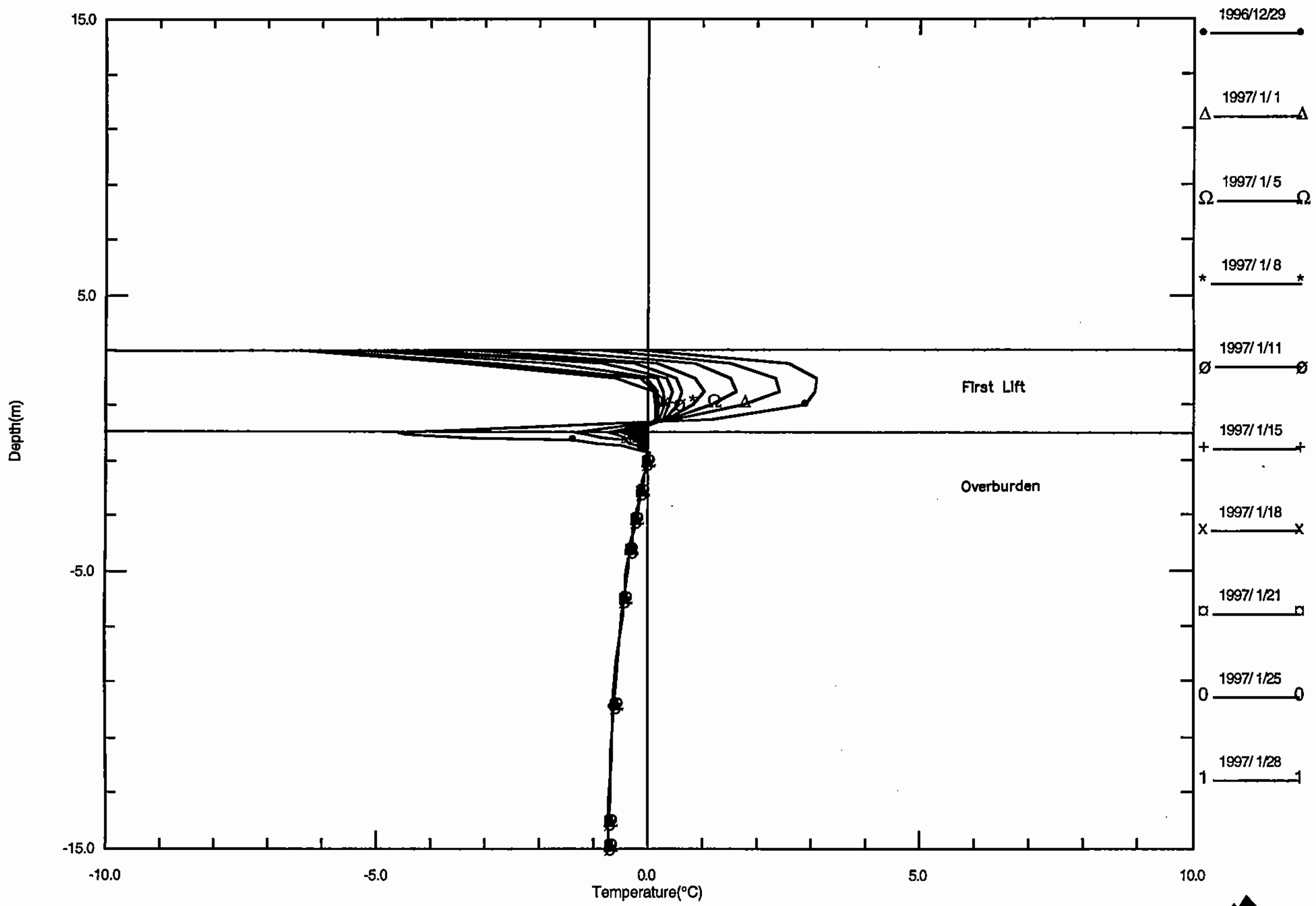

FIGURE 5: PREDICTED GROUND TEMPERATURE CHANGES DURING MONTH FOLLOWING PLACEMENT OF FIRST 3m LIFT

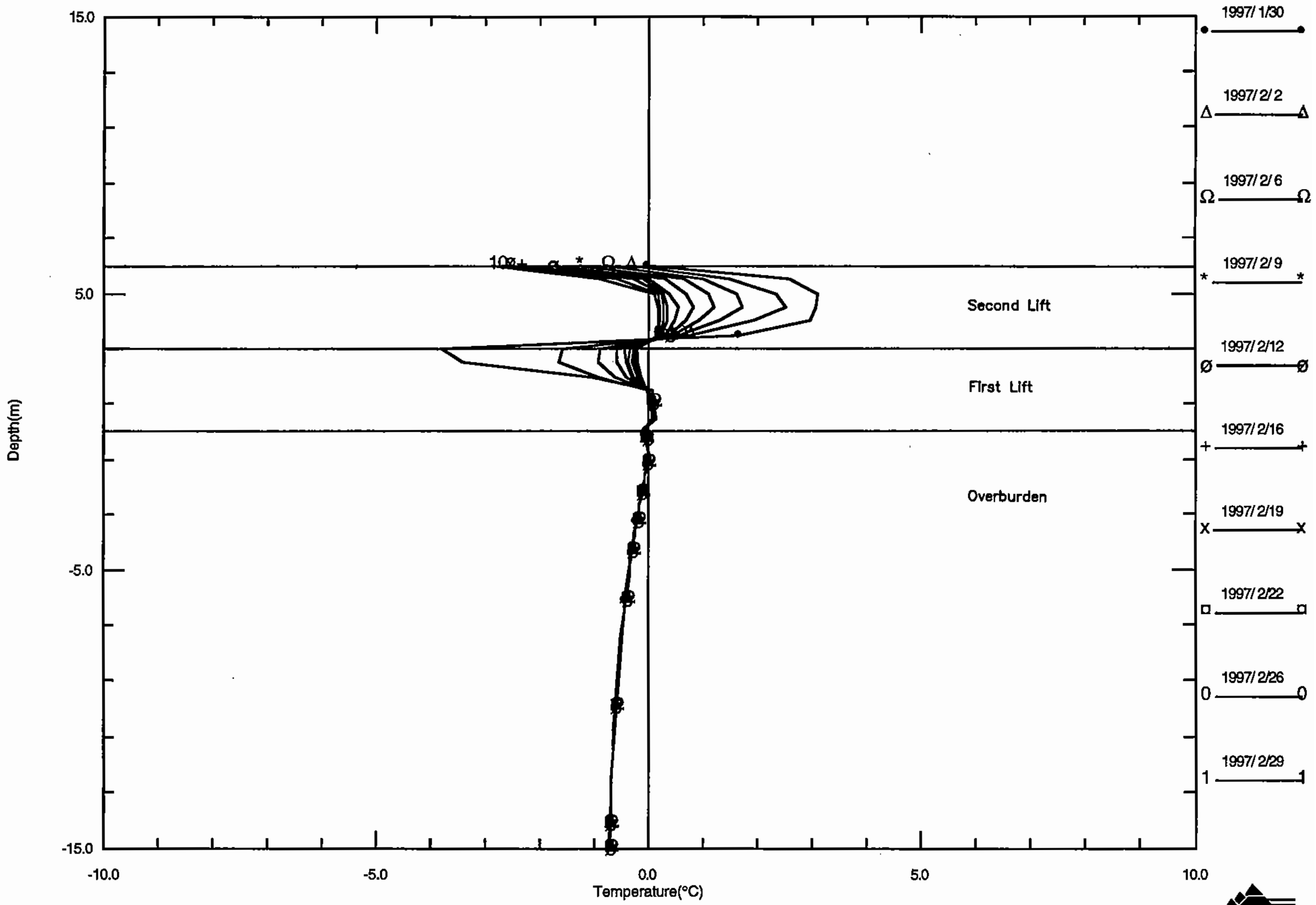

FIGURE 6: PREDICTED GROUND TEMPERATURE CHANGES DURING MONTH FOLLOWING PLACEMENT OF SECOND 3m LIFT

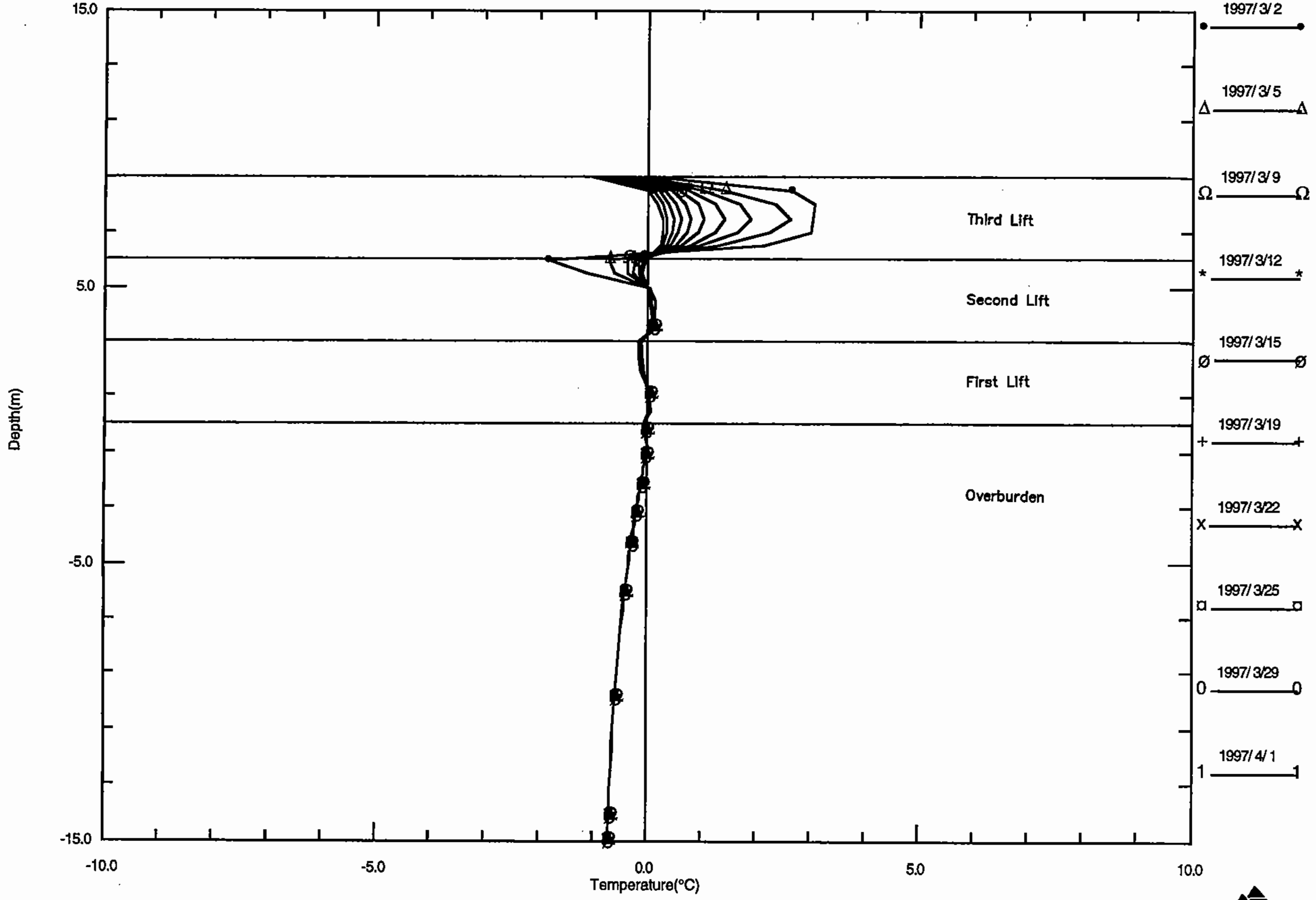

FIGURE 7: PREDICTED GROUND TEMPERATURE CHANGES DURING MONTH FOLLOWING PLACEMENT OF THIRD 3m LIFT

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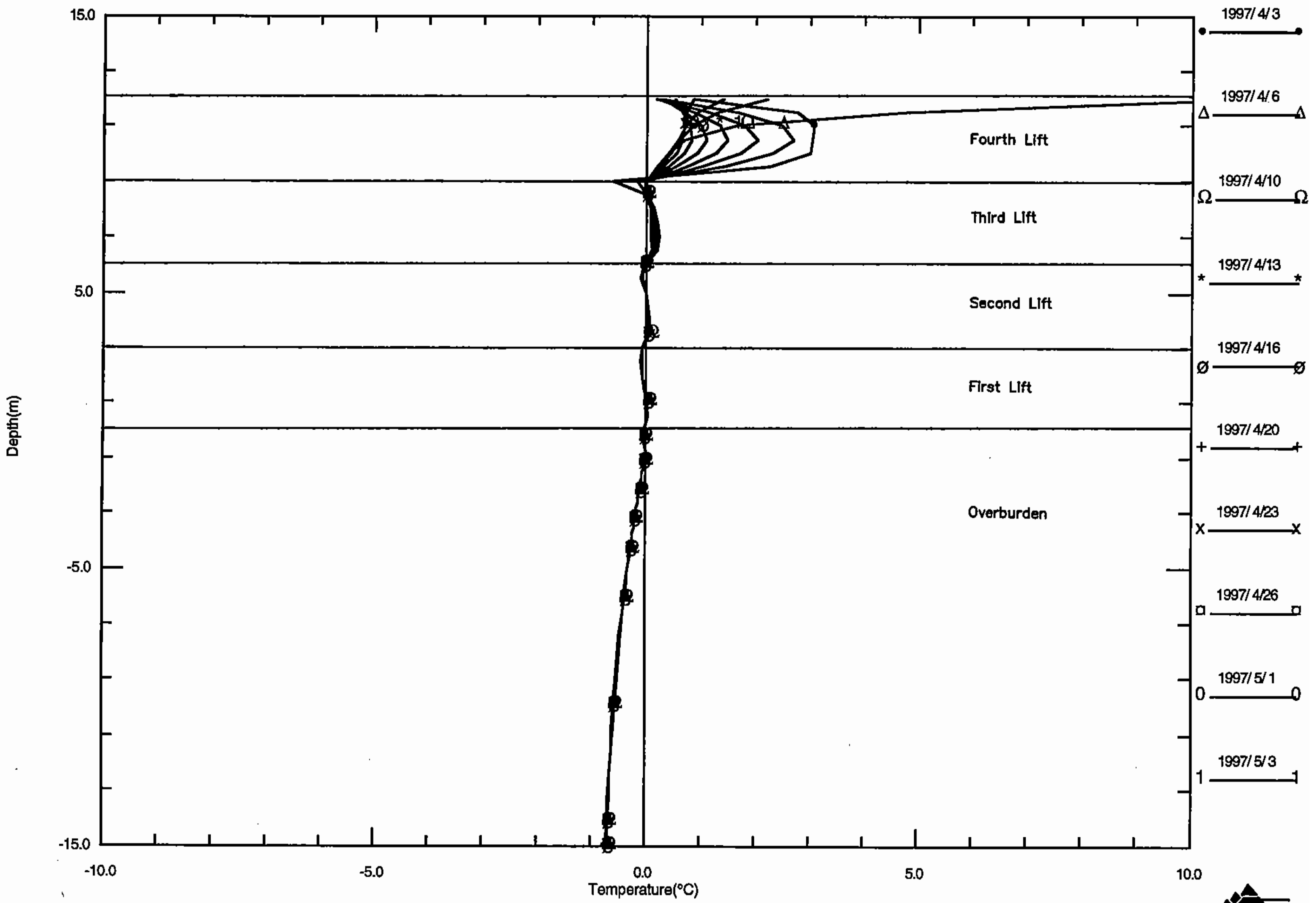


FIGURE 8: PREDICTED GROUND TEMPERATURE CHANGES DURING MONTH FOLLOWING PLACEMENT OF FOURTH 3m LIFT

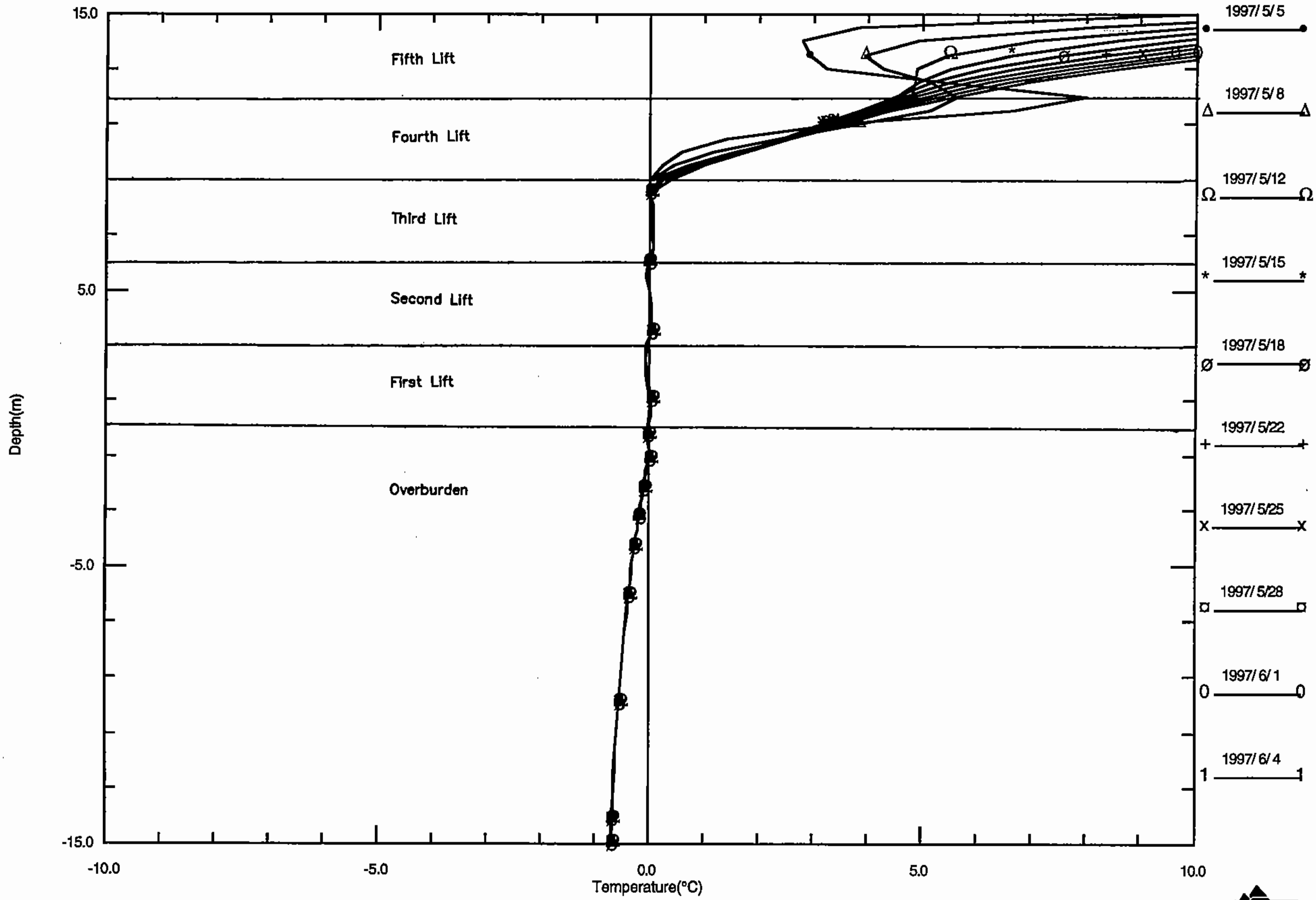


FIGURE 9: PREDICTED GROUND TEMPERATURE CHANGES DURING MONTH FOLLOWING PLACEMENT OF FIFTH 3m LIFT

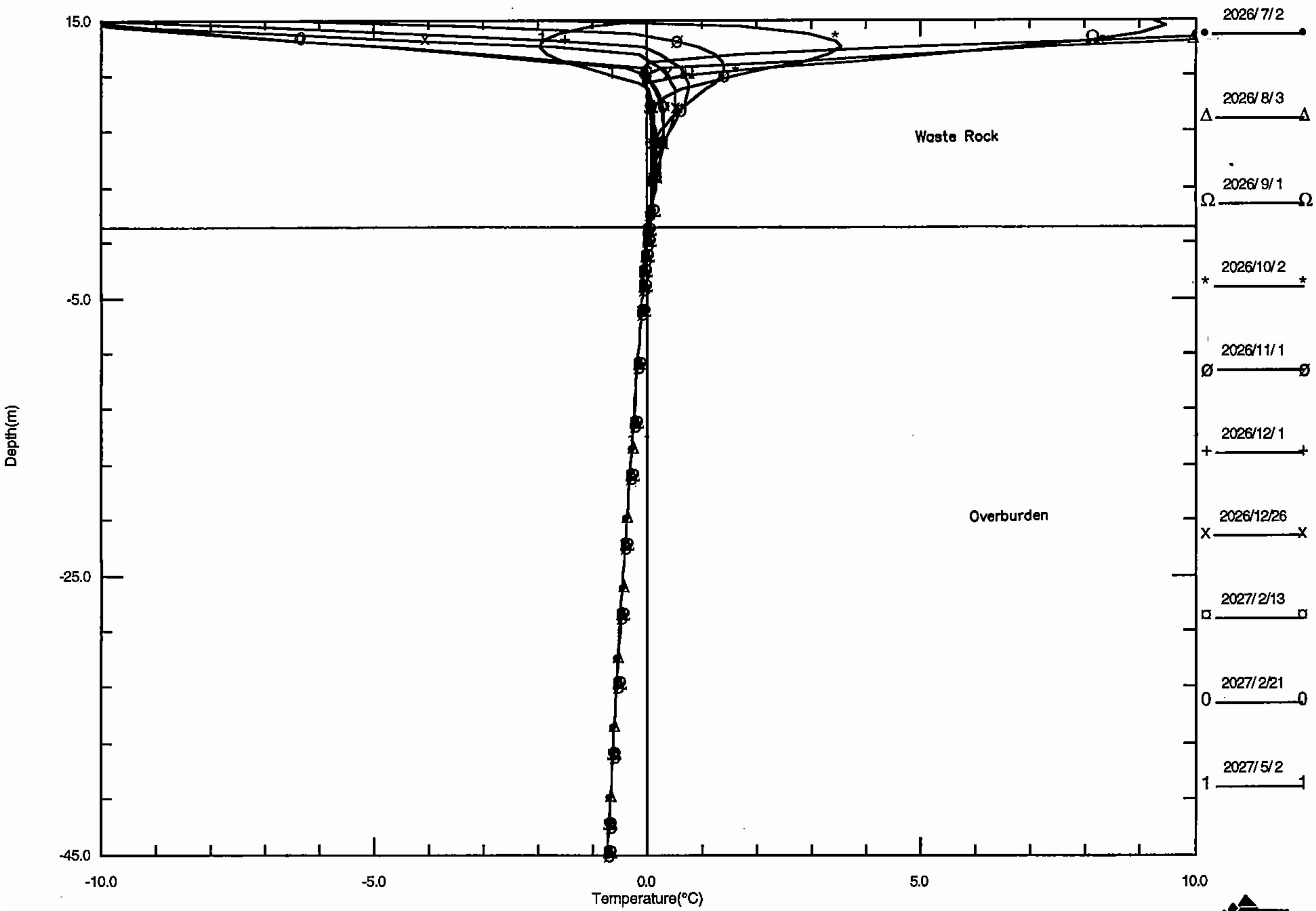
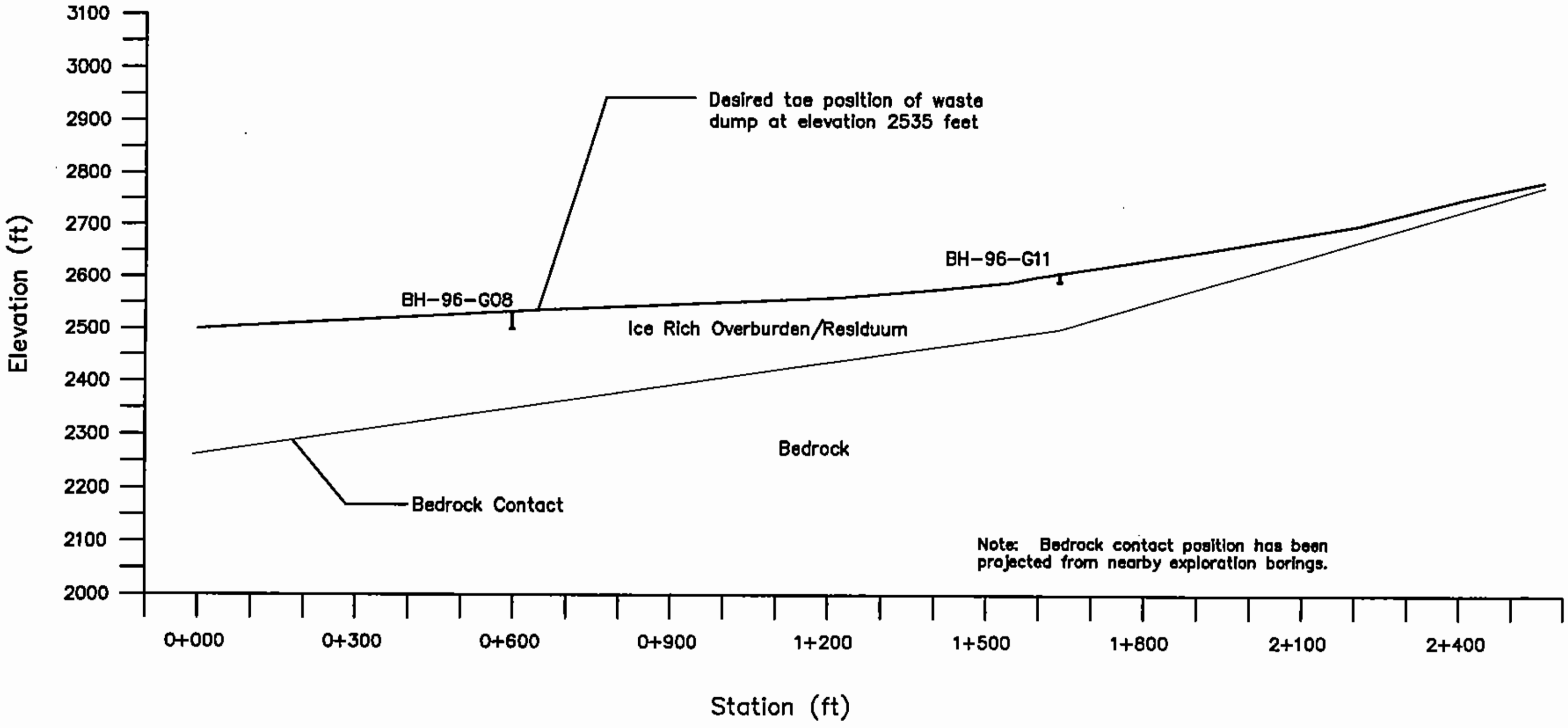
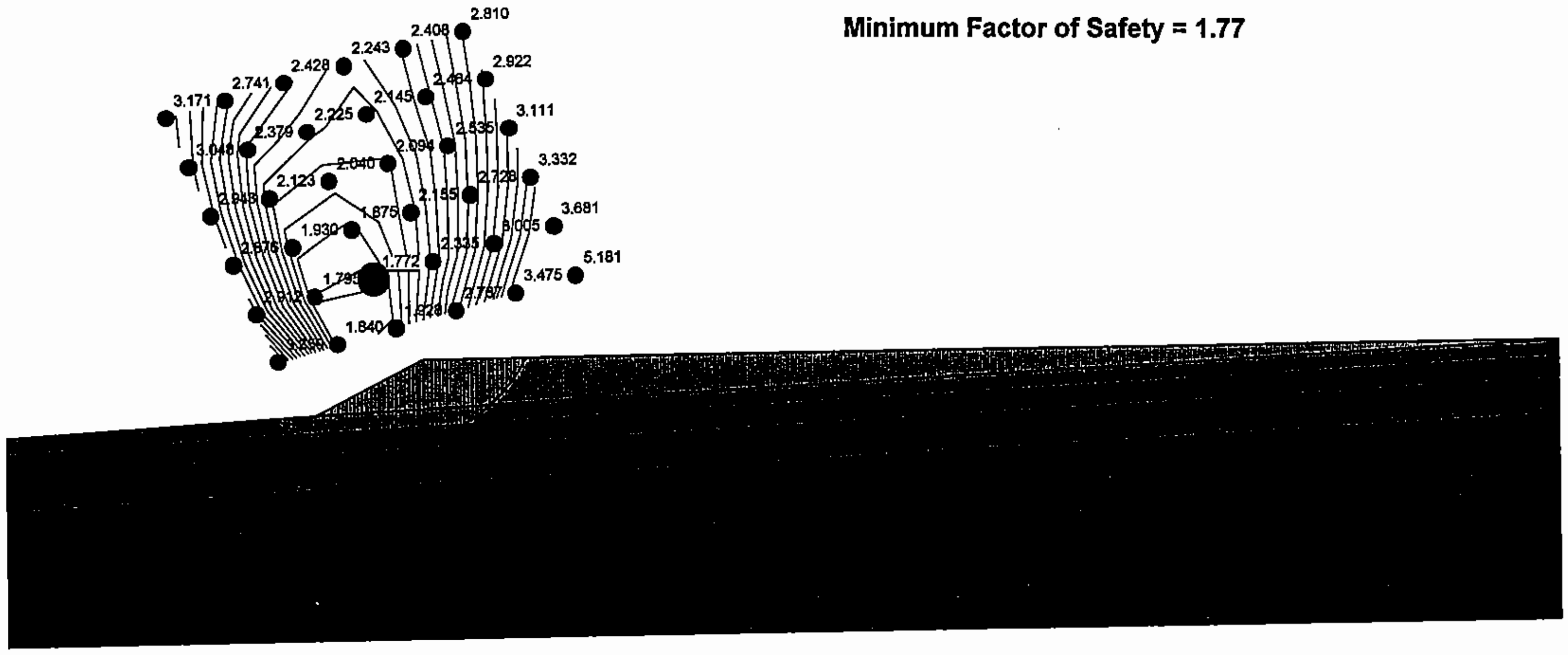


FIGURE 10: PREDICTED LONG-TERM ANNUAL GROUND TEMPERATURE PROFILE VARIATION AFTER WASTE DUMP CONSTRUCTION



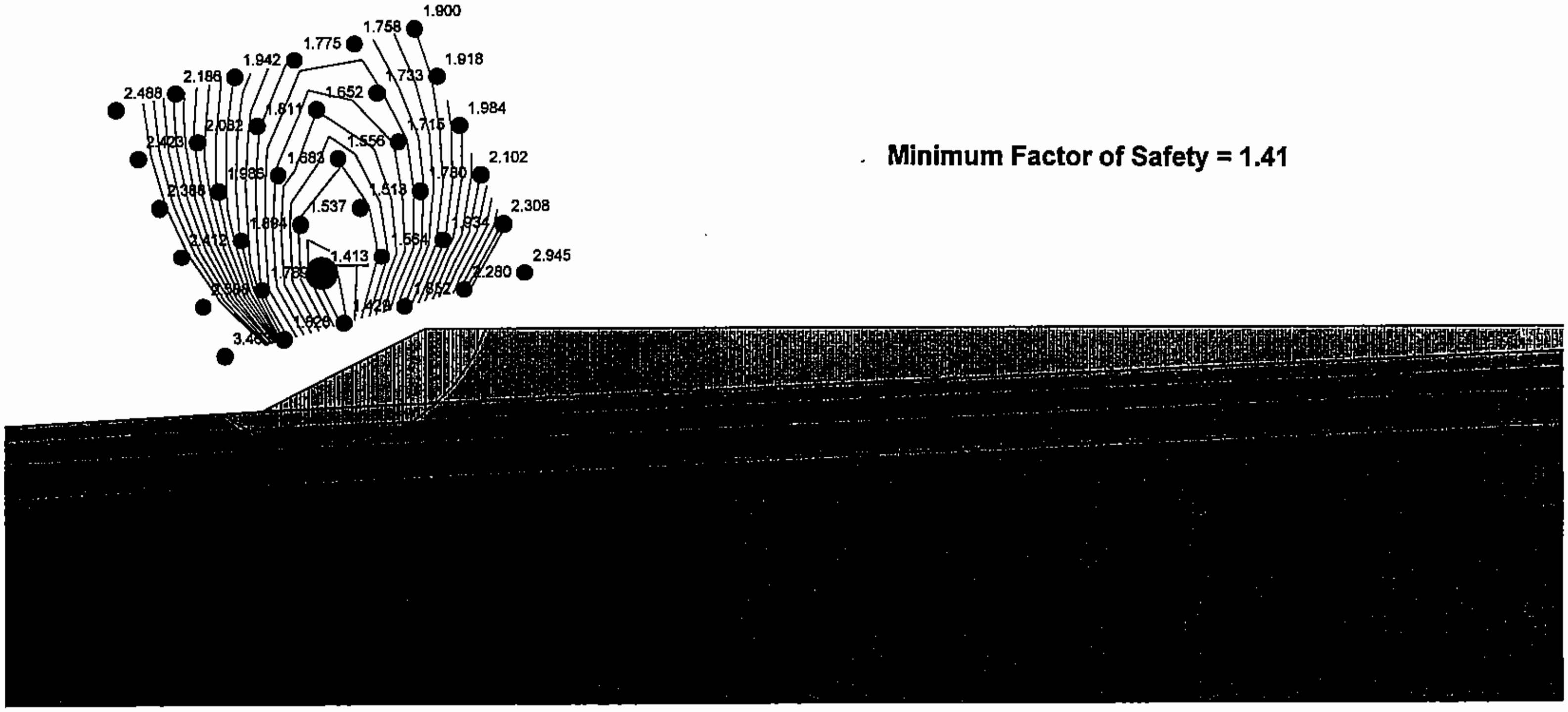
Note: Bedrock contact position has been projected from nearby exploration borings.

FIGURE 11: CROSS SECTION OF PROPOSED SOUTH WASTE DUMP AREA



Minimum Factor of Safety = 1.77

FIGURE 12: SHORT-TERM CRITICAL SLIP SURFACE,
SINGLE LIFT THICKNESS OF 3m



Minimum Factor of Safety = 1.41

FIGURE 13: SHORT-TERM CRITICAL SLIP SURFACE,
SINGLE LIFT THICKNESS OF 5m

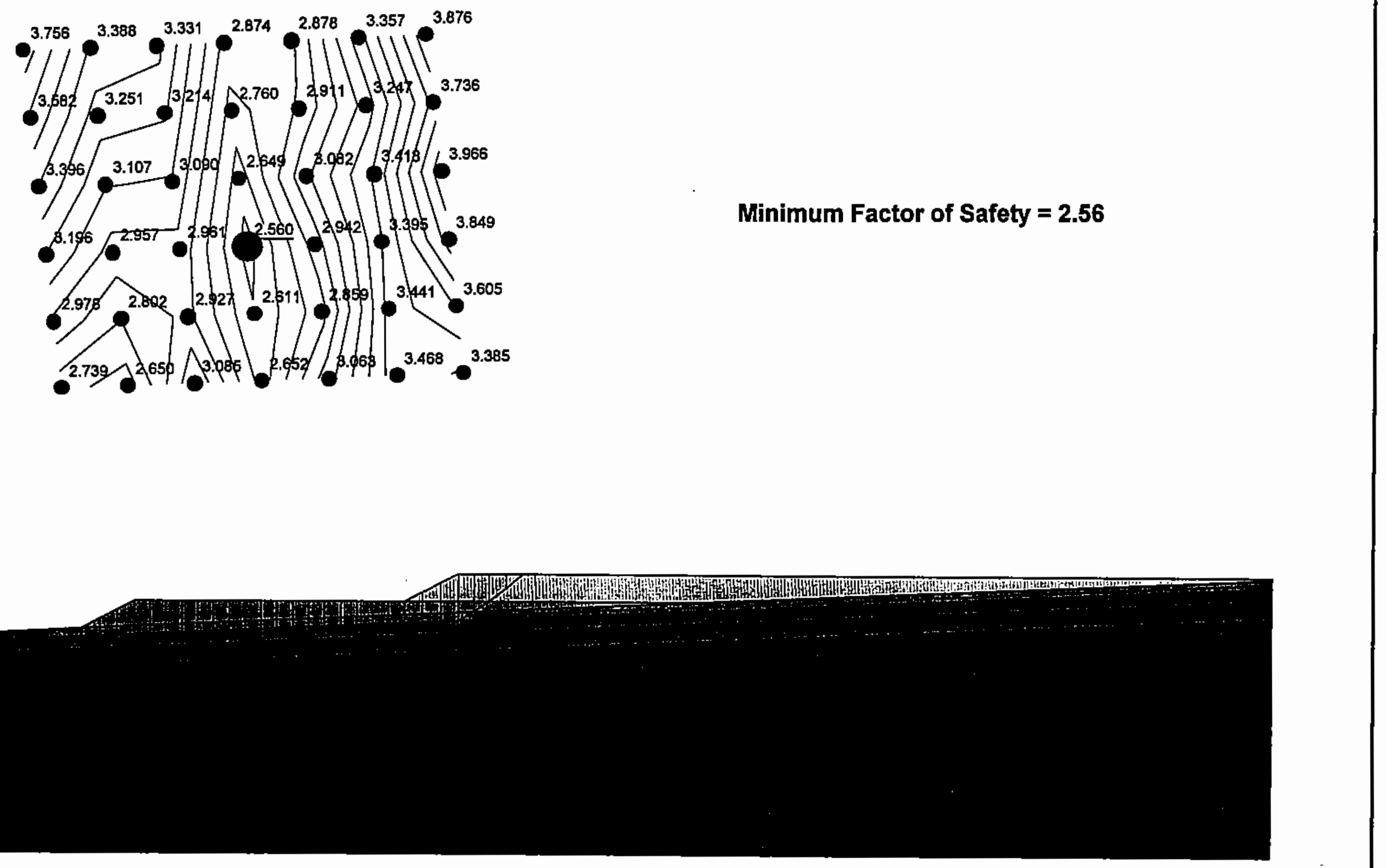
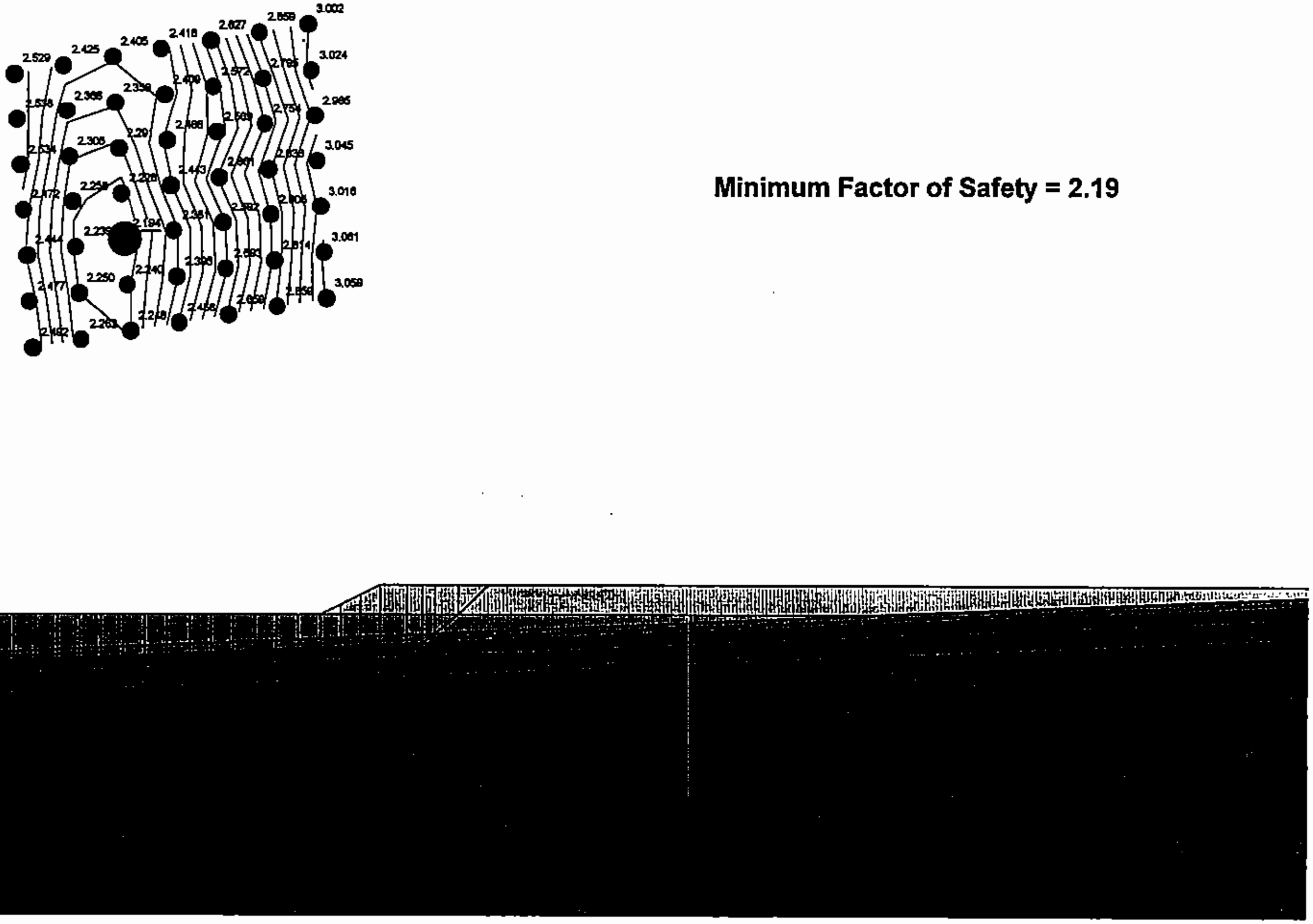
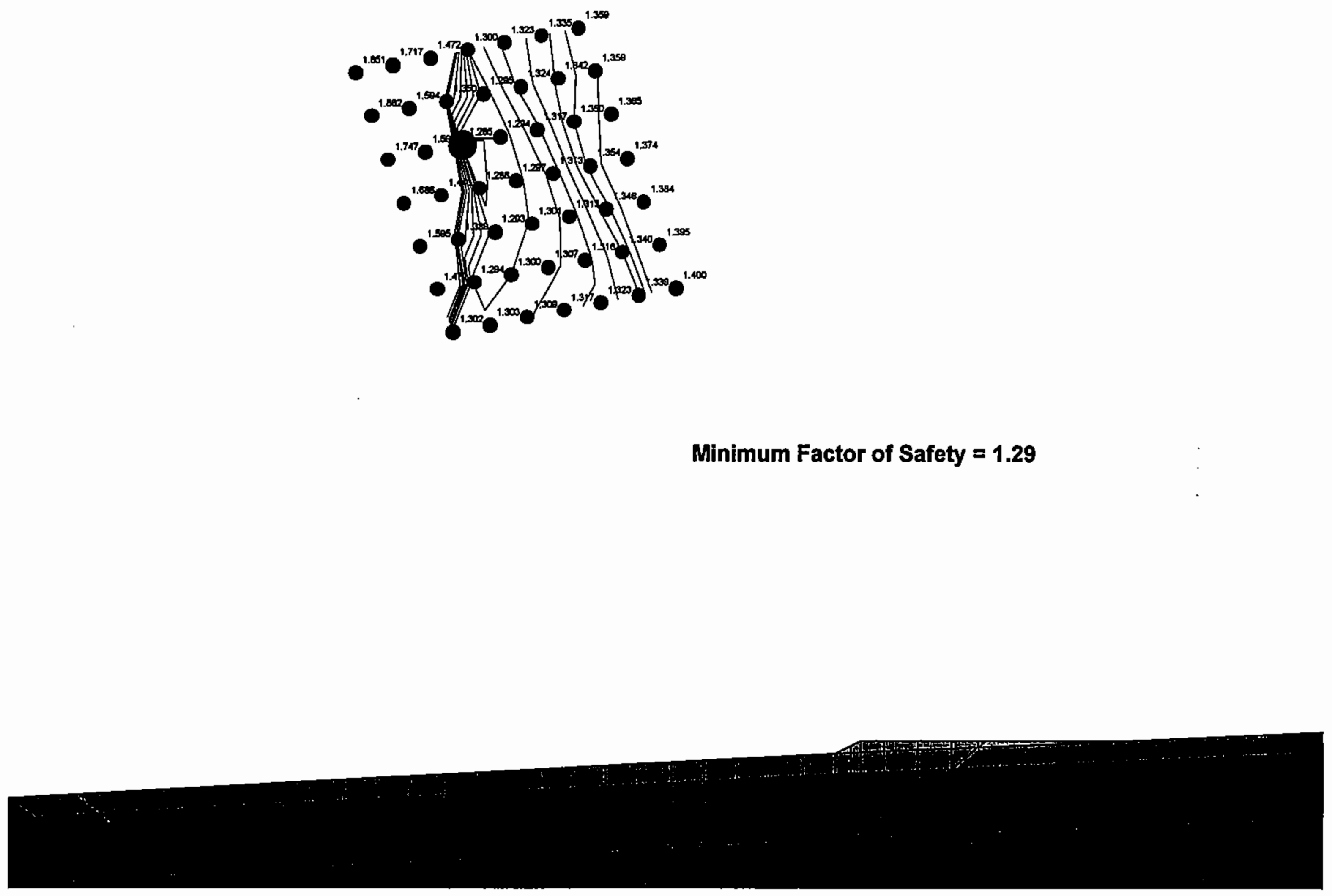


FIGURE 14: SHORT-TERM CRITICAL SLIP SURFACE, DOUBLE LIFT THICKNESSES OF 3m OVER 3m



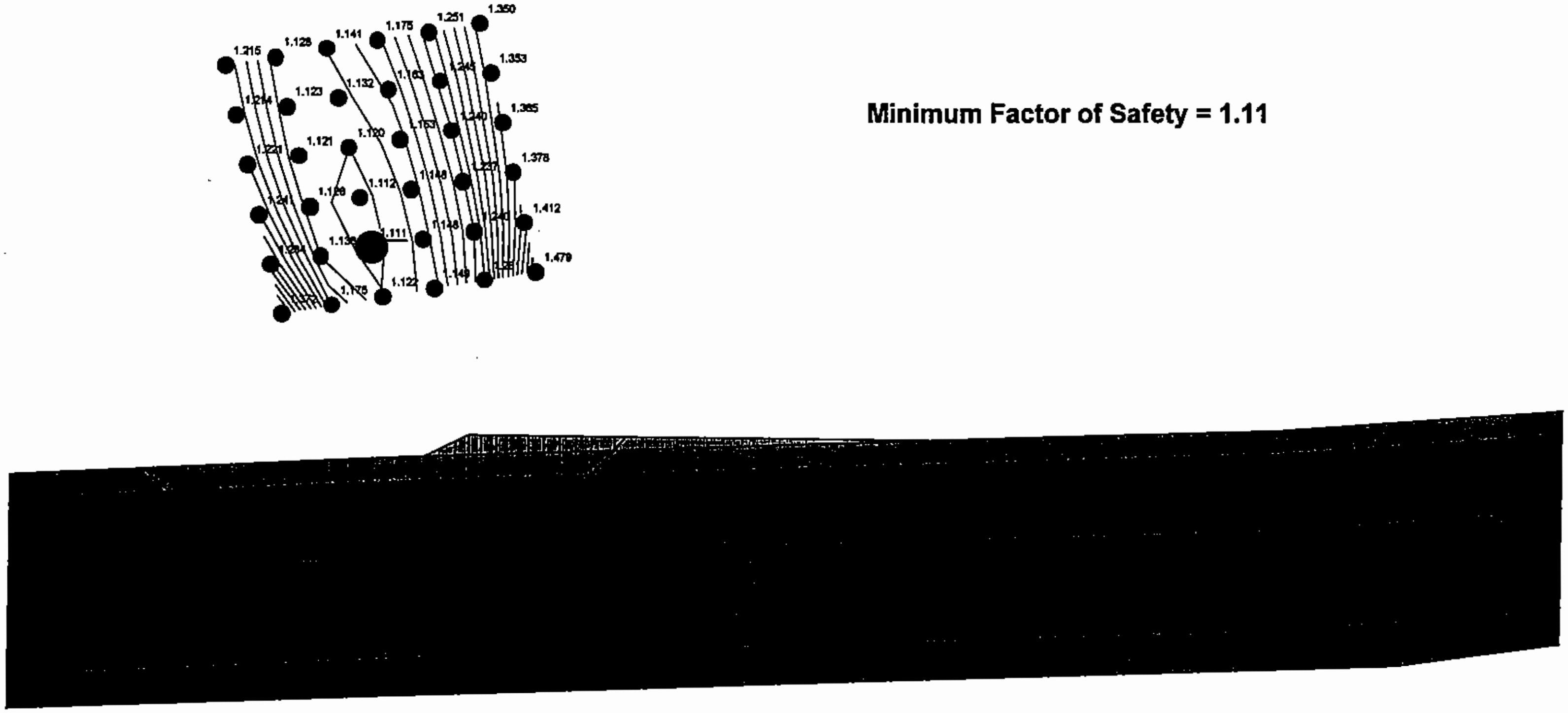
Minimum Factor of Safety = 2.19

FIGURE 15: SHORT-TERM CRITICAL SLIP SURFACE,
DOUBLE LIFT THICKNESSES OF 3m OVER 5m



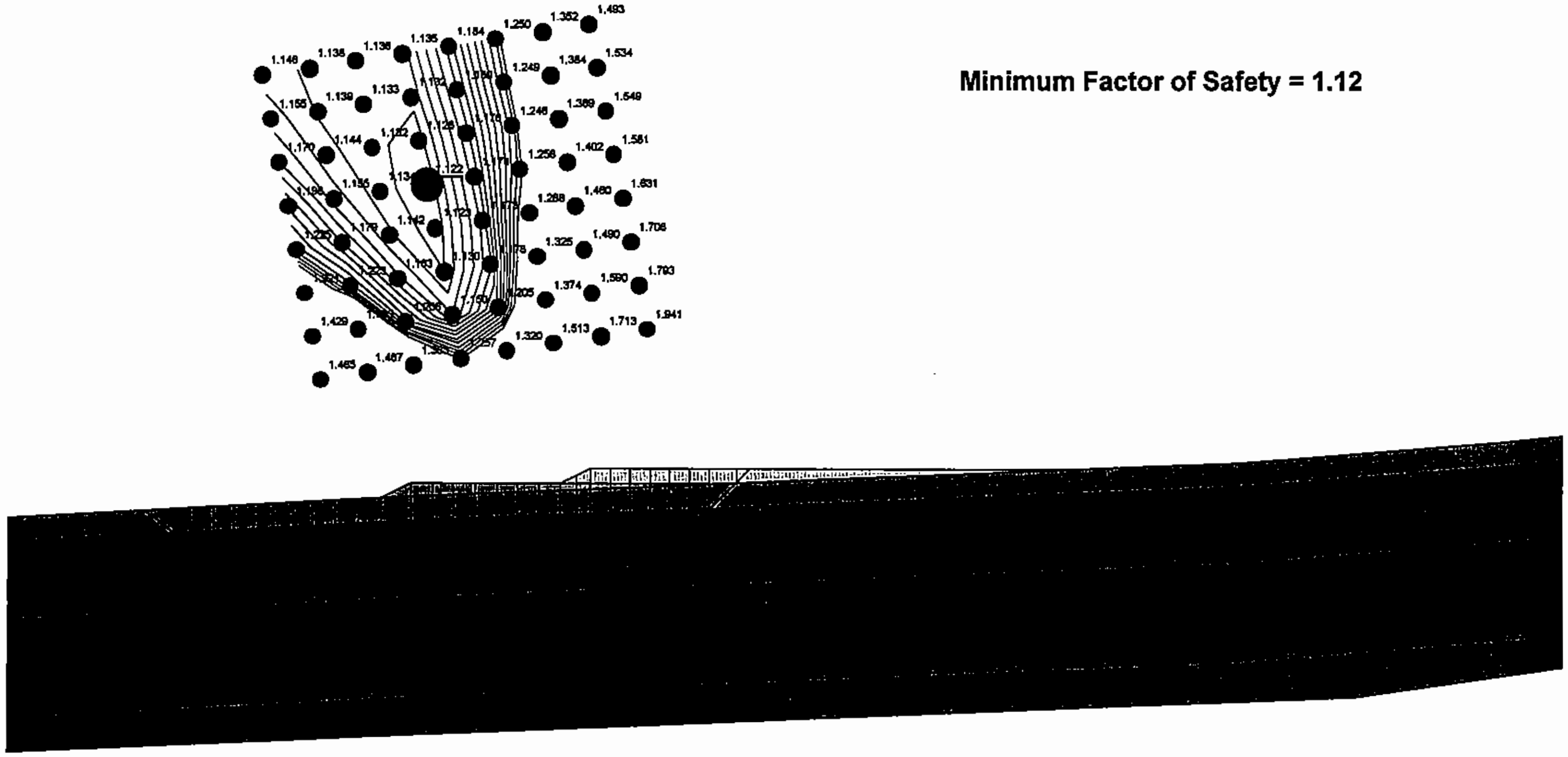
Minimum Factor of Safety = 1.29

FIGURE 16: LONG-TERM CRITICAL SLIP SURFACE, SINGLE LIFT THICKNESS OF 3m



Minimum Factor of Safety = 1.11

FIGURE 17: LONG-TERM CRITICAL SLIP SURFACE, SINGLE LIFT THICKNESS OF 5m



Minimum Factor of Safety = 1.12

FIGURE 18: LONG-TERM CRITICAL SLIP SURFACE,
DOUBLE LIFT THICKNESSES OF 3m OVER 3m

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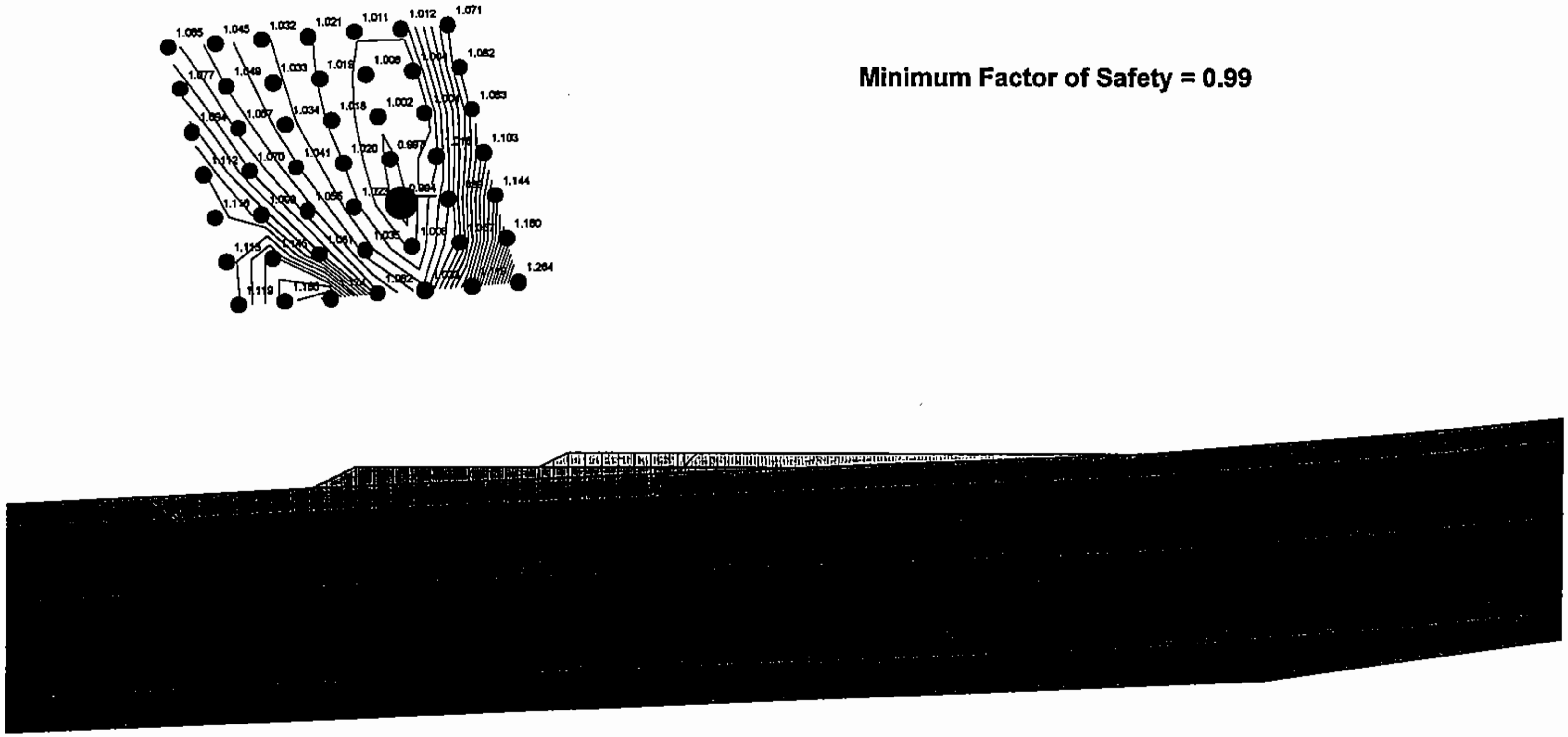

Minimum Factor of Safety = 0.99

FIGURE 19: LONG-TERM CRITICAL SLIP SURFACE,
DOUBLE LIFT THICKNESSES OF 3m OVER 5m