Safety in Mine Research Advisory Committee

Final Report

(Revised)

Infrared thermography of loose hangingwalls

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Research agency: CSIR: Division of Mining Technology

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Executive summary

This project is the continuation of GAP706 “Pre-feasibility investigation of infrared thermography for the identification of loose hangingwall and impending falls of ground”. The main concept behind the infrared thermography method is that with an exposed hangingwall surface area, loose sections of ventilated rock should have a lower temperature than solid sections of ventilated rock because the former acts like cooling fins. The temperature gradient between loose and solid rock depends on the thermal conductivity of the rock, the ventilation conditions, the looseness of the rock and, to a lesser extent, the type of rock and age of mining. Such a gradient could be anything from a tenth of a degree to a few degrees Centigrade.

Underground tests have been conducted at Anglo Platinum Townlands platinum mine and Gold Fields Driefontein 5 shaft gold mine. The obtained results demonstrate that the method of IR thermography for identification of loose hangingwall is only applicable for primary roof-bolt installation during the first 24 hours after a blast.

The concept of a mine worthy IR thermometer is proposed. It is recommended that the MX4 IR thermometer be modified in accordance with the proposed concept. These devices should be provided to a couple of development teams for practical evaluation. It is expected that the device will provide better identification of loose hanging walls, which are difficult to detect visually. The evaluation results, as obtained from the development teams, should facilitate a final decision on the applicability of the IR thermography for the South African mining industry.

Acknowledgement

I would like to express my gratitude towards Rustenburg Platinum Mine (Townlands shaft) and Driefontain 5 shaft for facilitating the underground tests and for their full support during the implementation of the project.

Special thanks to my colleagues at Miningtek: Mr K Walker and R Bilgeri for their persistence in the project implementation.

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1 Introduction

This project is the continuation of GAP706 “Pre-feasibility investigation of infrared thermography for the identification of loose hangingwall and impending falls of ground”. The main concept behind the infrared thermography method is the fact that due to the exposed hangingwall surface area, loose sections of ventilated rock should have a lower temperature than solid sections of ventilated rock because the former acts like cooling fins. The temperature gradient between loose and solid rock depends on the thermal conductivity of the rock, the ventilation conditions, the looseness of the rock and, to a lesser extent, the type of rock and age of mining. Such a gradient could be anything from a tenth of a degree to a few degrees Centigrade.

The results of project GAP706 have confirmed the presence of such a temperature gradient in South African gold and platinum mines. The main objectives of the current project were long-term underground tests in order to evaluate the applicability of the method and the technical specification of the instrumentation, suitable for implementation.

Underground tests were conducted at Anglo Platinum, Townlands platinum mine and Gold Fields Driefontein 5 shaft gold mine. This report presents mostly the measured results obtained and the conclusions drawn on the applicability of the method. It is worth noting in hindsight that the interpretation and presentation of the measured results were the most time consuming process, more time consuming than the actual measurements in underground conditions.

2. Instrument modification

As was proposed during the in pre-feasibility study *(Kononov, 2000),* the type of temperature measuring instrument used makes a significant impact on the obtained results. The MX4 infrared (IR) thermometer manufactured by Raytek (Germany) was selected for use during these projects mainly for two reasons: very good resolution and measurement repeatability. Another important factor was that Raytek expressed their interest to participate in the modifications to the device to comply with the requirements of the South African mining market.

As was concluded in the report for project GAP706, commercially available IR thermometers are unable to provide reliable operation in the hostile South African underground environments. They lack the general protection against dust, moisture and the robustness required of a mineworthy instrument.

Apart from these obvious drawbacks, commercial devices are usually designed to provide a very narrow measurement angle that enables the integration of the temperature from a surface of about 30-40 mm in diameter at a distance of 1,5-2 m. During this project it was proven that when the method is used for the identification of loose rock, a much wide angle or measuring area is required. It is proposed that a measurement area with a diameter of 80-120 mm provides better measurement results.

The best resolution provided by commercial devices is about 0,1 ^{0}C within the measuring range from – 10 ^{0}C up to + 900 ^{0}C. It was reasonable to propose that reduction in the temperature measurement range could enable the improvement of resolution. For South African mines, a measurement range from 0 ^{0}C to 90 ^{0}C is more than sufficient for the purpose of rock temperature monitoring.

To this end, together with Raytek, one of the MX4 IR thermometers was modified to comply with the following specification:

Special optics:	SF 28 mm @ 1152 mm (41:1)
	CF 9 mm @ 300 mm (33:1)
Temperature range:	0 … 90 ^{0}C

Temperature resolution: # 0,05 ^{0}C
Improved stability and repeatability
Environmental protection: IP54

A special coating for the PC board and an IR sensor was used to improve the reliability of the device. Underground tests conducted with the modified device demonstrated that the instrument could be used in a humid atmosphere without deterioration in its performance. It was also confirmed that a wide measurement area provides better rock temperature integration since the rock surface has a very uneven shape.

3. Rock emissivity

The intensity of a perfect radiator (black body) is a function of its temperature only. Rock can be thought of as a so-called "grey body", for which the true emissivity is always lower than that of a black body. When the IR thermometer is used for remote measurement of rock temperature, a true emissivity for the particular rock should be used to achieve the best accuracy. As it is difficult, in underground conditions, to correct for the rock emissivity during the measurement process, a few typical samples of rock were examined in order to identify their true level of emissivity.

The following measurement procedure was used. Rock samples were kept in an environment of stable temperature for about 10 hours assuring that a temperature equilibrium between air and rocks was reached. The real temperature of each rock sample was measured by a contact method using a thermocouple. Simultaneously, a remote measurement was taken from a distance of about 1 m with the MX4 IR Thermometer. The emissivity level was adjusted on the MX4 until the IR thermometer provided the same reading as the contact temperature. The obtained results are given in Table 2.1.

Emissivity of selected South African rocks

No	Type of rock	Emissivity
1	Quartzite	0,8
2	Anorthosite	0,8
3	Pyroxenite	0,8
4	Chromitite	1,0
5	Merensky Reef	0,6
6	Pyroxenite (coarse)	0,6
7	Green Bar Shale (Carbon Leader hanging wall	0,6
8	Alberton Porphyry Lava (VCR hanging wall)	0.9
9	VCR conglomerate	0,7
10	Norite (plagioclase+pyroxene)	0,75
11	Anorthosite (plagioclase+pyroxene)	0,8

The measured rock types (Table 2.1) are a representative spectrum of strata associated with Witwatersrand and Bushveld orebodies. It is therefore, concluded, that an average emissivity of 0,8 could be applied to any underground measurement when considering gold and platinum mines.

4. Test proceedings

During the project implementation the same testing procedure was used as for the GAP706 project. Hanging walls were divided into 1x1 m cells. The temperature of at least 5 locations within each cell was measured. Using a digital photo camera, pictures of all cells were taken. Each cell was measured at least three times during the duration of the project.

It was found that in order to provide a clear presentation of cracks and the unevenness of the hanging walls a special illumination technique, involving at least two light sources, should be used. Even using this technique, it was very difficult to apply a simple photographic image for three-dimensional evaluation of the hanging wall surface. It was almost impossible to perform imaging in the presence of dusty surfaces. Therefore, the surface profile of each cell was also recorded manually. Temperatures and rock shapes were compared in an attempt to determine the correlation between loose rock temperature and rock conditions. The mapping package Surfer 7.0 was used to convert manually measured temperatures into thermograms, most of which are shown in Appendices A and B. The white lines on thermograms represent manually taken profiles of the hanging wall. Small white crosses represent measuring points and small white stars depict roofbolt positions.

The thermograms have a colour resolution of 0,2 °C. In order to retain this resolution through all temperature variations, every thermogram has the same colour coding where dark blue is assigned to the lowest temperature obtained within the particular set of measurements. Orange represents the highest temperature obtained for a particular set of measurements. Therefore, comparison between different measurement sets should be performed using respective spot temperatures, not colours. Concerning the results of temperature distribution, it should be remembered that the lowest rock temperature is related to the presence of loose rock *(Kononov,2000)*.

Due to the high rate of face advance at Townlands platinum mine, the research team had the very rare opportunity to make measurements very close to the newly blasted face.

5 Results obtained at Townlands Platinum Mine

Tests were conducted at Townlands shaft, 21 Level, haulage east. In total, 188 cells were monitored in the haulage and crosscut. Some typical measurement results obtained during the tests at this mine are provided in Appendix A.

On analysing the obtained data, it was deduced that significant variations in airflow caused by a change in the main ventilation system and particularly by a local blow fan, affect rock temperature readings and made it difficult to compare measurement results over time.

The crosscut results show, for example, that the thermogram dated 20.07.2001, cells 1 to 8 (page 12, Appendix A) the lowest temperature of 30,4 ^{0}C was registered in cell No 8. The next measurement set of the same cells conducted six weeks later (page 14, Appendix A) revealed that this temperature increased to 32,6 ^{0}C, while at the same time, the temperature of cell No3 dropped from about 33,4 ^{0}C to 31,8 ^{0}C. The air speeds and ambient air temperatures while each of the sets of readings were taken were 5 m/s, 30,1 ^{0}C and 0,5 m/s, 32 ^{0}C, respectively. The significant drop in airflow was due to the termination of further development because of a massive roof fall beyond cell No 16.

The following explanation is given for the above circumstances. During the first set of measurements, cell No 8 was cooled effectively by a strong airflow from the local fan duct position. When development was stopped, reduction in airflow allowed cell No 8 to reach a temperature higher than the ambient air temperature. At the same time, roofbolted, loose rock in cell No 3 fully detached from the hanging wall and rested on the roofbolt only.

Thermograms (page 13, Appendix A) show that cells 15, 17, 18 and 19 have very low temperatures. Temperature gradients of up to 2 ^{0}C indicate the presence of loose rocks in these cells. This is tentatively related to the massive roof fall beyond cell No16 that took place just a week later, resulting in the crosscut development being postponed.

The tests conducted in the haulage yielded an unstable, non-conclusive temperature distribution along with airflow alteration and a longer interval between measurements. When the interval between measurement sets was short, the results were more compatible. This is demonstrated in cells 55-58 on 7.09.2001 and 14.09.2001 (pages 35 and 36, Appendix A).

During the test period, the hanging wall areas of cells 34, 35, 37, 38, 40, 43, and 44 in the haulage collapsed. They were between two and three weeks old. Only two of them, cells 35 and 44 could be confirmed as being loose by measurements dated 31.08.2001 (pages 33 and 42, Appendix A) The same cells gave no warning during the test conducted on 6.06.2001.

In three cases when hanging wall IR scanning was performed after blasting, the visual inspection, scaling and associated roofbolting (i.e. roofbolts were installed in areas of low temperature, therefore, loose hangingwall rocks), fully confirmed IR scanning results.

6 Comparison of the IR and vibration methods

At SIMRAC's request, a comparison of the IR and Acoustic energy methods was conducted on 14 September 2001 at Townlands shaft. Unfortunately, in their analysis, Ground Work compared the air temperature and the temperature of the rock in the places of hammering, instead of the temperature of the adjacent rocks and the temperature of the rock in the hammering place. This could be the reason, why no close correlation between the two methods was observed.

7. Results obtained at Driefontein Gold Mine

The tests were conducted at Driefontein 5 shaft, 44 level, 22 crosscut. In total, 70 cells were monitored. The obtained results are given in Appendix B. During the test period no hangingwall falls occurred.

In two cases when hanging wall IR scanning were performed after blasting, the visual inspection, scaling and the associated roofbolting fully confirmed the scanning results. No cells have been painted on the hanging walls in these cases as no team access under unsupported roof was allowed.

8. Proposed concept of instruments for underground application

Resulting from participation of Raytek in the modification of instruments for the project, the company announced the development of the ST80-IS Infrared Thermometer. This device is suitable for surface chemical plants and underground electrical and mechanical maintenance operations, but it's accuracy and repeatability does not satisfy the requirements for hanging wall monitoring. Another drawback of the device is the shape of the body, which makes it difficult to use underground.

Based on the prolonged underground tests conducted using the modified MX4 instrument, the following concept is proposed.

Besides the implemented increase in measurement area (see Section 2) for better temperature integration and providing good PC board coating and housing to protect optics and electronics against dust and humidity, the entire concept of the IR thermometer for underground use should be reconsidered.

Commercial devices have a number of functions such as different data presentation modes, alarm setting, $^0C/^0F$ and ^0K switch, ON/OFF laser maker etc. All of these make the device more complicated to use and more difficult to seal against dust and moisture. It is proposed that the device should have only the trigger button and a reading display with a backlight. A fixed emissivity of 0,8 should be programmed into the device. The operational temperature range from 0 ^0C to 90 ^0C will enable to improve resolution, stability and repeatability of the IR thermometer. The shape of the device should be suitable for pocket or belt pouch carrying (Figure 6.1).

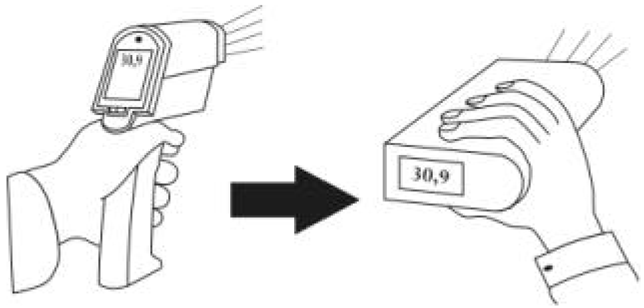


Figure 8.1 Proposed concept of the underground IR thermometer device

Functions such as a laser pointer and display illumination should always be activated when the trigger is pressed for measurement purposes. In addition, functions such as a differential temperature reading between two subsequent measurements should be implemented, as this simplifies the process of loose rock identification.

9. Conclusions

Results of the prolonged underground experiments, aimed at the evaluation of IR thermography for identification of loose hanging walls, enables the following conclusions to be drawn:

1. The modified IR thermometer provided better results than the commercially available instrument.

2. Significant variations in airflow, caused particularly by local blow fans affect temperature readings and make it difficult to compare measurement results separated in time, making the measurement process inconclusive.

3. Measurements within distances of 5 – 7 m in front of the local ventilation duct are unreliable.

4. Freshly washed wet walls have uneven temperature gradients. The wall should be reasonably dry before measurement.

5. The method of IR thermography for identification of loose hanging wall is only applicable for primary roofbolting after the face blast, before reinstallation of the ventilation duct.

6. The method is applicable for the few days following the blast, when ventilation conditions are stable.

10. Recommendations

In order to make the final decision on the implementation of the method for primary roofbolt installation, the following recommendations are formulated as an extension of this project.

1. A workshop on the use of the method for primary roofbolt installation should be conducted.

2. A few MX4 IR thermometers should be modified by CSIR Miningtek in accordance with the proposed concept.

3. These devices should be given to development teams selected during the workshop for practical evaluation. It is expected that the device will assist in the identification of loose hanging walls after face blasting, thereby facilitating appropriate and efficient roofbolting.

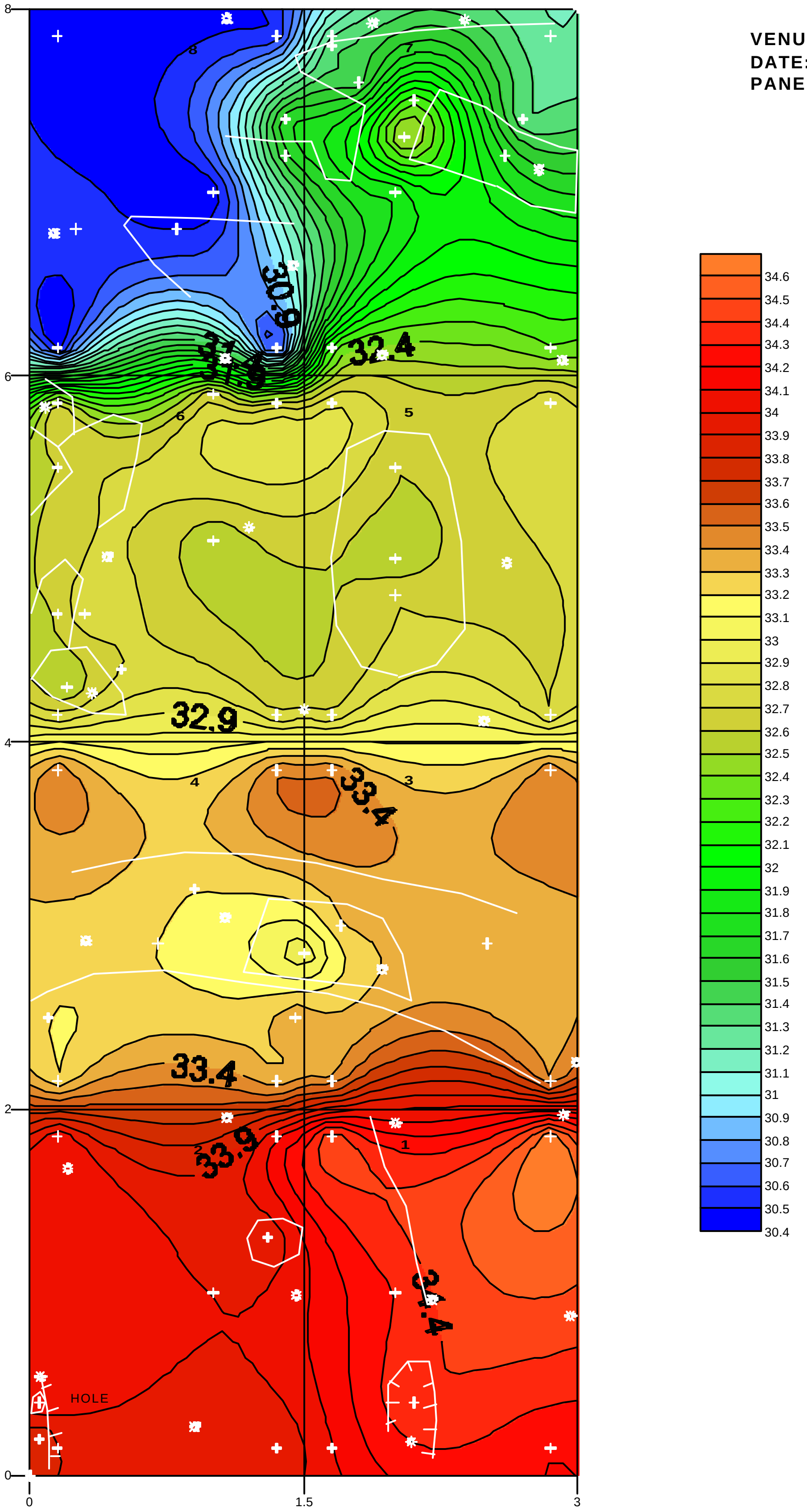
4. The feedback obtained from the development teams will enable SIMRAC to make a final decision on the applicability of IR thermography for the South African mining industry.

Reference.

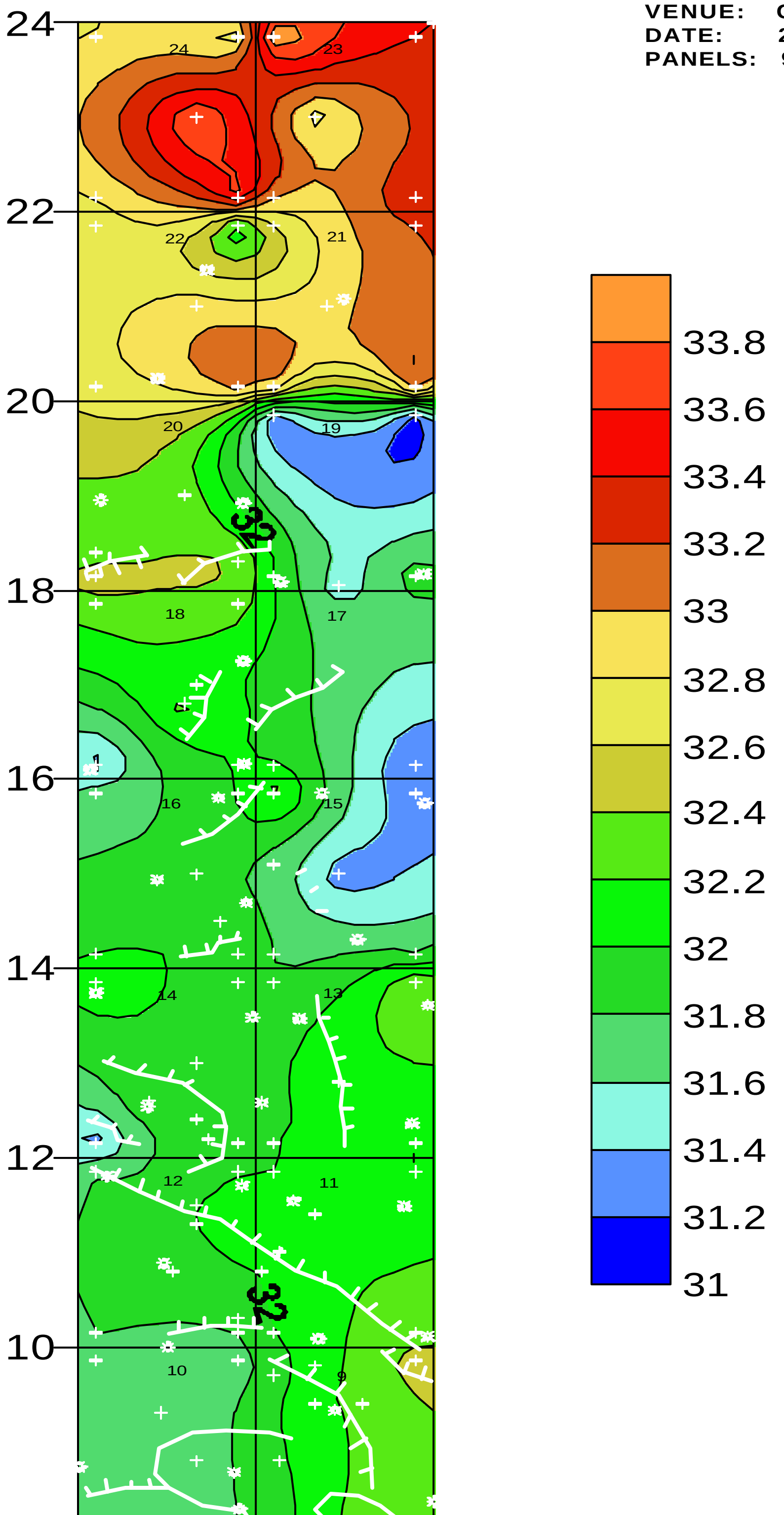
Kononov, V.A. 2000. Pre-feasibility investigation of infrared thermography for the identification of loose hangingwalls and impending falls of ground. *SIMRAC Final Project Report GAP706*. Pretoria Department of Minerals and Energy, 26p.

Appendix A: Thermograms, Townland Platinum Mine

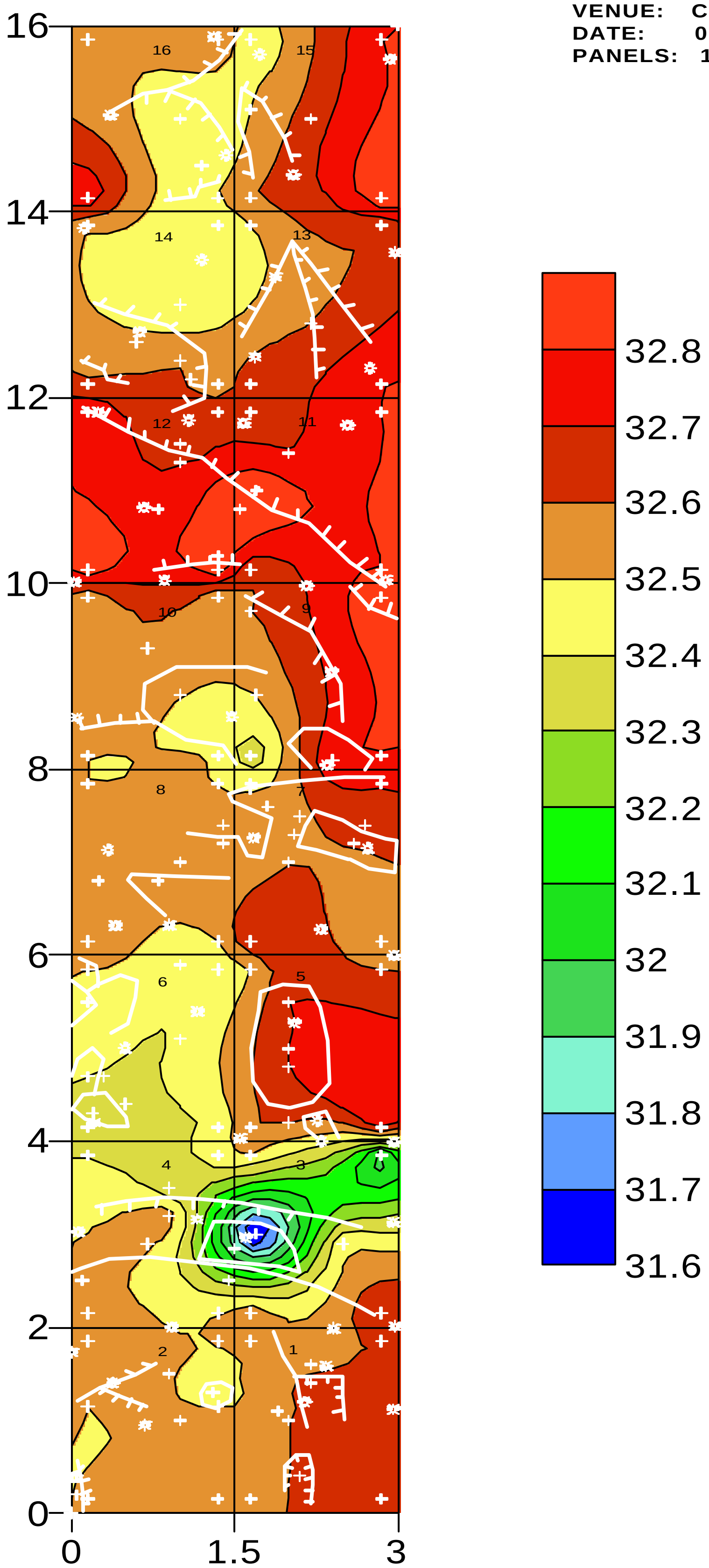
VENUE: CROSS CUT
DATE: 20 JULY 2001
PANELS: 1 - 8



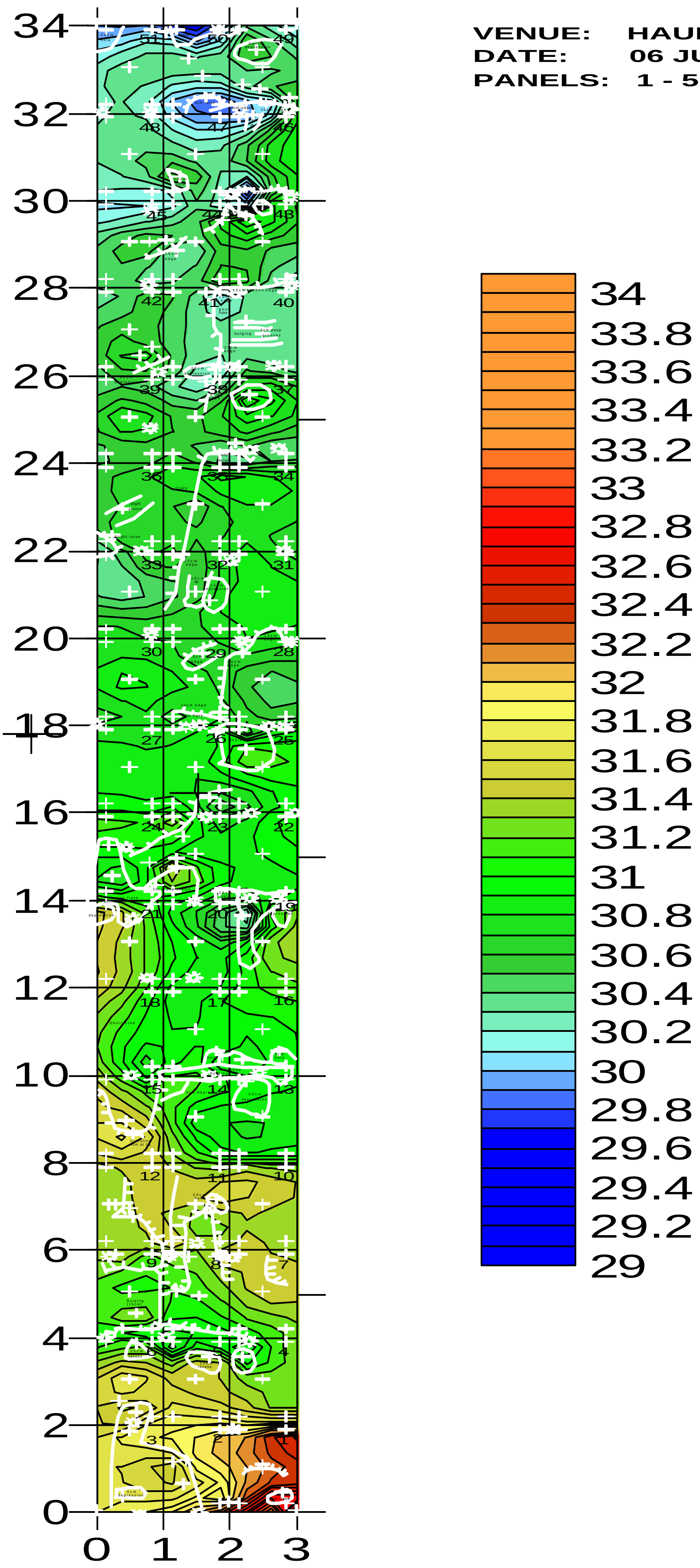
VENUE: CROSS CUT
DATE: 27 JULY 2001
PANELS: 9 - 24

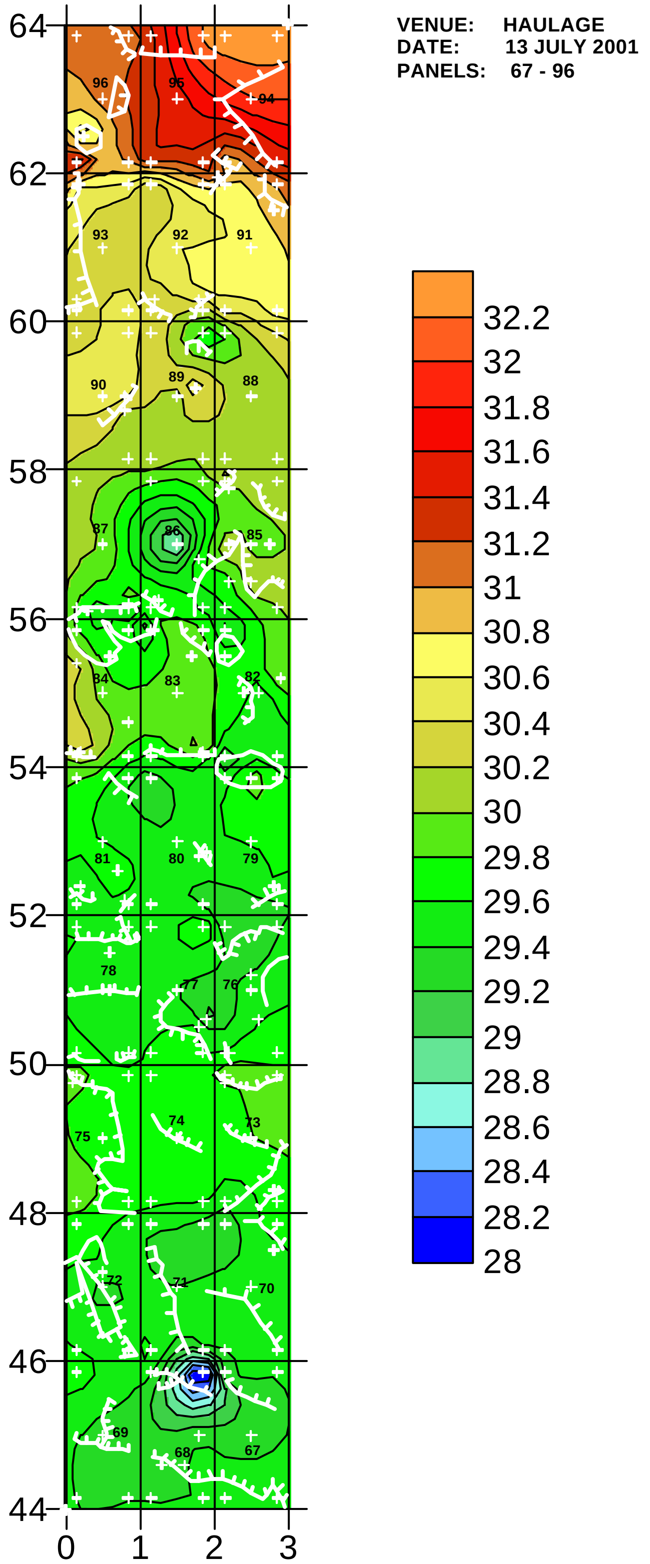


VENUE: CROSS CUT
DATE: 07 SEPTEMBER 2001
PANELS: 1 - 16



VENUE: HAULAGE
DATE: 06 JULY 2001
PANELS: 1 - 51





VENUE: HAULAGE
DATE: 13 JULY 2001
PANELS: 67 - 96
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31.6
31.4
31.2
31
30.8
30.6
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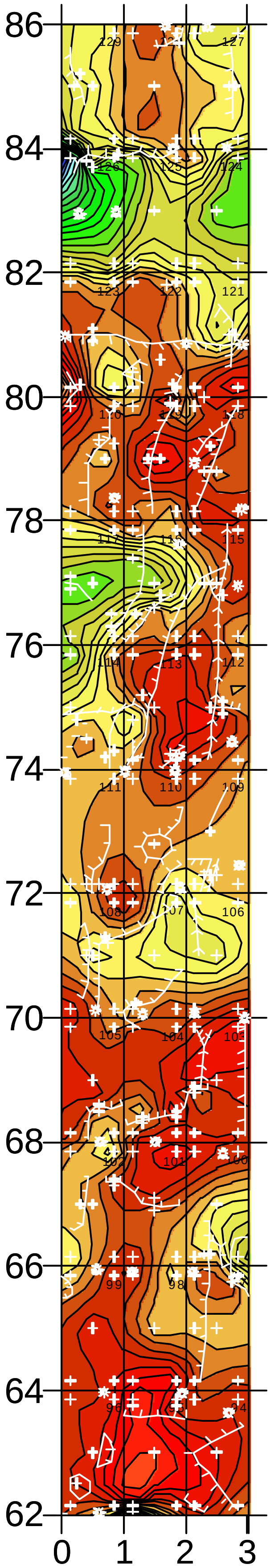
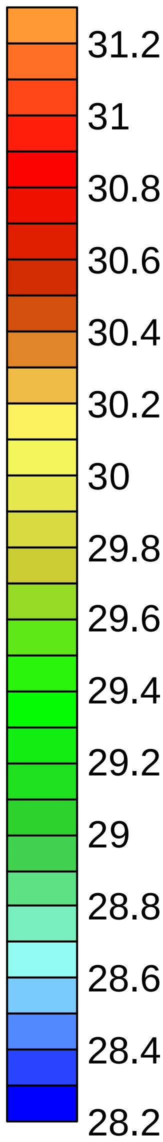
28.4
28.2
28



VENUE: HAULAGE
DATE: 03 AUGUST 2001
PANELS: 94 - 129



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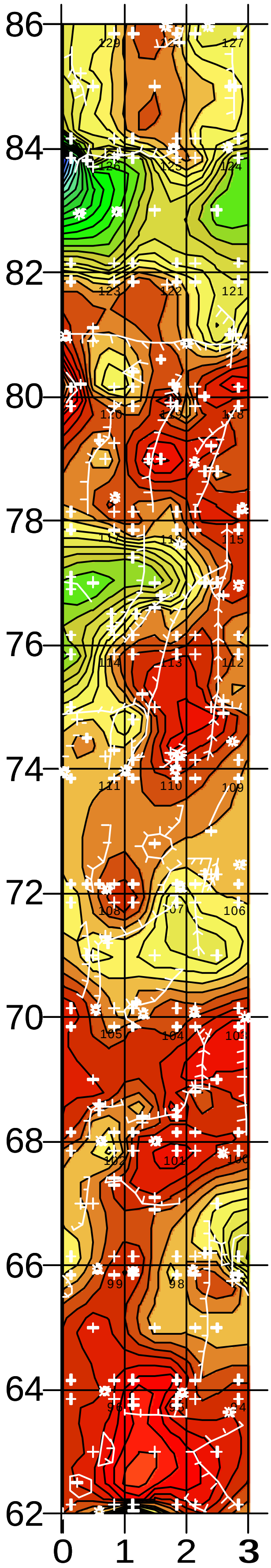
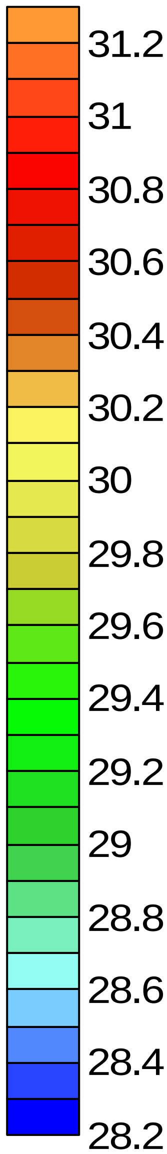
PANELS: 94 - 129





VENUE: HAULAGE
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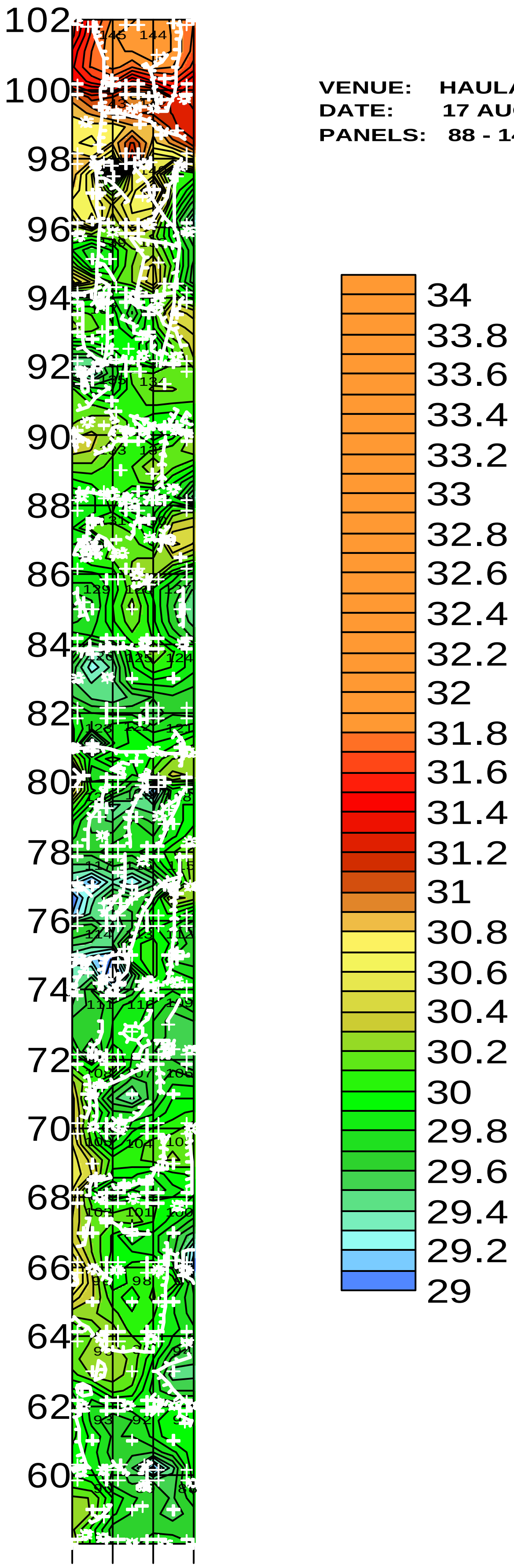
PANELS: 88 - 145



VENUE: HAULAGE
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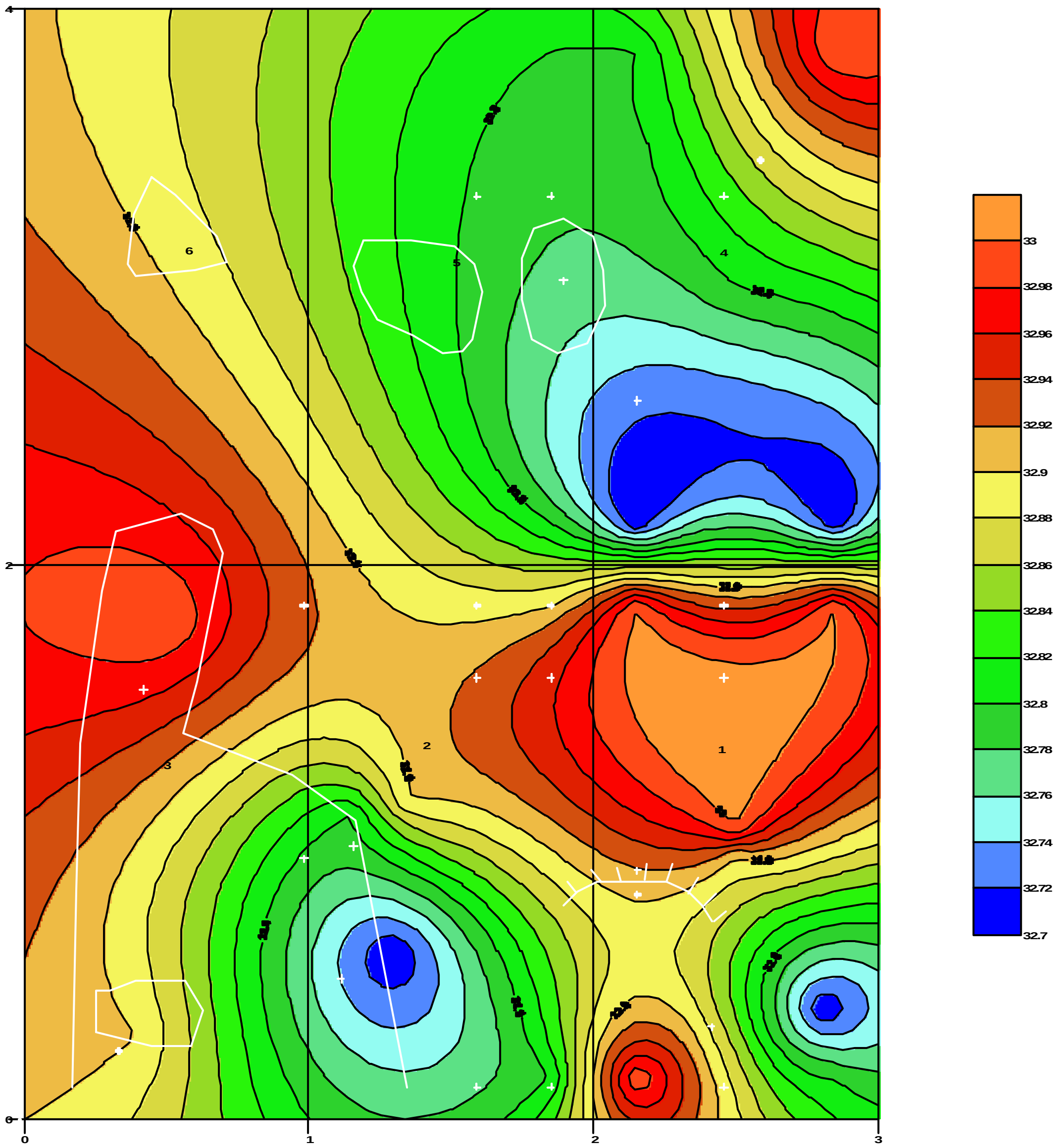
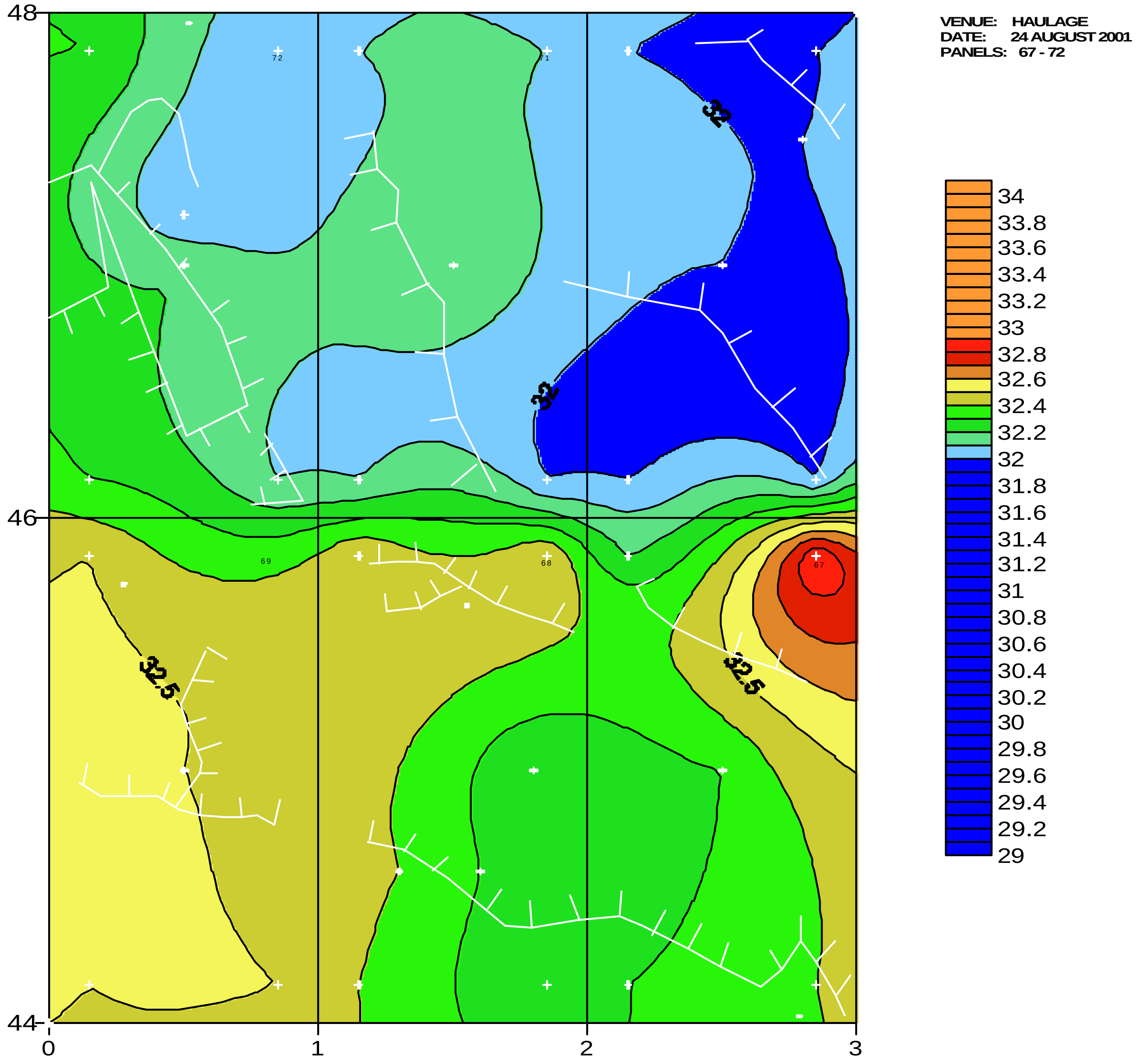
PANELS: 1 - 6

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PANELS: 67 - 72
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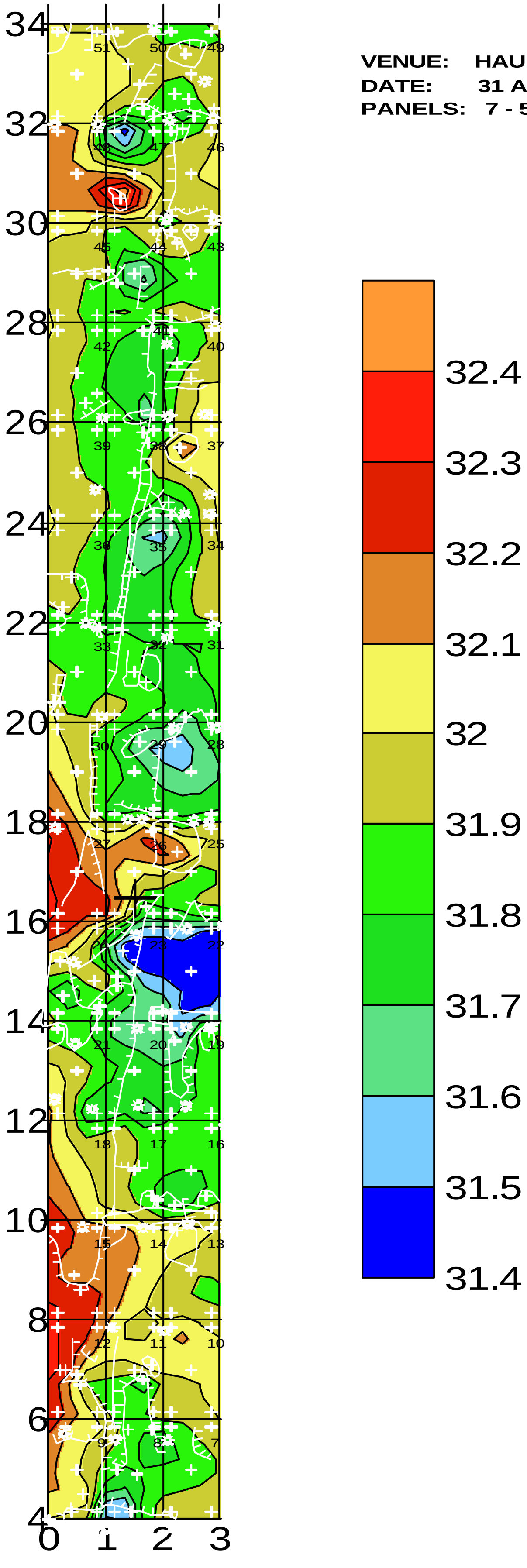
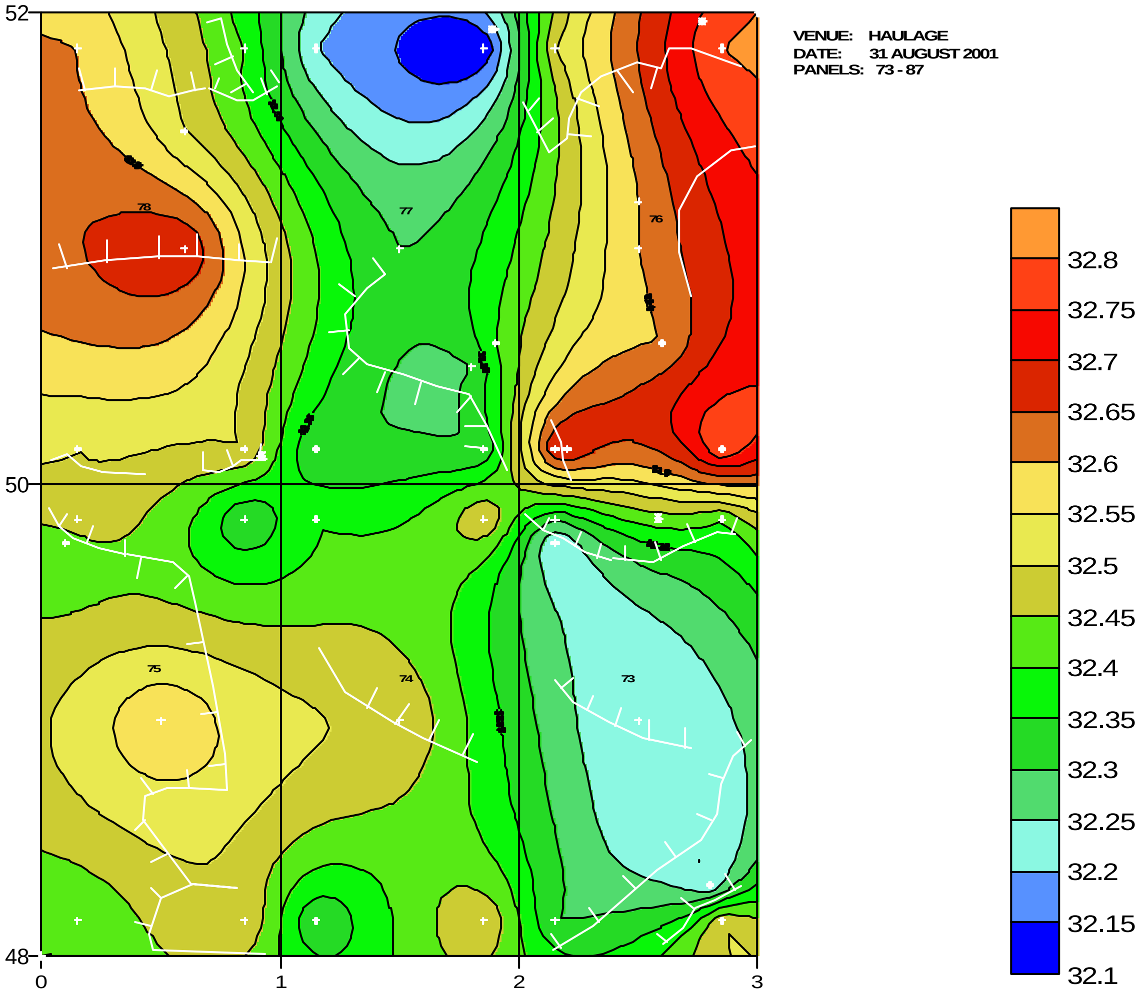
VENUE: HAULAGE
DATE: 31 AUGUST 2001
PANELS: 7 - 51

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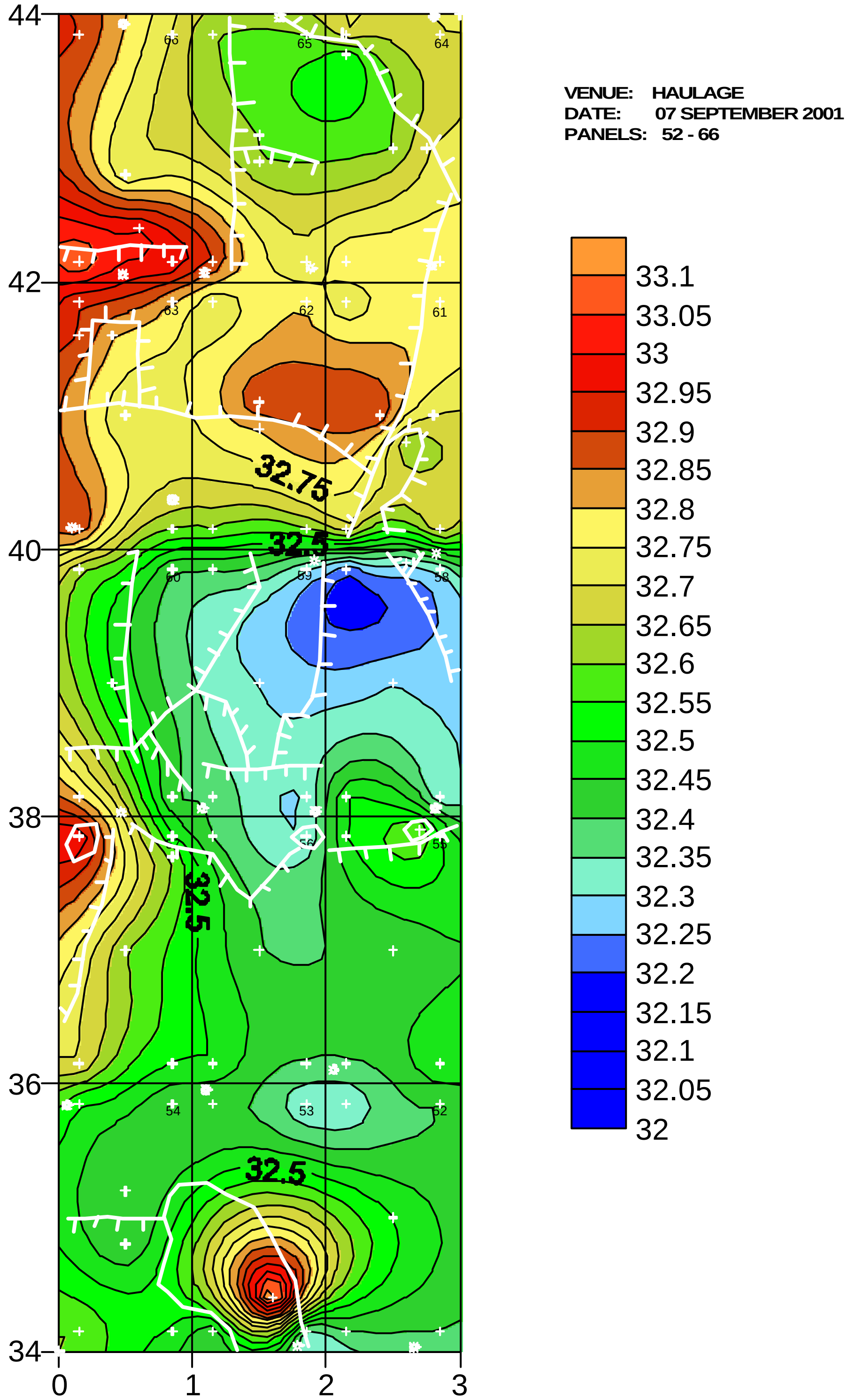
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VENUE: HAULAGE
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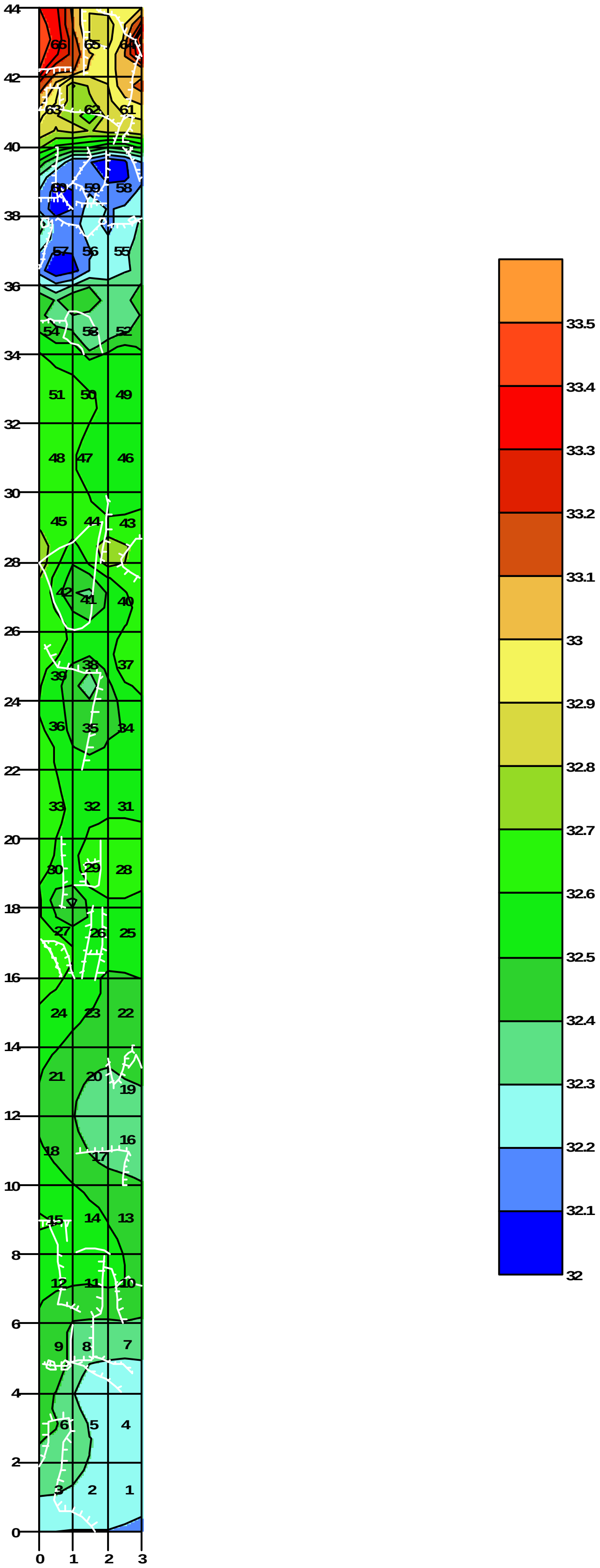


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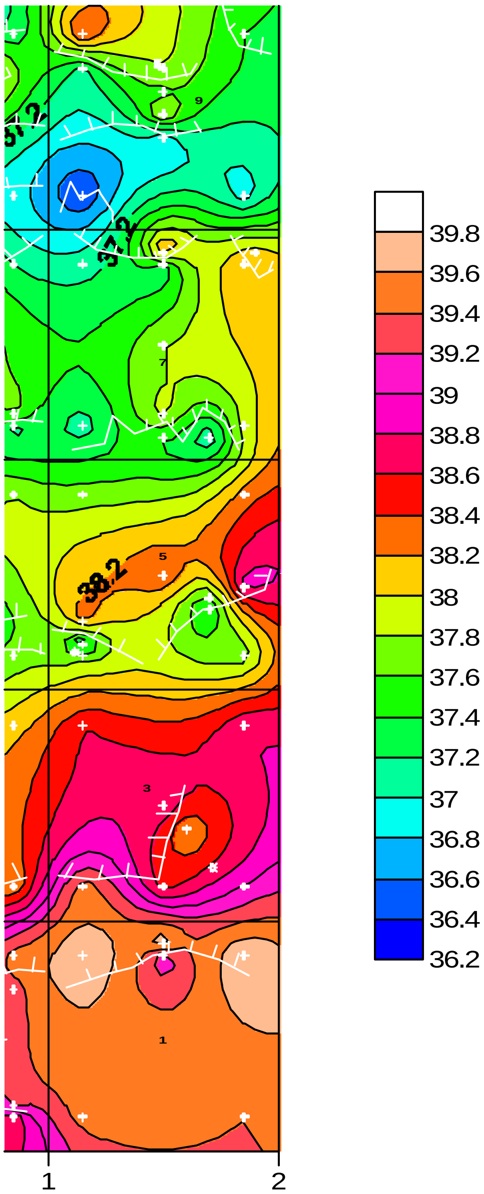
Appendix B: Thermograms, Driefontein Gold Mine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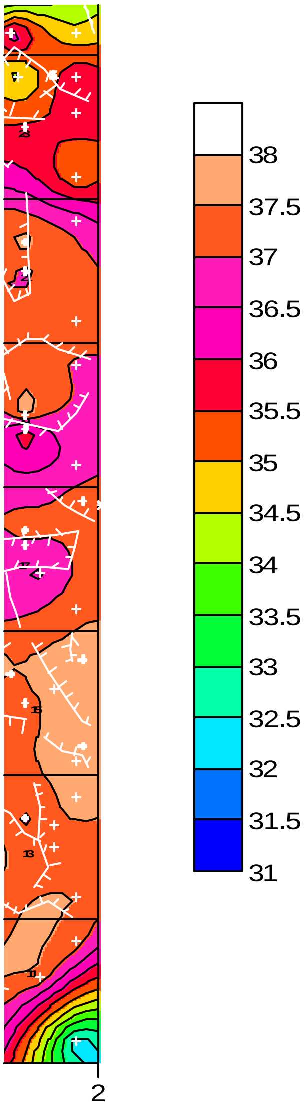

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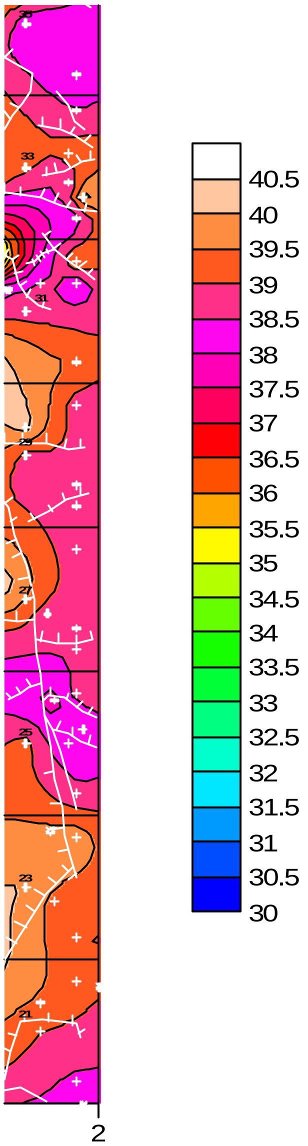
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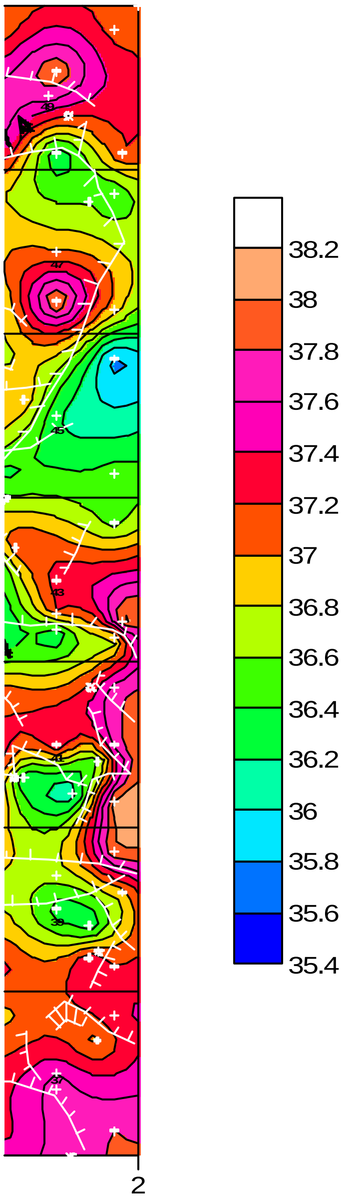

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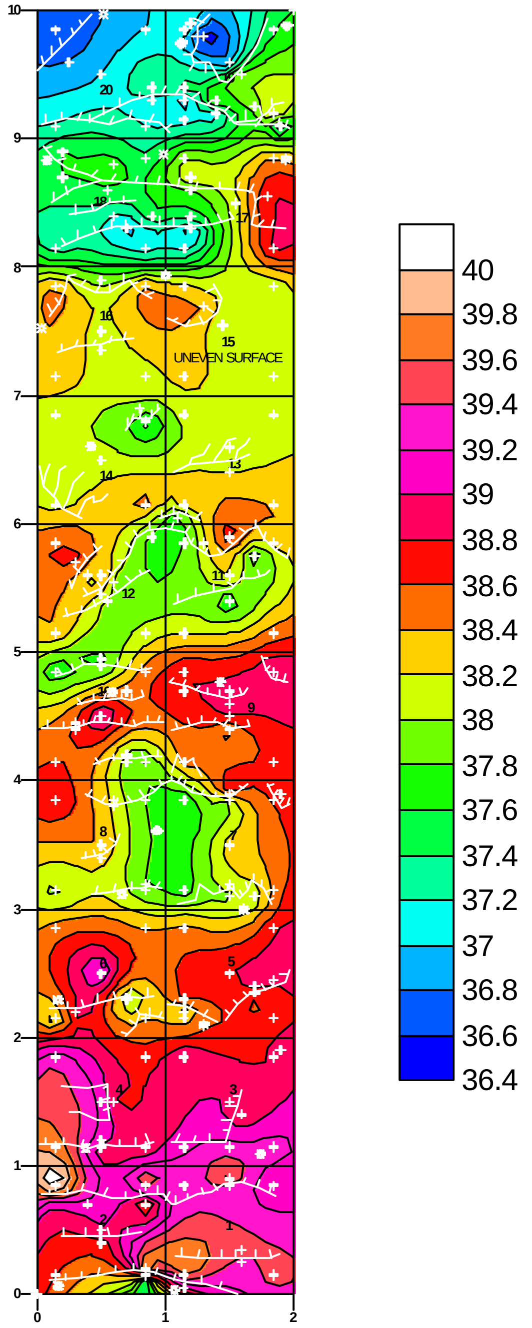

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