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**SHALLOW ELECTROMAGNETIC SURVEYS OF AN ABANDONED  
BUNKER, DENVER FEDERAL CENTER, COLORADO**

By

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# SHALLOW ELECTROMAGNETIC SURVEYS OF AN ABANDONED BUNKER, DENVER FEDERAL CENTER, COLORADO

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Abstract: This study compared three shallow-penetration EM systems by making surveys along identical grids over a 1940s-era, abandoned, buried coal(?) bunker at the Denver Federal Center. These systems were the Geophex GEM-2, GSSI GEM-300, and Geonics EM-31. All three systems detected many subsurface structures and objects. This report presents a folio of color maps of the results.

## Purpose of study:

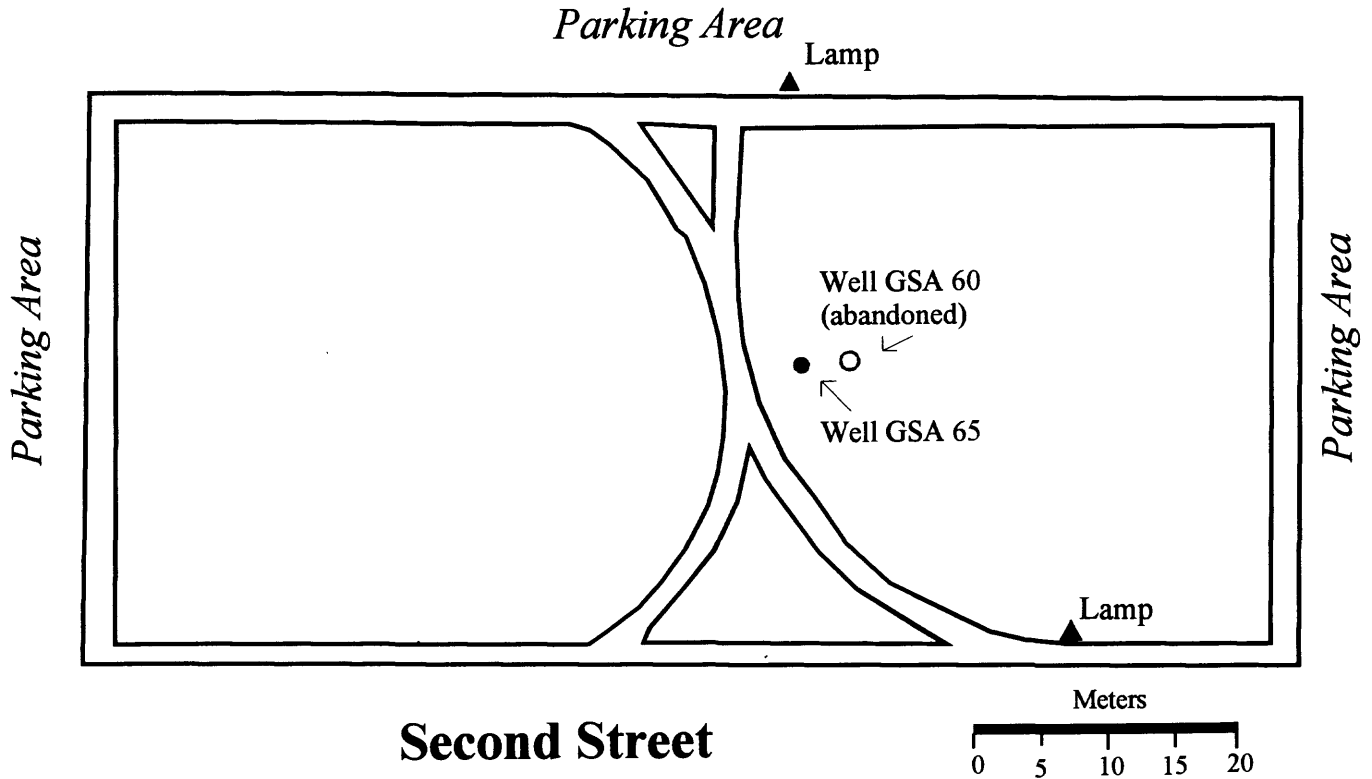
- To examine the subsurface of the study area with different electromagnetic instruments, in order to develop a permanent testing area for similar types of instruments.
- To compile a series of data sets for the study area in order to better understand the capabilities of selected electromagnetic instruments.
- To uncover more of the history of the Denver Federal Center.

## Instruments:

The three shallow penetration electromagnetic instruments we tested are commercially available, and are, to an extent, competitors for the same market niches. The EM-31, built by Geonics Ltd, Mississauga, Ontario, Canada, is described by McNeal (1960, 1996). EM-31 units have been available for many years, and there are many published case histories describing their use (some examples: Bauman and others, 1997, Rogers and others, 1996). The GEM-300 was designed by Geophex Ltd., Raleigh NC (Won and others, 1996), and is licensed to Geophysical Survey Systems Inc., Salem NH, for commercial production. The GEM-2 unit we used is a modification of that basic design, also by Geophex Ltd. All three units are two-loop frequency-domain instruments. The EM-31 operates at a fixed frequency (9.8 kHz for the newer models), while both GEM-300 and GEM-2 use up to 5 or 6 frequencies specified by the operator.

## Study Area:

The study area chosen for this project ("Bldg. 20 Bunker") is a grassy rectangular area measuring approximately 43.2 meters by 87.5 meters, and is located east of Building 20, Denver Federal Center (DFC). The study area is bounded on all sides by a 1.6 to 2 meter sidewalk. It is further bounded by Second Street on its westernmost side, and by a parking area on its remaining sides (sketch map follows).



#### DFC History:

The DFC was opened in 1942 as the Denver Ordinance Plant (DOP), to produce 30 caliber ammunition for U.S. forces to use in the Second World War. During and after the War, the DOP/DFC underwent many changes, one of which probably added the structures observed beneath the study area. A thorough records search (National Archives, 1998) was conducted, but little relevant information was found. DOP plans from 1946 show an acetylene magazine and a coal bunker or system of oil tanks immediately south of the study area. These plans show rail lines located approximately where First and Second Streets are now. Tradition has it that Kaiser Industries built, but may have never operated, a foundry for 8" artillery shells on or near the study area at the very close of the War (Kate Power, Woodward-Clyde Consultants, oral commun., 11/9/98). The area was used as a parking lot during the 1970s and 1980s, but a drillhole bored there in the early 1990s found a void: as a result, cars were kept off, and the area reverted to grass (Larry Volkening, U.S. Geological Survey, oral commun., 11/10/98). Several photographs taken in 1994 show a trench running along the western edge of the study area, as well as structural footings beneath Second Street (National Archives). It is interesting that, except for the 1994 trench (for sewer or electrical lines?), there are several documented structural features located near the study area, but none on it.

### Methodology:

Each survey was performed as follows:

1. Equipment was assembled and prepared according to the manufacturers' manuals (Geophex Ltd., 1998; GSSI, 1998; Geonics Ltd., 1994).
2. Surveys began at the NW corner of the study area, which was set as the (0,0) coordinate. Surveys proceeded by walking straight lines from West to East, then East to West, and so on. Each pass was made 2.5 meters south of the previous line.
3. At the end of each survey the data collected was downloaded as directed by the manufacturer's manuals.
4. Data was gridded and plotted using Surfer 6.01 commercial software, written by Golden Software Inc., 809 14th Street, Golden CO 80401-1866. This data is presented in figures 1-24.

Table A gives survey dates, equipment, and frequencies used, together with a key to the color figures, which follow at the end of the report.

Table A: Survey dates, equipment, and frequencies used.

GEM-2				GEM-300	EM-31	
7/13/98	7/17/98	7/31/98	8/13/98	9/1/98	new	old
90		90	1050	1050		
	2430			4770		
	7230					
9810			9810		9800	
	15210	15210				
21630			21930	21930		
						31000

Table A notes and key to color figure pages:

- 7/13/98: Figures not shown; this was a test day for the GEM-2.  
7/17/98: Figures 7-8, 11-12 and 15-16.  
7/31/98: Figures 1-2 and 17-18.  
8/13/98: Figures 3-4, 13-14 and 19-20.  
9/1/98: Figures 5-6 and 9-10; Frequency 21930 Hz not shown.  
New EM-31: Figures 21-24.  
Old EM-31: Figures not shown; one test line only was run.

On all figures, "IP" stands for inphase component, and "OP" for out-of-phase (also called "quadrature") component. Units on IP and OP plots are nominal parts per million. Units on conductivity plots are mS/m.

### Results:

1. Results of repeated frequencies with the same instrument (GEM-2), look alike (Figs. 15-18).

2. Results of repeated frequencies with different instruments (GEM-2 & GEM-300, GEM-2 & New EM-31), look alike (Figs. 3-6, 13-14 and 21-24).
3. EM-31 conductivities (Fig. 22) and conductivities derived from the GEM-2 (Fig. 14 data -- derived conductivity values are not shown) do not agree well. The GEM-2 calibration appears to be somewhat in error, giving quadrature values that are too high by about a factor of 1.5. No measurements were made at the EM-31 frequency (about 9.8 kHz) with the GEM-300, so that we did not make this test of its calibration.
4. GEM-2 nominally can use frequencies 90 Hz to 22 kHz. Data sets taken at 90 Hz (Figs. 1-2) produce images that are muted relative to those at higher frequencies. Nevertheless, certain features remain visible at 90 Hz. Note that both the wall along  $y = 7.5$  and light post at about  $x = 72$ ,  $y = 2$  are visible on the inphase plot, fig. 1. The quadrature plot, fig. 2, shows these and other features.
5. EM-31 inphase values varied over an extreme range at this site. Because of time limitations, we did not try to bring the inphase meter on scale everywhere. This resulted in the recorded values being set at >30 (saturation value) over much of the survey area (Figs. 21,23).
6. Notice that the "wall" (linear feature at  $y = 7.5$ ) is a quadrature maximum at low frequencies and a minimum at high frequencies. At intermediate frequencies the wall is obscure. EM-31 uses such an intermediate frequency (9.8 kHz), and does not see the wall well. We conclude that multifrequency systems, such as the GEM-2 and GEM-300, are advantageous for performing detailed archaeological and reconnaissance studies. However, better-calibrated systems like the EM-31 should be used where it is important to find true conductivity values, as in the studies of geology, water resources, and ore deposits.

Acknowledgement: We thank Dr. I.J. Won and Dean Keiswetter of Geophex Ltd. for lending us a newer design GEM-2 unit to make our tests.

References:

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- Geonics Limited, 1994, EM-31 Operating Manual (For Models With Two Digital Meters), dated Sept, 1994: Geonics Ltd., 1745 Meyerside Dr. Unit 8, Mississauga, Ontario, Canada L5T 1C6, 40 p.
- Geophex, Ltd., 1998, GEM-2 Operations Manual: Geophex Ltd, 605 Mercury Street, Raleigh, NC 27603, 13 p.

- Geophysical Survey Systems, Inc., 1998, GEM-300 Multi Frequency Electromagnetic Profiler (manual), Operating System Version 1.05a, dated Jan, 1998: GSSI, 13 Klein Drive, PO Box 97, North Salem NH 03073-0097, 139 p.
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- McNeal, J.D., 1996, Why doesn't Geonics Limited build a multi-frequency EM31 or EM34?: Geonics Ltd., 1745 Meyerside Dr. Unit 8, Mississauga, Ontario, Canada L5T 1C6, Technical Note TN-30, 5 p.
- National Archives, 1998: National Archives and Records Administration, Bldg. 48, DFC, Internal Record Numbers 8NS-121-97-469, Box 6: 211, 238, and 239.
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- Won, I.J., Keiswetter, Dean A., Fields, George R.A., and Sutton, Lynn C., 1996, GEM-2: A New Multifrequency Electromagnetic Sensor: Journal of Environmental and Engineering Geophysics, v. 1, issue 2, p.129-137.

Fig. 1 - Bldg. 20 Bunker - GEM 2 - 90 Hz IP

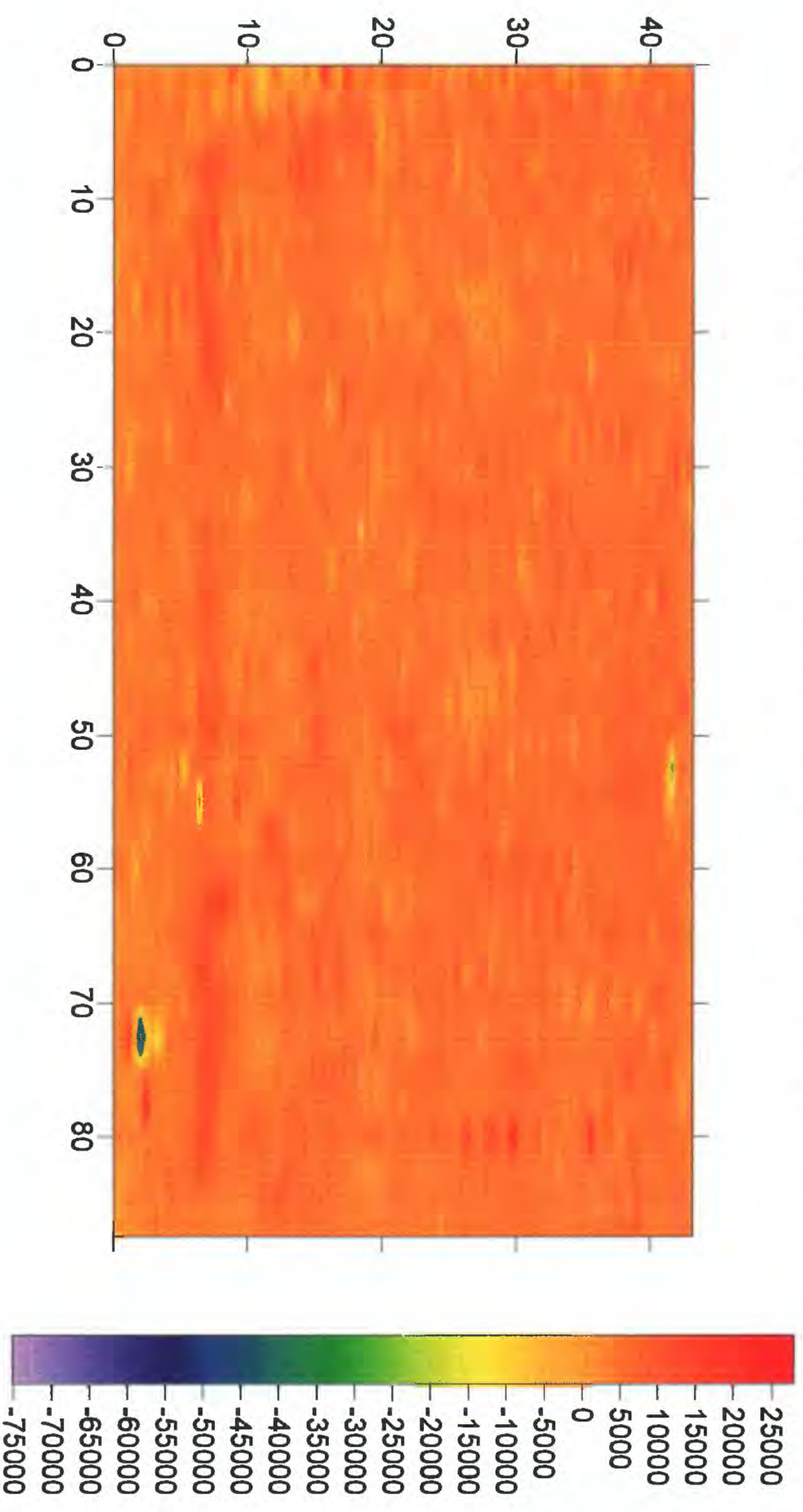




Fig. 2 - Bldg. 20 Bunker - GEM 2 - 90 Hz OP

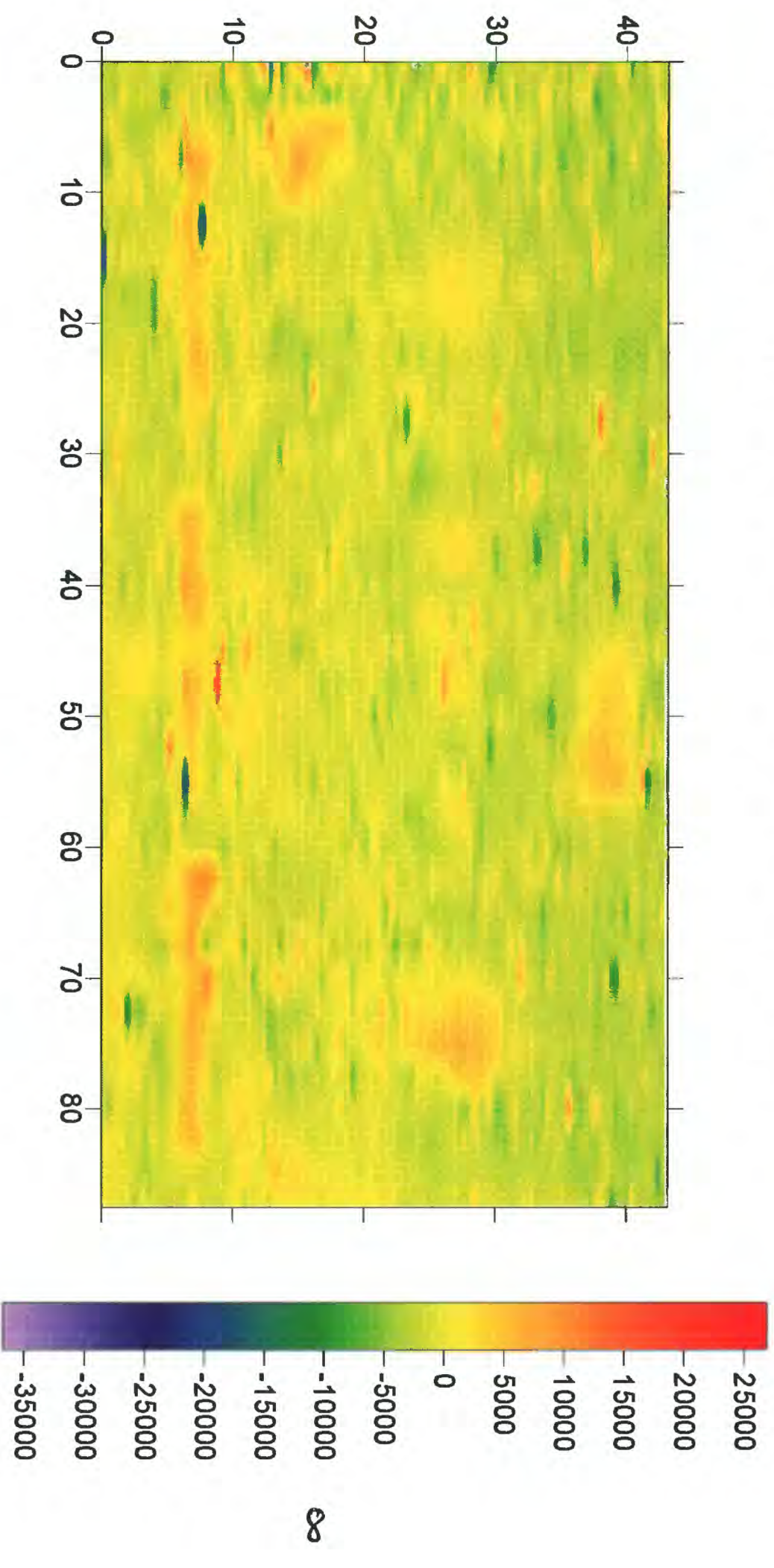




Fig. 3 - Bldg. 20 Bunker - GEM 2 - 1050 Hz IP

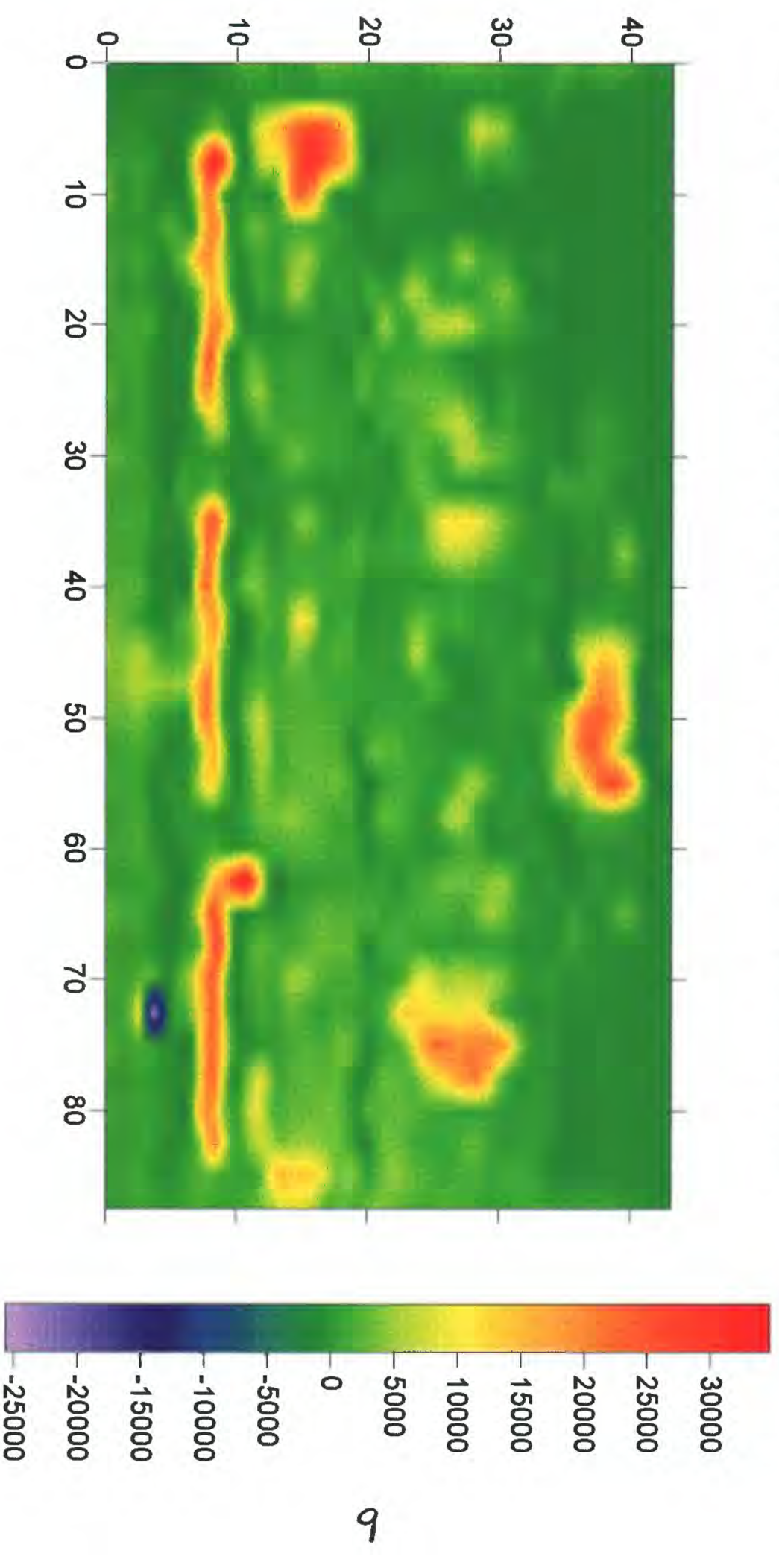
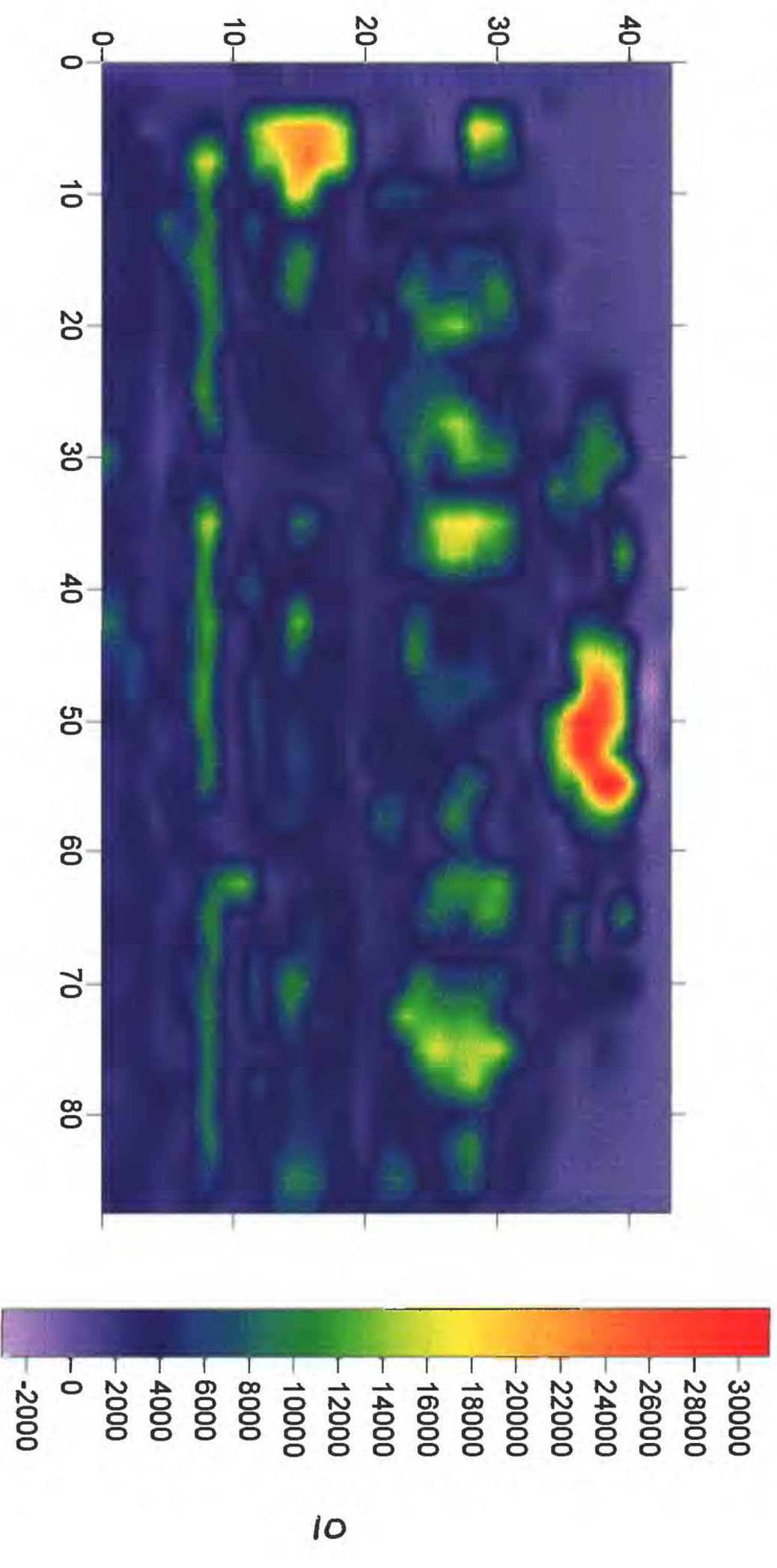


Fig. 4 - Bldg. 20 Bunker - GEM 2 - 1050 Hz OP





**Fig. 5 - Bldg. 20 Bunker - GEM 300 - 1050 Hz IP**

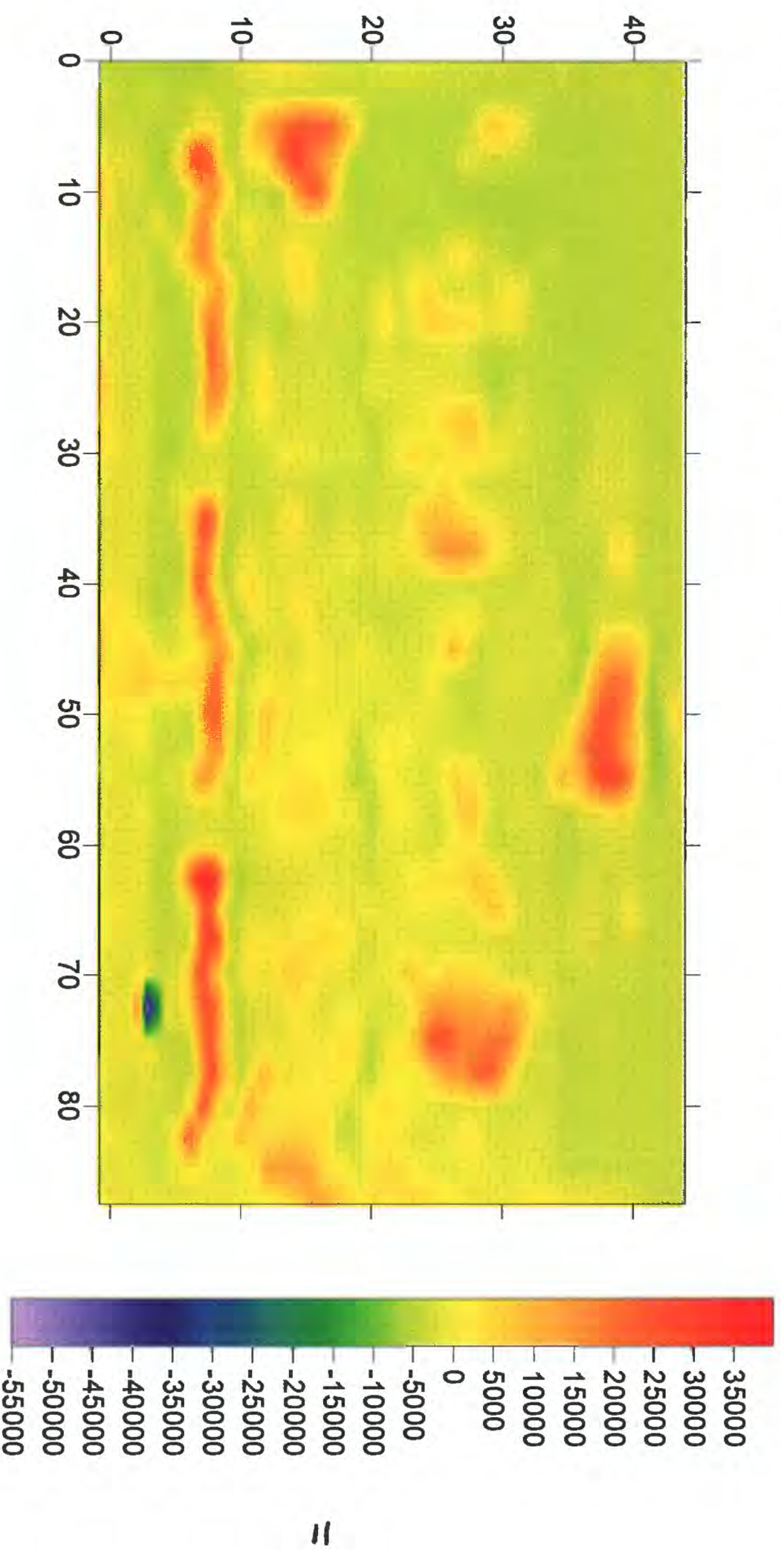


Fig. 6 - Bldg. 20 Bunker - GEM 300 - 1050 Hz OP

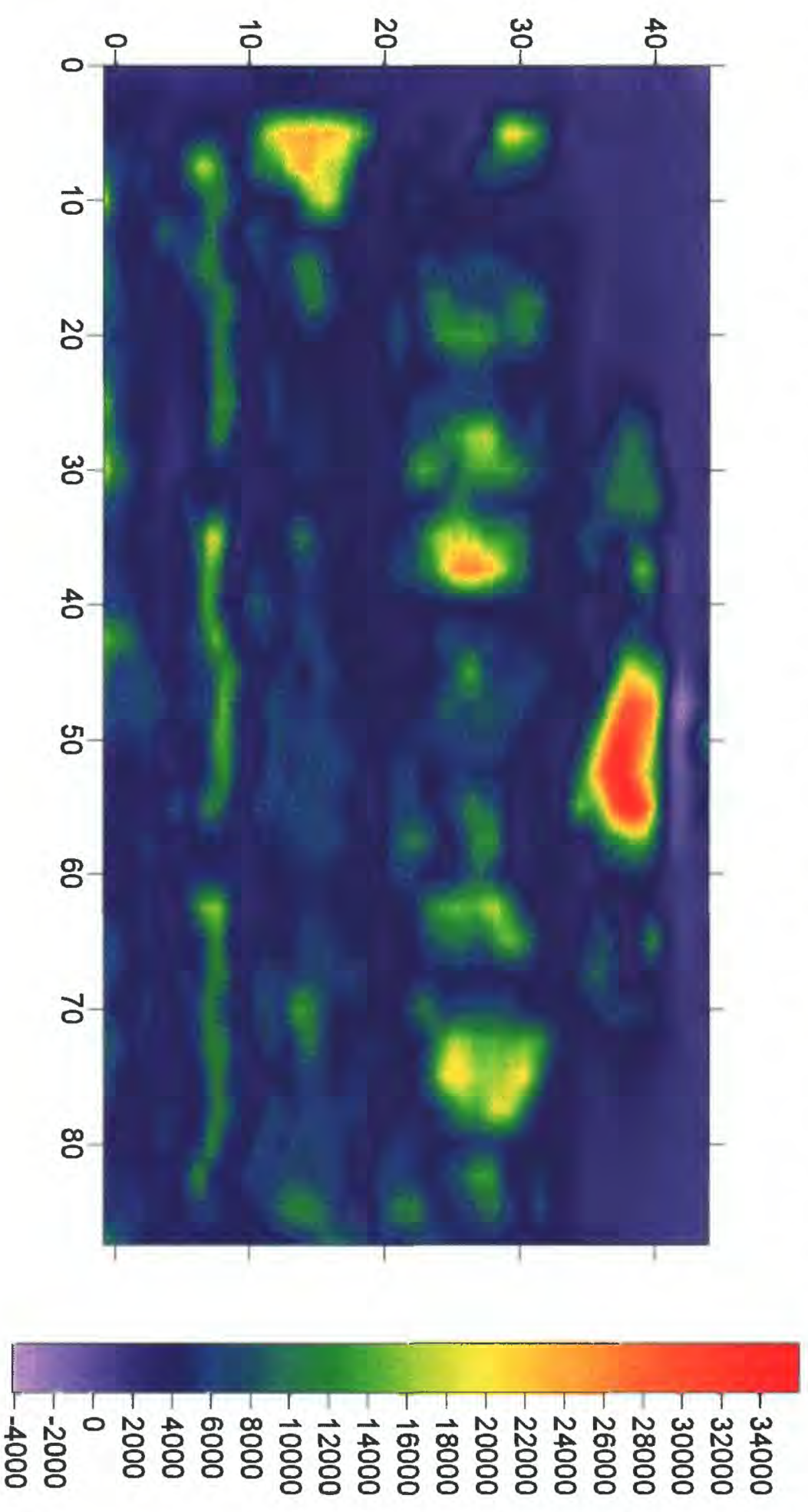




Fig. 7 - Bldg. 20 Bunker -GEM 2 - 2430 Hz IP

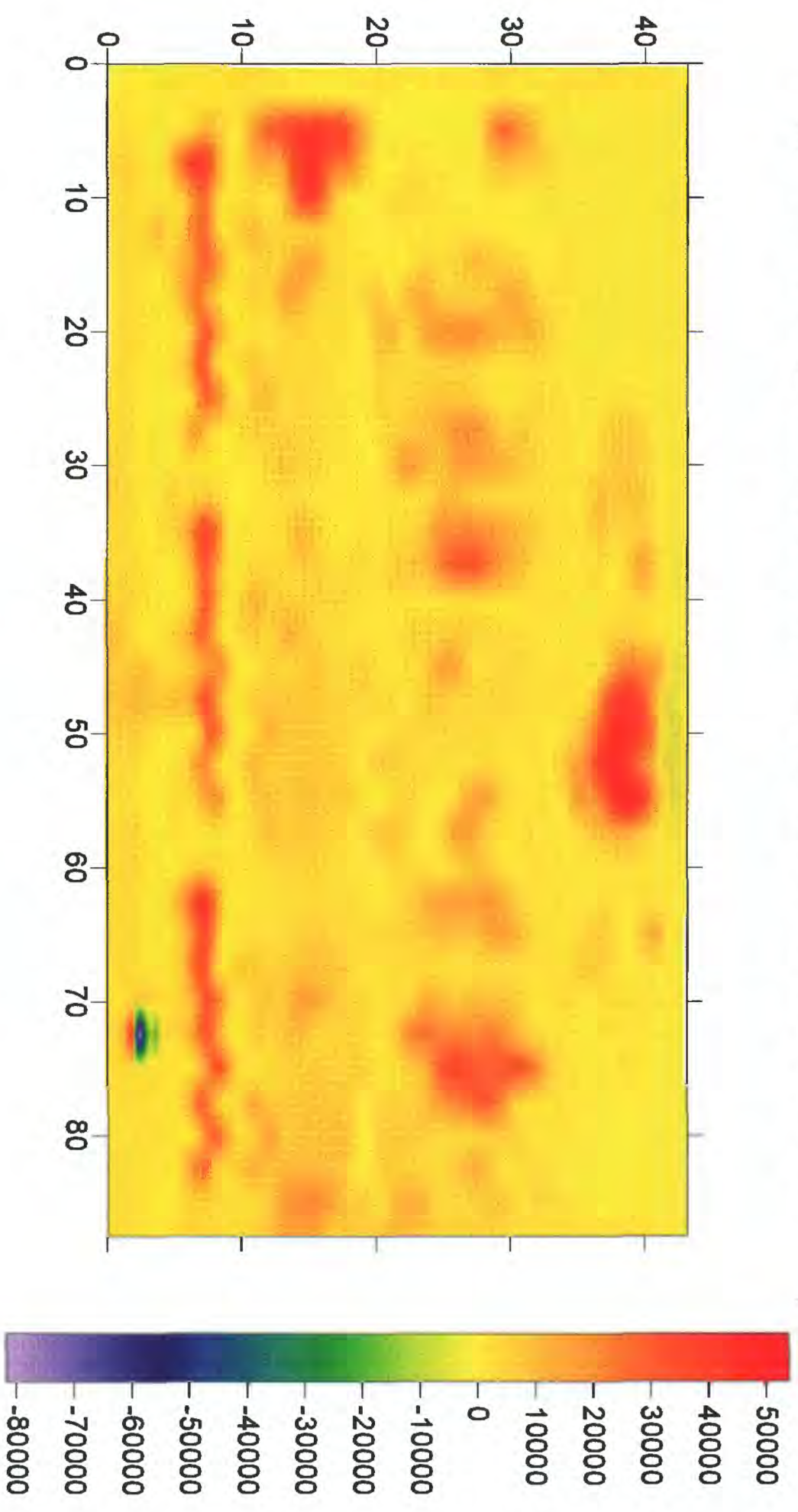


Fig. 8 - Bldg. 20 Bunker - GEM 2 - 2430 Hz OP

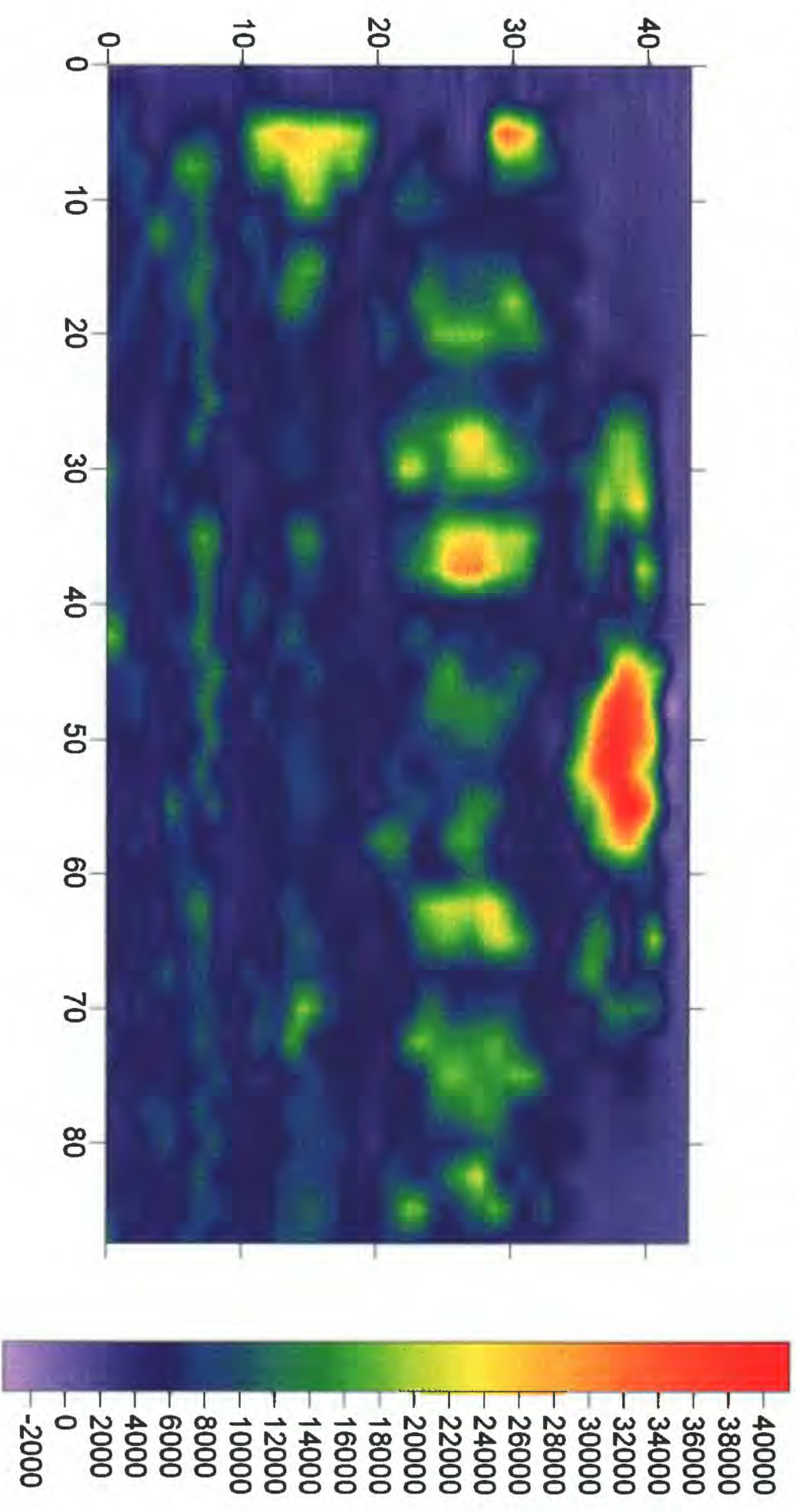




Fig. 9 - Bldg. 20 Bunker - GEM 300 - 4770 Hz IP

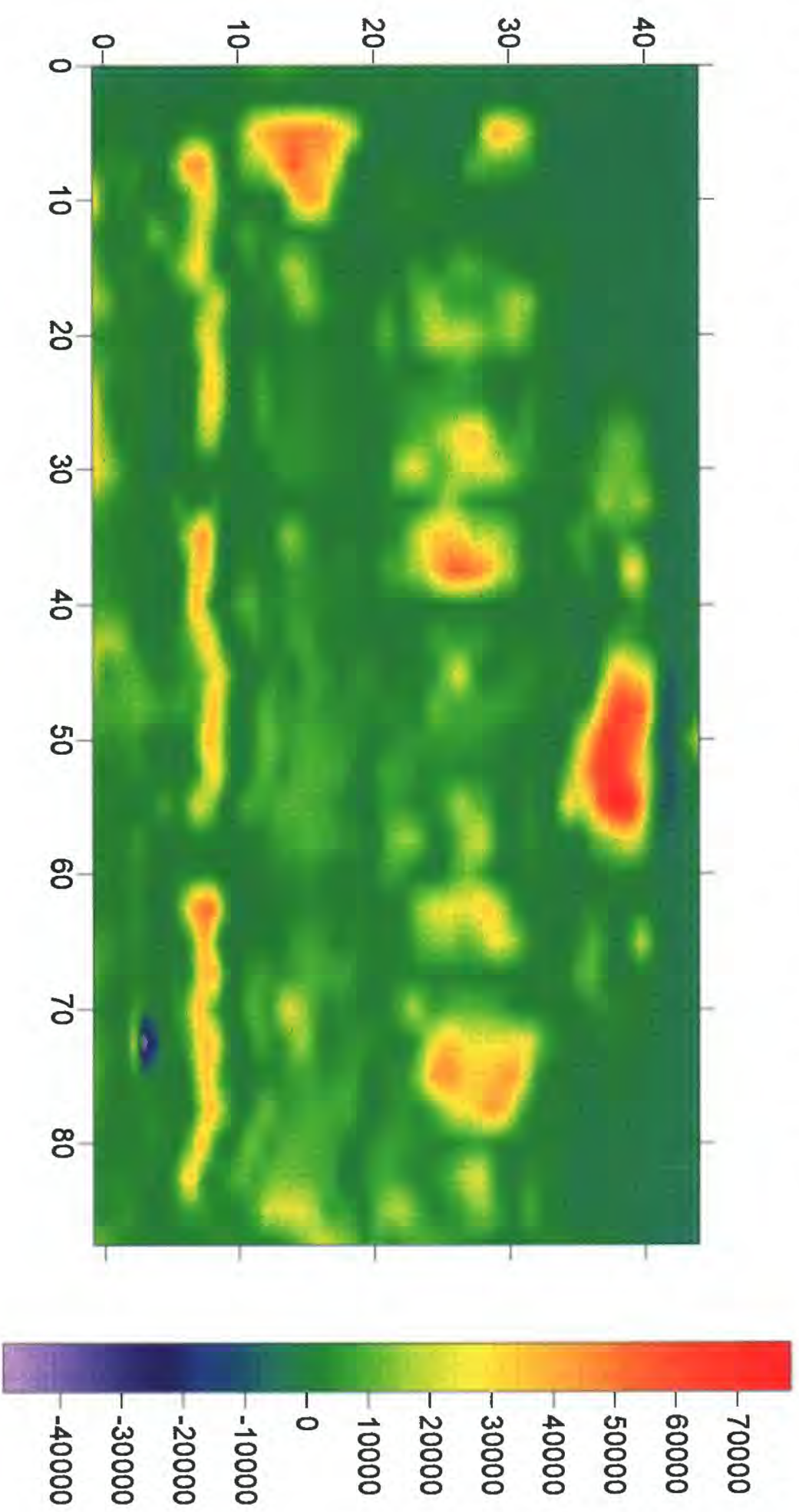




Fig. 10 - Bldg. 20 Bunker - GEM 300 - 4770 Hz OP

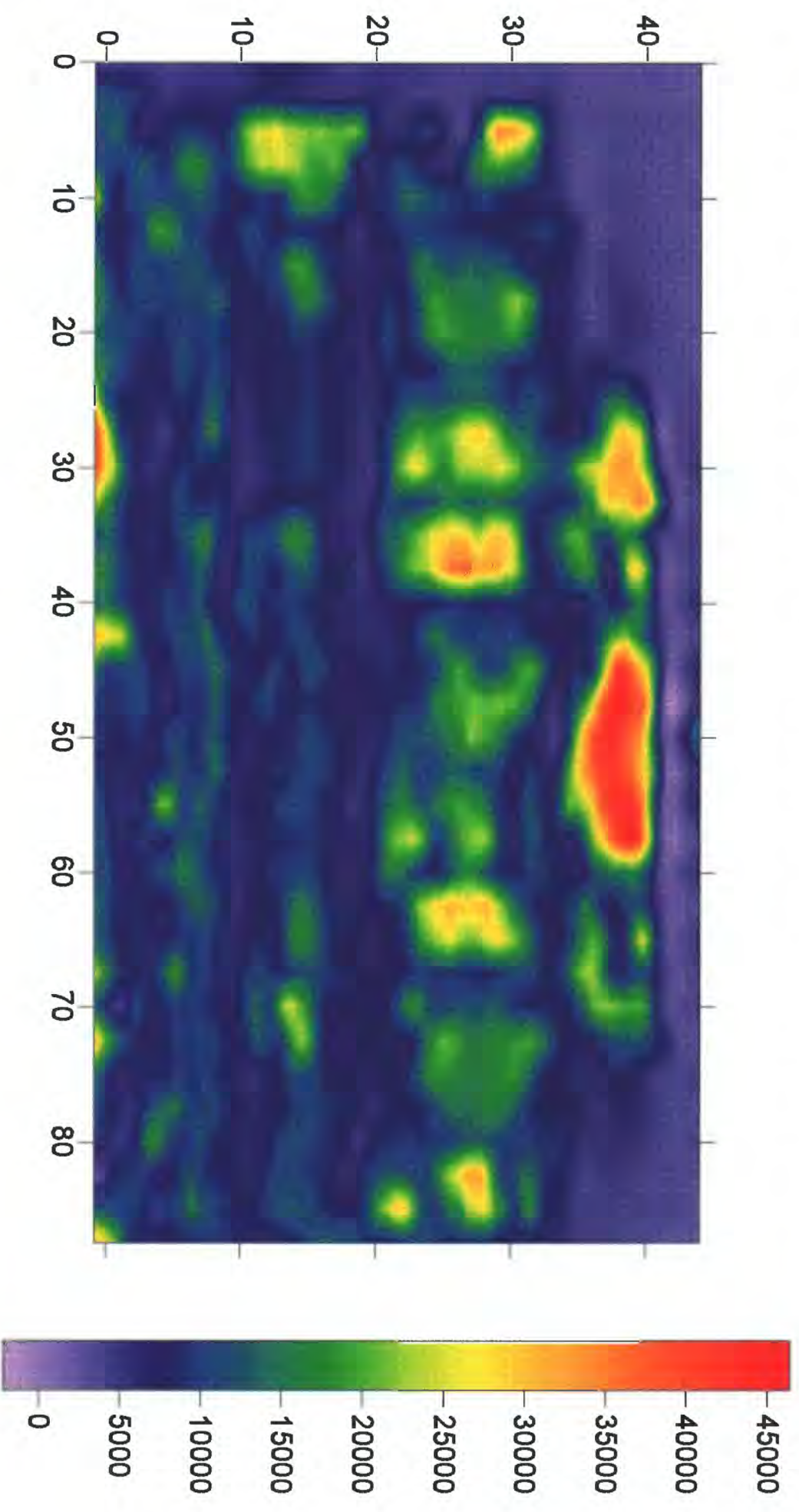


Fig. 11 - Bldg. 20 Bunker - GEM 2 - 7230 Hz IP

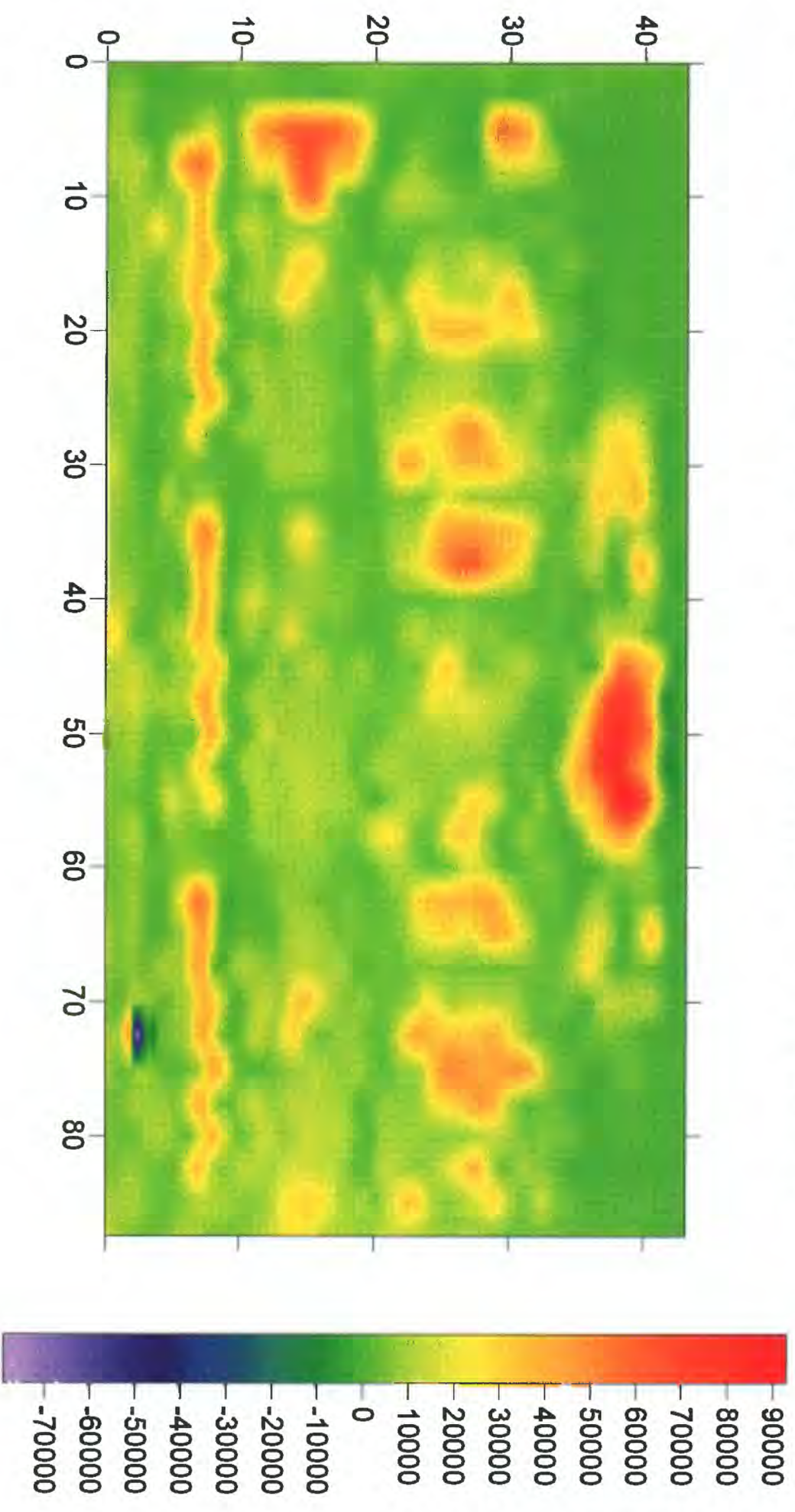




Fig. 12 - Bldg. 20 Bunker - GEM 2 - 7230 Hz OP

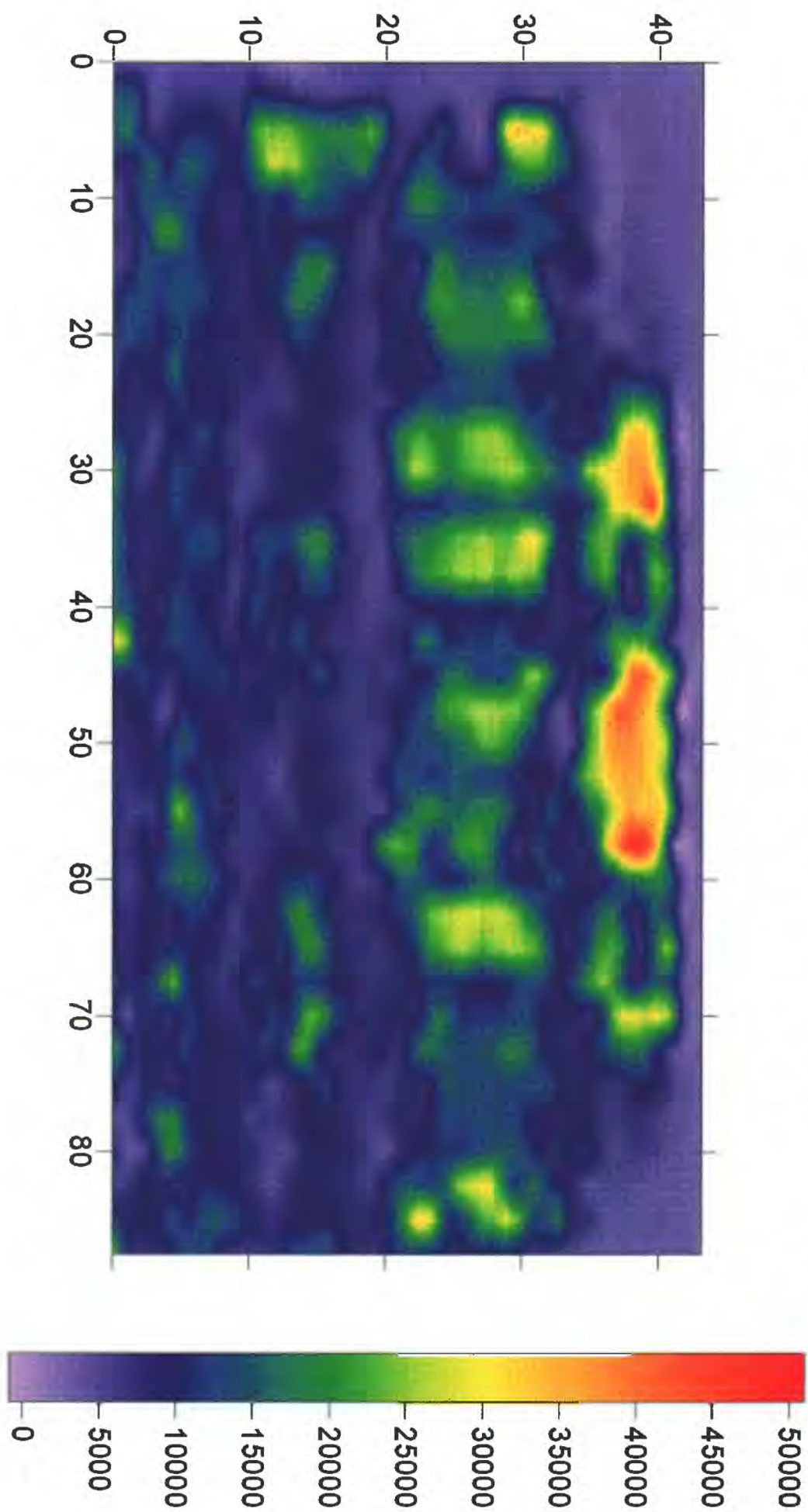


Fig. 13 - Bldg. 20 Bunker -GEM 2 - 9810 Hz IP

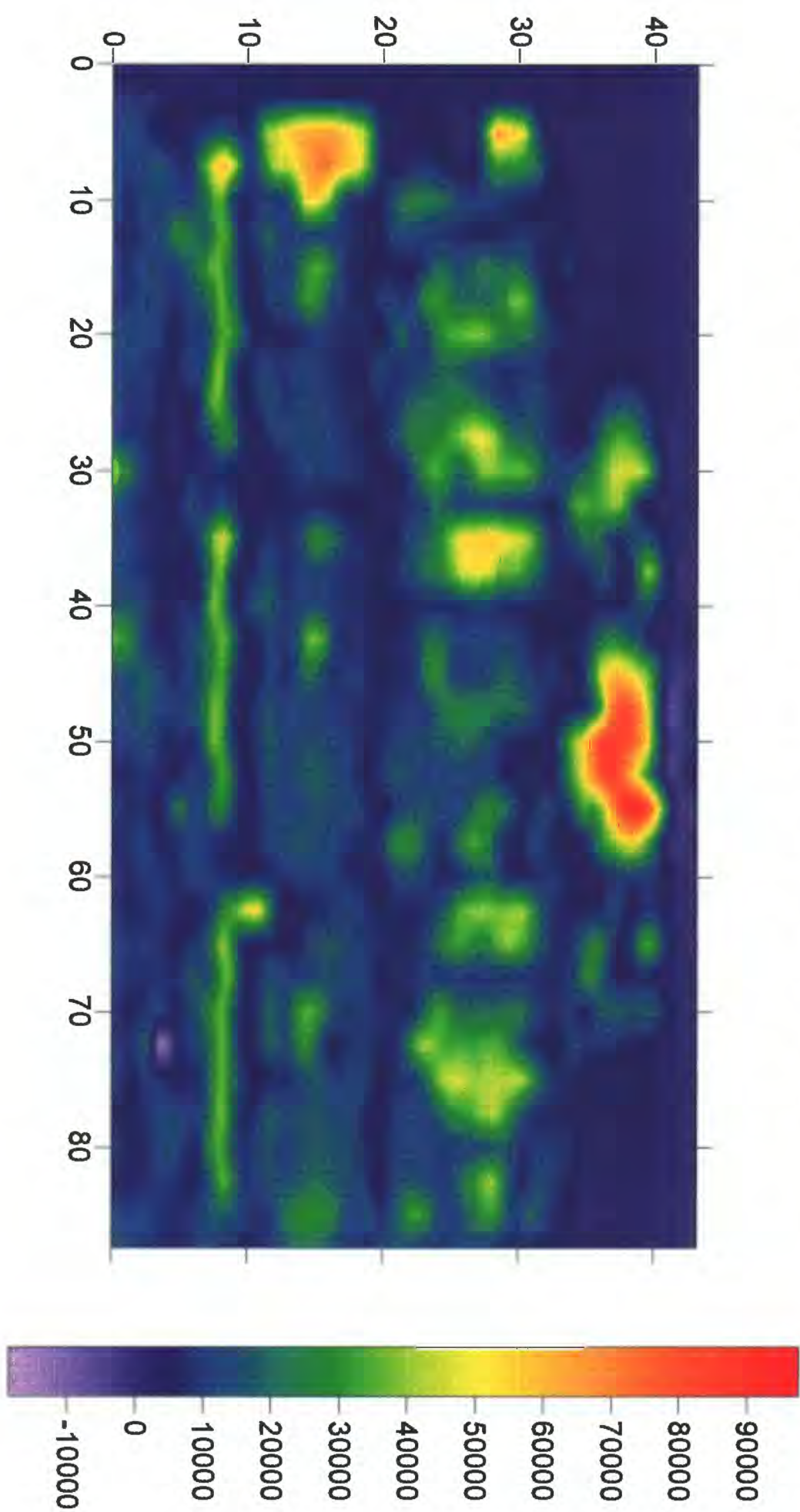




Fig. 14 - Bldg. 20 Bunker - GEM 2 - 9810 Hz OP

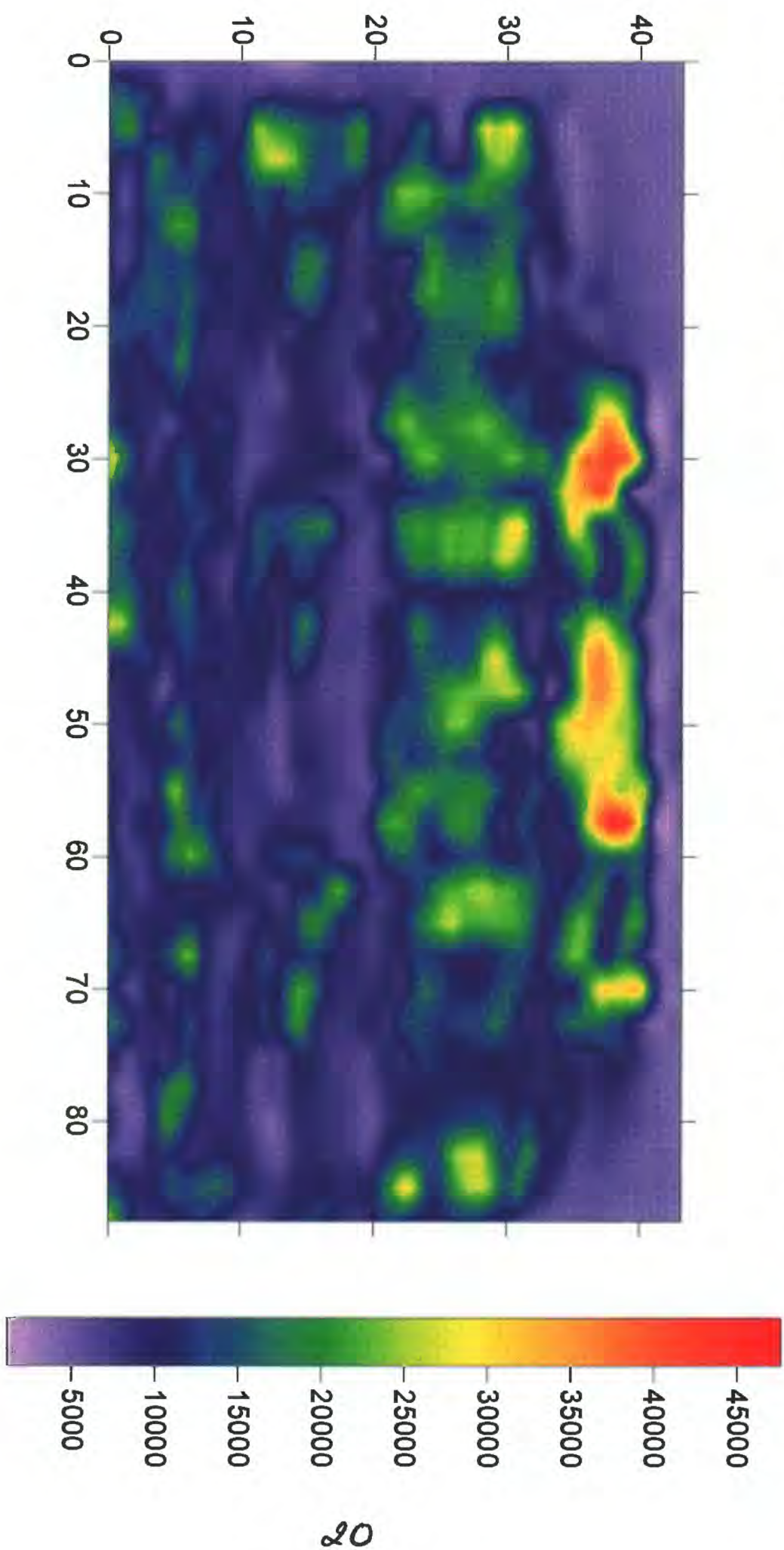


Fig. 15 - Bldg. 20 Bunker - GEM 2 - 15210 Hz IP

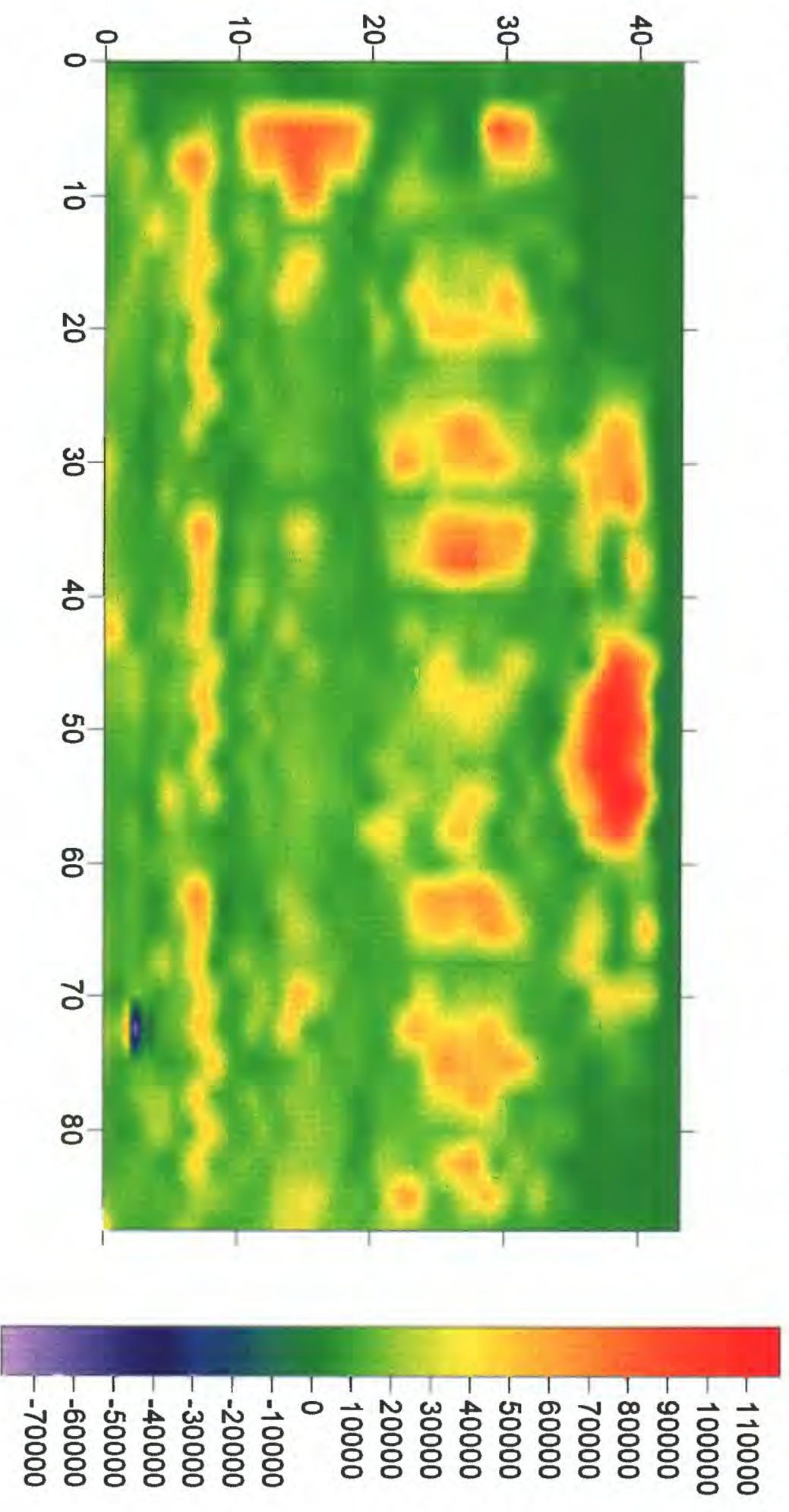




Fig. 16 - Bldg. 20 Bunker - GEM 2 - 15210 Hz OP

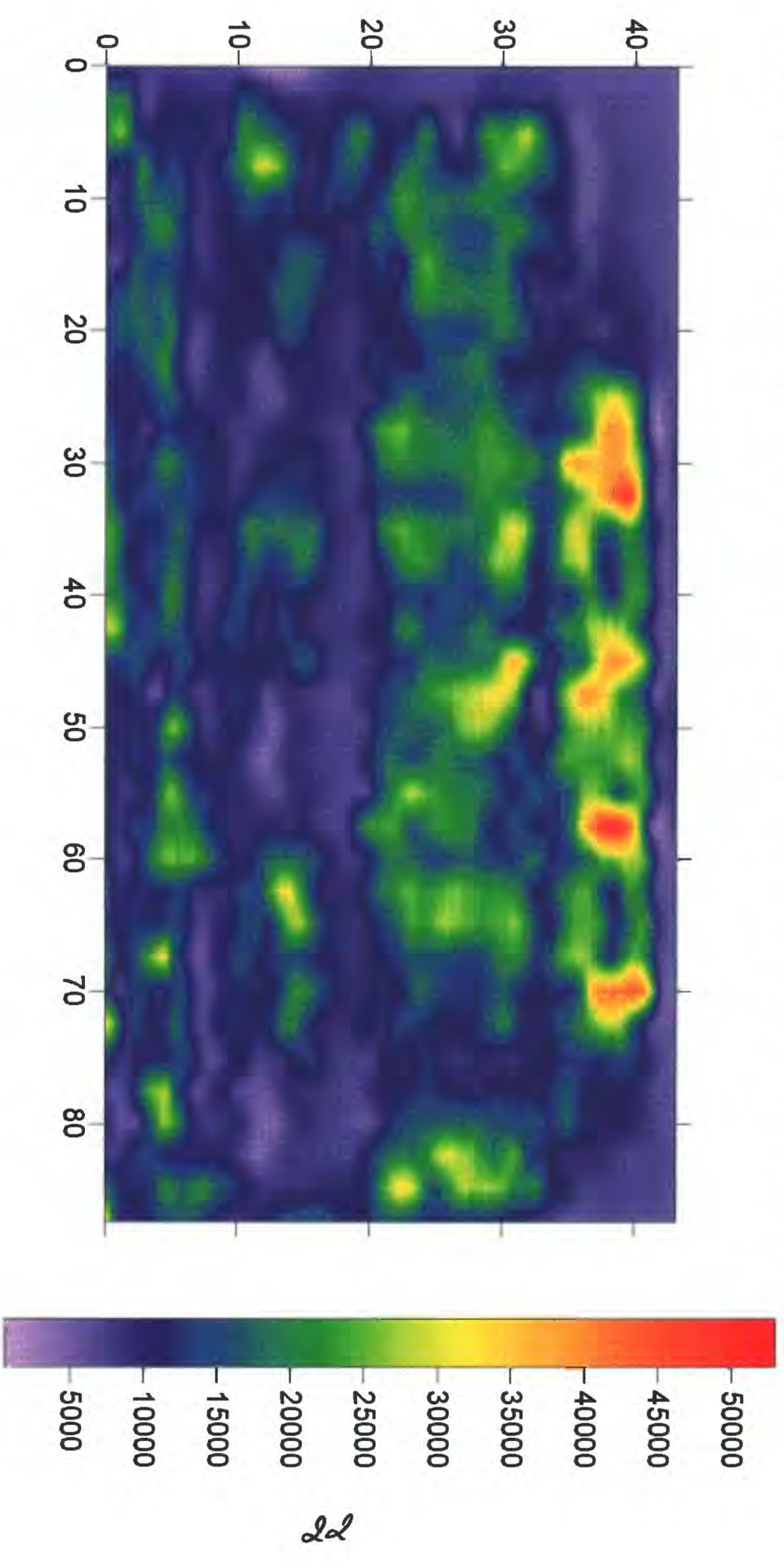




Fig. 17 - Bldg. 20 Bunker - GEM 2 - 15210 Hz IP

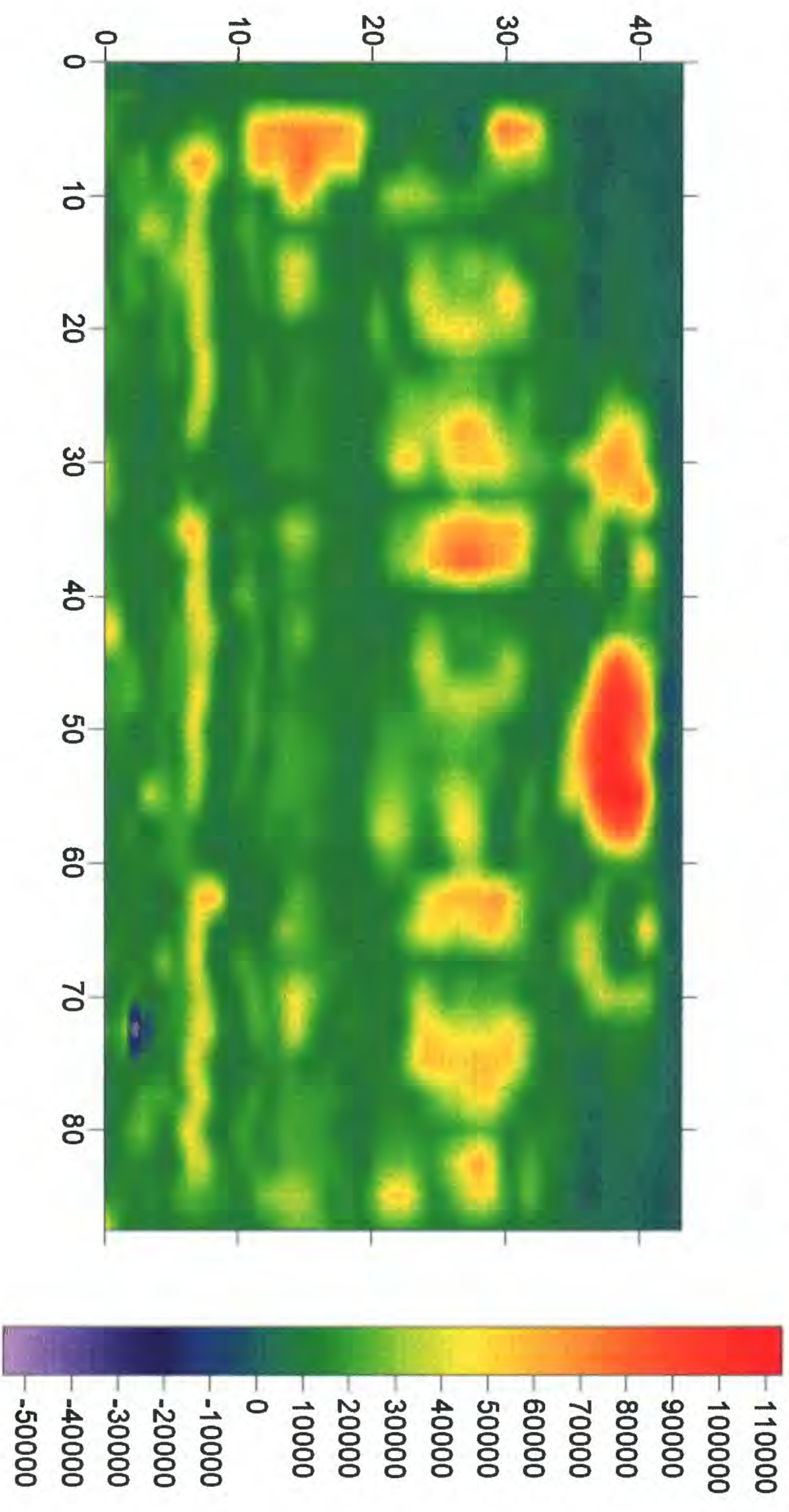


Fig. 18 - Bldg. 20 Bunker - GEM 2 - 15210 Hz OP

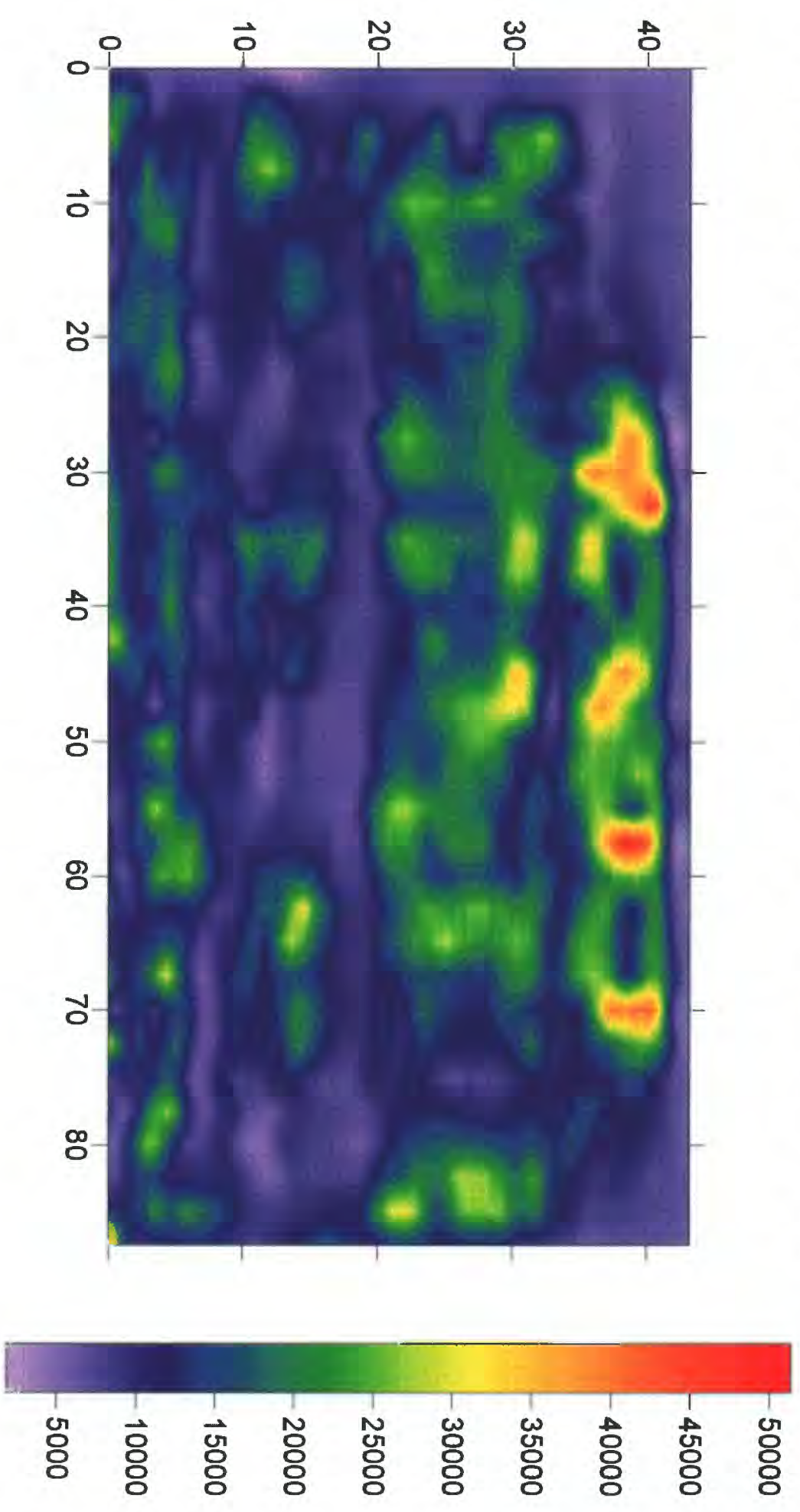




Fig. 19 - Bldg. 20 Bunker - GEM 2 - 21930 Hz IP

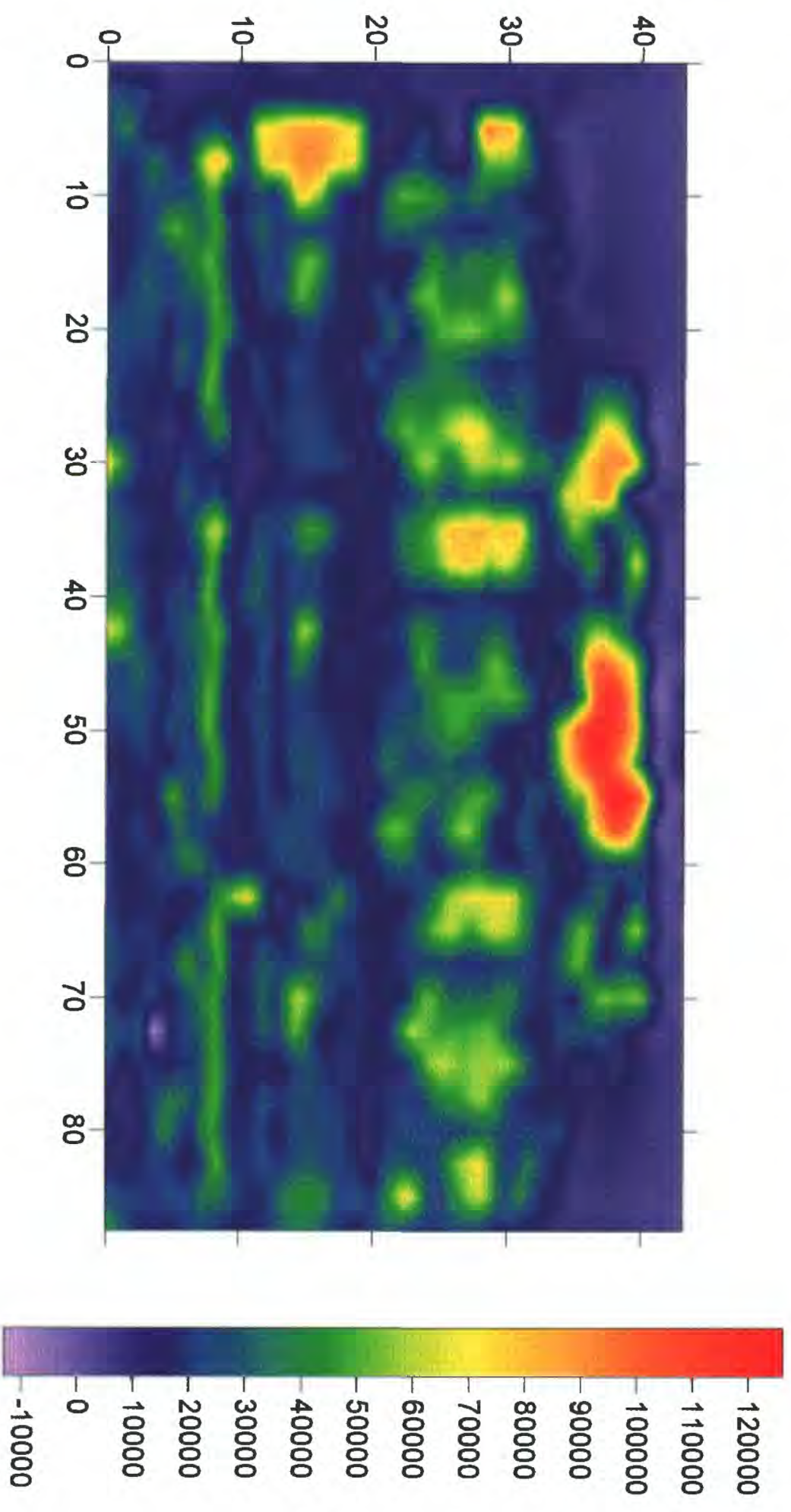


Fig. 20 - Bldg. 20 Bunker -GEM 2 - 21930 Hz OP

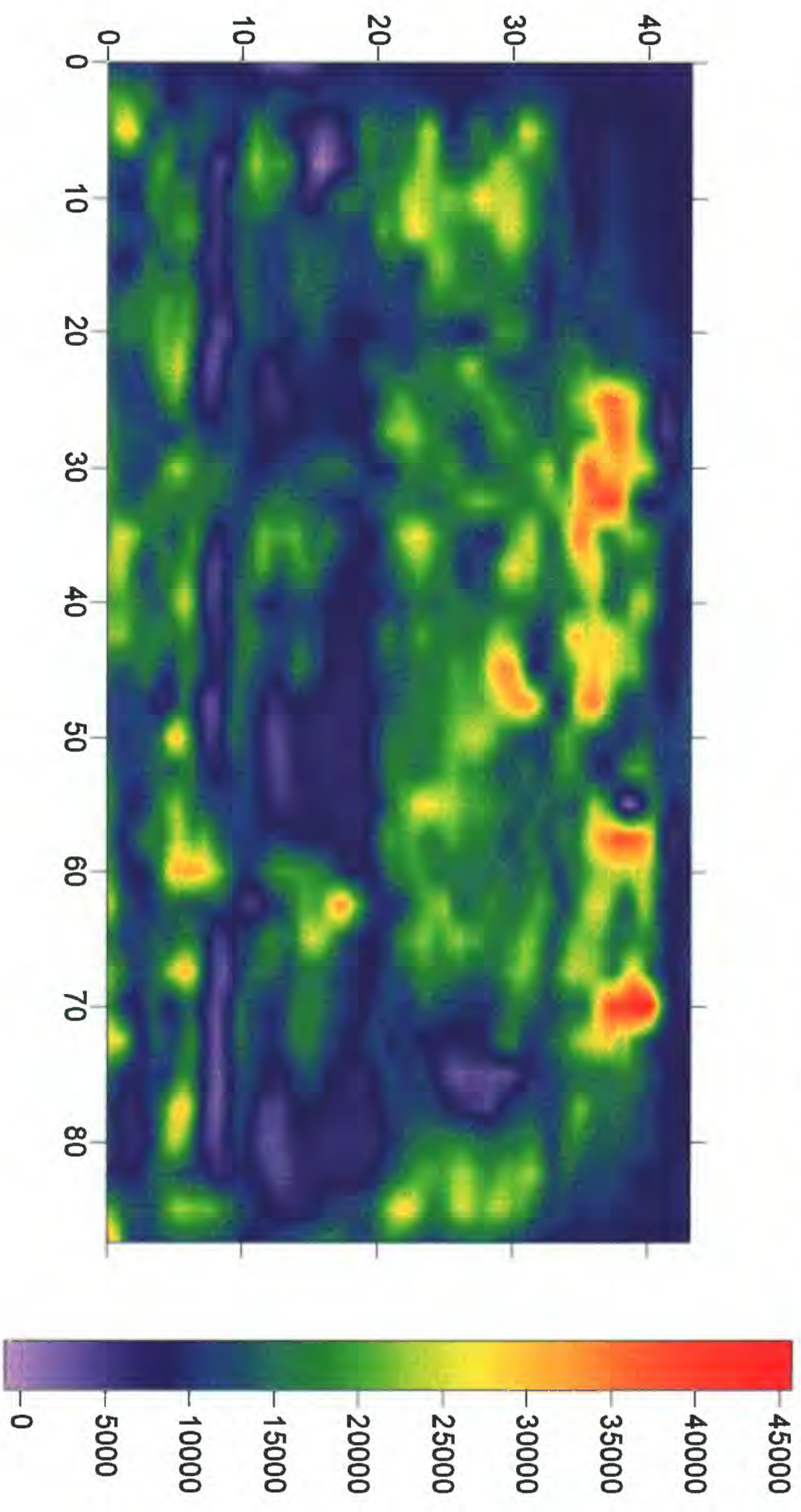




Fig 21 - Bldg. 20 Bunker - EM 31 Inphase  
Vertical Dipole - 9.8 kHz

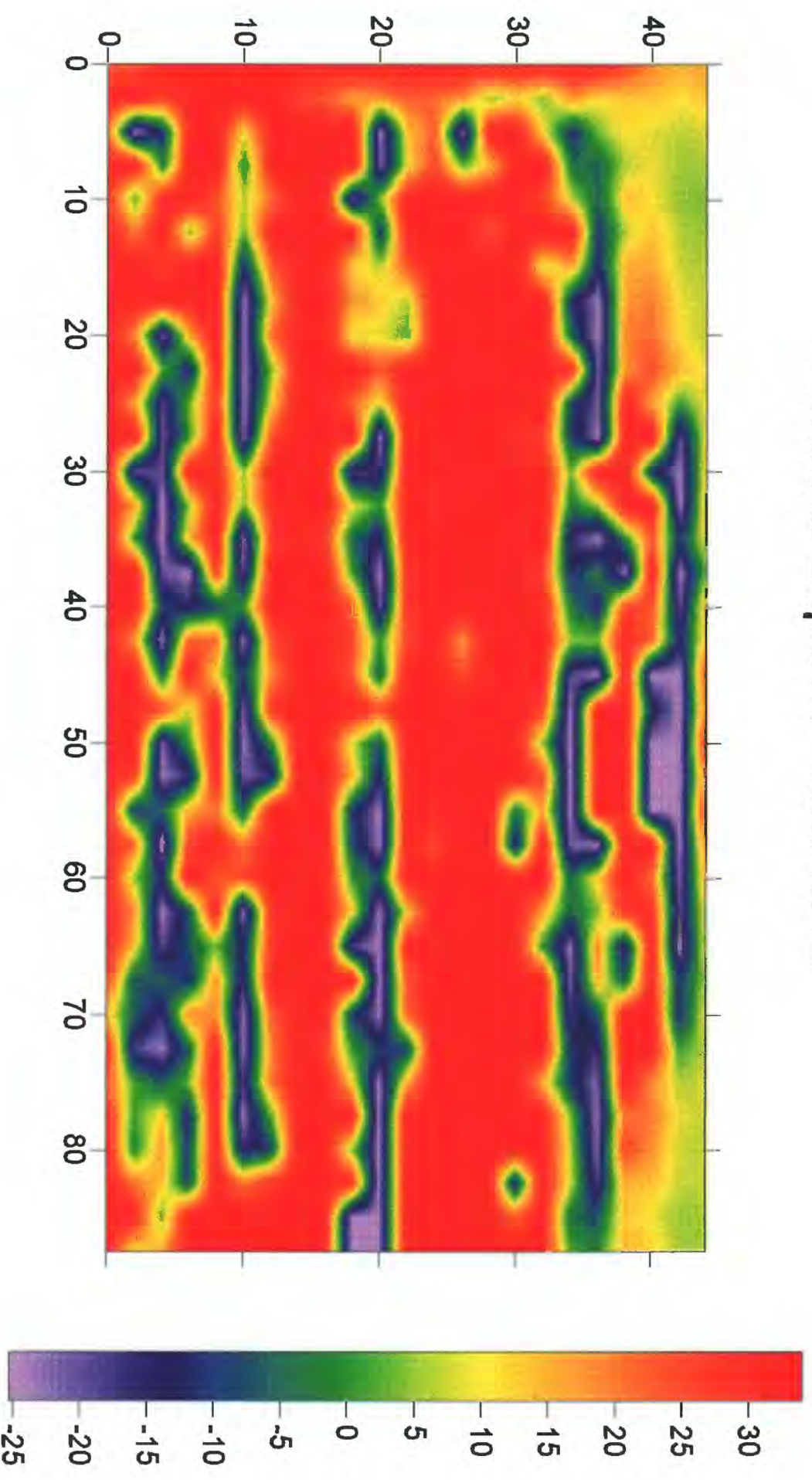


Fig. 22 - Bldg. 20 Bunker - EM 31 Conductivity  
Vertical Dipole - 9.8 kHz

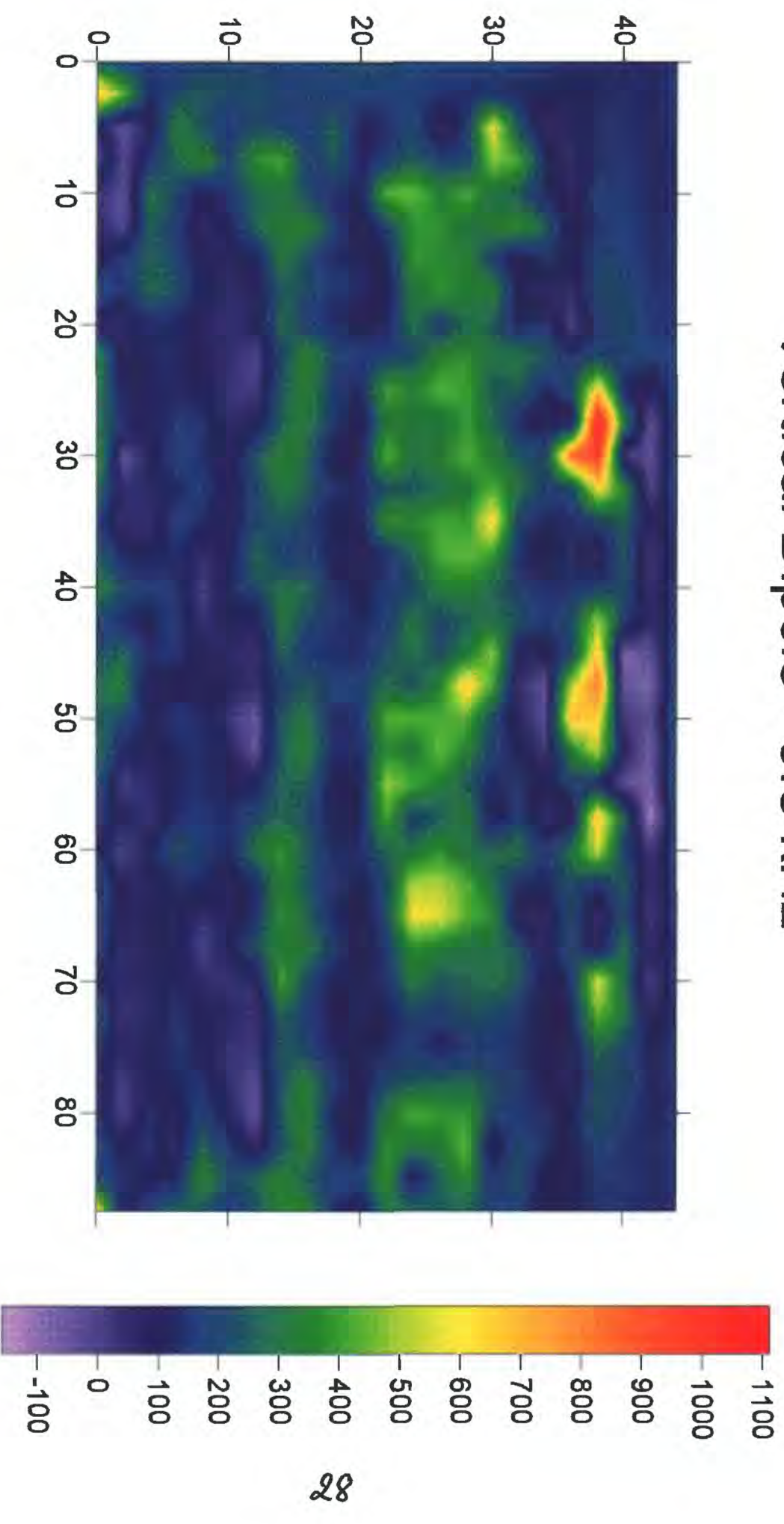




Fig. 23 - Bldg. 20 Bunker - EM 31 Inphase  
Horizontal Dipole - 9.8 kHz

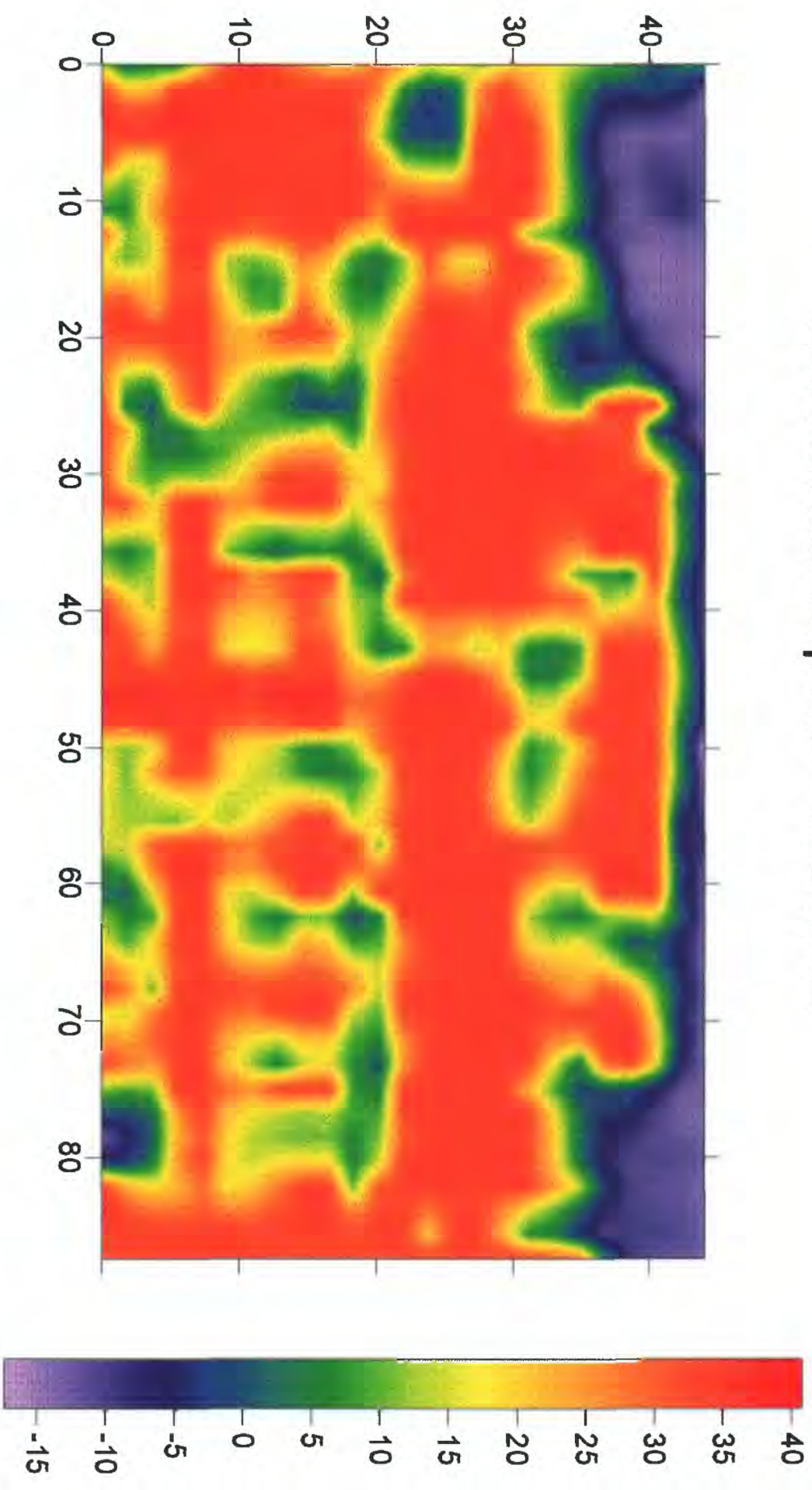




Fig. 24 - Bldg. 20 Bunker - EM 31 Conductivity  
Horizontal Dipole - 9.8 kHz

