DOE/NV/10833--T2

Tomographic Data Developed Using the ABEM RAMAC Borehole Radar System at the Mixed Waste Landfill Integrated Demonstration

prepared for Sandia National Laboratories
by Raytheon Services Nevada
LPG Arms Control and Nonproliferation

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ABSTRACT

The ABEM RAMAC borehole radar system was run as part of the Mixed Waste Landfill Integrated Demonstration for Sandia National Laboratories at Kirtland AFB. Tomograms were created between three test boreholes--UCAP #1, UCAP #2, and UCAP #3. These tomograms clearly delineate areas of amplitude attenuation and residual time of arrival or slowness differences. Plots for slowness were made using both the maximum and minimum of the first arrival pulse. The data demonstrates that the ABEM RAMAC 60-MHz pulse sampling radar system can be used to collect usable data in a highly conductive environment.

Tomographic Data Developed Using the ABEM RAMAC Borehole Radar System at the Mixed Waste Landfill Integrated Demonstration

The ABEM RAMAC borehole radar system was run as part of the Mixed Waste Landfill Integrated Demonstration for Sandia National Laboratories at Kirtland AFB. The surveys were run using dual computer-controlled winches. Data was collected using the fan method as opposed to level run. The fan method, where one sonde is held stationary and the other is moved to positions centered on the stationary sonde, was chosen because of the RAMAC tomographic software interface requirements. The equipment is capable of recording automatically in either collection mode. Two data collection periods of one week each were needed to collect the data. The initial data collection period was hampered by equipment instability. The instability was found and repaired between the two collection periods. Data collected during the initial period proved that the equipment would transmit through the media. The second period of data collection was unimpaired by any equipment malfunctions.

The Sandia Mixed Waste Landfill Integrated Demonstration project area is a landfill site for Sandia National Laboratories which was active into the 1970s. The surveyed boreholes are in the unlined chromic acid pit (UCAP) portion of the landfill. These boreholes were equipped with SEAMIST liners which allowed simultaneous vadose zone monitoring cf the borehole and sonde access. The SEAMIST liners also prevented contamination of the sondes during operation.

The UCAP #3 borehole was drilled roughly in the center of the western edge of the chromic acid pit. UCAP #1 was drilled to the southwest of the chromic acid pit, and UCAP #2 was drilled to the north of the western edge. All boreholes are nearly 30 meters in depth and, for the purpose of this study, were assumed to be at equal elevations.

The RAMAC borehole radar system was developed by ABEM in Mala, Sweden, for characterization of the Strippa Nuclear Waste Repository. The radar system uses a sampled pulse method to record the received signal. Only one point on the received signal trace is recorded for each pulse from the transmitter, and a compr site signal is built. This method avoids any signal pileup caused by reflection and allows the use of slower data transmission electronics to record data at rates greater than 4 GHz.

The RAMAC transmitter and receiver used in this demonstration were omnidirectional and centered at a frequency of 60 MHz. The transmitter and receiver sondes each have their own battery pack for power. Their transmitting and receiving functions and timing are controlled via fiber-optic links to the surface control unit. The transmitting and receiving of data occurs while the tools are stationary and at the predetermined levels. The sondes are positioned by the computer using an ABEM automated winch control program. This program frees the operator from the tedious task of positioning the sondes and prevents taking data prior to positioning the sondes at the desired depths. The winch cable consists of a protective outer jacket of neoprene-like material, four optical fibers individually protected in neoprene and kevlar, and a central fiberglass-strength member. No electrically conductive material is present in the cable. The antennae are completely isolated from any outside conductors.

The data collected from the surveys was processed using the ABEM-supplied software. The ABEM RAMAC system signal is unamplified. The digital signal range is plus or minus 32,000 bits. The signal range during this survey was typically less than plus or minus 100 bits. This low range required the data to be band pass filtered to remove system noise spikes before the automatic picker could be used to process the survey. Two types of tomographic images have been created from each survey--a peak-to-peak attenuation tomogram and a slowness (residual travel time) tomogram as described by Olsson et al. (1989). Slowness tomograms were made from both the maximum and minimum of the arrival pulse. The tomographic inversion was made using the iterative conjugated gradient (CG) method described by Ivansson (1986). This method of tomographic inversion is fairly quick and can be easily run on PCs.

The measurement points were taken every .5 meters over a 5-meter fan centered on the transmitter. The data was recorded at a rate of 2 nano-seconds per sample for 512 samples. This recording rate allowed for easy differentiation between the system noise spikes and the signal pulse.

Timing checks were conducted at the borehole distances prior to entry into the boreholes. Entry into the boreholes was achieved through neoprene baffles into the SEAMIST liners to maintain pressure and keep the collapsible liners open. The baffles were reinforced with cloth tape.

Tomogram sets for each of the boreholes are attached (Appendixes 1, 2, and 3) along with the raw and processed data in the original formats and in ASCII hexadecimal. The following reviews of the tomograms use the following conventions when referring to slowness and attenuation. The maximum slowness value is the largest residual time value and therefore is a point with slow travel time. The maximum amplitude attenuation is equivalent to the smallest amplitude and is the smallest value on the attenuation tomogram key.

Tomograms of different borehole depth ranges were made in an attempt to expand the scale of the tomograms and are included in the Appendixes. The expanded tomographic images when compared to the full tomograms appear to be internally consistent and are therefore felt to be representative of the whole and not artifacts of the iterative process.

Tomogram Set UCAP2-UCAP3

The receiver was placed in UCAP #2 and the transmitter was placed in UCAP #3. The maximum depth reached in UCAP #3 was 24 meters and is the right side of the UCAP2-UCAP3 tomograms. A thin band of high amplitude attenuation is present in the first two meters of the tomogram. This zone is also recognizable on the slowness tomograms but is not near the maximum slowness values and is therefore felt to be an artifact of construction or geology. The high attenuation zone between 13 meters and 21 meters with two lens-shaped maximum amplitude attenuation values and corresponding maximum slowness values are highly probable areas of contamination. There also appears to be a possible area of corresponding high amplitude attenuation and maximum slowness below 24 meters in UCAP #2.

Tomogram Set UCAP1-UCAP3

The receiver was placed in UCAP #1 and the transmitter was placed in UCAP #3. The maximum depth reached in UCAP #3 was 23 meters and in UCAP #1 28 meters. UCAP #3 corresponds to the right side of the tomogram. The zone of maximum amplitude attenuation extends from 2 to 15 meters. Within this zone, several lenses of higher amplitude attenuation exist. The largest layer extends from 10 to 12 meters between the boreholes. This zone is also recognizable on the slowness plots as areas of maximum slowness. There is considerable difference in the size of this region between the two slowness plots and the attenuation plot. The areas of maximum slowness and maximum amplitude attenuation are the same in all plots. This area is the most likely location for the presence of contamination.

Tomogram Set UCAP1-UCAP2

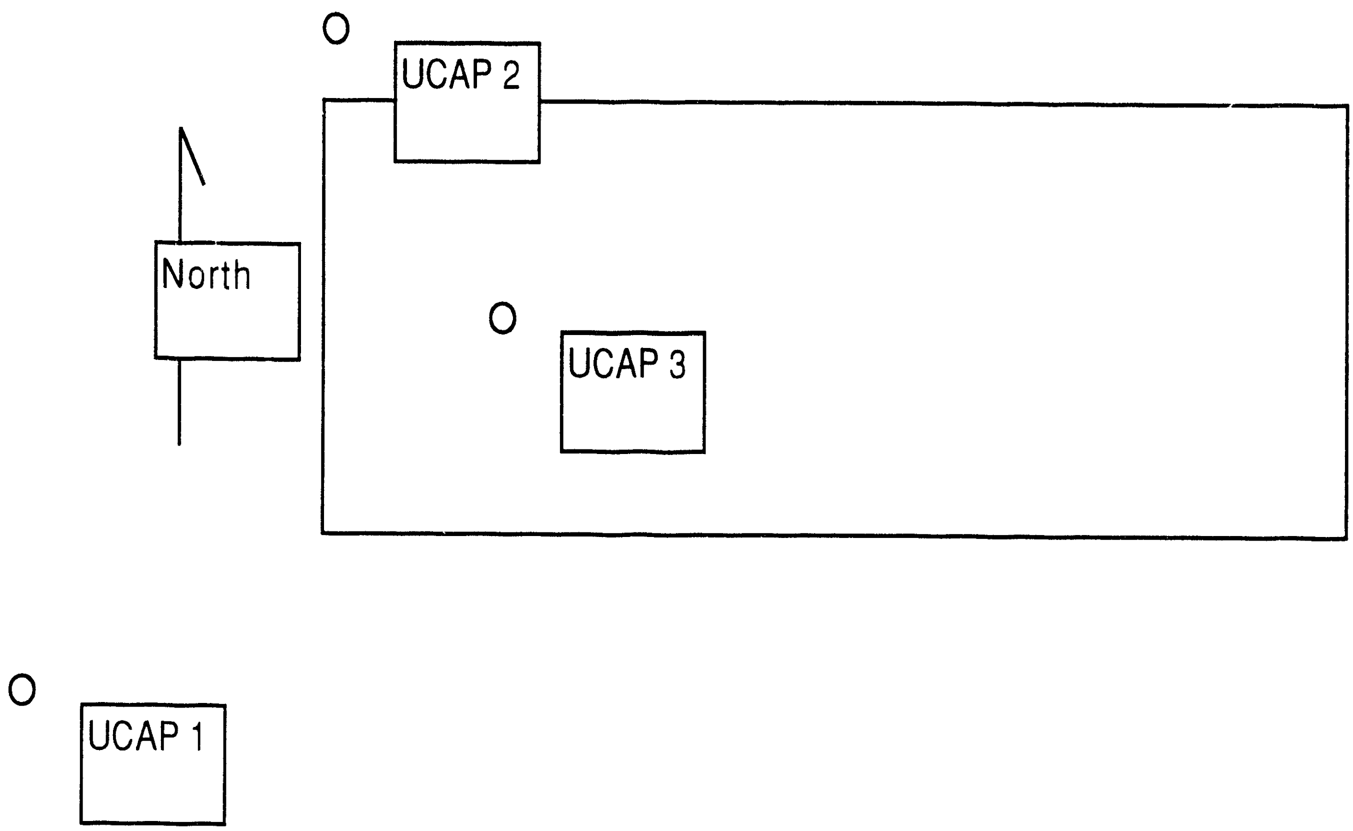
The receiver was located in UCAP #2 and the transmitter was located in UCAP #1. Both boreholes are outside and down-dip of the chromic acid pit, UCAP #1 to the southwest and UCAP #2 to the northwest of the pit. The maximum depths reached are 23 and 28 meters for UCAP #1 and UCAP #2, respectively. UCAP #2 corresponds to the right side of the tomogram. The area of highest amplitude attenuation is a tongue-shaped body stretching from UCAP #2 toward UCAP #1. This occurs at a depth of 12 to 15 meters. The area of maximum slowness occurs between 11 and 16 meters in UCAP #2 and 14 and 17 meters in UCAP #1. This area of correlation between the tomograms is the most likely area of contamination.

The ABEM RAMAC borehole radar system is capable of operating in a highly conductive environment, 10 ohm/m (David Borns, 1993. Verbal communication), and can be used to create tomograms useful in characterizing the geology and possible contaminant plumes of suspect waste areas. In highly conductive zones, the slowness tomograms have much finer detail than the amplitude attenuation but both tomograms are needed to determine likely areas of contamination. The sampled pulse method of ground penetrating radar should be considered when creating the data collection plan for waste characterization, documentation of a remediation process, and long-term monitoring.

REFERENCES

Ivansson, S., 1986. Seismic Borehole Tomography Theory and Computational Methods. Proceedings of the IEEE, vol. 74, pgs. 328-338.

Olsson, O., Andersson, P., Carlsten, S., Falk, L., Borje, N., Sandberg, E., 1989. Fracture Characterization in Crystaline Rock. ABEM AB Report ID-no. 89.



Unlined Chromic Acid Pit Area at the Sandia National Laboratories Mixed Waste Landfill Integrated Demonstration Area

Figure 1

OCT.21,1993 TO OCT.22,1993

SANDIA TRACE #	UCAP3 XMIT	UCAP2 REC. DEPTH		TRACE #	UCAP3 XMIT	UCAP2 REC. DEPTH
20-29	2.0	2.0-7.0		593-613	17.0	12.0-22.0
30-40	2.5	2.0-7.5		614-634	17.5	12.5-22.5
41-53	3.0	2.0-8.0		635-655	18.0	13.0-23.0
54-67	3.5	2.0-8.5		656-676	18.5	13.5-23.5
68-82	4.0	2.0-9.0		677-697	19.0	14.0-24.0
83-98	4.5	2.0-9.5		698-718	19.5	14.5-24.5
99-115	5.0	2.0-10.0		719-739	20.0	15.0-25.0
116-133	5.5	2.0-10.5		740-760	20.5	15.5-25.5
134-152	6.0	2.0-11.0		761-781	21.0	16.0-26.0
153-172	6.5	2.0-11.5		782-802	21.5	16.5-26.5
173-192	7.0	2.0-12.0		803-823	22.0	17.0-27.0
193-214	7.5	2.5-12.5		824-844	22.5	17.5-27.5
215-235	8.0	3.0-13.0		845-865	23.0	18.0-28.0
236-256	8.5	3.5-13.5		866-885	23.5	18.5-28.0
257-277	9.0	4.0-14.0		886-903	24.0	19.0-28.0
278-298	9.5	4.5-14.5				
299-319	10.0	5.0-15.0				
320-340	10.5	5.5-15.5				
341-361	11.0	6.0-16.0				
362-382	11.5	6.5-16.5				
383-403	12.0	7.0-17.0				
404-424	12.5	7.5-17.5				
425-445	13.0	8.0-18.0				
446-466	13.5	8.5-18.5				
467-487	14.0	9.0-19.0				
488-508	14.5	9.5-19.5				
509-529	15.0	10.0-20.0				
530-550	15.5	10.5-20.5				
551-571	16.0	11.0-21.0				
572-592	16.5	11.5-21.5				

APPENDIX 1

Licensee 1992: Raytheon Services Nevada

Site and borehole:

Date:

T-R Distance:

Equipment name:

Operator's name:

Date of plot: Mon Nov 29 14:15:23 1993

RAMAC MEASUREMENT PROGRAM VERSION 6.4,

Maximum Time Gain 1.01

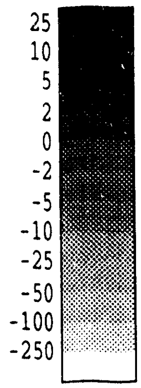
Lin. coefficient 0.010

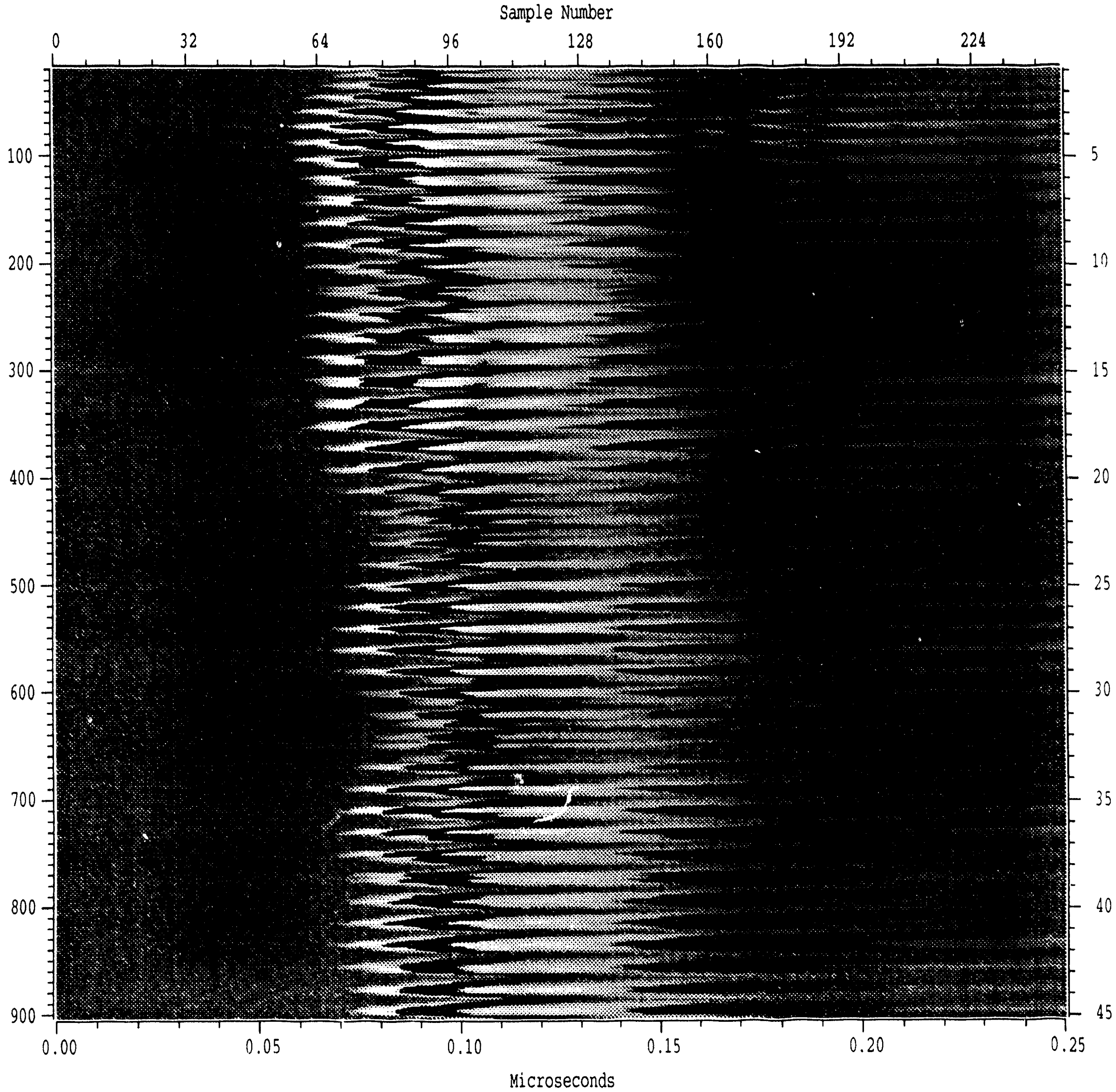
Exp. coefficient 0.000

Start time of gain 0.000

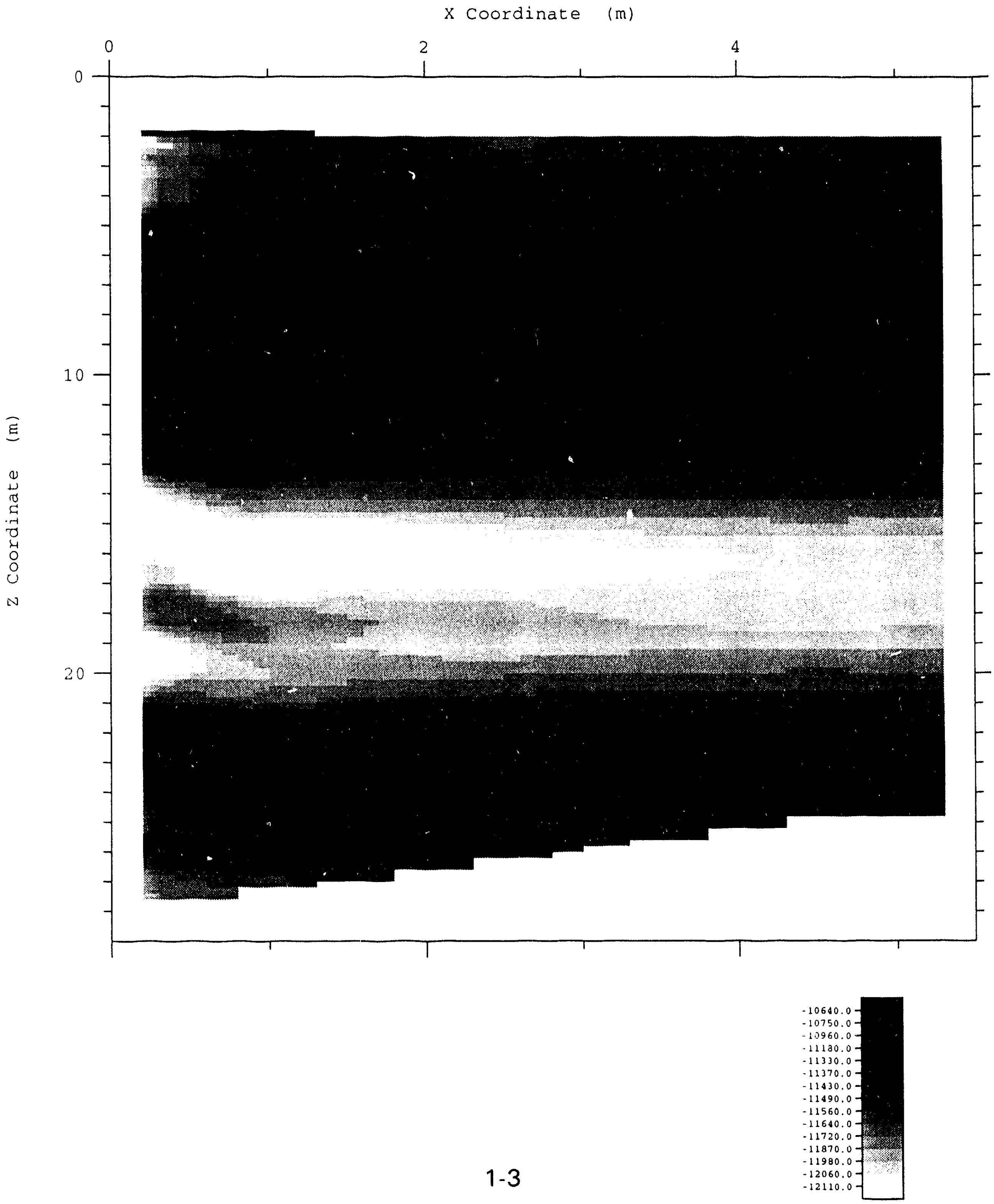
DC level subtracted.

Dipole Antenna.



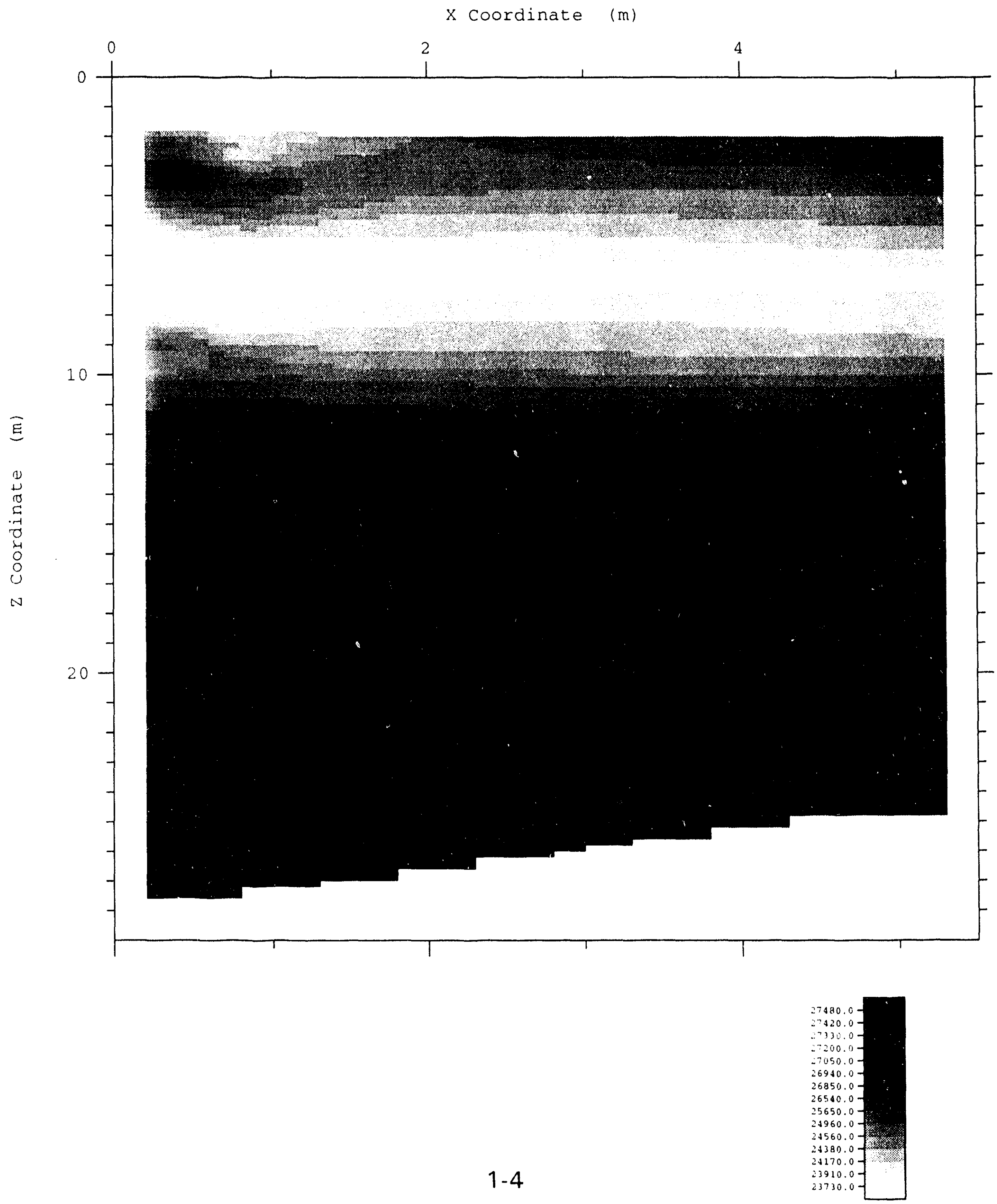


SANDIA UCAP2-UCAP3 ATTENUATION PEAK to PEAK



19931116

SANDIA UCAP2-UCAP3 SLOWNESS MAXIMUM



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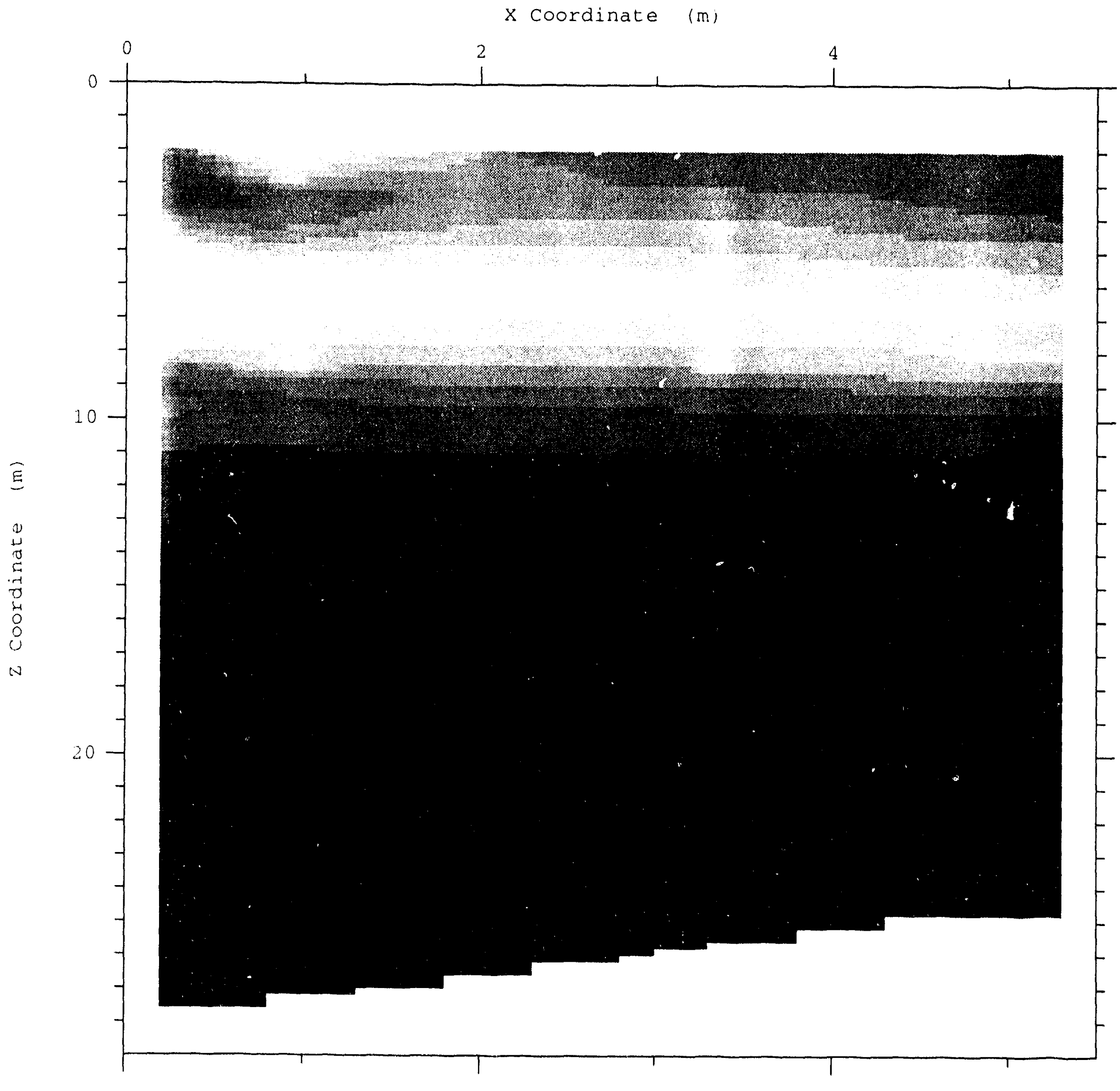

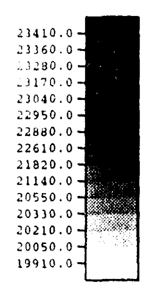

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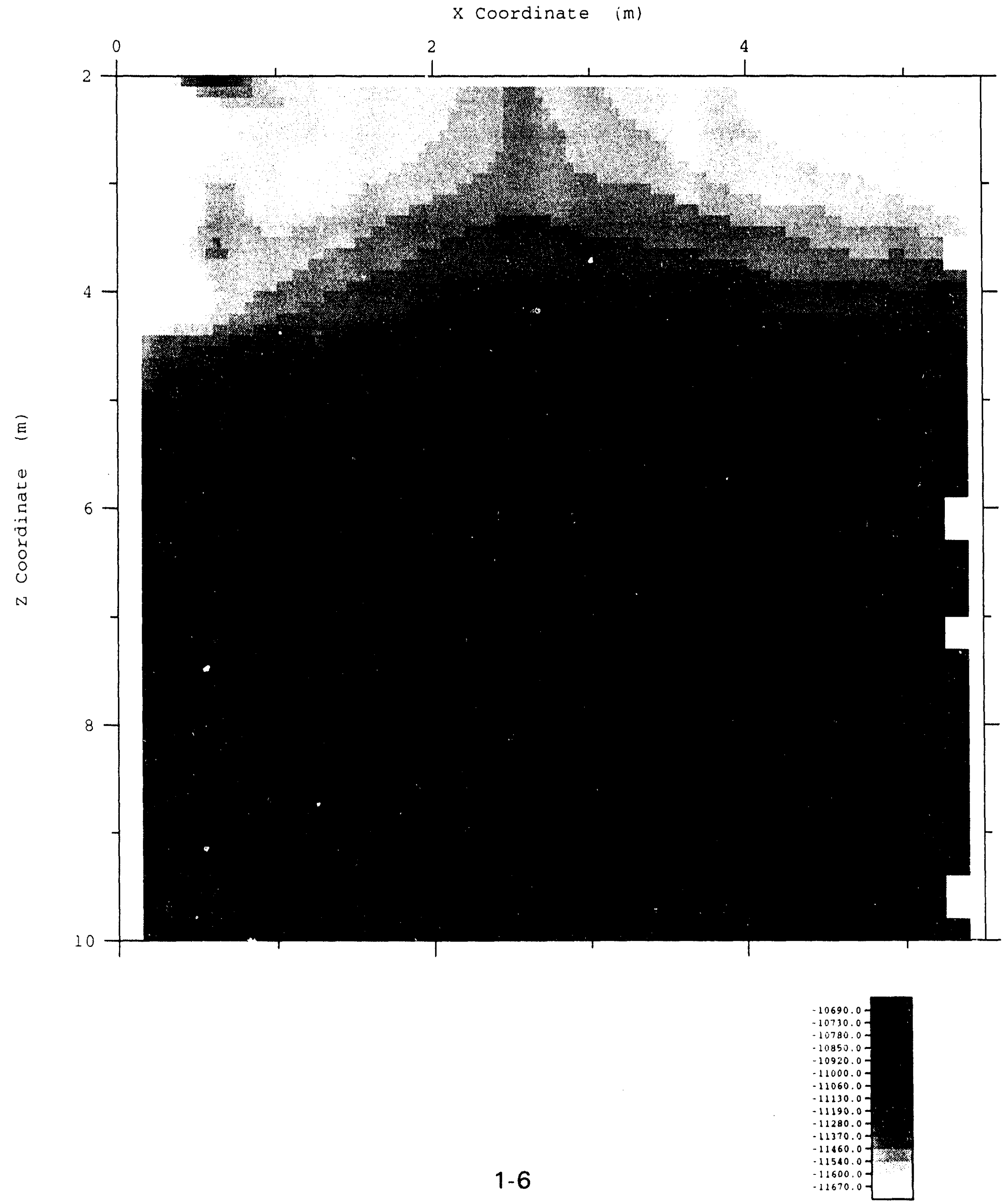

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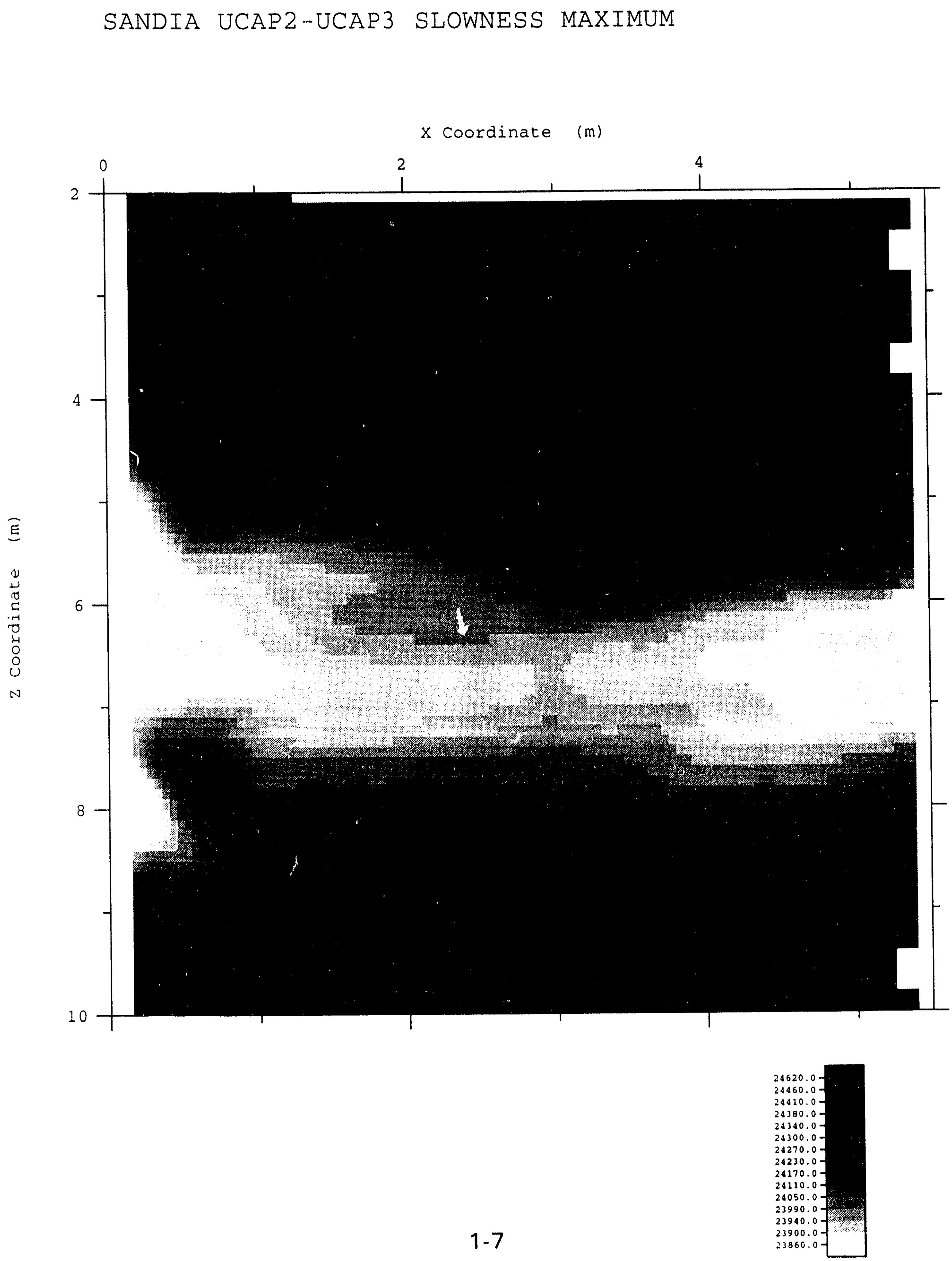
SANDIA UCAP2-UCAP3 SLOWNESS MAXIMUM
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2
4
Z Coordinate (m)
2
4
6
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24300.0
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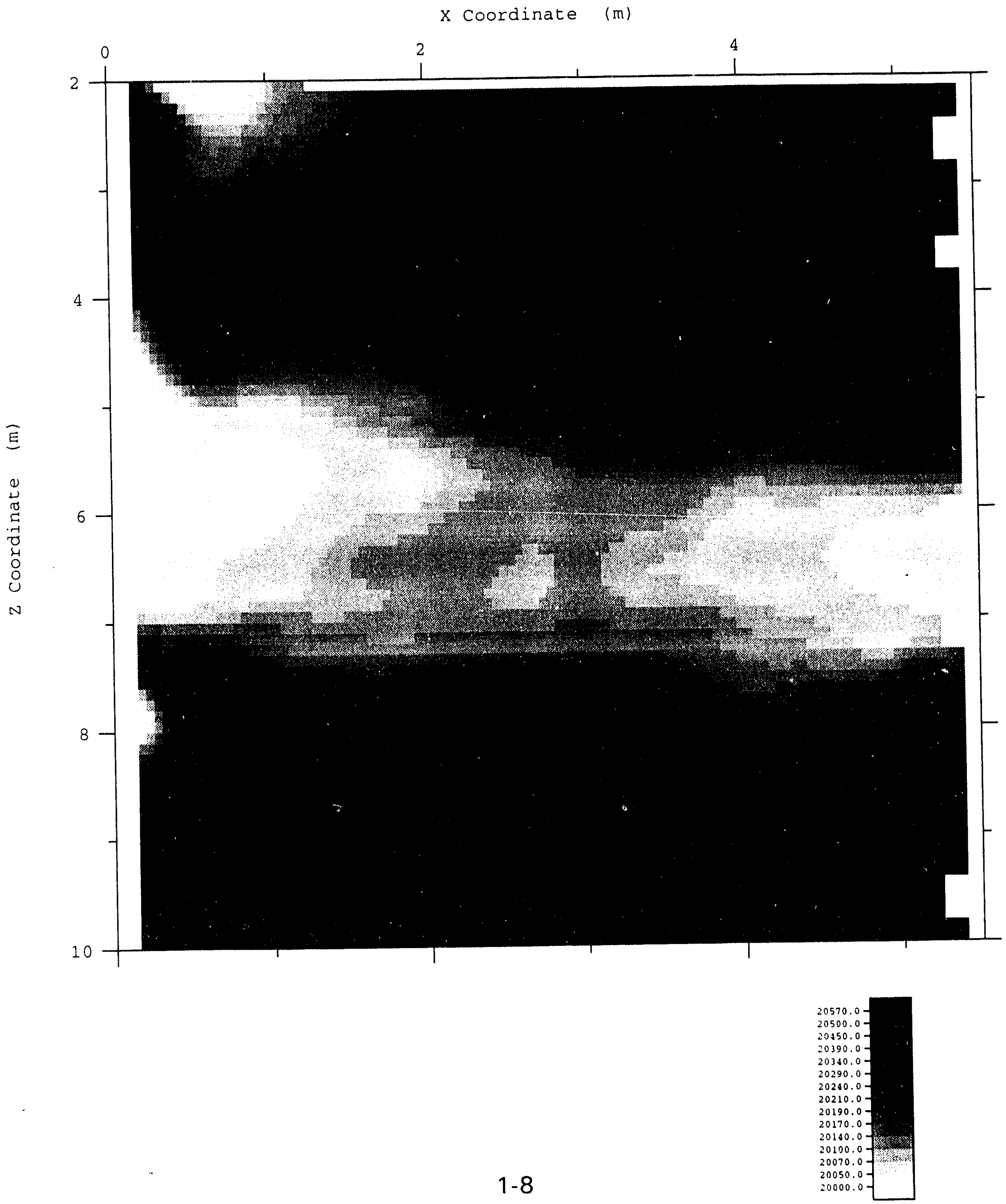

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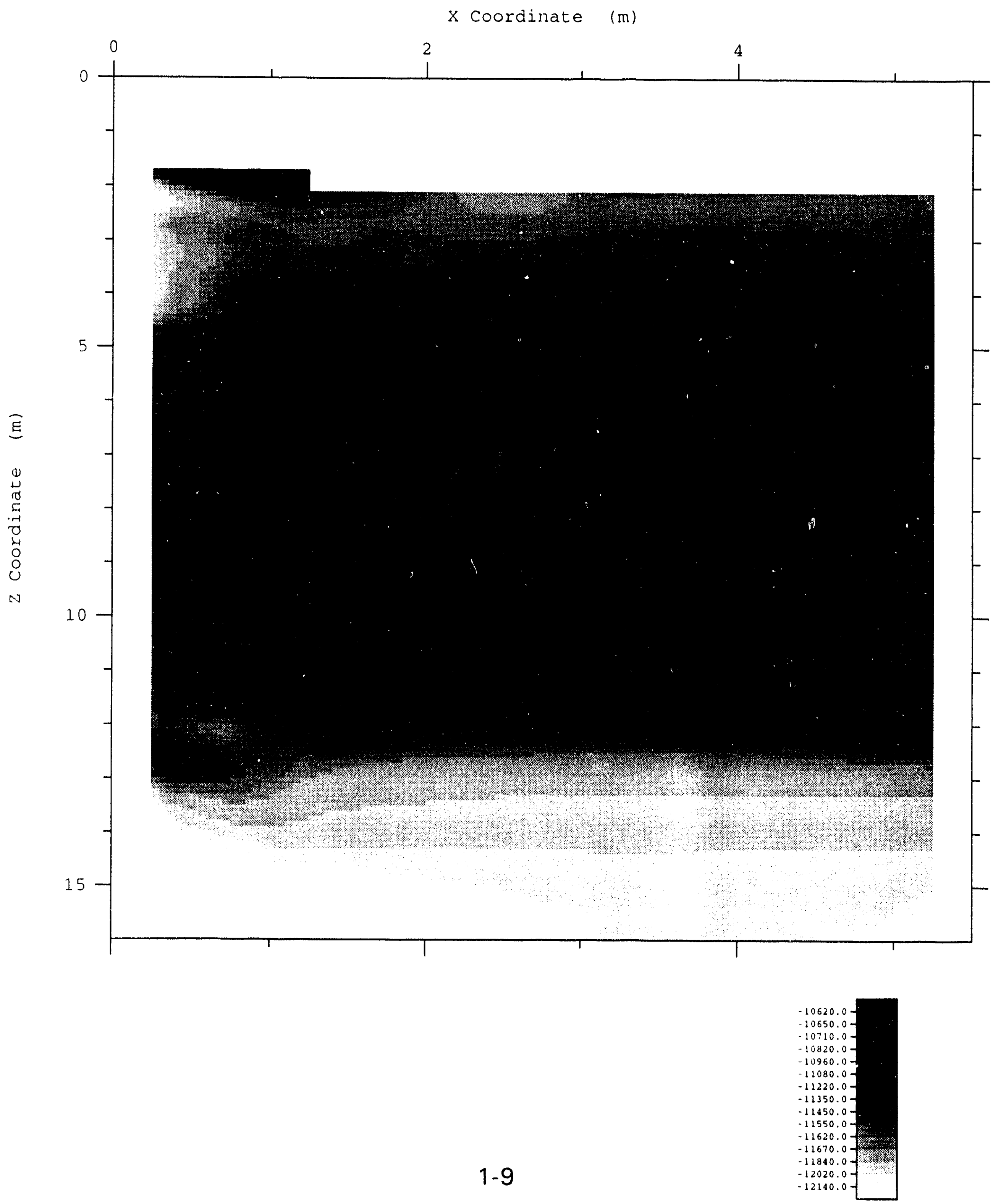

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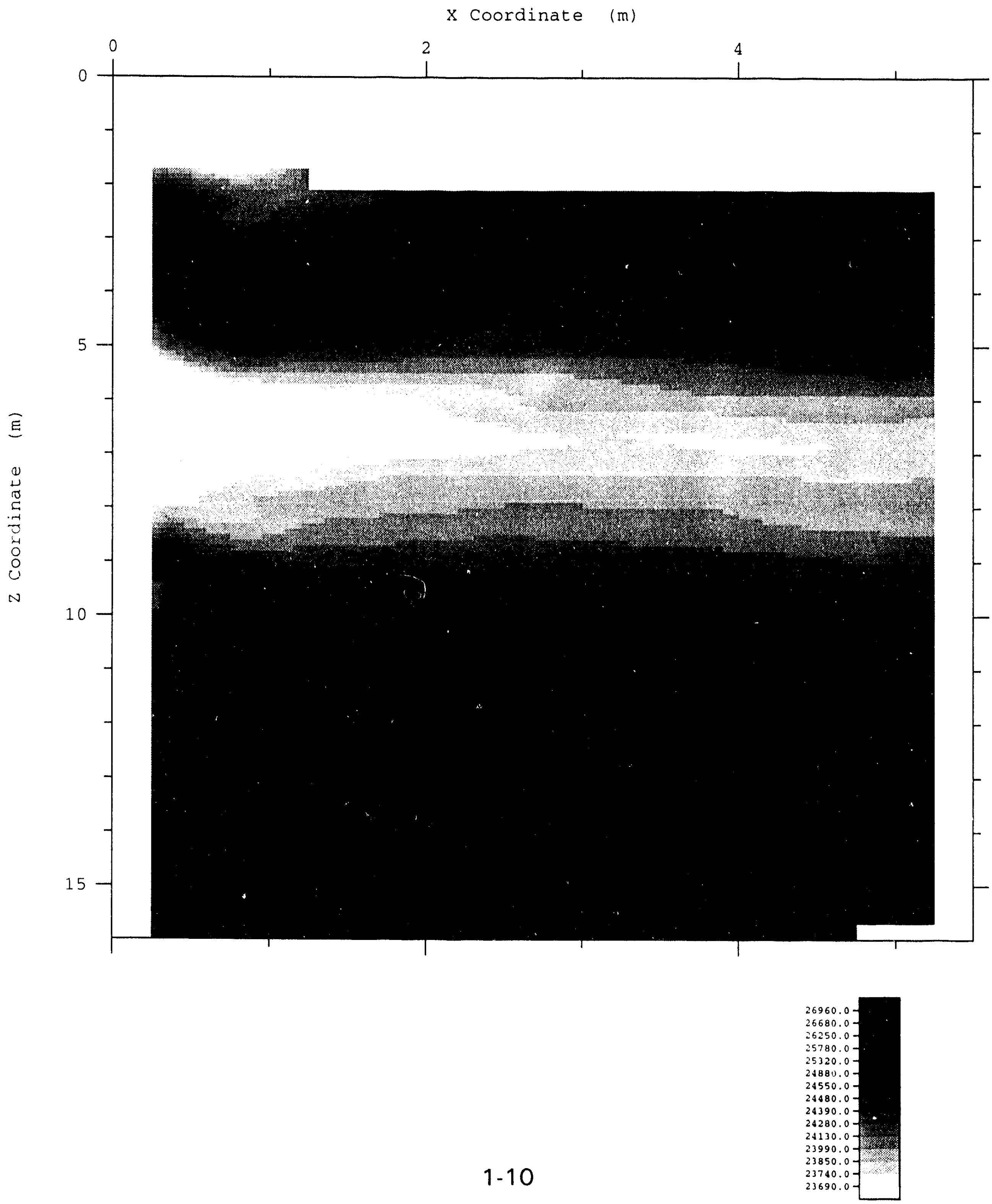

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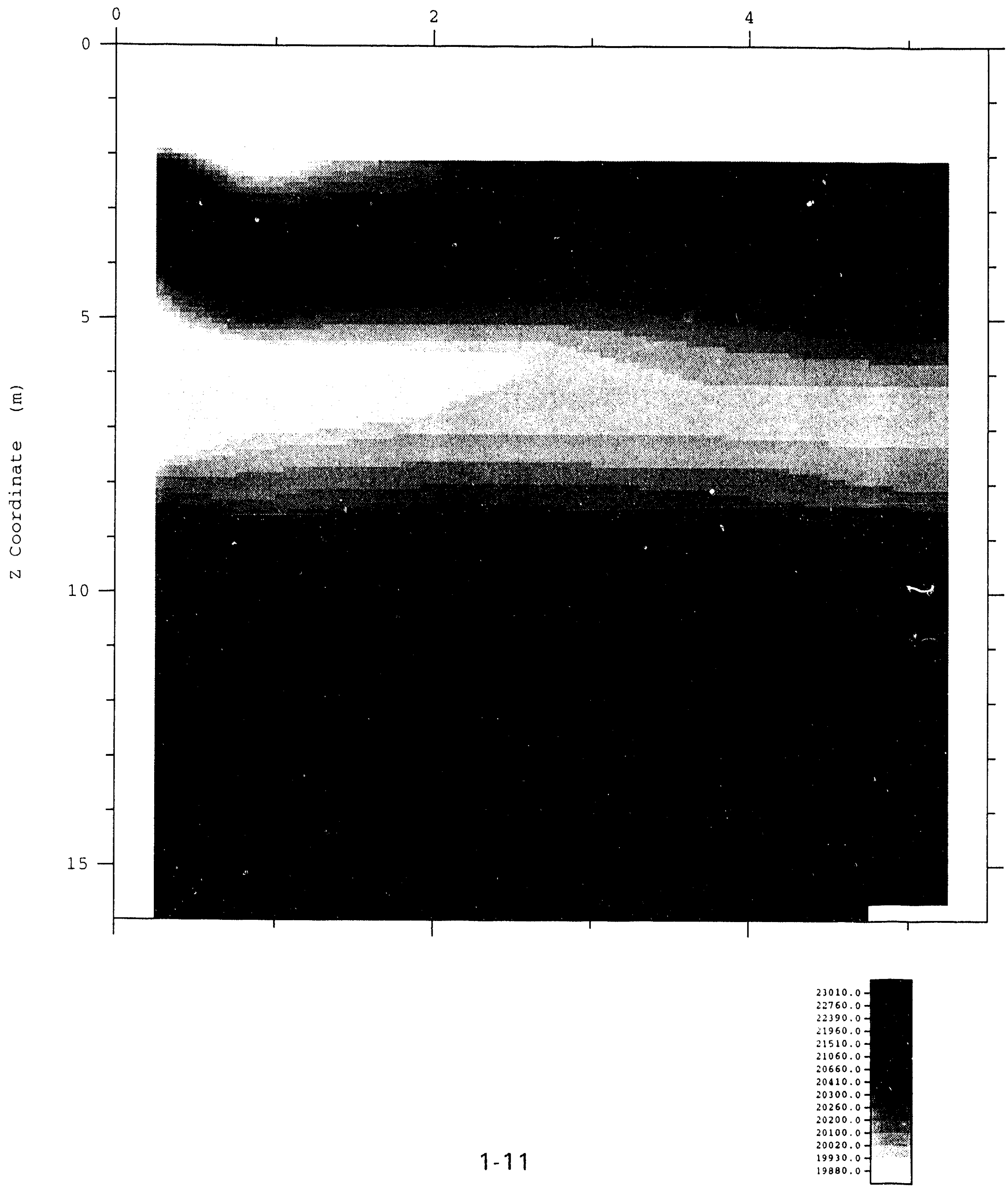

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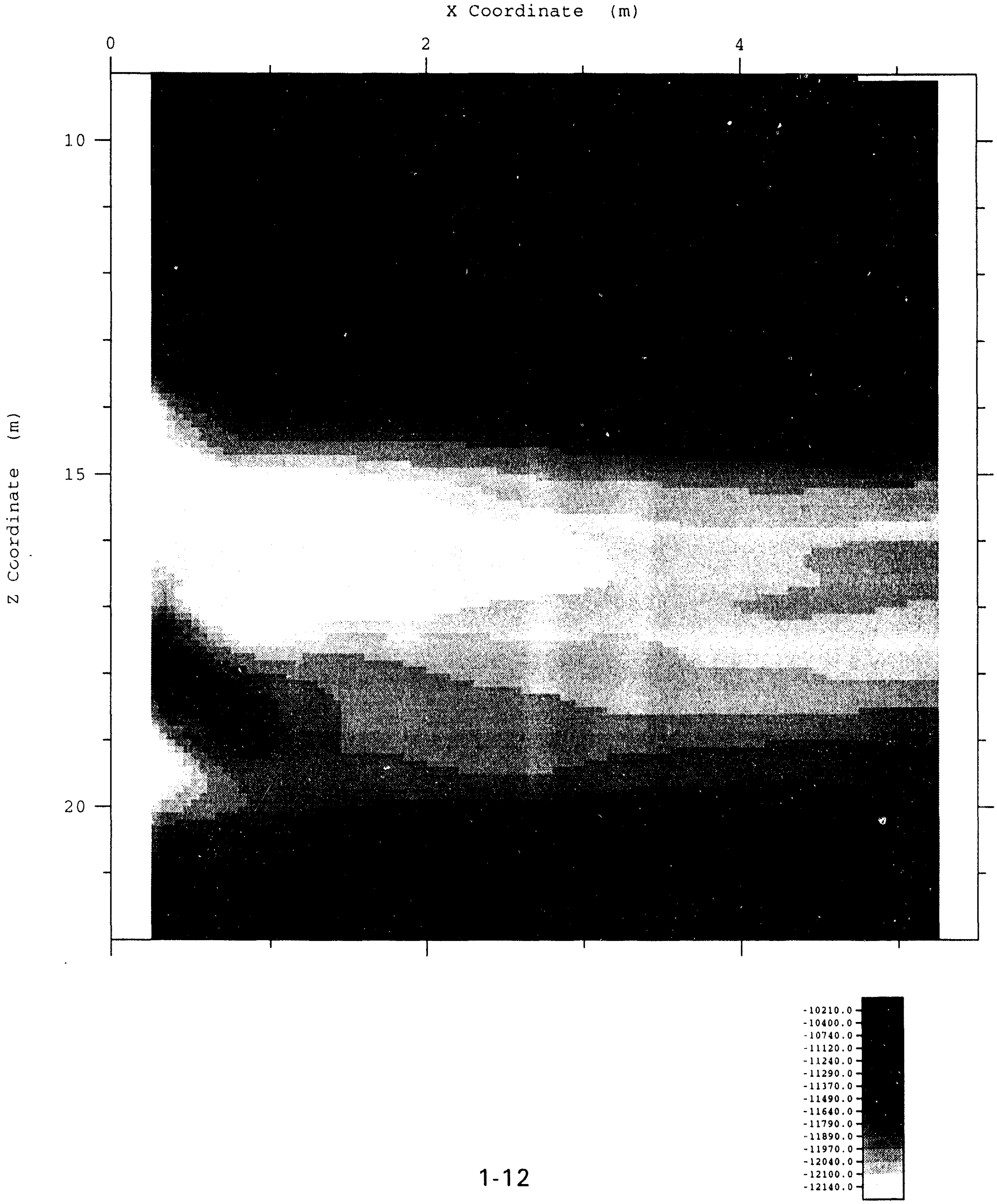

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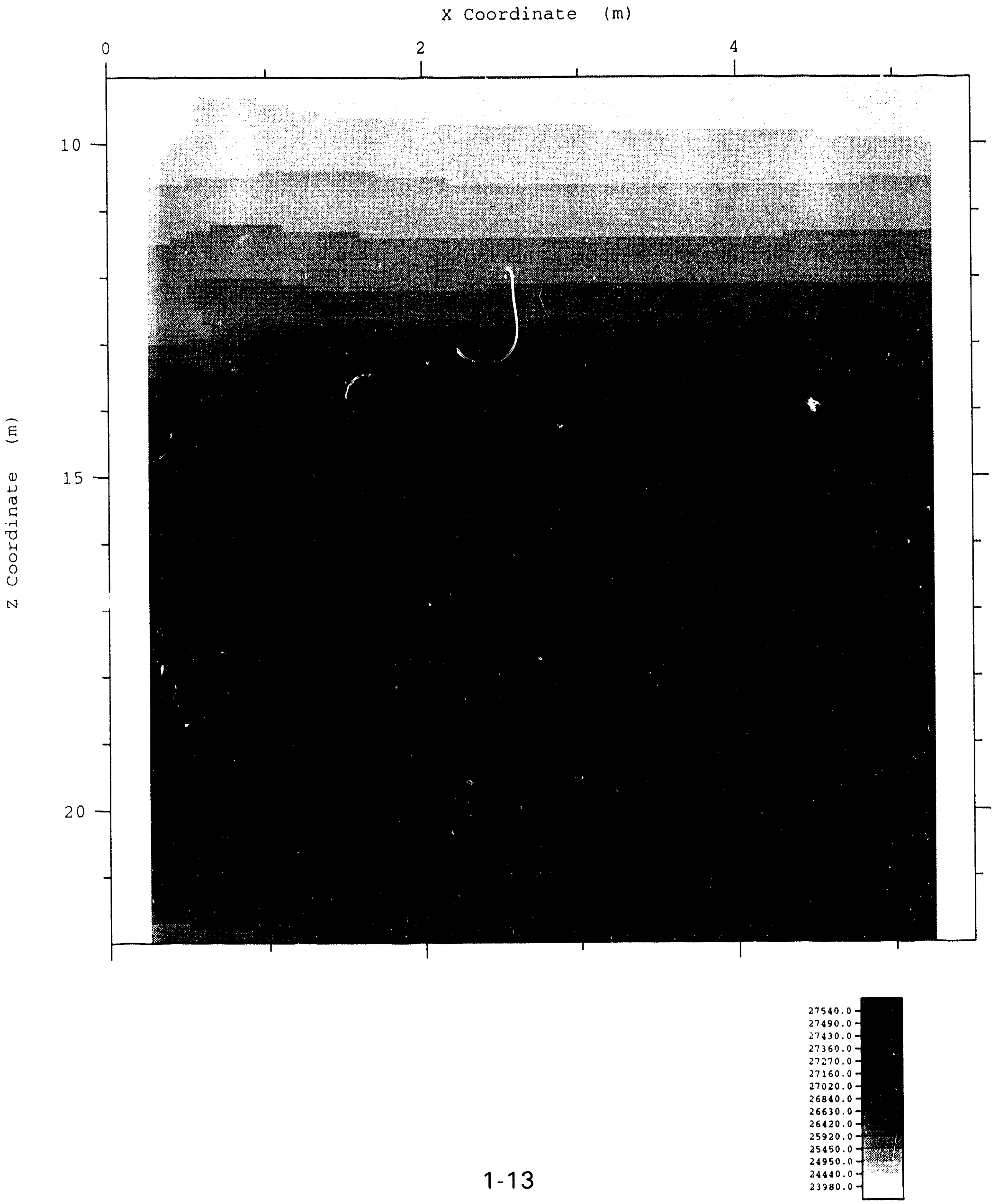

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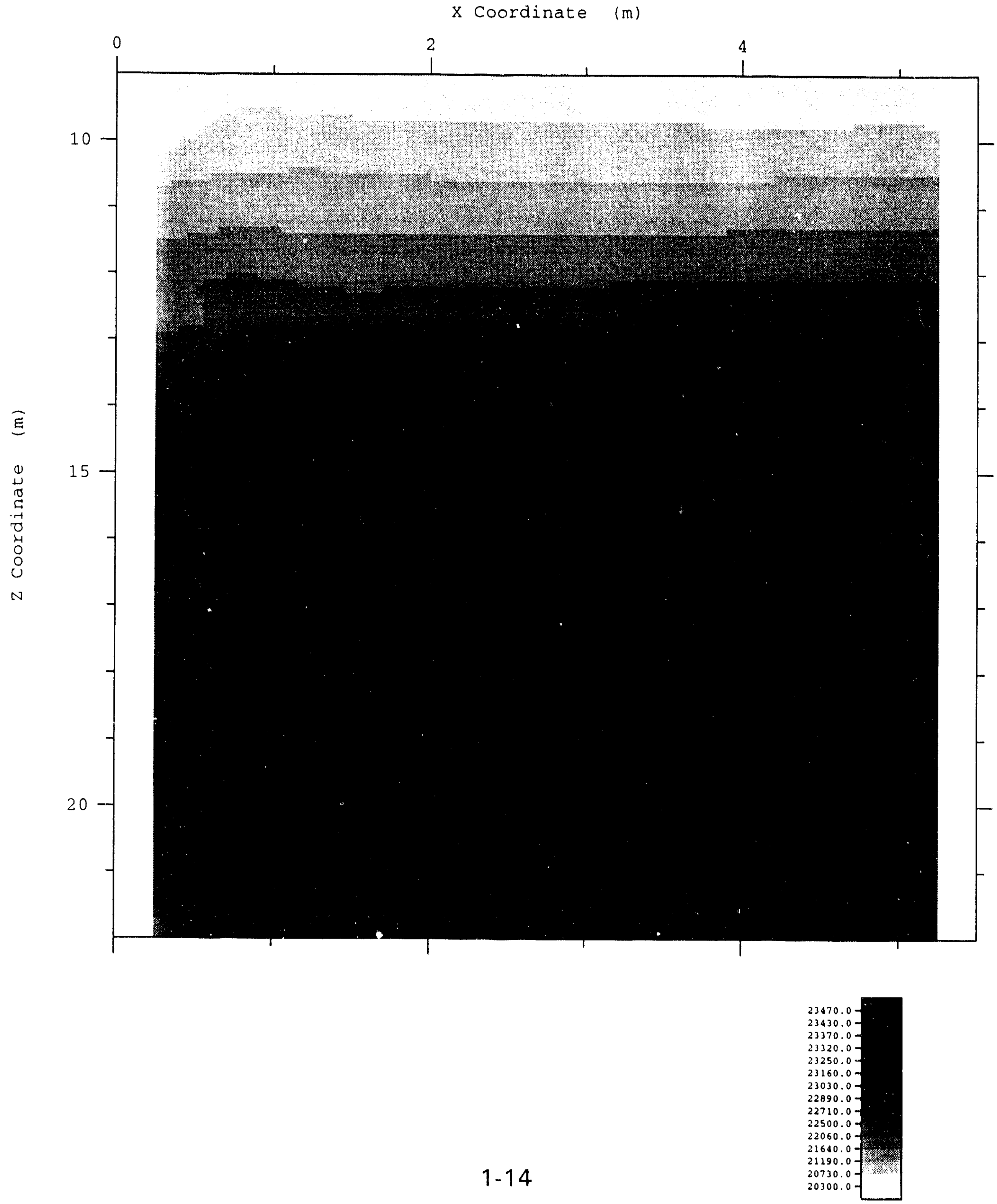

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SANDIA OCT.25,1993 TO OCT.26,1993

TRACE #	UCAP3 XMIT	UCAP1 REC.DEPTH		TRACE #	UCAP3 XMIT	UCAP1 REC.DEPTH
001-011	2.0	2.0-7.0		471-491	14.5	9.5-19.5
012-023	2.5	2.0-7.5		492-512	15.0	10.0-20.0
024-036	3.0	2.0-8.0		513-533	15.5	10.5-20.5
037-050	3.5	2.0-8.5		534-554	16.0	11.0-21.0
051-065	4.0	2.0-9.0		555-575	16.5	11.5-21.5
066-081	4.5	2.0-9.5		576-596	17.0	12.0-22.0
082-098	5.0	2.0-10.0		597-617	17.5	12.5-22.5
099-116	5.5	2.0-10.5		618-638	18.0	13.0-23.0
117-135	6.0	2.0-11.0		639-659	18.5	13.5-23.5
136-155	6.5	2.0-11.5		660-680	19.0	14.0-24.0
156-176	7.0	2.0-12.0		681-701	19.5	14.5-24.5
177-197	7.5	2.5-12.5		702-722	20.0	15.0-25.0
198-218	8.0	3.0-13.0		723-743	20.5	15.5-25.5
219-239	8.5	3.5-13.5		744-764	21.0	16.0-26.0
240-260	9.0	4.0-14.5		765-785	21.5	16.5-26.5
261-281	9.5	4.5-14.5		786-806	22.0	17.0-27.0
282-302	10.0	5.0-15.0		807-827	22.5	17.5-27.5
303-323	10.5	5.5-15.5				
324-344	11.0	6.0-16.0				
345-365	11.5	6.5-16.5				
366-386	12.0	7.0-17.0				
387-407	12.5	7.5-17.5				
408-428	13.0	8.0-18.0				
429-449	13.5	8.5-18.5				
450-470	14.0	9.0-19.0				

APPENDIX 2

Licensee 1992: Raytheon Services Nevada

Site and borehole:

Date:

T-R Distance:

Equipment name:

Operator's name:

Date of plot: Tue Nov 23 12:18:45 1993

RAMAC MEASUREMENT PROGRAM VERSION 6.4,

Maximum Time Gain 1.01

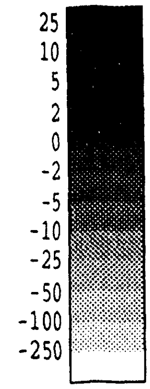
Lin. coefficient 0.010

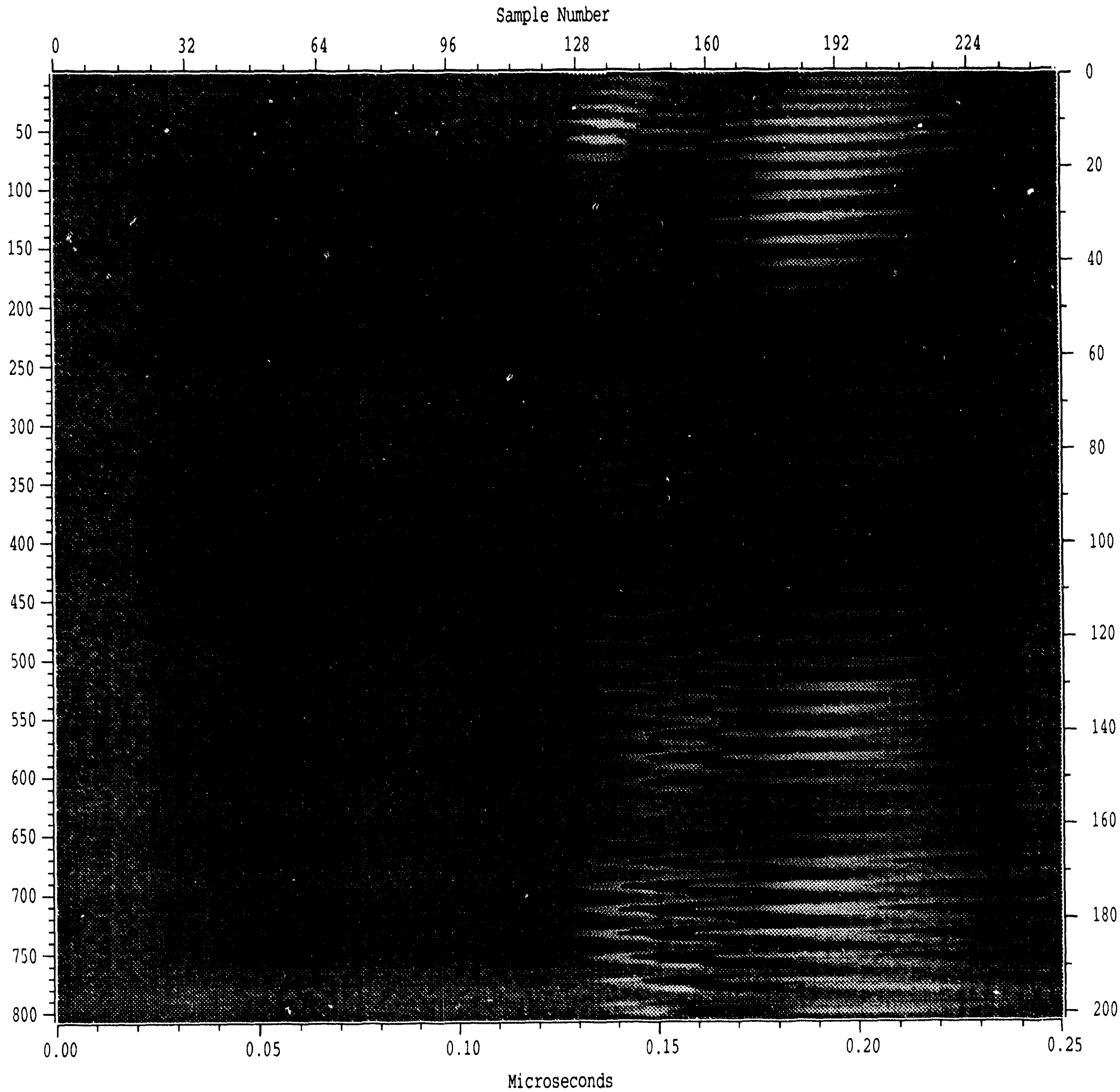
Exp. coefficient 0.000

Start time of gain 0.000

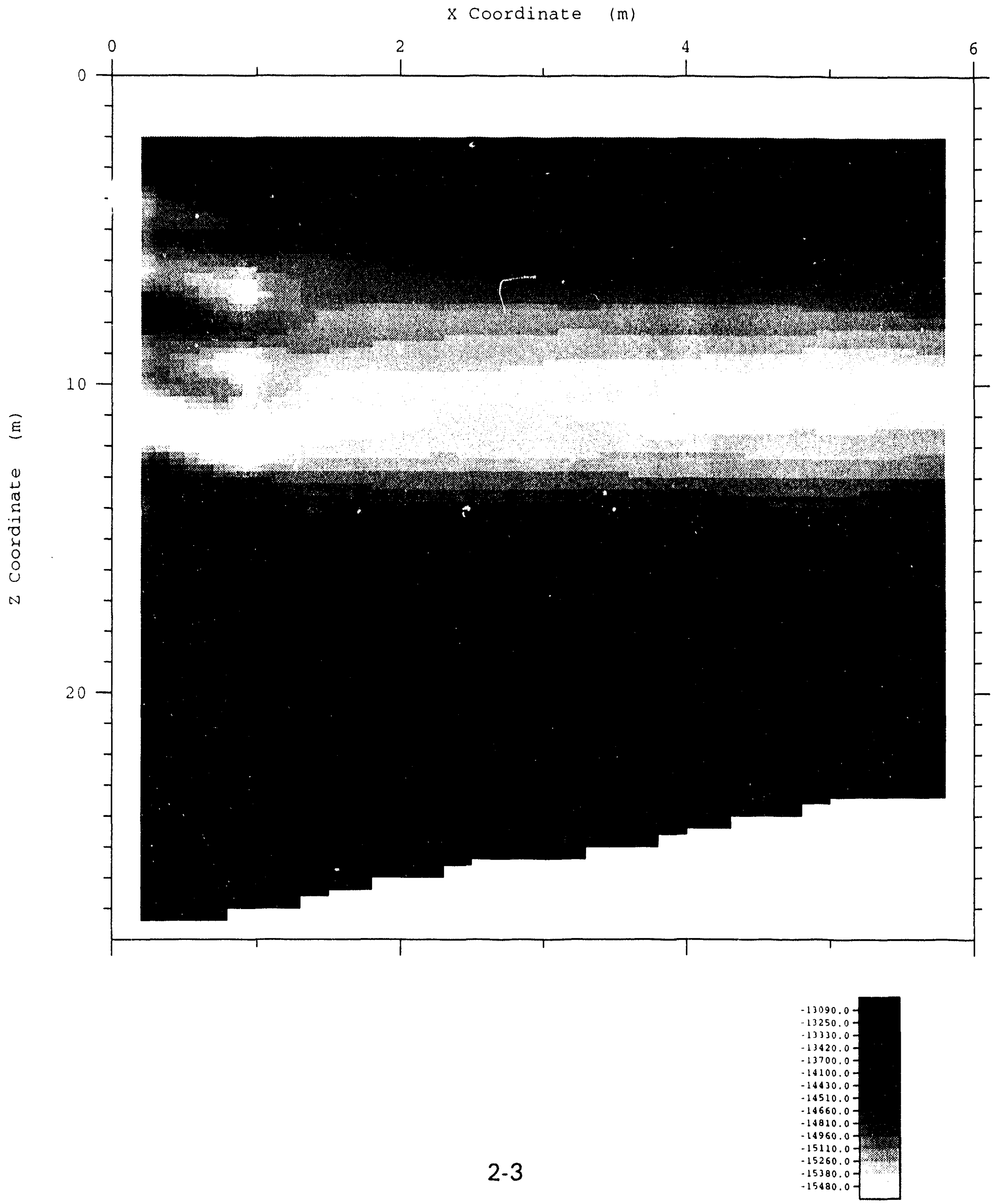
DC level subtracted.

Dipole Antenna.





SANDIA UCAP1-UCAP3 ATTENUATION PEAK to PEAK



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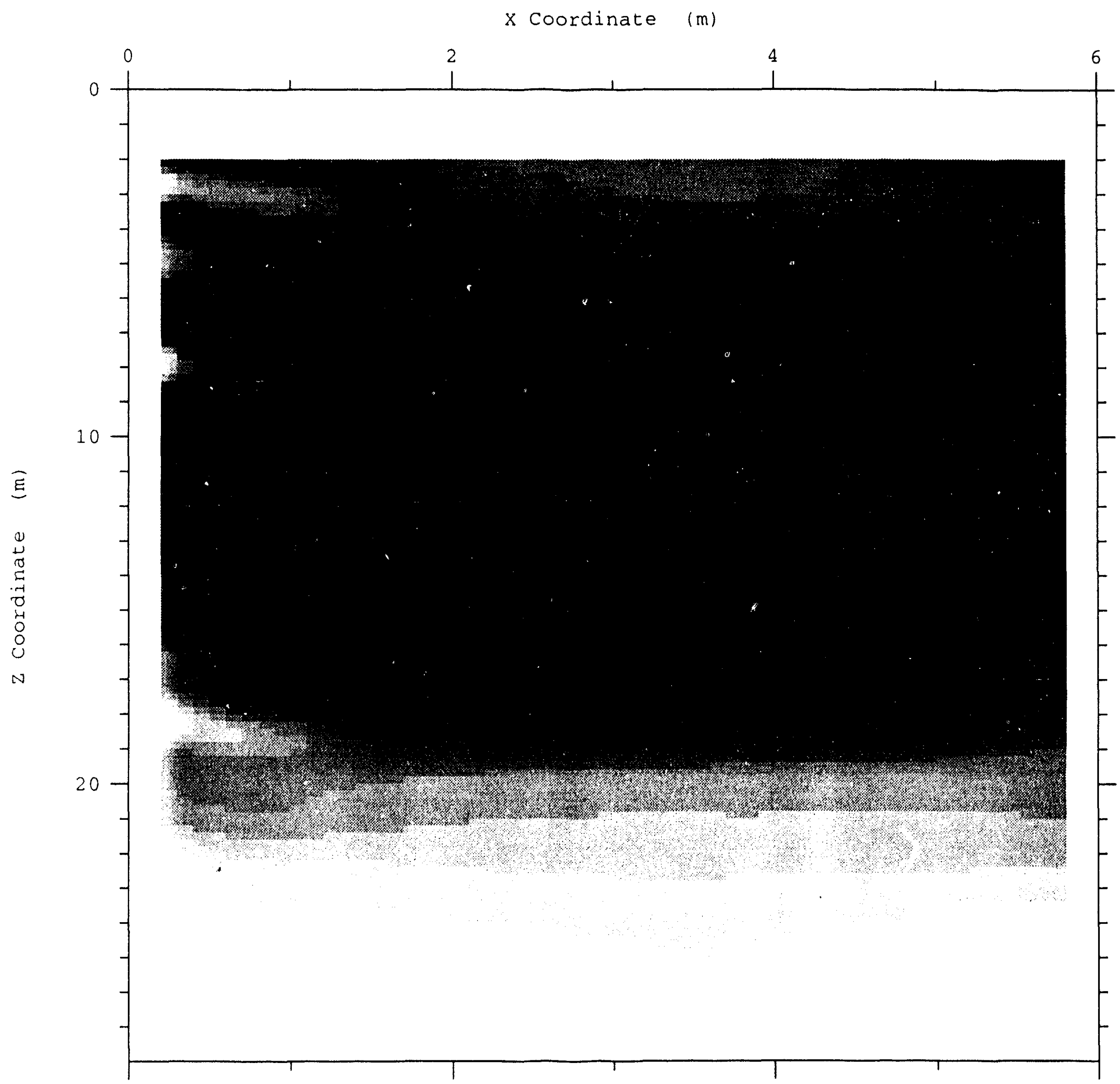

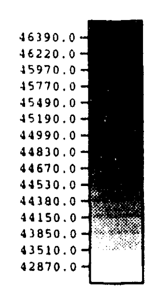

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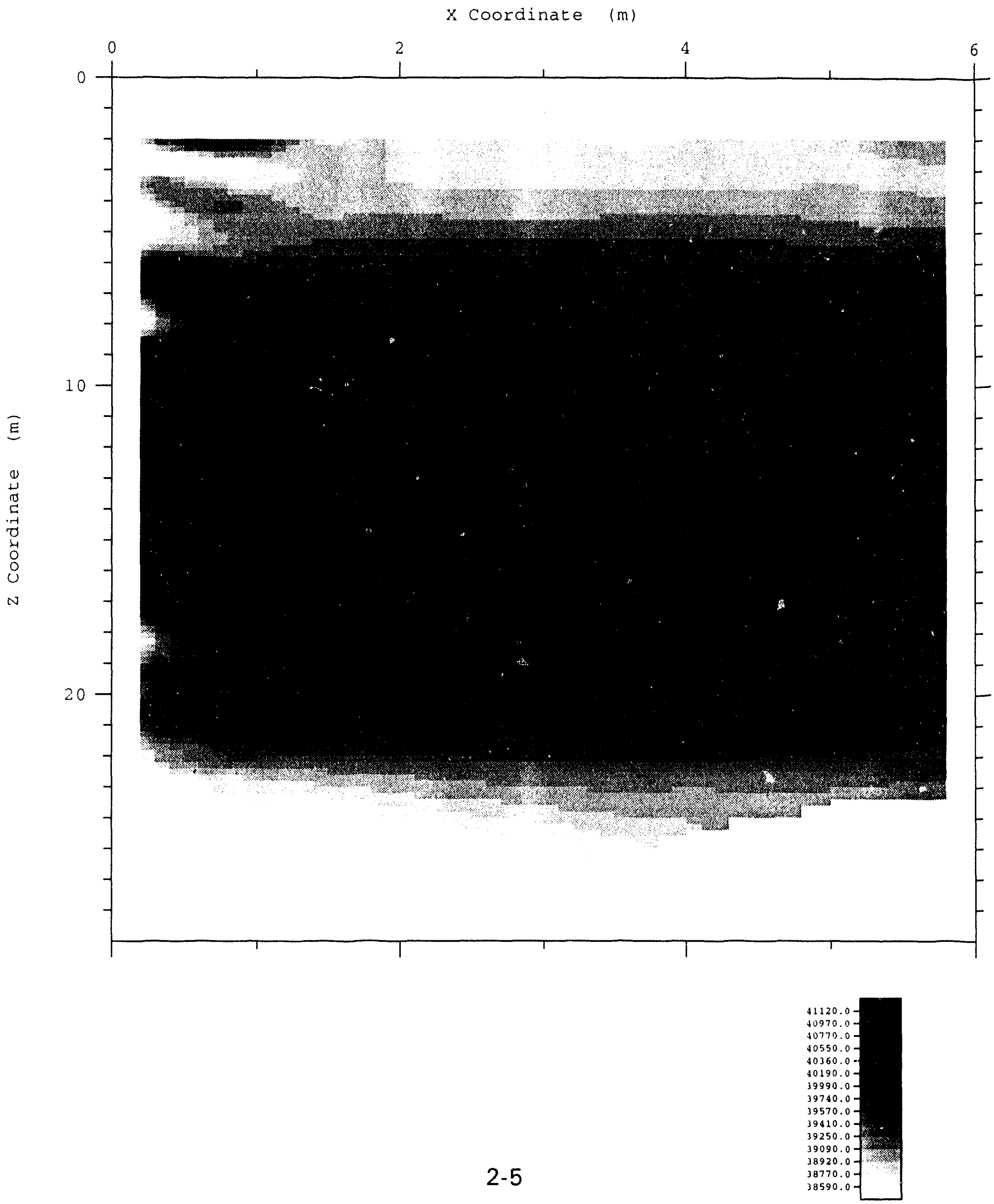

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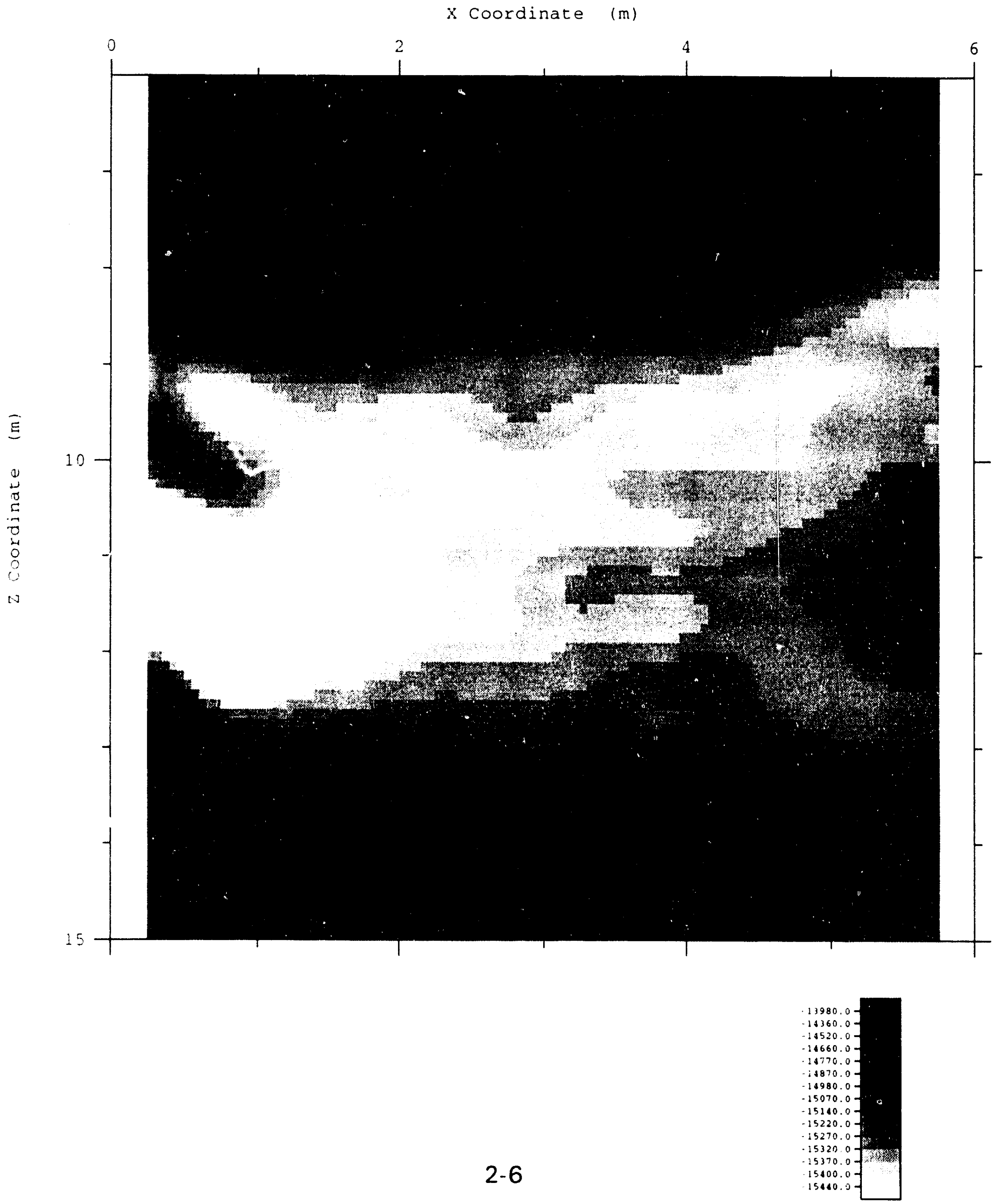

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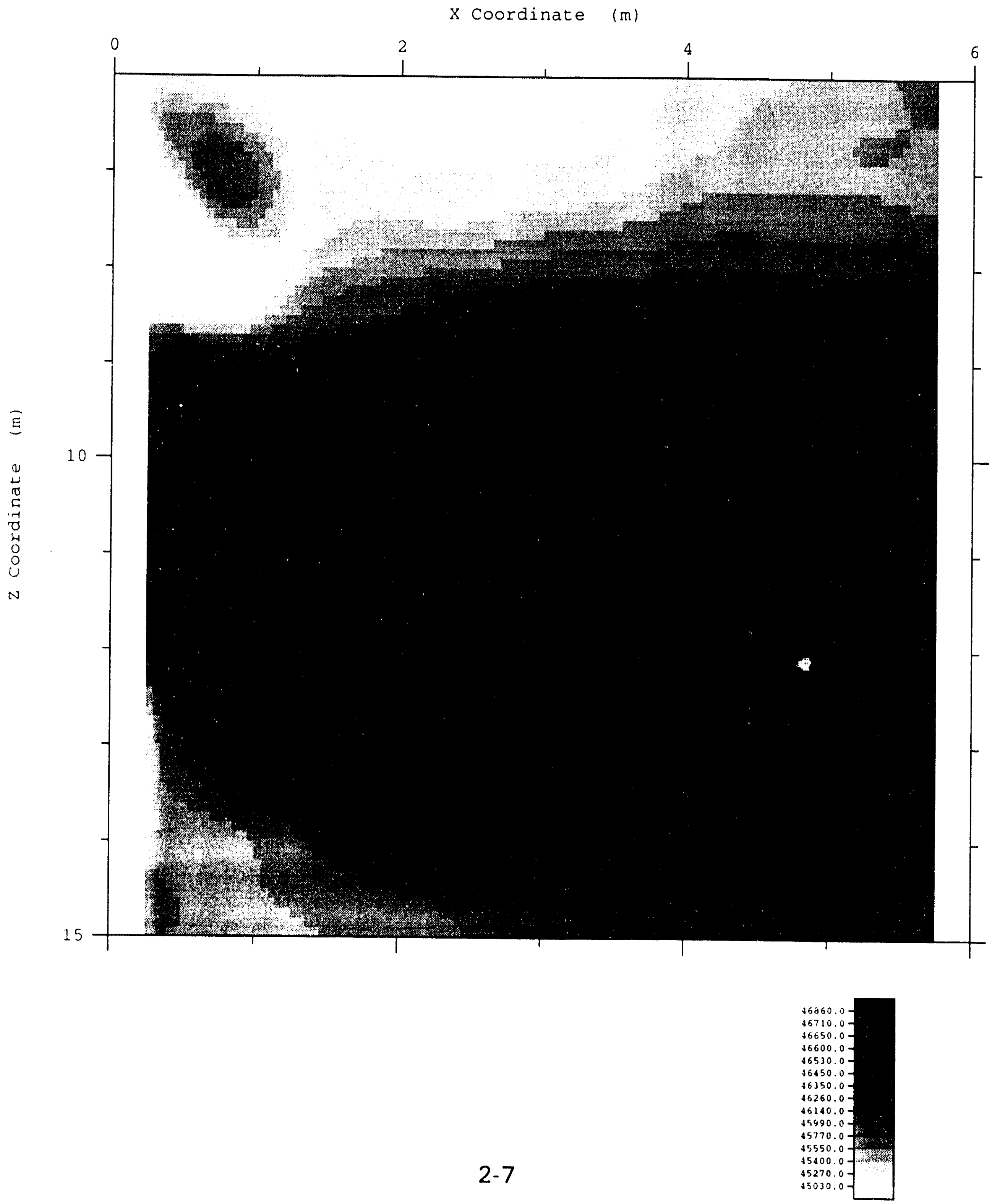

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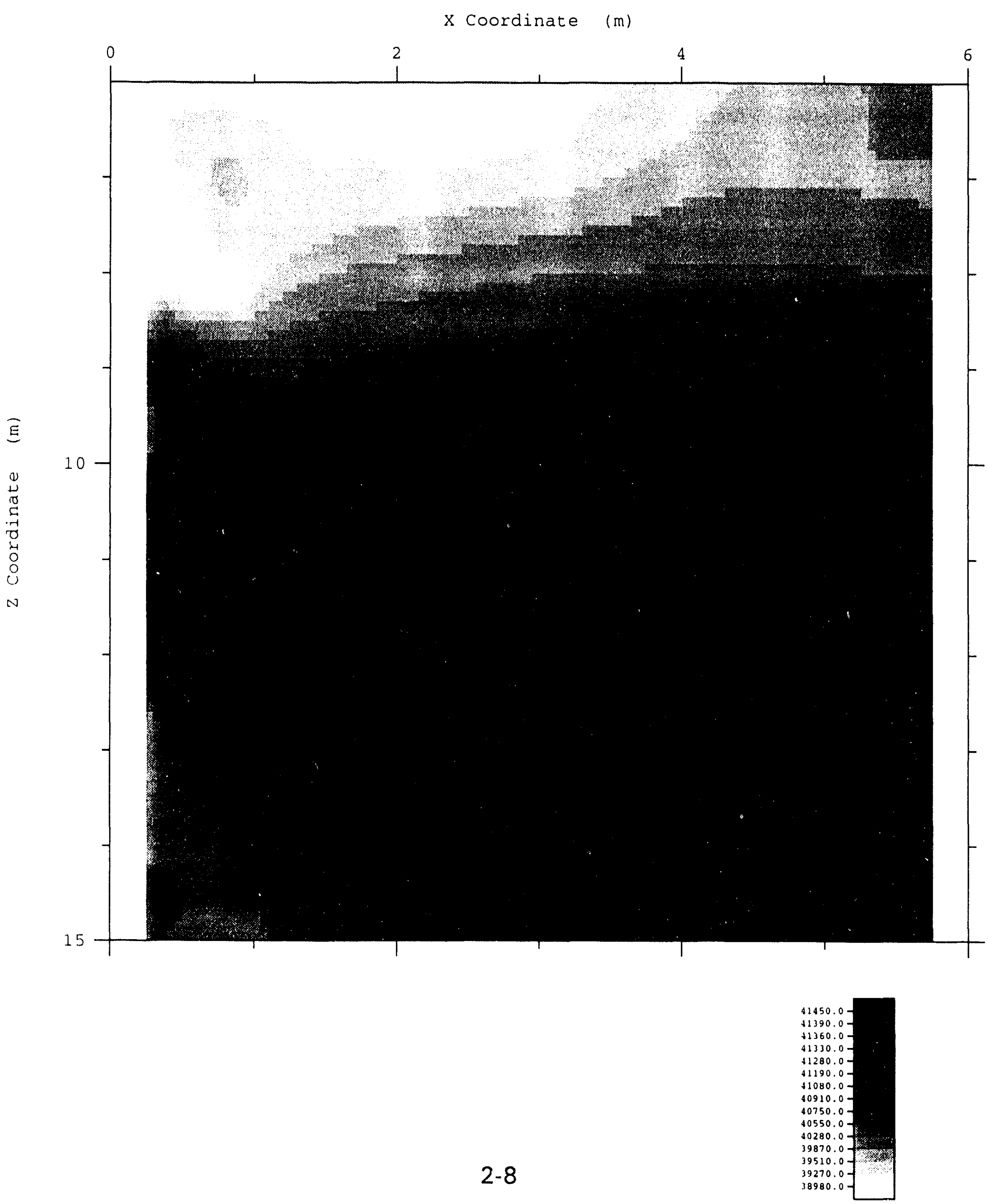

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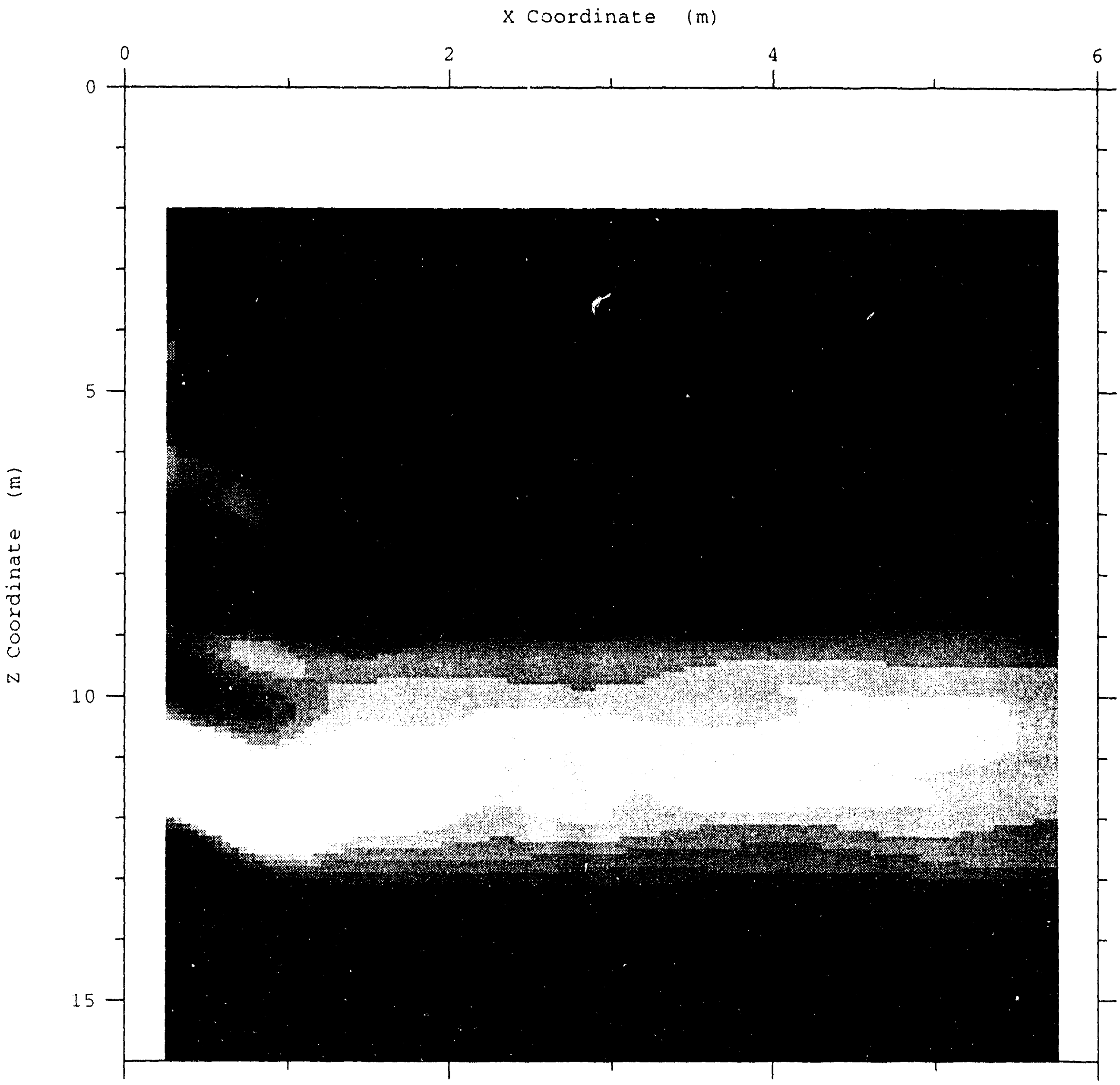

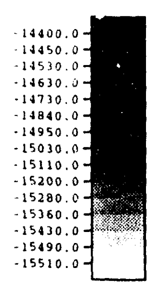

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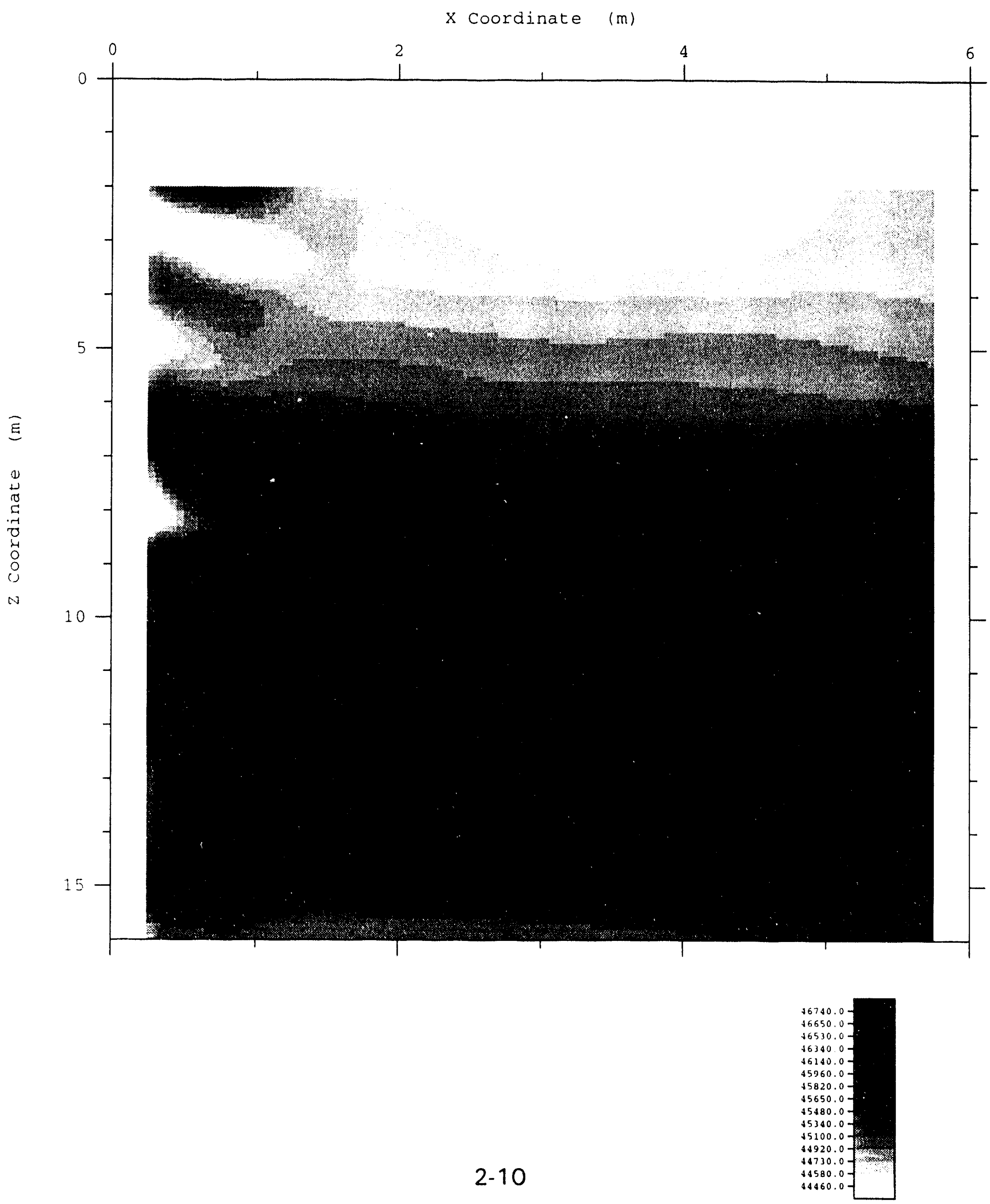

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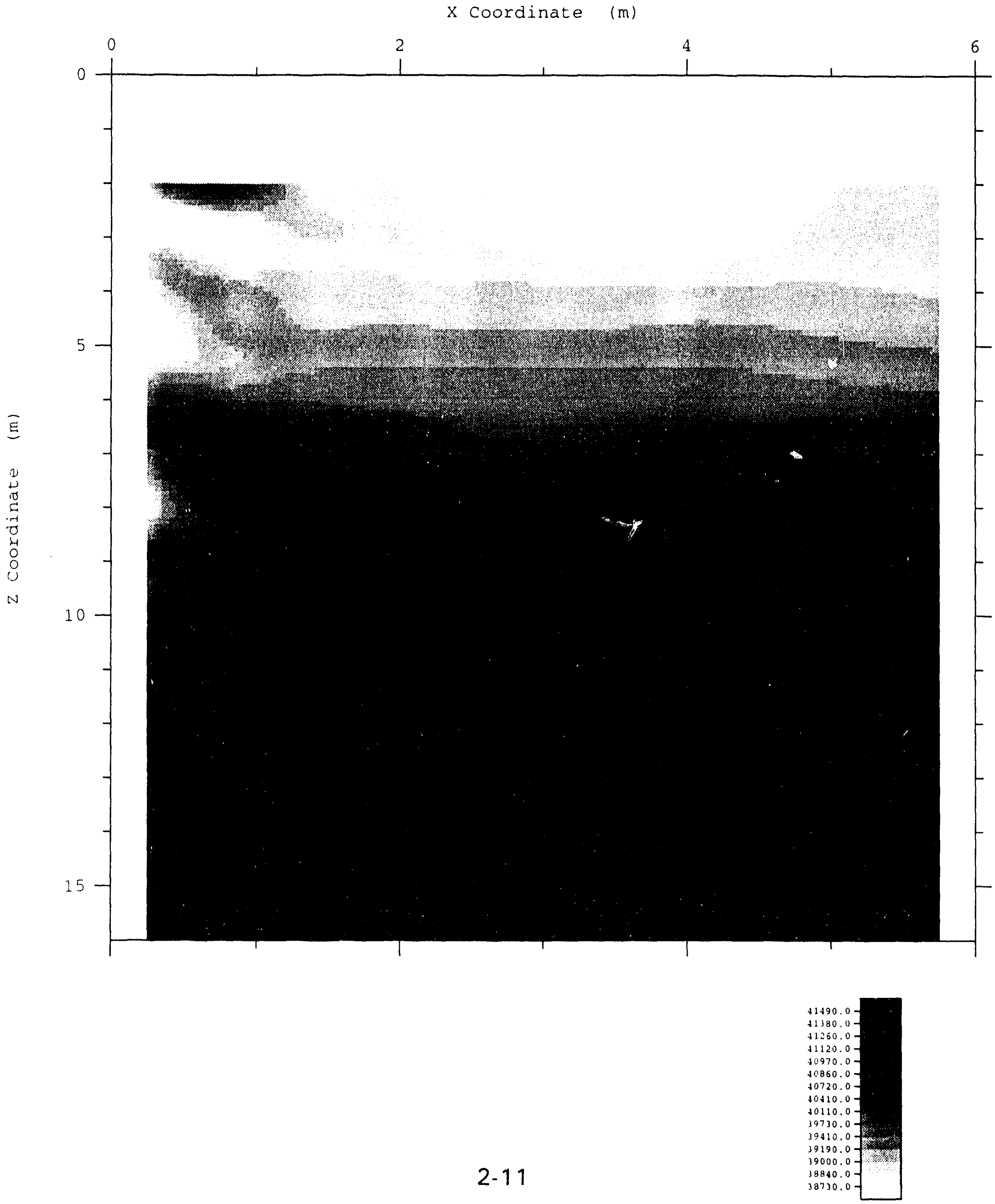

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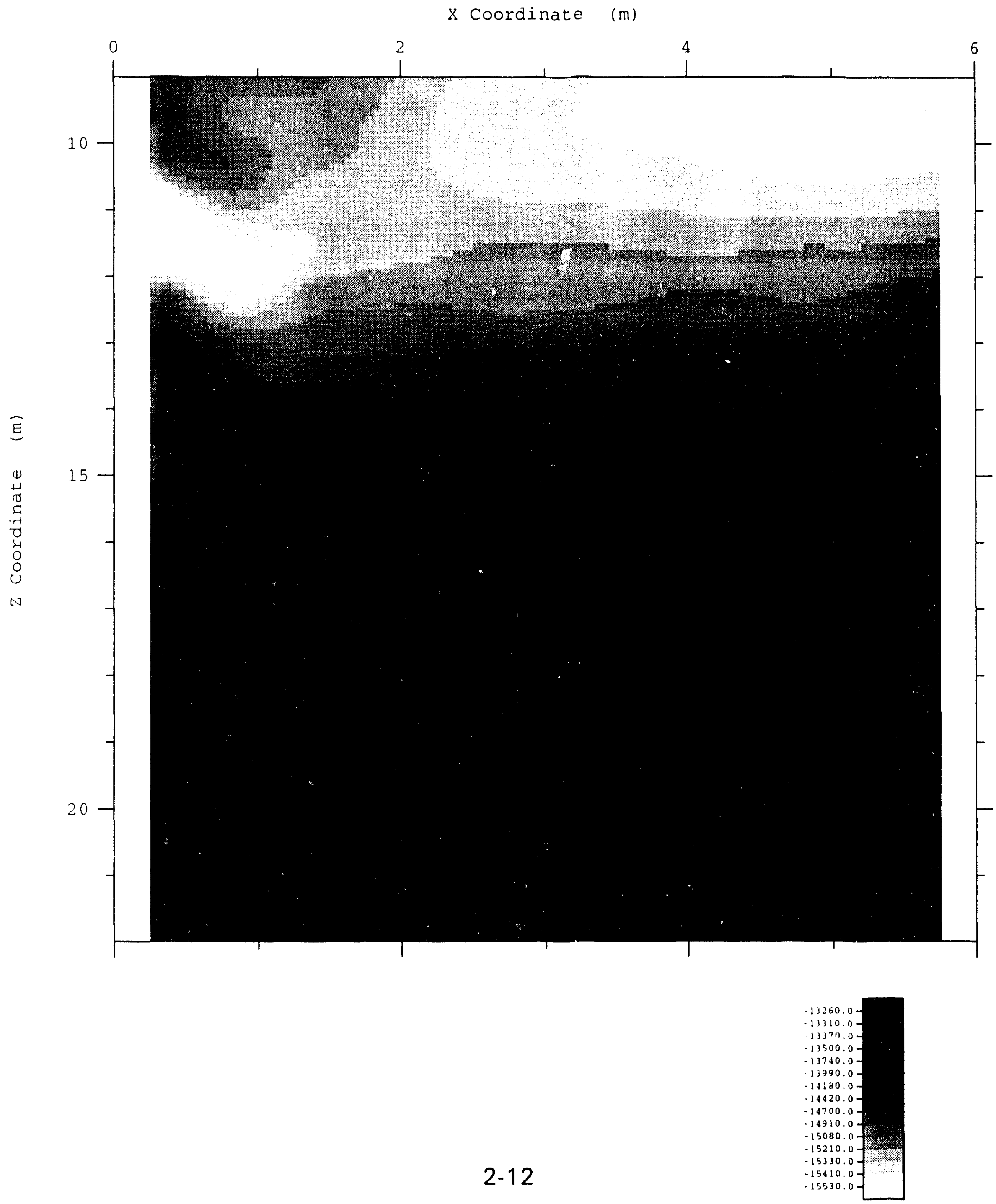
SANDIA UCAP1-UCAP3 ATTENUATION PEAK to PEAK



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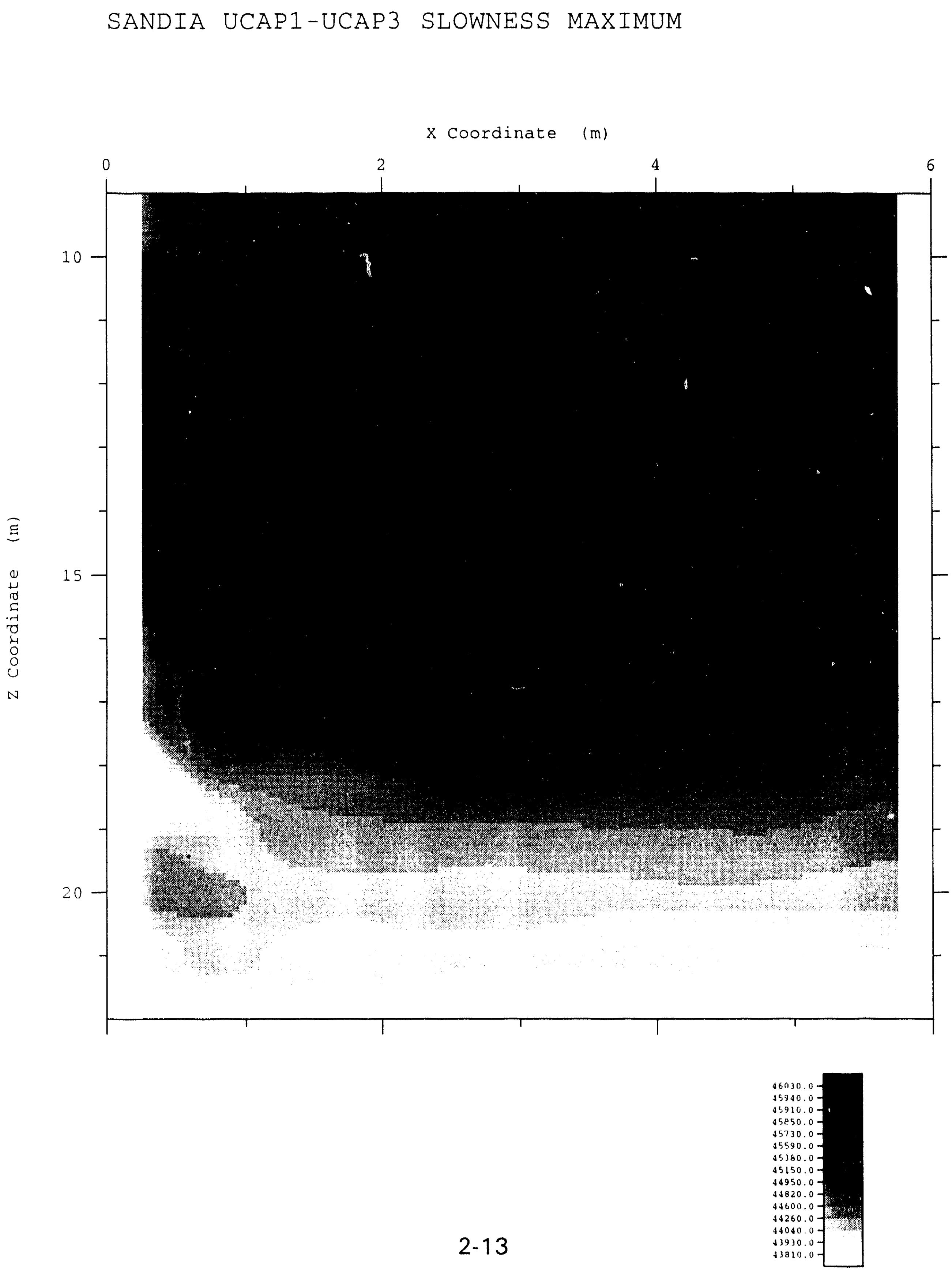
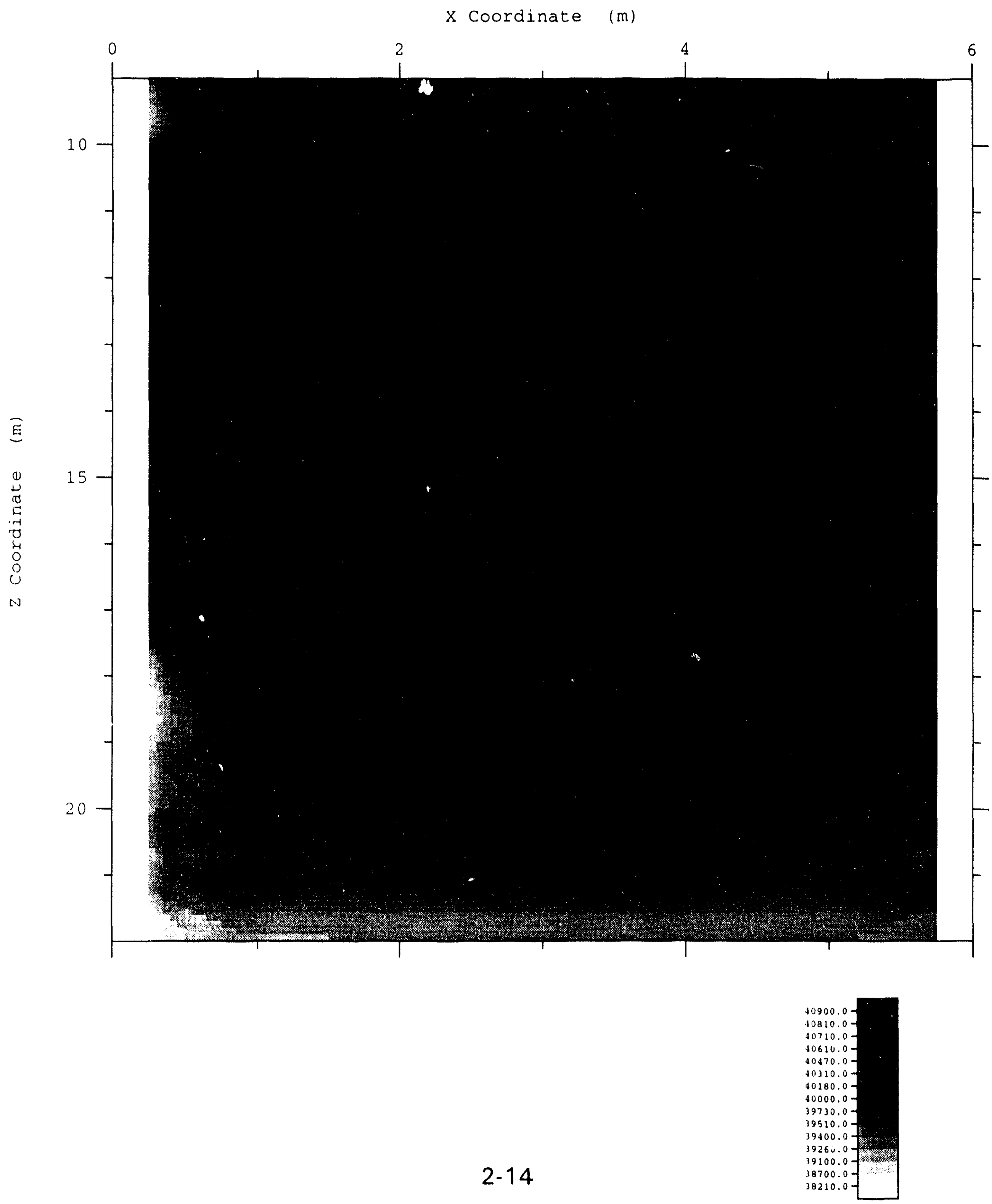

SANDIA UCAP1-UCAP3 SLOWNESS MAXIMUM
X Coordinate (m)
0
2
4
6
Z Coordinate (m)
10
15
20
46030.0
45940.0
45910.0
45850.0
45730.0
45590.0
45380.0
45150.0
44950.0
44820.0
44600.0
44260.0
44040.0
43930.0
43810.0

SANDIA UCAP1-UCAP3 SLOWNESS MINIMUM



19931117

SANDIA OCT.22,1993 TO OCT.25,1993

TRACE #	UCAP1 XMIT	UCAP2 REC.DEPTH		TRACE #	UCAP1 XMIT	UCAP2 REC.DEPTH
001-011	2.0	2.0-7.0		471-491	14.5	9.5-19.5
012-023	2.5	2.0-7.5		492-512	15.0	10.0-20.0
024-036	3.0	2.0-8.0		513-533	15.5	10.5-20.5
037-050	3.5	2.0-8.5		534-554	16.0	11.0-21.0
051-065	4.0	2.0-9.0		555-575	16.5	11.5-21.5
066-081	4.5	2.0-9.5		576-596	17.0	12.0-22.0
082-098	5.0	2.0-10.0		597-617	17.5	12.5-22.5
099-116	5.5	2.0-10.5		618-638	18.0	13.0-23.0
117-135	6.0	2.0-11.0		639-659	18.5	13.5-23.5
136-155	6.5	2.0-11.5		660-680	19.0	14.0-24.0
156-176	7.0	2.0-12.0		681-701	19.5	14.5-24.5
177-197	7.5	2.5-12.5		702-722	20.0	15.0-25.0
198-218	8.0	3.0-13.0		723-743	20.5	15.5-25.5
219-239	8.5	3.5-13.5		744-764	21.0	16.0-26.0
240-260	9.0	4.0-14.5		765-785	21.5	16.5-26.5
261-281	9.5	4.5-14.5		786-806	22.0	17.0-27.0
282-302	10.0	5.0-15.0		807-827	22.5	17.5-27.5
303-323	10.5	5.5-15.5		828-848	23.0	18.0-28.0
324-344	11.0	6.0-16.0				
345-365	11.5	6.5-16.5				
366-386	12.0	7.0-17.0				
387-407	12.5	7.5-17.5				
408-428	13.0	8.0-18.0				
429-449	13.5	8.5-18.5				
450-470	14.0	9.0-19.0				

APPENDIX 3

Licensee 1992: Raytheon Services Nevada

Site and borehole:

Date:

T-R Distance:

Equipment name:

Operator's name:

Date of plot: Tue Nov 23 11:50:49 1993

RAMAC MEASUREMENT PROGRAM VERSION 6.4,

Maximum Time Gain 1.01

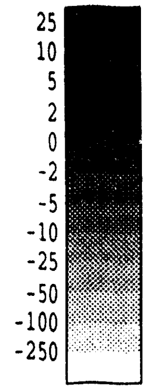
Lin. coefficient 0.010

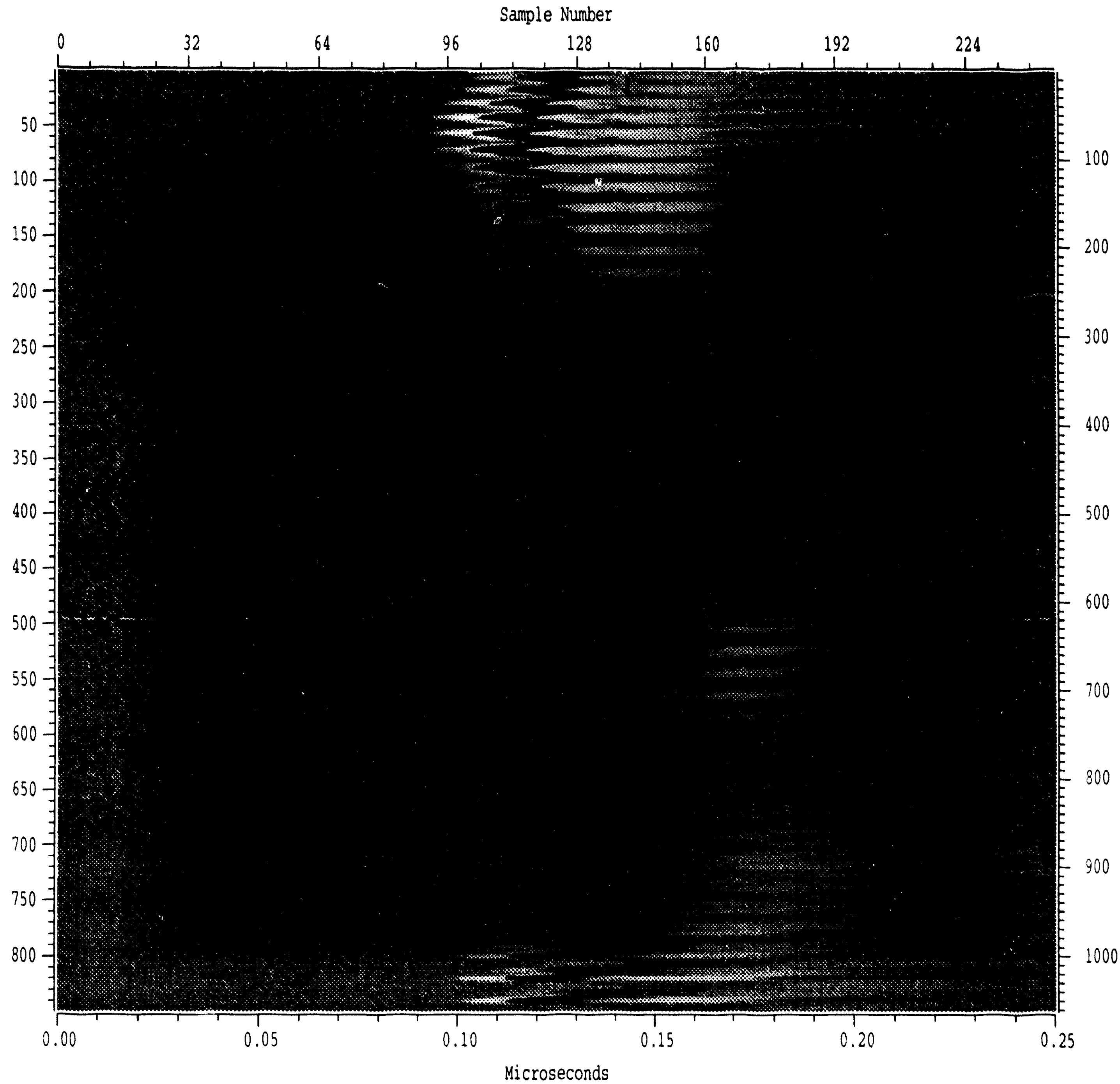
Exp. coefficient 0.000

Start time of gain 0.000

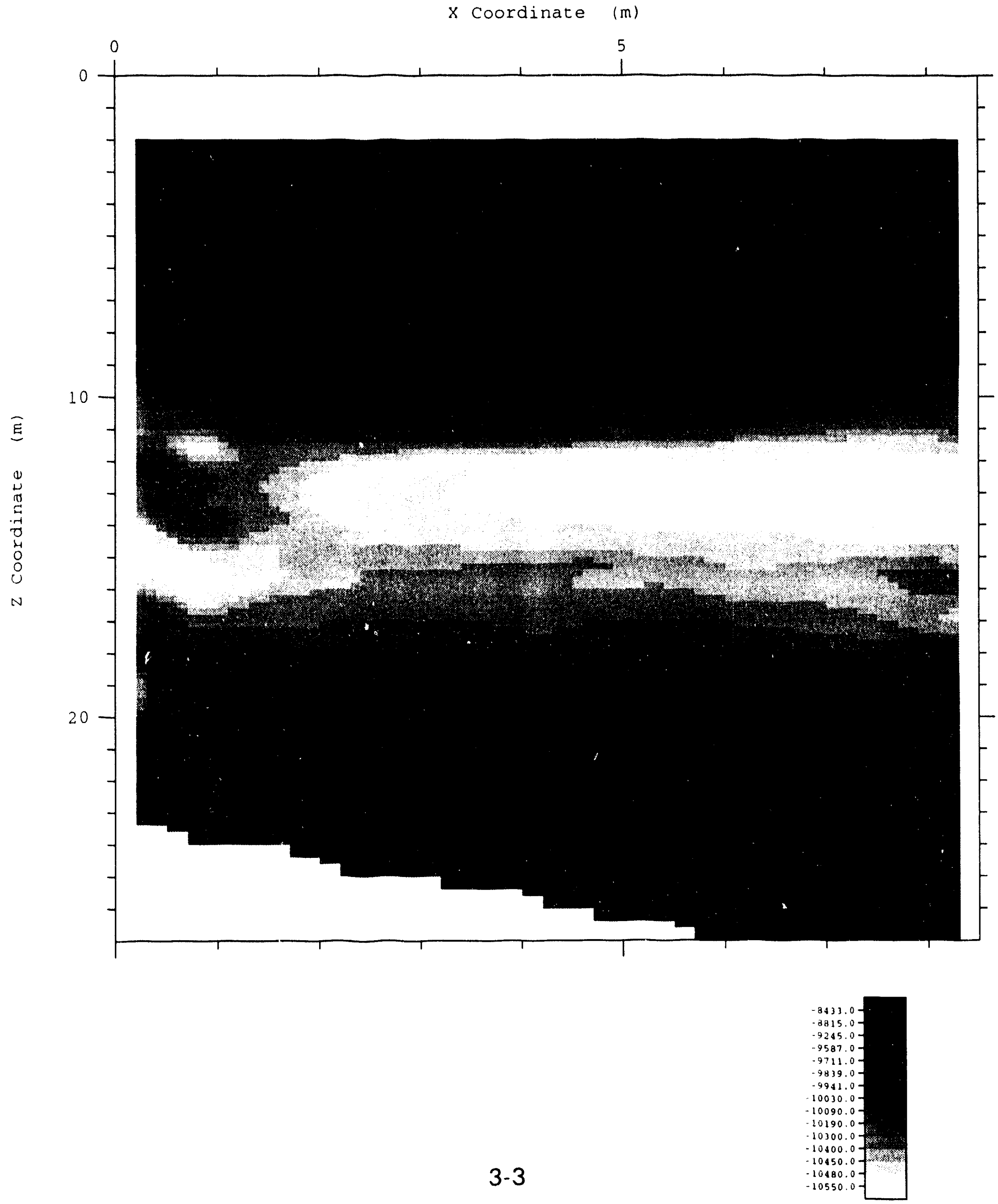
DC level subtracted.

Dipole Antenna.





SANDIA UCAP1-UCAP2 ATTENUATION PEAK to PEAK



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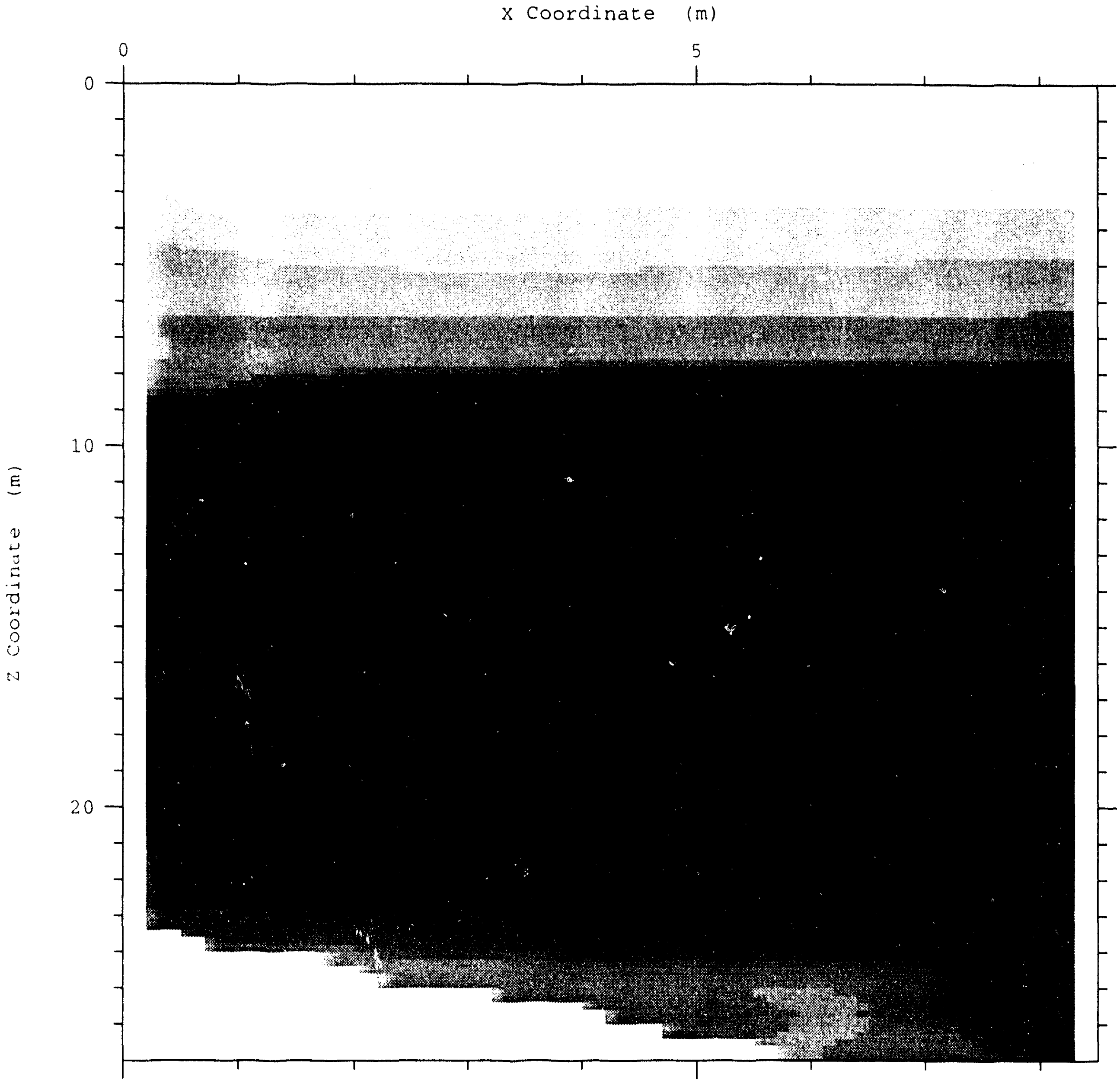
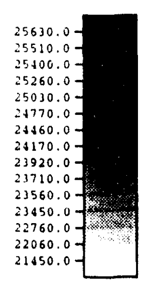
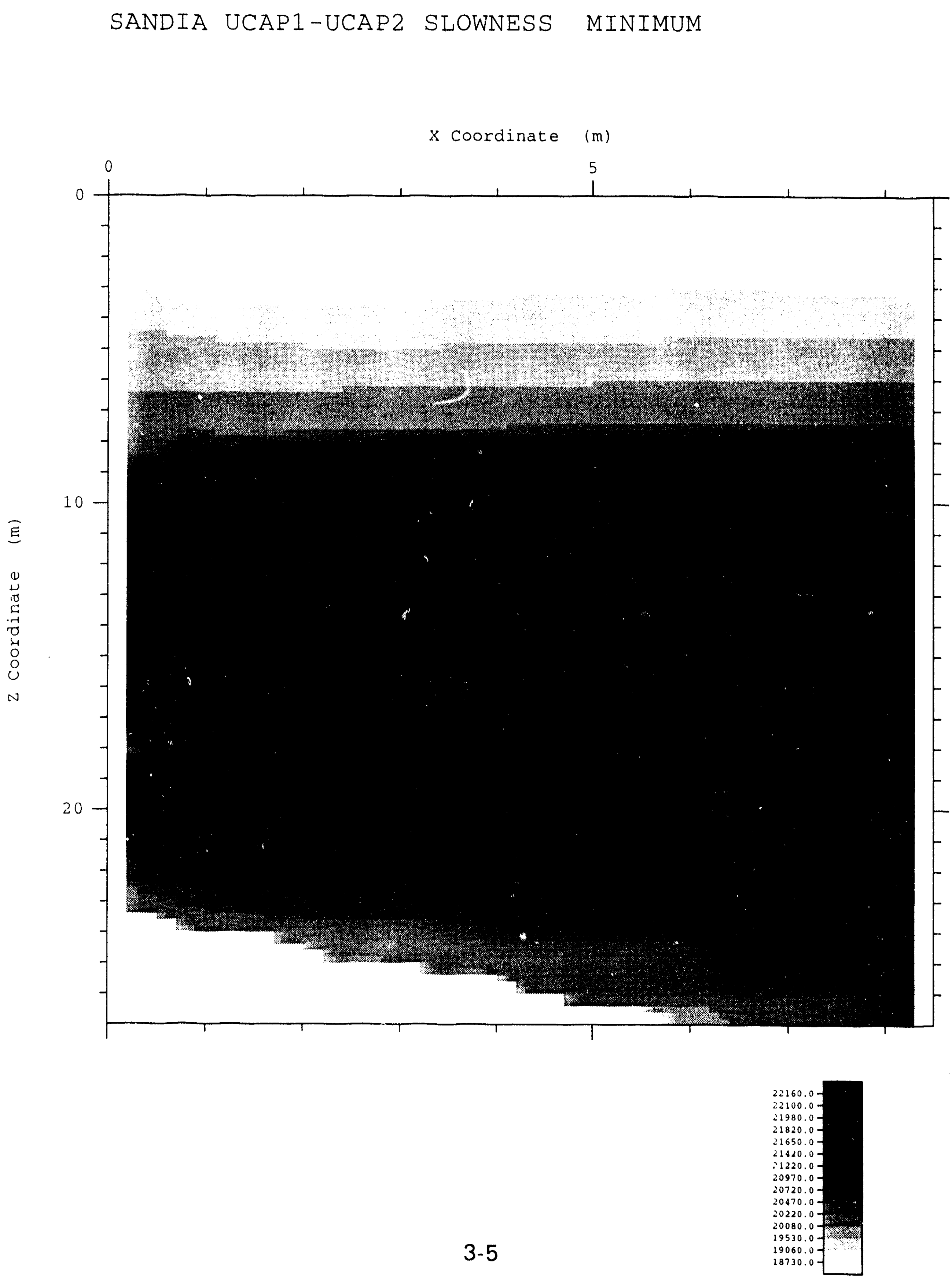
SANDIA UCAP1-UCAP2 SLOWNESS MAXIMUM







SANDIA UCAP1-UCAP2 SLOWNESS MINIMUM
X Coordinate (m)
0
5
Z Coordinate (m)
0
10
20
22160.0
22100.0
21980.0
21820.0
21650.0
21420.0
21220.0
20970.0
20720.0
20470.0
20220.0
20080.0
19530.0
19060.0
18730.0

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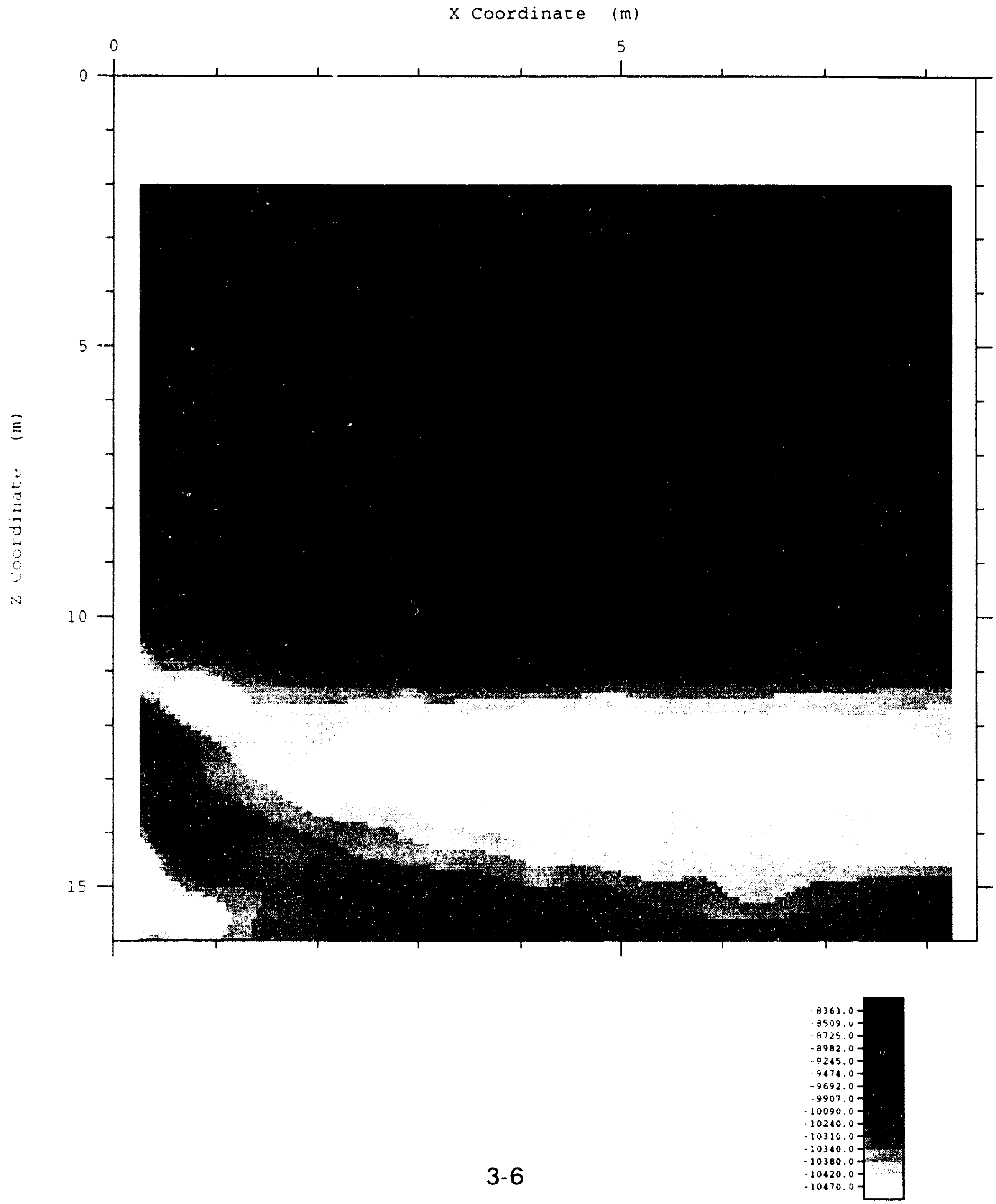
SANDIA UCAP1-UCAP2 ATTENUATION PEAK to PEAK



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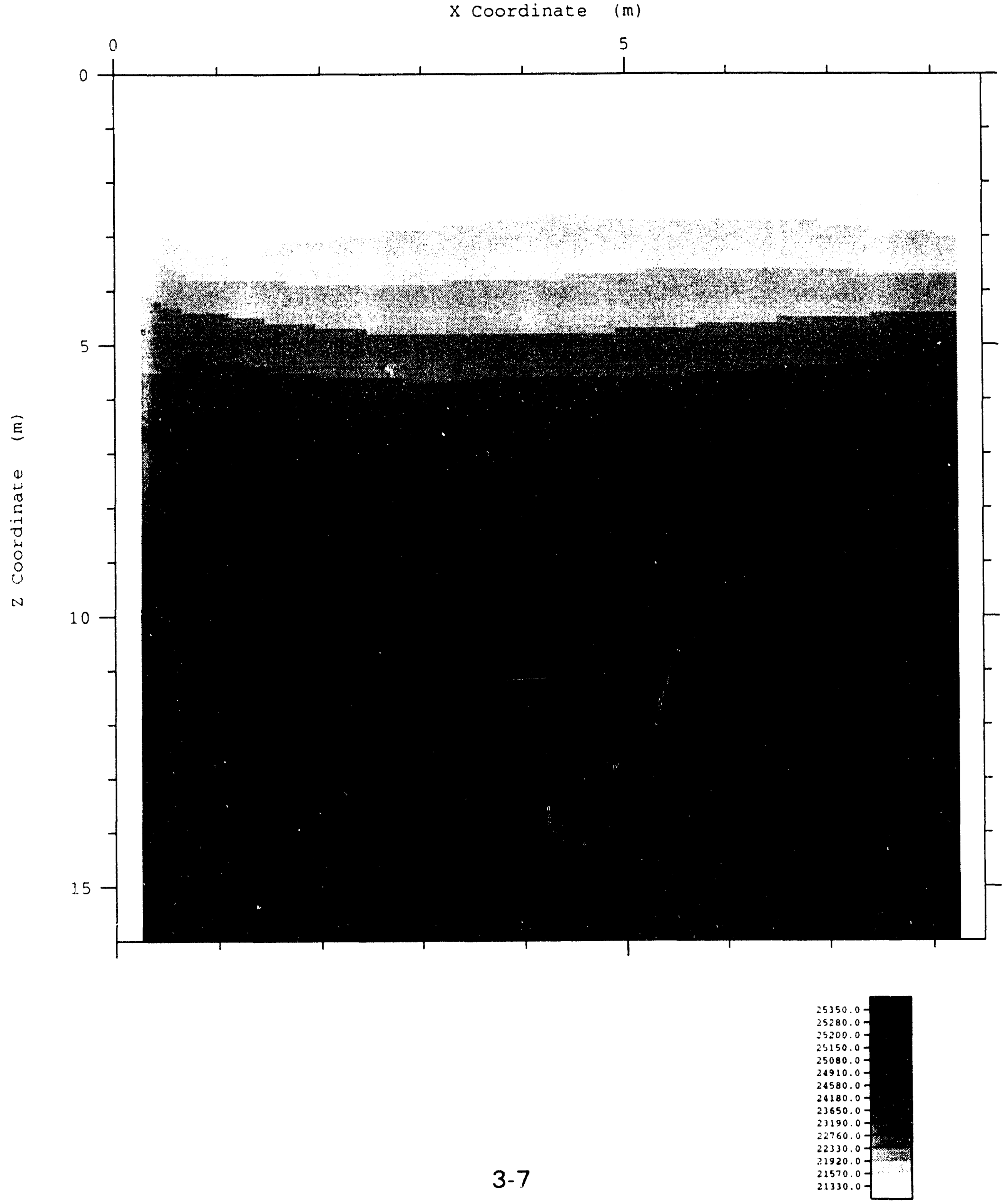

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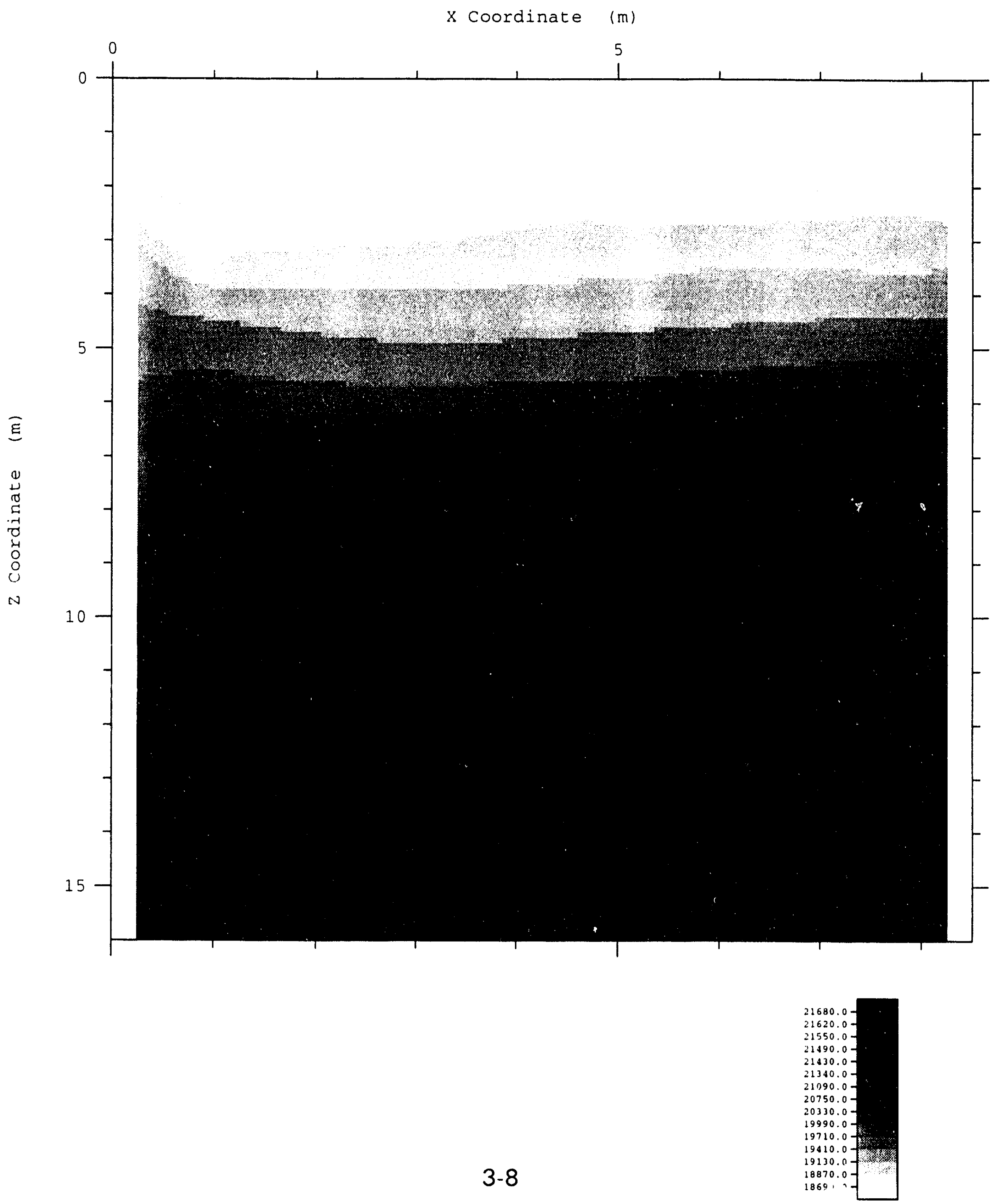

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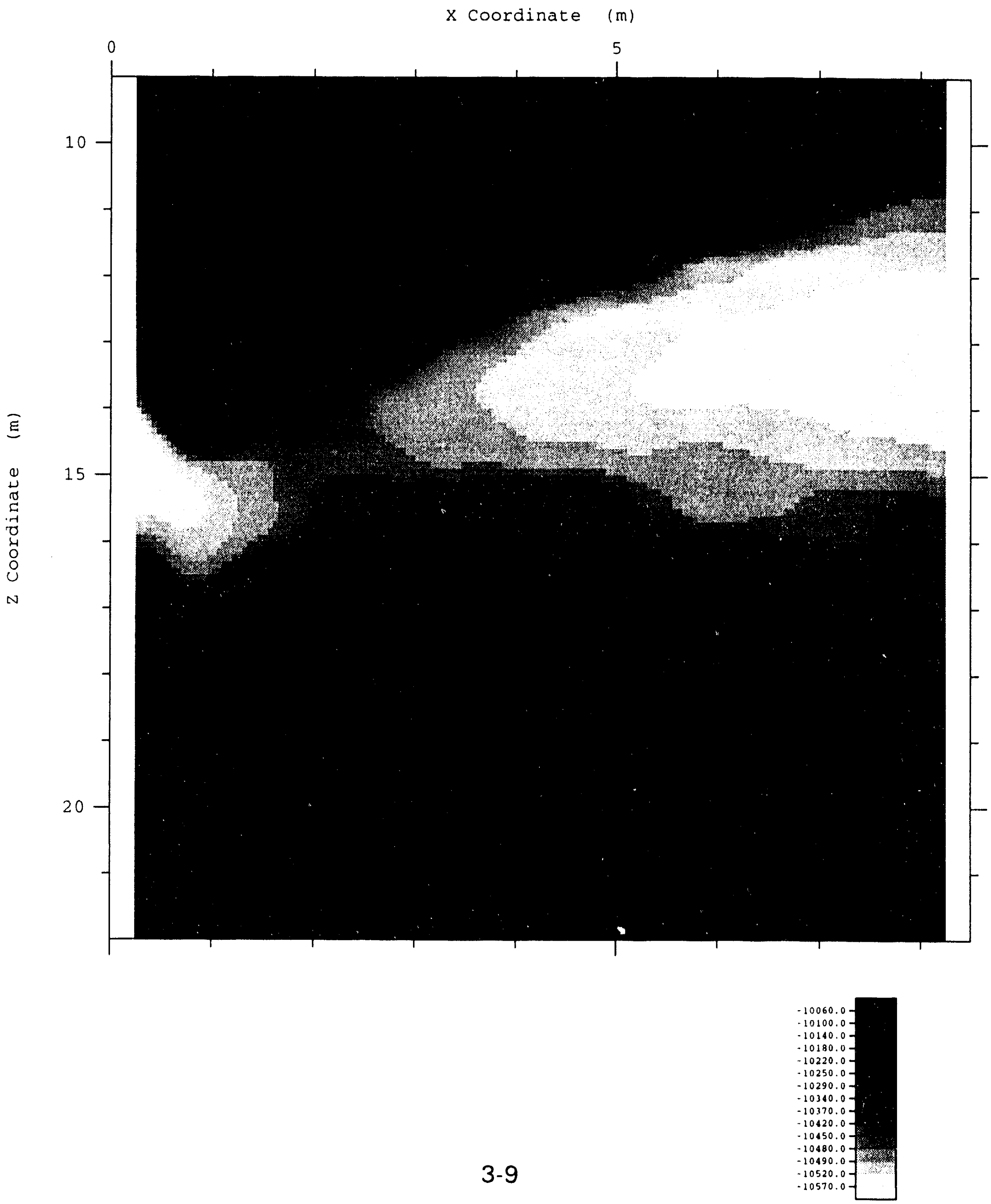

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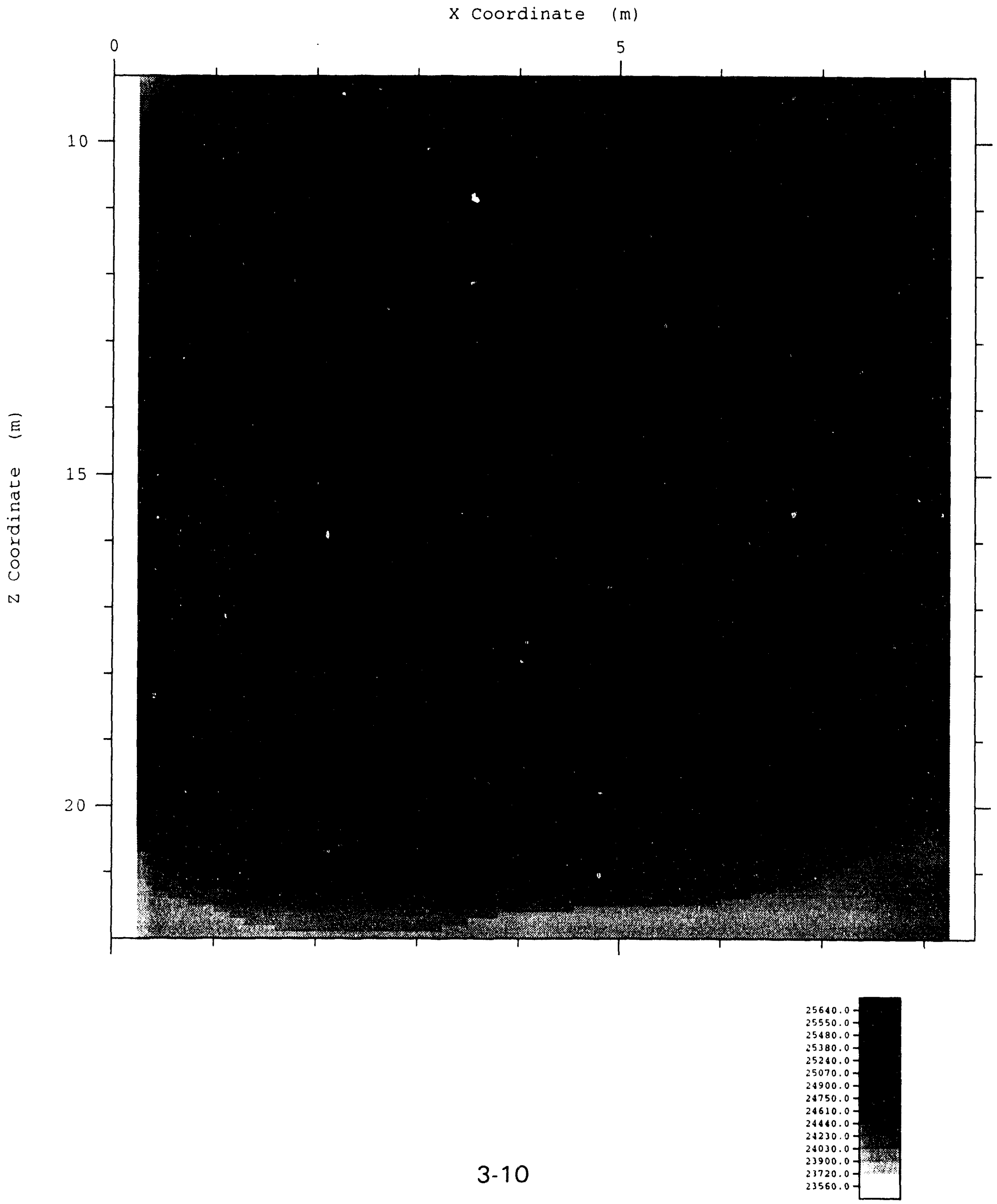

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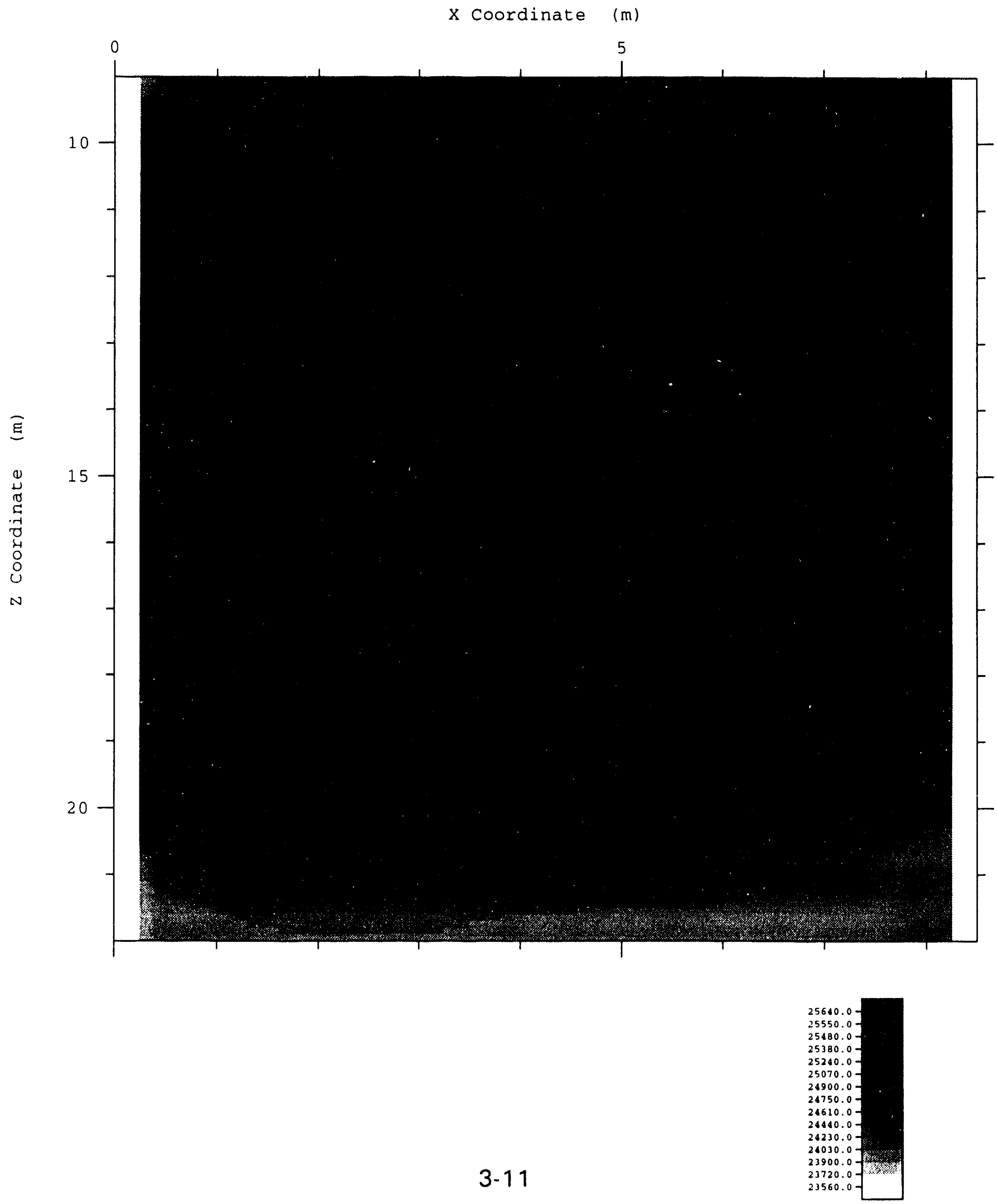

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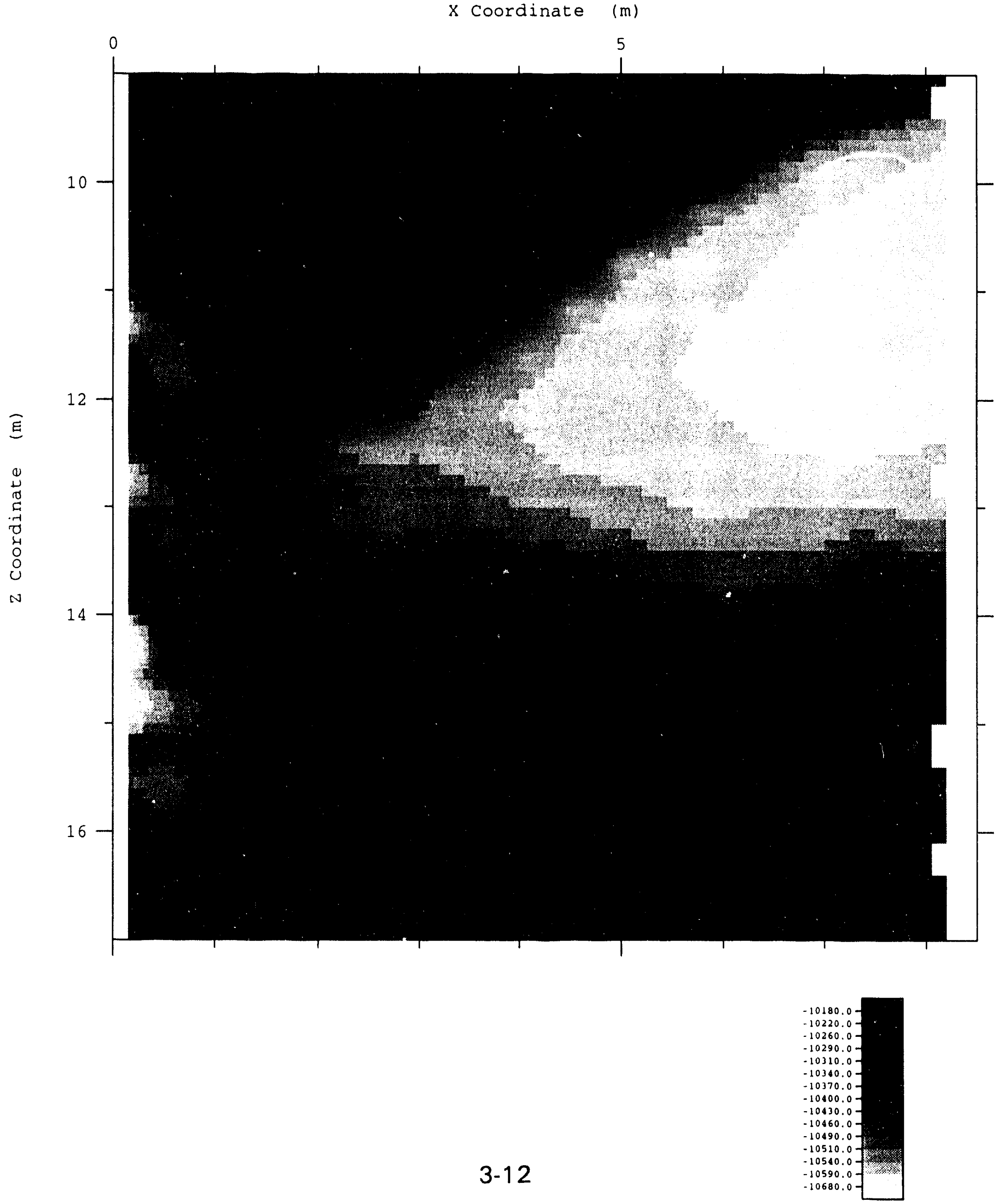

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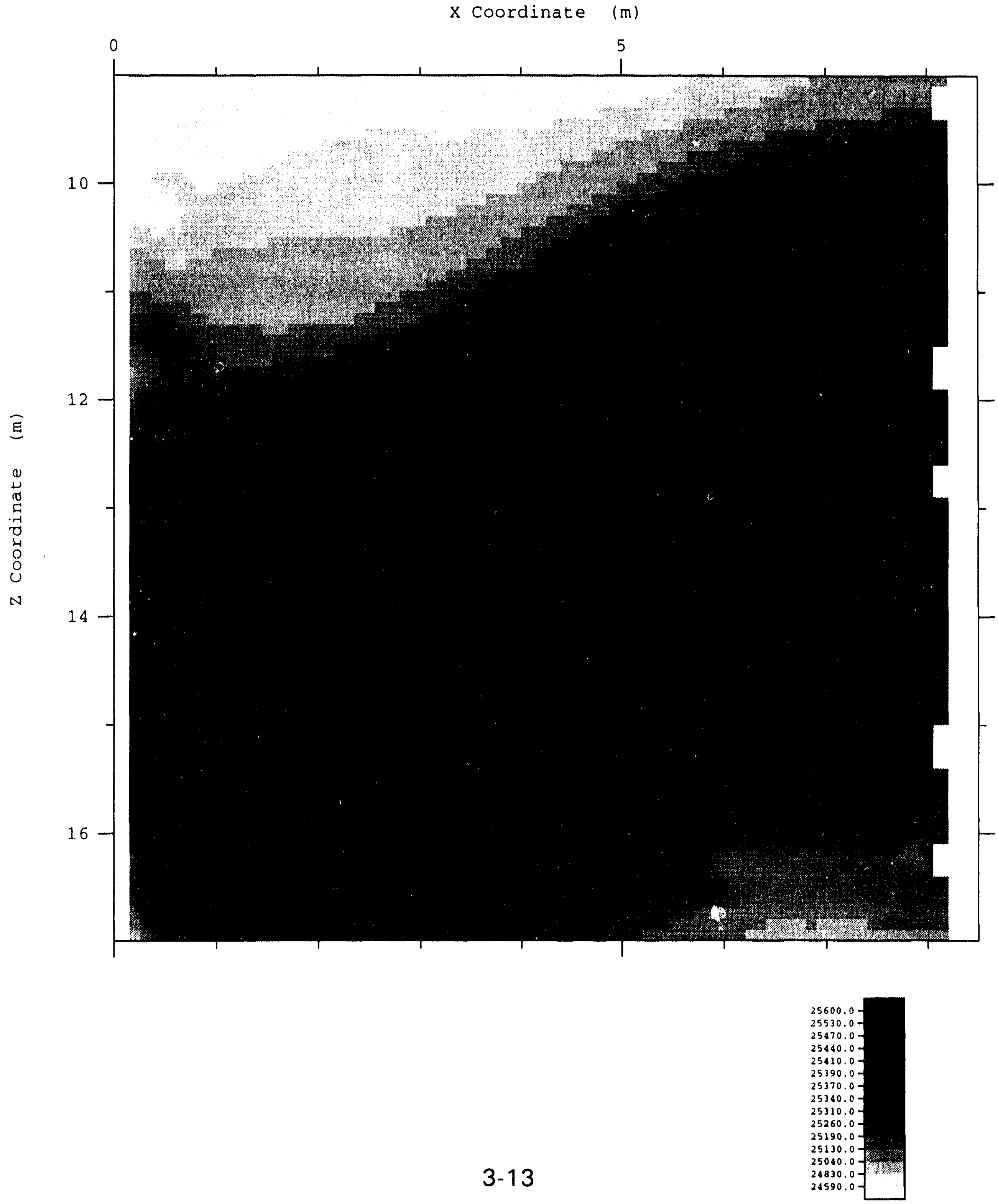

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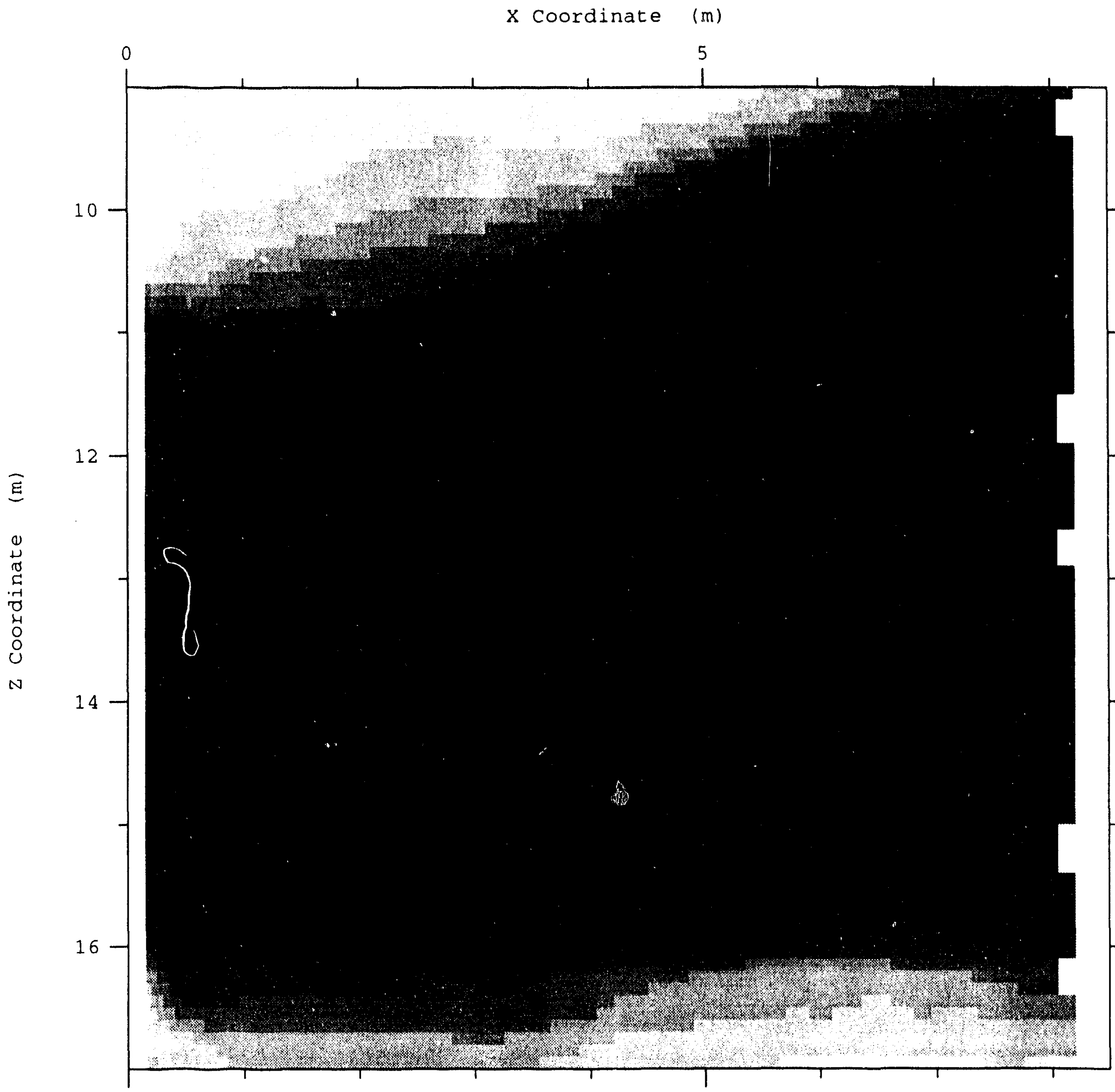
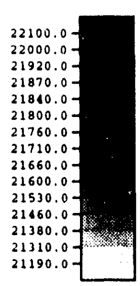
SANDIA UCAP1-UCAP2 SLOWNESS MINIMUM





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END

DATE
FILMED
3/18/94