EXTECH IV Sub-project 9T: A 3D Audio-Magnetotelluric Survey at the McArthur River Mining Camp

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Abstract

A 3D audio-magnetotelluric (AMT) survey was conducted in the McArthur River uranium mining camp, northern Saskatchewan. The AMT data were acquired to provide a 3D view into the subsurface conductivity structure of the McArthur deposit, the overlying Athabasca Group Sandstones, the basement lithologies and offsets, and the alteration assemblages associated with the deposit. In total, 135 AMT sites were acquired along eleven profiles over the P2 and P2 North mineralized zones with an average site spacing of 300 m.

Keywords: *McArthur River, uranium, geophysics, Athabasca Group, sandstones, magnetotelluric.*

1. Introduction

Under the auspices of a steering committee representative of the key partners (the Geological Survey of Canada, Saskatchewan Industry and Resources, the Alberta Geological Survey, COGEMA Resources Inc., and Cameco Corp.), the EXTECH IV Athabasca Uranium Multi-disciplinary Studies Project consists of a diverse set of scientific components to enhance the development of a mature uranium exploration and mining camp. The magnetotelluric (MT) component was added to the EXTECH IV program during 2000 utilizing funding provided by the Targeted Geoscience Initiative program and the EXTECH IV industrial partners. Reports of the 2D profiling in 2000 and 2001 can be found in Craven *et al.* (2001), (2002). Here we detail a recent 3D survey and present preliminary plots of the data.

2. Objectives of the Magnetotelluric Sub-project

The overall objectives of the MT sub-project are two-fold:

1) Evaluate a natural source electromagnetic technique, magnetotellurics (MT), as a tool in the search for graphitic material associated with deep (400 to 650 m) uranium ore in the Athabasca Basin.
2) Map regional resistivity contrasts within the Athabasca Basin and underlying crust associated with:
   - changes in basin sandstone porosity, or brine content of an interconnected fluid phase;
   - undulation of the basement-sediment interface;
   - alteration zones associated with subvertical faults or the unconformity; and
   - tectonically disturbed graphitic conductors in the sub-Athabasca basement.

Both goals were tested in 2000 and 2001 with 2D MT profiling at Shea Creek and McArthur River (Craven *et al.*, 2001, 2002). A primary observation from those studies was that MT can detect subsurface conductivity contrasts attributable to basement and sedimentary alteration assemblages and that, overall, MT was an effective tool for exploration for structures such as those observed in the McArthur area. The success of these activities was the catalyst for the submission to the EXTECH IV steering committee of a proposal for a 3D survey in the McArthur region. The primary goal of the proposed 3D acquisition was to determine the ability of AMT to map variations in these features along strike.

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3. The AMT Acquisition Program

The proposal was approved in March 2002 with an expectation that the data collection would be during the spring melt, when contact resistance should be at their lowest. The survey was completed, however, in July having been delayed in part by forest fires in the area. Nonetheless, contact resistance was considerably lower than had been observed during previous work. The AMT data were acquired in the frequency range 1 to 20,000 Hz with three Metronix 24-bit ADU-06 systems. One system was used as a fixed reference station in a culturally quiet location; the remaining two systems were deployed within the survey area. More information regarding the recording instruments and systems can be found in Appendix A. Each AMT measurement site (Figure 1 and Table 1) utilized a perpendicular pair of 50 m dipoles, two orthogonal magnetic field sensors, and one vertical magnetic field sensor.

Survey lines (Figure 1) were chosen to match a recent pole-dipole survey to reduce the line cutting required for the survey and to facilitate possible future comparison and constrained inversion of the two data sets. Two crews collected the data over the period of one week in July 2002 at a rate of about 16 to 26 sites per day. All soundings were recorded during the daytime using the schedule in Table 2. This schedule was repeated every 20 minutes at the sounding and remote site locations.

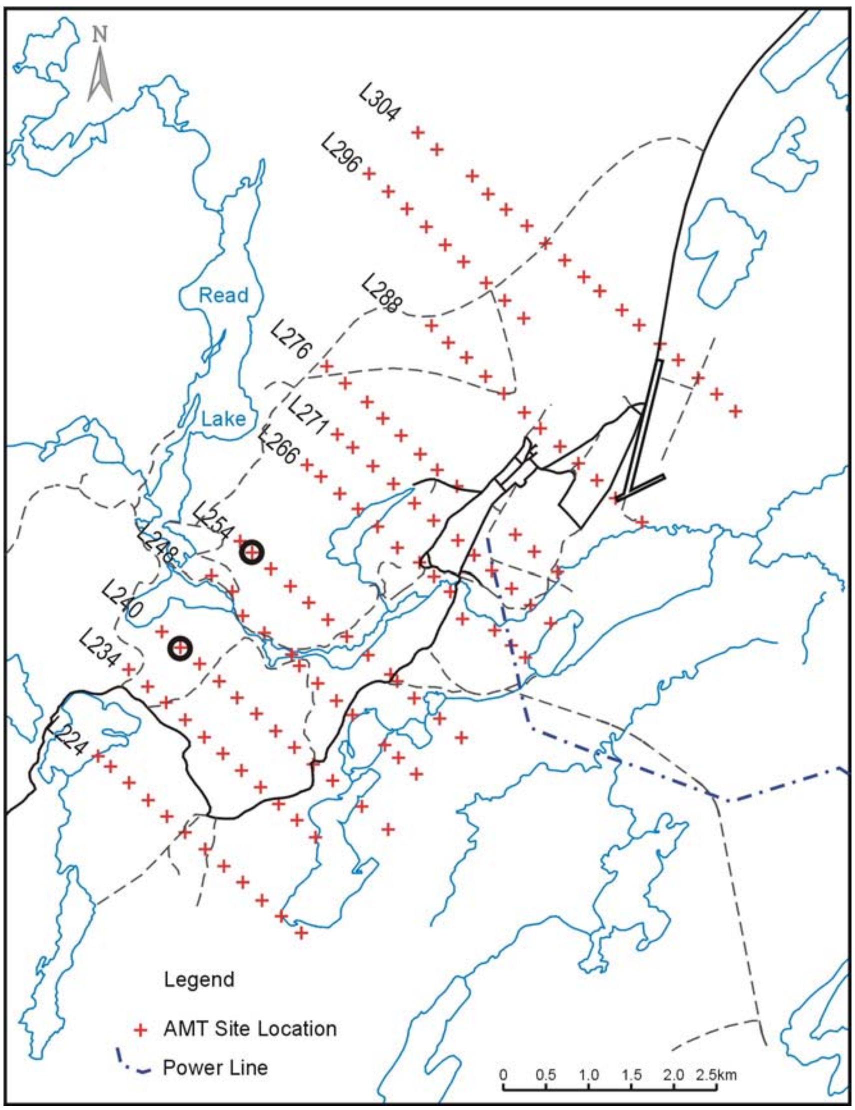

Figure 1 - Three-dimensional AMT sites sampled in 2002. Data from two sites (open circles) are shown in Figure 3.

4. Preliminary Analysis of the Data

The time series at each site were initially examined and it was soon determined that a strong harmonic noise source was contaminating the time series (Figure 2). The origin of this noise source is unknown. Digital comb filters tuned to the harmonics were utilized to remove the effects of these harmonics and robust MT responses were calculated (Larsen *et al.*, 1996). The responses shown in Figure 3 were obtained using the multifrequency capability of the McNeice and Jones (2001) decomposition technique for the two sites indicated on Figure 1. The data in Figure 3 are of extremely good quality and generally representative of the overall data quality, however, the data collected near the mine site are of lesser quality owing to the presence of electrical activity associated with the mine workings.

As described in Craven *et al.* (2001) induction arrows point towards lateral contrasts in conductivity within the subsurface and therefore arrows should be aligned orthogonal to the prevailing electrical strike directions. In the region to the southwest of L254 (Figure 4) the strike direction indicated by the induction arrows is generally orthogonal to the profiles (i.e., northeast-southwest). This is in agreement with the earlier

Table 1 - Site locations. UTM positions calculated using UTM grid (zone 13). Spheroid: International Hayford 1924. Datum: North America 1927 (Northwest Territories and Saskatchewan). Central Meridian: -105°E of Greenwich Latitude origin: 0°N. Elevations listed are in meters above mean sea level and based on single site GPS.

	Easting	Northing	Latitude	Longitude	Elev
22401S	493660	6398021	-105:07:02.88	57:43:34.25	529
22402N	493441	6398211	-105:07:16.14	57:43:40.39	583
22404S	493877	6397834	-105:06:49.99	57:43:28.22	552
22405N	493218	6398416	-105:07:29.76	57:43:47.00	554
22407S	494101	6397636	-105:06:35.71	57:43:21.83	566
22408N	492994	6398607	-105:07:42.90	57:43:53.16	557
22410N	494313	6398728	-105:07:51.74	57:43:57.07	514
22410S	492778	6397437	-105:06:22.45	57:43:15.41	548
22413S	494528	6397249	-105:06:09.02	57:43:09.34	575
22416S	492555	6397035	-105:05:55.41	57:43:02.43	587
22419S	494745	6396851	-105:05:41.67	57:42:56.49	510
22422S	494053	6396654	-105:05:27.52	57:42:50.13	498
23401S	493826	6398758	-105:06:23.24	57:43:58.12	564
23402N	494278	6398950	-105:06:36.50	57:44:04.32	516
23404S	493616	6398560	-105:06:10.11	57:43:51.73	585
23405N	494498	6399154	-105:06:50.00	57:44:10.90	524
23407S	493386	6398364	-105:05:56.55	57:43:45.40	590
23408N	493161	6399357	-105:07:03.57	57:44:17.45	518
23410S	494946	6398167	-105:05:43.72	57:43:39.04	552
23411N	492944	6399544	-105:07:16.65	57:44:23.49	523
23413S	493003	6397977	-105:05:30.71	57:43:32.91	531
23414N	492784	6399744	-105:07:30.15	57:44:29.94	516
23416S	493216	6397776	-105:05:17.58	57:43:26.42	515
24001S	493452	6399226	-105:05:59.53	57:44:13.27	550
24002N	493671	6399413	-105:06:13.27	57:44:19.31	537
24004S	493893	6399023	-105:05:45.91	57:44:06.72	501
24005N	494118	6399606	-105:06:25.99	57:44:25.54	537
24007S	494345	6398830	-105:05:32.59	57:44:00.49	512
24008N	494579	6399811	-105:06:39.91	57:44:32.16	537
24010S	495288	6398632	-105:05:19.22	57:43:54.10	512
24011N	495597	6400002	-105:06:53.54	57:44:38.32	537
24013S	495558	6398441	-105:05:05.48	57:43:47.93	506
24014N	495718	6400188	-105:07:06.68	57:44:44.32	550
24017S	496811	6398138	-105:04:44.78	57:43:38.14	548
24020S	497266	6397868	-105:04:26.09	57:43:29.42	548
24801N	496402	6399920	-105:05:34.62	57:44:35.73	521
24801S	496173	6399788	-105:05:29.16	57:44:31.47	530
24804S	495972	6399582	-105:05:16.09	57:44:24.82	519
24805N	497088	6400174	-105:05:54.05	57:44:43.93	508
24807S	495535	6399378	-105:05:02.89	57:44:18.23	517
24808N	497310	6400374	-105:06:09.37	57:44:50.39	522
24809S	495351	6399211	-105:04:51.45	57:44:12.84	509
24811N	497582	6400659	-105:06:16.83	57:44:59.60	524
24814N	495094	6400844	-105:06:31.55	57:45:05.57	512
24814S	494877	6398859	-105:04:28.51	57:44:01.47	517
24817S	498998	6398709	-105:04:18.83	57:43:56.62	498
24820S	499230	6398518	-105:04:06.19	57:43:50.45	514
25400N	499448	6400329	-105:05:09.01	57:44:48.98	527
25403N	499670	6400529	-105:05:22.63	57:44:55.43	556
25403S	495748	6400131	-105:04:55.63	57:44:42.58	518
25406N	497044	6400722	-105:05:35.59	57:45:01.67	572
25407S	496963	6399914	-105:04:40.50	57:44:35.58	523
25409N	496746	6400920	-105:05:49.46	57:45:08.06	579
25410S	496481	6399687	-105:04:24.52	57:44:28.25	513
25411S	496266	6399606	-105:04:19.80	57:44:25.63	490
25412N	496044	6401109	-105:06:02.78	57:45:14.16	575
25414N	495818	6401243	-105:06:11.32	57:45:18.49	556
25414S	495599	6399408	-105:04:07.69	57:44:19.23	516
25417S	495373	6399169	-105:03:49.66	57:44:11.51	516
25420S	497041	6398944	-105:03:34.23	57:44:04.25	519
26600N	495244	6401165	-105:04:19.78	57:45:16.06	538
26603N	495030	6401413	-105:04:33.83	57:45:24.05	533
26603S	494809	6400993	-105:04:04.04	57:45:10.49	513
26606N	494646	6401621	-105:04:47.69	57:45:30.77	923
26606S	495906	6400833	-105:03:53.81	57:45:05.32	505
26609N	496131	6401801	-105:05:00.65	57:45:36.58	831
26609S	495182	6400657	-105:03:42.24	57:44:59.63	516
26612N	495002	6402001	-105:05:14.04	57:45:43.04	813
26612S	498078	6400338	-105:03:33.28	57:44:49.32	515
26614N	498338	6402137	-105:05:23.91	57:45:47.43	831
26615S	497891	6400205	-105:03:10.71	57:44:45.03	511
26618S	498539	6400027	-105:02:58.91	57:44:39.28	0
26620S	497667	6399886	-105:02:48.99	57:44:34.73	1031
27101N	498786	6401687	-105:04:07.65	57:45:32.93	539
27102S	497442	6401485	-105:03:54.03	57:45:26.40	520
27105N	497224	6401915	-105:04:22.61	57:45:40.29	536
27105S	496979	6401252	-105:03:36.89	57:45:18.88	547
27108N	496768	6402123	-105:04:37.20	57:45:47.01	521
27108S	496583	6401078	-105:03:25.33	57:45:13.26	522
27111N	496168	6402342	-105:04:51.50	57:45:54.08	545
27111S	495946	6400900	-105:03:12.86	57:45:07.50	506
27114N	496414	6402495	-105:05:02.43	57:45:59.04	632
27114S	496605	6400693	-105:02:58.76	57:45:00.82	503
27117S	495927	6400499	-105:02:45.33	57:44:54.55	510
27120S	495703	6400287	-105:02:31.11	57:44:47.70	563
27601S	495903	6401887	-105:03:37.65	57:45:39.41	515
27602N	496201	6402078	-105:03:51.52	57:45:45.58	513
27605N	496456	6402264	-105:04:03.69	57:45:51.59	540
27608N	492559	6402481	-105:04:17.26	57:45:58.60	530
27610S	492342	6401320	-105:02:56.13	57:45:21.09	548
27611N	492196	6402683	-105:04:30.16	57:46:05.12	528
27613S	494719	6401120	-105:02:42.69	57:45:14.63	506
27614N	494466	6402875	-105:04:41.31	57:46:11.32	526
27616S	494556	6400885	-105:02:26.23	57:45:07.04	497
27617N	494772	6403095	-105:04:56.88	57:46:18.43	526
27620N	494990	6403294	-105:05:10.02	57:46:24.85	532
28801S	493892	6402752	-105:02:49.78	57:46:07.40	522
28802N	495179	6402973	-105:03:04.31	57:46:14.54	515
28804S	493769	6402566	-105:02:38.39	57:46:01.39	545
28805N	493526	6403175	-105:03:17.33	57:46:21.07	546
28807S	494890	6402354	-105:02:24.53	57:45:54.54	555
28808N	495111	6403397	-105:03:30.90	57:46:28.24	537
28810S	494451	6402155	-105:02:11.45	57:45:48.11	544
28811N	495361	6403572	-105:03:43.80	57:46:33.89	572
28813S	494222	6401956	-105:01:58.32	57:45:41.68	508
28814N	495625	6403771	-105:03:55.73	57:46:40.32	542
28816S	494002	6401747	-105:01:45.12	57:45:34.92	506
28819S	493861	6401465	-105:01:26.30	57:45:25.81	492
29606N	494665	6403858	-105:02:50.31	57:46:43.16	530
29609N	494145	6404066	-105:03:03.81	57:46:49.88	545
29612N	495659	6404272	-105:03:16.96	57:46:56.54	552
29615N	495418	6404520	-105:03:33.01	57:47:04.55	573
29618N	497194	6404718	-105:03:46.04	57:47:10.95	587
29621N	496954	6404930	-105:03:59.49	57:47:17.80	573
29624N	497382	6405141	-105:04:13.19	57:47:24.61	549
29627N	496739	6405345	-105:04:26.46	57:47:31.20	532
29630N	497611	6405554	-105:04:40.16	57:47:37.95	513
30401N	496515	6404177	-105:01:56.32	57:46:53.50	575
30402S	497827	6403954	-105:01:40.58	57:46:46.29	589
30404N	496302	6404342	-105:02:07.65	57:46:58.83	574
30405S	498044	6403778	-105:01:28.41	57:46:40.60	556
30407N	496105	6404538	-105:02:21.22	57:47:05.16	561
30408S	498262	6403558	-105:01:13.45	57:46:33.49	493
30410N	498573	6404736	-105:02:34.84	57:47:11.56	553
30411S	495705	6403368	-105:01:00.62	57:46:27.35	495
30413N	495473	6404942	-105:02:48.05	57:47:18.22	546
30414S	495965	6403157	-105:00:46.58	57:46:20.53	488
30416N	496134	6405134	-105:03:02.89	57:47:24.42	573
30417S	496325	6402968	-105:00:33.38	57:46:14.41	495
30419N	496468	6405315	-105:03:15.68	57:47:30.27	576
30420S	496846	6402766	-105:00:19.95	57:46:07.88	489
30422N	497205	6405526	-105:03:26.89	57:47:37.08	541
30426N	497501	6405837	-105:03:52.04	57:47:47.13	569
30430N	497186	6406036	-105:04:05.49	57:47:53.56	558

Table 2 - Recording schedule.

Sampling frequency (Hz)	Duration, seconds	Data quantity, MByte
40,960	7	5
2,048	420	17

observations made by Craven *et al.* (2001) from the single 2D profile. However, in the northern part of the survey area, the strike directions inferred from the induction arrows appear to be aligned parallel the profiles and suggest the electrical structure is more complex.

5. Plans for Future Work

Full 2D and 3D modeling of the magnetotelluric data is an ambitious task, however, the acquired data grid is perfect for such analyses. The primary hurdle to overcome is the determination of the appropriate lines to utilize 2D algorithms. A useful by-product of this determination will be the identification of regions requiring 3D analysis. The data examination and modeling should take into account, wherever possible, the vertical magnetic field as, incorporation of this data into inversion has been shown to be particularly effective in discriminating multiple conductors (Siripunvaraporn and Egbert, 2000). Integration with rock property and borehole data must also be taken into account during the inversion process in order to constrain the inversion procedure.

6. Acknowledgments

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7. References

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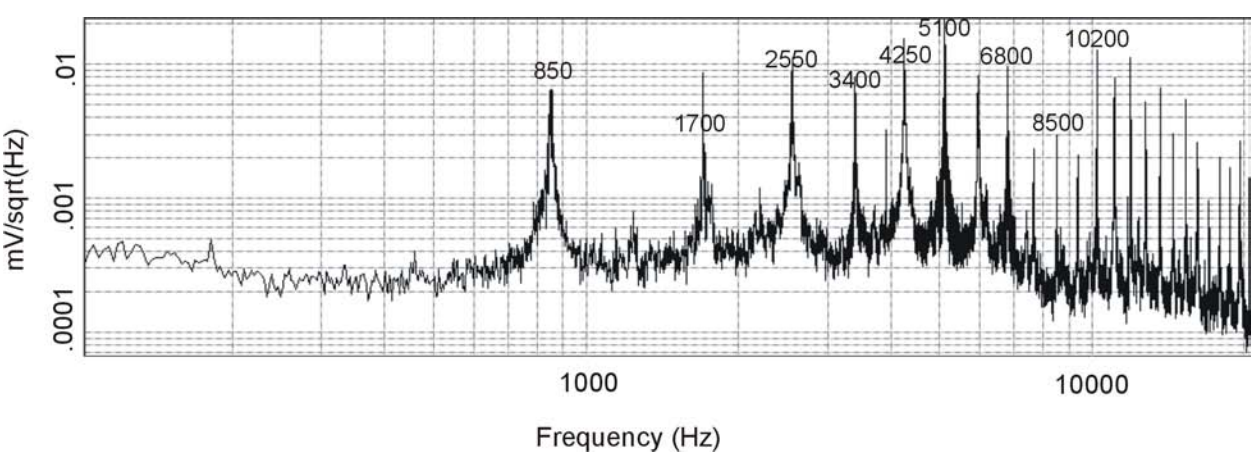

Figure 2 - Harmonics of 850 Hz within the electric field data collected at the remote site.

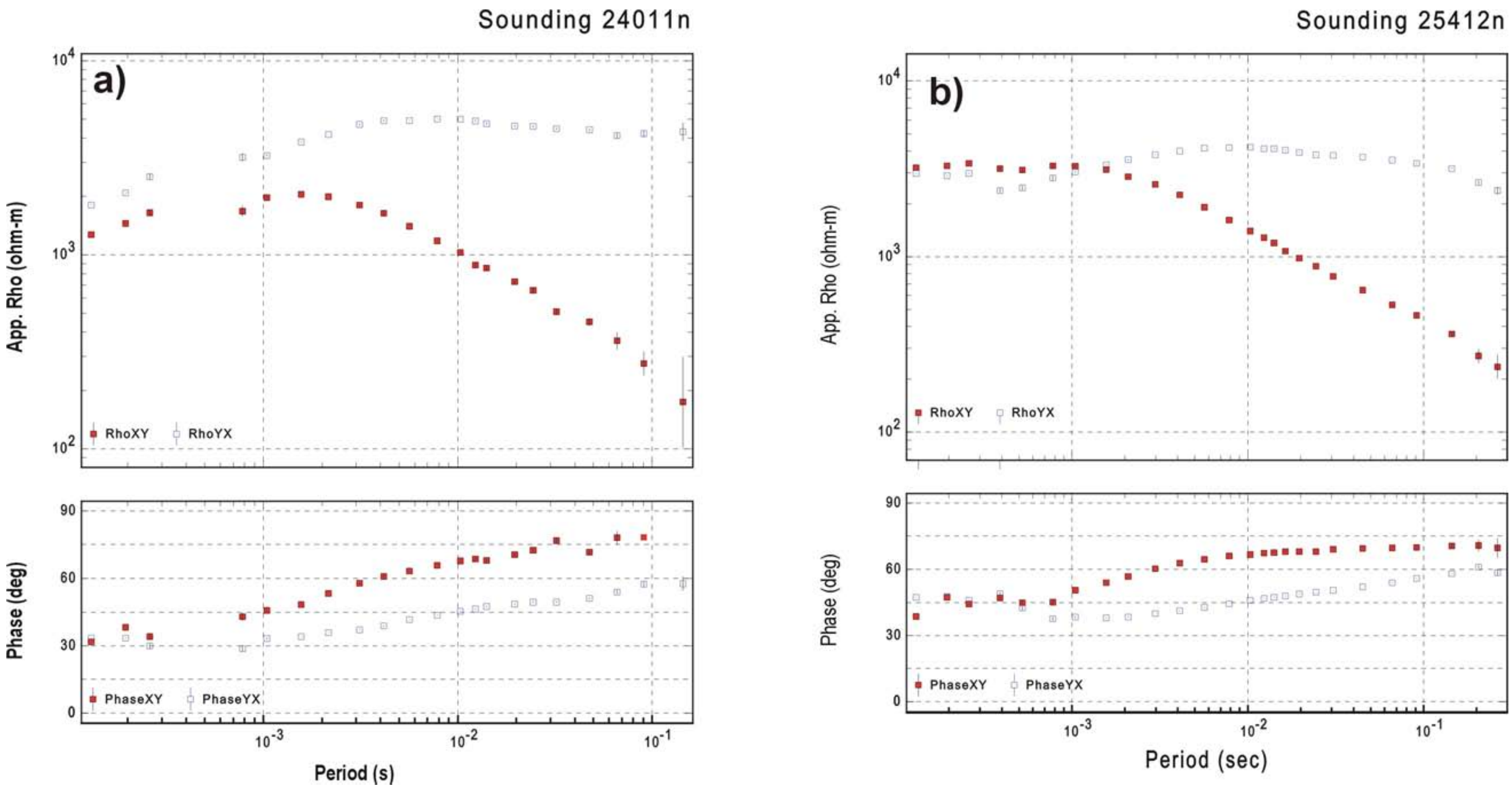

Figure 3 - Plot of response at: a) site 240-11N and b) site 254-12N.

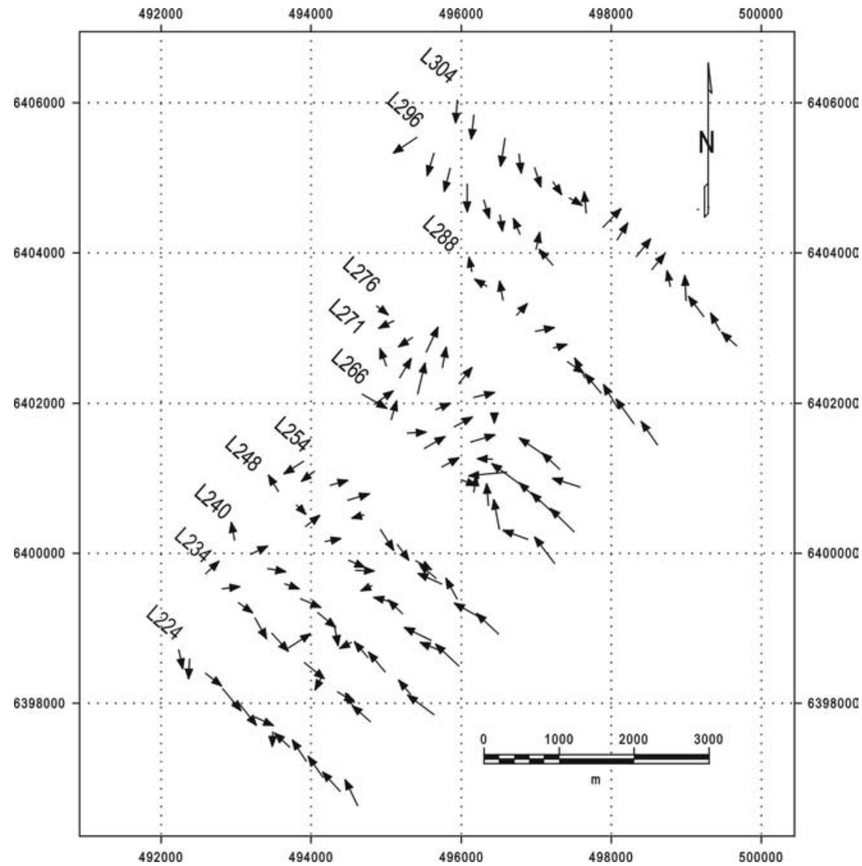

Figure 4 - Real induction arrows at 100 Hz.

McNeice, G.W. and Jones A.G. (2001): Multisite, multifrequency tensor decomposition of magnetotelluric data; Geophys., v66, no1, p158-173.

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Appendix A – AMT System Technical Specifications

ADU-06 (data acquisition unit):
32 bit internal computer, two 24 bit A/D converter, 4096 sample/sec and 49K sample/sec data rate, standard LAN connection for transfer to system computer

GPS System:
Motorola internal GPS receiver; clock precision ±130 ns to satellite reference; eight parallel channels; L1 1575.42 MHz; C/A code

Magnetic Sensors, AMT:
Hx, Hy, Hz Geosystem AMT (2 to 20,000 Hz); sensitivity 0.04 V/nT

Electric Sensors:
4 x 25 m dipoles, AWG #12 wire with stainless steel rods

System Computer:
Ruggedized Pentium notebook PC Computer, with 32 Mb RAM and 3.2 Gb hard disk

Power Supply:
ADU-06 12 V 34 Ah sealed lead acid battery

Environmental:
Temperature:

ADU-06	-40°C to +75°C
GSY-AMT Sensor	-30°C to +50°C

Weights:

ADU-06	5.0 kg
GSY–AMT Sensor	2.5 kg