



Marine EM Studies of Scarborough Gas Field

Detailed Survey Plan

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INTRODUCTION

The Marine EM Laboratory of the Scripps Institution of Oceanography plans to carry out studies of the Scarborough gas field using marine EM methods, supported with funding from BHP Billiton. The main objective of the research is to demonstrate how marine CSEM works and drive the future development of the method by:

Delivering a calibration data set over a known structure. Scarborough has excellent 3D seismic coverage, in addition to five exploration and appraisal wells. Such a data set will provide a test-bed for CSEM inversion methods.

Providing a data set suitable for joint MT/CSEM/Seismic interpretation.

Showing how shallow confounding resistors can be incorporated into the interpretation. Scarborough has regions of shallow gas and inferred gas hydrate above the reservoir.

Showing that the background resistivity can be understood from MT data.

Investigating the ability of CSEM data to differentiate the various qualities of the reservoir.

Other priorities of the research include:

Understanding how to optimize CSEM acquisition geometries and source signatures.

Examining sources of noise and the repeatability of CSEM data collection.

Extending acquisition technologies by including

Long baseline receivers that measure electric field gradients very precisely.

Inclusions of vertical electric and horizontal magnetic data into CSEM.

Towing a pair of fixed-offset 3-axis electric field receivers for all transmitter tows.

Using a dedicated long baseline acoustic navigation system and installing compass/tiltmeters on all receiver instruments.

To carry out this research we have scheduled time on the Research Vessel Roger Revelle from 20 May to 22 June 2009. We will supply the following equipment for the project:

40 Mark III seafloor electric field recorders, with two axes of horizontal B and three axes of E recording.

10 Mark II seafloor electric field recorders, with two axes of horizontal B and two axes of horizontal E recording.

2 SUESI EM transmitters, with a peak current capability of about 500 amps and GPS controlled waveform, with 2 topside power units. The transmission antennas will be:

A primary 500 A antenna of 250 m length.

A backup 500 A antenna of 100 m length.

Two 200 A hydrate/shallow gas antennas of 50 m length.

2 Vulcan towed 3-axis electric field recorders with pitch/roll/heading/depth sensors.

2 Long-wire EM (LEM) receivers configured for gradient field measurement.

Anchors for 160 receiver deployments and 7 LEM deployments.

All necessary topside support equipment.

All transmissions will be carried out at a flying height of 50–100 m using a broadband binary waveform (below) with a 0.25 Hz fundamental frequency and usable bandwidth up to 20 Hz. The project will be carried out in 4 phases of seafloor receiver deployments and transmitter tows.

PHASE 1.

In the first phase of the experiment we will deploy 50 seafloor receivers along with 2 LEM receivers (at sites 7 and 30) in two lines across the large, quasi-1D, part of the reservoir. Site spacing on line 1 will be 2000, 1000, and 500 m, with the densest site spacing across the SE edge of the reservoir. A significant amount of data will be collected off-target. Sites 51 and 52 will be recovered and redeployed to tie into Phase 2 and to establish repeatability of deployments. Line 1 will be towed a second time (as Line 3), again to test repeatability. Transmitter run-in and run-outs will be 6 km.

PHASE 2.

In the second phase we will recover all Phase 1 instruments and redeploy 51 of them in a grid pattern over the more 3D part of the reservoir structure. Sites 51 and 52 will be redeployments from Phase 1, and sites 95 and 98 will be LEMs. If there are no instrument losses or failures, we will leave site 39 from Phase 1 deployed to tie into Phase 3. Site spacing will be 2 km and receiver line spacing will be 2.5–6.0 km. We will transmit along all receiver lines, as well as along the mid-points between the lines. We will also make 3 crossline tows (more if time permits). This phase is designed to collect a 3D data set, as well as examine the utility of off-line tows.

Line 8, with the two LEMs, is designed to provide off-target control for Phase 3, which targets the deep Ganymede structure.

PHASE 3.

For Phase 3 we will recover 20 seafloor receivers and the two LEMs and redeploy over Ganymede at a site spacing of 1 km over the structure and 2 km for the outer three instruments. If possible, we will leave site 39 from Phase 1 deployed to provide an extra off-target receiver. We will tow Line 12 twice (once in each direction) and carry out two off-line tows. If time permits we will also tow some cross-line, tying into the instruments remaining from Phase 2. Sites 108 and 113 will be LEMs, which are specifically designed for this type of target.

PHASE 4.

If time permits, we will finish the survey after recovering all the instruments by deploying 25 seafloor receivers at a site spacing of 500 m over an area of shallow gas and inferred gas hydrate. At this time we have positioned this line where the BHP shallow hazards report confirms the existence of shallow gas; if examination of the seismic data shows gas and hydrate along line 2 from Phase 1, we will carry out the shallow resistors survey along that line instead.

TIME BUDGET

Receiver deployment/recovery times. We have budgeted **45 minutes for receiver deployment**. It takes less than 30 minutes to prepare an instrument for deployment, but there will be some significant transits between lines, and it would be ideal to watch the instruments to the seafloor (about 20 minutes), although for closely spaced stations this can be done during preparation and deployment of the next instrument. We have also budgeted 45 minutes for recoveries. It takes about 12 minutes to send a release command and have the burnwire release activate, about 50 minutes for the instrument to float to the surface, and another 10 minutes or so to recover it and land it on deck. However, for closely spaced lines of receivers we can have two or three instruments in the water column at once, reducing the recovery time.

LEM deployment times. LEM deployments are more involved than standard receiver deployments, and we are budgeting **5 hours total for each**, made up of 1 hour transit to station; 1 hour to deploy the antenna with electrodes; 1 hour to attach the antenna to the LEM, test systems, and lower into the water; 1 hour to deeptow the LEM to the seafloor (1500 m at 25 m/minute); 0.6 hour to recover the tow cable after release (1500 m at 40 m/minute); 0.4 hour to recover the launch system.

SUESI deployment and recovery times. The time to deploy our transmitter includes transit to a starting point 6 nm from the end of the lines (1.5 hours), 2 hours to prepare and deploy both Vucan receivers, 1 hour to deploy the antenna

with electrodes, and 1 hour to deeptow the instrument to flying height (1,500 m cable at 25 m/minute), for a total of **6.5 hours to deploy SUESI**. Recovery is the reverse operation but somewhat faster; 0.8 hour to recover the cable (1,500 m at 30 m/minute), 1 hour to land SUESI on deck, 1.5 hours to recover the antenna, 1 hour to recover the Vulcans for a total of **4.3 hours to recover SUESI**.

These times are conservative – peak receiver deployment and recovery times on recent cruises have been about 15 minutes each, and the LEM and SUESI deployments should go faster after the initial setup. However, this is a long cruise (for us) with a lot of work, and so we should plan on setting a sustainable pace.

SUMMARY:

Transit: 770 nm at 11.5 knots = 2.8 days

Deploy 50 Phase 1 receivers at 45 minutes each: 1.6 days

Deploy 2 LEMs at 5 hours each: 0.4 days

Navigate receivers by driving lines (48km + 12km) 3 times at 4 knots: 1 day

Launch SUESI to flying height: 0.3 days

Tow Lines:

Tow line 1 (60km) at 1.5 knots: 0.9 days

1 mile radius turn plus 30km transit to line 2 at 2.0 knots: 0.5 days

Tow line 2 (20km) at 1.5 knots: 0.3 days

1 mile radius turn plus 40km transit to line 1 at 2.0 knots: 0.6 days

Tow line 1 (60km) at 1.5 knots: 0.9 days

Total towing Phase 1: 3.2 days

Recover SUESI: 0.2 day

Recover 52 Phase 1 receivers at 45 minutes each: 1.6 days

Total Phase 1: 8.3 days

Deploy 48 Phase 2 receivers at 45 minutes each: 1.5 days

Deploy 2 LEMs: 0.4 days

Navigate receivers: 1 day

Launch SUESI: 0.3 days

Tow lines:

9 lines at 11 hours each: 99 hours

3 lines at 10 hours each: 30 hours

11 turns at 3 hours each: 33 hours

Total towing Phase 2: 6.7 days

Recover SUESI: 0.2 days

Recover 22 instruments at 45 minutes each: 0.7 days

Total Phase 2: 10.8 days

Deploy 20 Phase 3 receivers at 45 minutes each: 0.6 days

Deploy 2 LEMs: 0.4 days

Navigate receivers: 0.4 days

Deploy SUESI: 0.3 days

Tow line four times (twice on and two flank lines):

Tow line: 13 hours

Turn: 4 hours

Four tows and three turns: 64 hours

Total tow Phase 3: 2.7 days

Recover SUESI: 0.2 days

Recover 52 instruments at 45 minutes: 1.7 days

Total Phase 3: 6.3 days

Deploy 25 instruments: 0.8 day

Navigate receivers: 0.2 day

Tow once: 0.5 day plus 0.3 days = 0.8 days

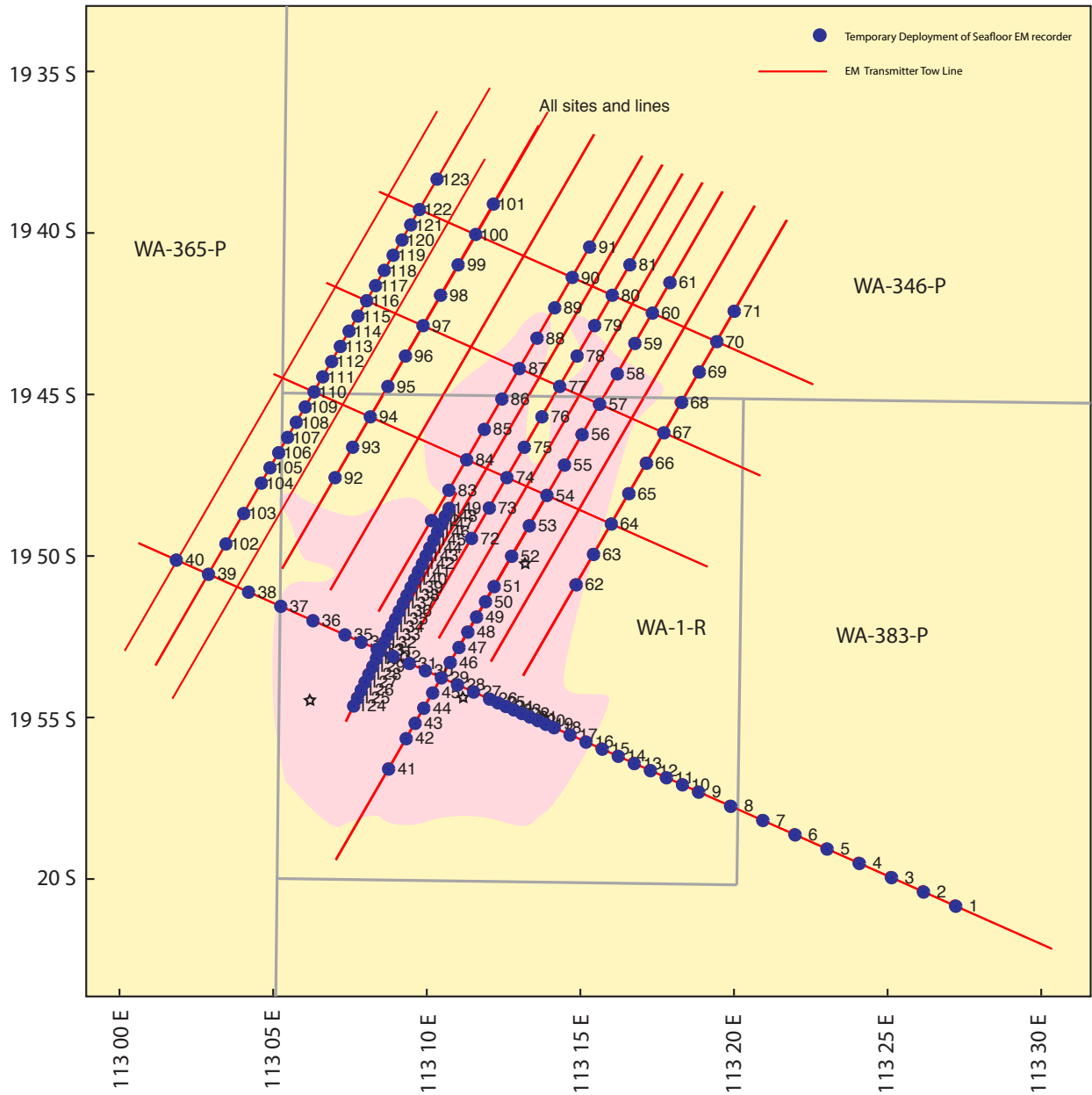
Recover 25 instruments at 30 minutes each: 0.5 days

Total Optional Phase 4: 2.3 days

Transit: 770 nm at 11.5 knots = 2.8 days

Total operations: 33.3 days (total shiptime available: 33.33 days)

APPENDIX: Coordinates of all sites and lines



In the following tables all UTM coordinates, taken from the BHP-supplied base map (above), have been converted to latitudes and longitudes using the the m.map MATLAB routines assuming UTM zone 49 (southern hemisphere) and the WGS84 ellipsoid.

SITES

site	Easting	Northing	Latitude (decimal)	Longitude (decimal)	Latitude (Deg., Min.)	Longitude (Deg., Min.)
1	756733	7785734	-20.00815	113.45386	-20 0.489	113 27.231
2	754906	7786548	-20.00105	113.43629	-20 0.063	113 26.177
3	753079	7787361	-19.99395	113.41873	-19 59.637	113 25.124
4	751252	7788175	-19.98684	113.40117	-19 59.210	113 24.070
5	749425	7788988	-19.97973	113.38361	-19 58.784	113 23.016
6	747598	7789802	-19.97262	113.36605	-19 58.357	113 21.963
7	745771	7790615	-19.96551	113.34849	-19 57.930	113 20.909
8	743944	7791429	-19.95839	113.33093	-19 57.503	113 19.856
9	742117	7792242	-19.95127	113.31338	-19 57.076	113 18.803
10	741203	7792649	-19.94772	113.30460	-19 56.863	113 18.276
11	740290	7793056	-19.94416	113.29583	-19 56.649	113 17.750
12	739376	7793462	-19.94060	113.28705	-19 56.436	113 17.223
13	738463	7793869	-19.93703	113.27827	-19 56.222	113 16.696
14	737549	7794276	-19.93347	113.26950	-19 56.008	113 16.170
15	736635	7794683	-19.92991	113.26072	-19 55.795	113 15.643
16	735722	7795089	-19.92635	113.25195	-19 55.581	113 15.117
17	734808	7795496	-19.92279	113.24317	-19 55.367	113 14.590
18	733895	7795903	-19.91923	113.23440	-19 55.154	113 14.064
19	733438	7796106	-19.91744	113.23001	-19 55.047	113 13.801
20	732981	7796310	-19.91566	113.22563	-19 54.940	113 13.538
21	732525	7796513	-19.91388	113.22124	-19 54.833	113 13.274
22	732068	7796716	-19.91210	113.21685	-19 54.726	113 13.011
23	731611	7796920	-19.91032	113.21247	-19 54.619	113 12.748
24	731154	7797123	-19.90853	113.20808	-19 54.512	113 12.485
25	730697	7797326	-19.90675	113.20369	-19 54.405	113 12.222
26	730241	7797530	-19.90497	113.19931	-19 54.298	113 11.959
27	729327	7797937	-19.90140	113.19054	-19 54.084	113 11.432
28	728414	7798343	-19.89784	113.18176	-19 53.870	113 10.906
29	727500	7798750	-19.89427	113.17299	-19 53.656	113 10.380
30	726586	7799157	-19.89071	113.16422	-19 53.442	113 9.853
31	725673	7799563	-19.88714	113.15545	-19 53.228	113 9.327
32	724759	7799970	-19.88357	113.14668	-19 53.014	113 8.801
33	723846	7800377	-19.88000	113.13791	-19 52.800	113 8.275
34	722932	7800784	-19.87643	113.12914	-19 52.586	113 7.748
35	722019	7801190	-19.87286	113.12037	-19 52.372	113 7.222
36	720192	7802004	-19.86573	113.10283	-19 51.944	113 6.170
37	718365	7802817	-19.85858	113.08530	-19 51.515	113 5.118
38	716537	7803631	-19.85144	113.06776	-19 51.086	113 4.066
39	714254	7804648	-19.84251	113.04585	-19 50.551	113 2.751
40	712426	7805461	-19.83536	113.02832	-19 50.122	113 1.699
41	724500	7793554	-19.94154	113.14499	-19 56.493	113 8.699
42	725500	7795286	-19.92579	113.15432	-19 55.547	113 9.259
43	726000	7796152	-19.91791	113.15899	-19 55.074	113 9.539
44	726500	7797018	-19.91003	113.16366	-19 54.602	113 9.820
45	727000	7797884	-19.90215	113.16833	-19 54.129	113 10.100
46	728000	7799616	-19.88639	113.17766	-19 53.184	113 10.660
47	728500	7800482	-19.87851	113.18233	-19 52.711	113 10.940
48	729000	7801348	-19.87064	113.18699	-19 52.238	113 11.219
49	729500	7802214	-19.86276	113.19166	-19 51.765	113 11.499

50	730000	7803080	-19.85488	113.19632	-19	51.293	113	11.779
51	730500	7803946	-19.84700	113.20098	-19	50.820	113	12.059
52	731500	7805678	-19.83124	113.21031	-19	49.874	113	12.619
53	732500	7807410	-19.81548	113.21964	-19	48.929	113	13.178
54	733500	7809142	-19.79972	113.22896	-19	47.983	113	13.738
55	734500	7810874	-19.78396	113.23828	-19	47.038	113	14.297
56	735500	7812606	-19.76820	113.24760	-19	46.092	113	14.856
57	736500	7814338	-19.75244	113.25692	-19	45.146	113	15.415
58	737500	7816071	-19.73668	113.26624	-19	44.201	113	15.974
59	738500	7817803	-19.72092	113.27555	-19	43.255	113	16.533
60	739500	7819535	-19.70516	113.28486	-19	42.309	113	17.092
61	740500	7821267	-19.68940	113.29418	-19	41.364	113	17.651
62	735154	7804051	-19.84549	113.24539	-19	50.730	113	14.723
63	736154	7805783	-19.82973	113.25471	-19	49.784	113	15.283
64	737154	7807515	-19.81397	113.26403	-19	48.838	113	15.842
65	738154	7809247	-19.79821	113.27335	-19	47.893	113	16.401
66	739154	7810979	-19.78245	113.28267	-19	46.947	113	16.960
67	740154	7812712	-19.76669	113.29198	-19	46.001	113	17.519
68	741154	7814444	-19.75093	113.30129	-19	45.056	113	18.078
69	742154	7816176	-19.73516	113.31061	-19	44.110	113	18.636
70	743154	7817908	-19.71940	113.31992	-19	43.164	113	19.195
71	744154	7819640	-19.70364	113.32923	-19	42.218	113	19.754
72	729216	7806695	-19.82233	113.18839	-19	49.340	113	11.303
73	730216	7808427	-19.80657	113.19772	-19	48.394	113	11.863
74	731216	7810159	-19.79081	113.20704	-19	47.449	113	12.423
75	732216	7811891	-19.77505	113.21637	-19	46.503	113	12.982
76	733216	7813623	-19.75929	113.22569	-19	45.557	113	13.541
77	734216	7815355	-19.74353	113.23501	-19	44.612	113	14.101
78	735216	7817087	-19.72777	113.24433	-19	43.666	113	14.660
79	736216	7818819	-19.71201	113.25364	-19	42.721	113	15.219
80	737216	7820551	-19.69625	113.26296	-19	41.775	113	15.778
81	738216	7822284	-19.68049	113.27227	-19	40.829	113	16.336
82	726932	7807712	-19.81341	113.16647	-19	48.805	113	9.988
83	727932	7809444	-19.79765	113.17580	-19	47.859	113	10.548
84	728932	7811176	-19.78189	113.18513	-19	46.914	113	11.108
85	729932	7812908	-19.76614	113.19446	-19	45.968	113	11.667
86	730932	7814640	-19.75038	113.20378	-19	45.023	113	12.227
87	731932	7816372	-19.73462	113.21310	-19	44.077	113	12.786
88	732932	7818104	-19.71886	113.22242	-19	43.132	113	13.345
89	733932	7819836	-19.70310	113.23174	-19	42.186	113	13.904
90	734932	7821568	-19.68734	113.24106	-19	41.241	113	14.463
91	735932	7823300	-19.67158	113.25037	-19	40.295	113	15.022
92	721451	7810152	-19.79200	113.11388	-19	47.520	113	6.833
93	722451	7811884	-19.77624	113.12321	-19	46.575	113	7.393
94	723451	7813616	-19.76049	113.13255	-19	45.629	113	7.953
95	724451	7815348	-19.74473	113.14188	-19	44.684	113	8.513
96	725451	7817081	-19.72898	113.15120	-19	43.739	113	9.072
97	726451	7818813	-19.71322	113.16053	-19	42.793	113	9.632
98	727451	7820545	-19.69746	113.16986	-19	41.848	113	10.191
99	728451	7822277	-19.68171	113.17918	-19	40.902	113	10.751
100	729451	7824009	-19.66595	113.18850	-19	39.957	113	11.310
101	730451	7825741	-19.65019	113.19782	-19	39.012	113	11.869
102	715254	7806380	-19.82676	113.05519	-19	49.605	113	3.311

103	716254	7808112	-19.81101	113.06453	-19	48.660	113	3.872
104	717254	7809844	-19.79525	113.07387	-19	47.715	113	4.432
105	717754	7810710	-19.78738	113.07854	-19	47.243	113	4.712
106	718254	7811576	-19.77950	113.08321	-19	46.770	113	4.992
107	718754	7812442	-19.77162	113.08788	-19	46.297	113	5.273
108	719254	7813308	-19.76375	113.09254	-19	45.825	113	5.553
109	719754	7814174	-19.75587	113.09721	-19	45.352	113	5.833
110	720254	7815040	-19.74799	113.10188	-19	44.880	113	6.113
111	720754	7815906	-19.74012	113.10654	-19	44.407	113	6.393
112	721254	7816772	-19.73224	113.11121	-19	43.934	113	6.673
113	721754	7817638	-19.72436	113.11588	-19	43.462	113	6.953
114	722254	7818504	-19.71648	113.12054	-19	42.989	113	7.232
115	722754	7819370	-19.70861	113.12521	-19	42.516	113	7.512
116	723254	7820236	-19.70073	113.12987	-19	42.044	113	7.792
117	723754	7821102	-19.69285	113.13453	-19	41.571	113	8.072
118	724254	7821968	-19.68497	113.13920	-19	41.098	113	8.352
119	724754	7822834	-19.67710	113.14386	-19	40.626	113	8.632
120	725254	7823700	-19.66922	113.14852	-19	40.153	113	8.911
121	725754	7824566	-19.66134	113.15319	-19	39.680	113	9.191
122	726254	7825432	-19.65346	113.15785	-19	39.208	113	9.471
123	727254	7827164	-19.63771	113.16717	-19	38.262	113	10.030
124	722510	7797142	-19.90937	113.12555	-19	54.562	113	7.533
125	722727	7797593	-19.90527	113.12757	-19	54.316	113	7.654
126	722944	7798043	-19.90118	113.12958	-19	54.071	113	7.775
127	723161	7798494	-19.89709	113.13160	-19	53.825	113	7.896
128	723378	7798944	-19.89300	113.13362	-19	53.580	113	8.017
129	723595	7799395	-19.88890	113.13563	-19	53.334	113	8.138
130	723812	7799845	-19.88481	113.13765	-19	53.089	113	8.259
131	724029	7800296	-19.88072	113.13966	-19	52.843	113	8.380
132	724245	7800746	-19.87662	113.14168	-19	52.597	113	8.501
133	724462	7801197	-19.87253	113.14370	-19	52.352	113	8.622
134	724679	7801647	-19.86844	113.14571	-19	52.106	113	8.743
135	724896	7802098	-19.86434	113.14773	-19	51.861	113	8.864
136	725113	7802548	-19.86025	113.14974	-19	51.615	113	8.985
137	725330	7802999	-19.85616	113.15176	-19	51.369	113	9.106
138	725547	7803449	-19.85206	113.15377	-19	51.124	113	9.226
139	725764	7803900	-19.84797	113.15579	-19	50.878	113	9.347
140	725981	7804350	-19.84388	113.15780	-19	50.633	113	9.468
141	726198	7804801	-19.83978	113.15982	-19	50.387	113	9.589
142	726415	7805251	-19.83569	113.16183	-19	50.141	113	9.710
143	726631	7805702	-19.83160	113.16385	-19	49.896	113	9.831
144	726848	7806152	-19.82750	113.16586	-19	49.650	113	9.952
145	727065	7806603	-19.82341	113.16788	-19	49.405	113	10.073
146	727282	7807053	-19.81932	113.16989	-19	49.159	113	10.194
147	727499	7807504	-19.81522	113.17191	-19	48.913	113	10.314
148	727716	7807954	-19.81113	113.17392	-19	48.668	113	10.435
149	727933	7808405	-19.80704	113.17594	-19	48.422	113	10.556

LINES

line	Easting	Northing	Latitude (decimal)	Longitude (decimal)	Latitude (Deg., Min.)	Longitude (Deg., Min.)
1 beg	762215	7783294	-20.02945	113.50656	-20 1.767	113 30.393
1 end	707402	7807698	-19.81570	112.98011	-19 48.942	112 58.807
3 beg	721500	7788358	-19.98881	113.11696	-19 59.329	113 7.018
3 end	733500	7809142	-19.79972	113.22896	-19 47.983	113 13.738
4 beg	728500	7800482	-19.87851	113.18233	-19 52.711	113 10.940
4 end	743500	7826463	-19.64211	113.32210	-19 38.527	113 19.326
4a beg	727358	7800990	-19.87406	113.17136	-19 52.443	113 10.282
4a end	742358	7826971	-19.63766	113.31115	-19 38.260	113 18.669
5 beg	732154	7798855	-19.89277	113.21741	-19 53.566	113 13.045
5 end	747154	7824836	-19.65635	113.35714	-19 39.381	113 21.428
5a beg	730327	7799669	-19.88565	113.19987	-19 53.139	113 11.992
5a end	745327	7825649	-19.64923	113.33962	-19 38.954	113 20.377
6 beg	726216	7801499	-19.86960	113.16040	-19 52.176	113 9.624
6 end	741216	7827480	-19.63321	113.30020	-19 37.992	113 18.012
6a beg	725074	7802007	-19.86514	113.14944	-19 51.908	113 8.966
6a end	740074	7827988	-19.62876	113.28925	-19 37.725	113 17.355
7 beg	723932	7802516	-19.86068	113.13848	-19 51.641	113 8.309
7 end	738932	7828496	-19.62430	113.27831	-19 37.458	113 16.698
7a beg	721192	7803736	-19.84997	113.11217	-19 50.998	113 6.730
7a end	736192	7829717	-19.61361	113.25204	-19 36.817	113 15.122
8 beg	718451	7804956	-19.83926	113.08587	-19 50.356	113 5.152
8 end	733451	7830937	-19.60292	113.22577	-19 36.175	113 13.546
9 beg	748635	7815467	-19.74075	113.37251	-19 44.445	113 22.350
9 end	723970	7826449	-19.64454	113.13595	-19 38.672	113 8.157
10 beg	745635	7810271	-19.78805	113.34458	-19 47.283	113 20.675
10 end	720970	7821253	-19.69180	113.10797	-19 41.508	113 6.478
11 beg	742635	7805075	-19.83534	113.31665	-19 50.120	113 18.999
11 end	717970	7816057	-19.73906	113.07997	-19 44.344	113 4.798
12 beg	711254	7799452	-19.88976	113.01781	-19 53.386	113 1.068
12 end	730254	7832360	-19.59044	113.19513	-19 35.426	113 11.708
12a beg	712852	7798740	-19.89602	113.03315	-19 53.761	113 1.989
12a end	731852	7831649	-19.59668	113.21045	-19 35.801	113 12.627
12b beg	709655	7800163	-19.88351	113.00246	-19 53.010	113 0.148
12b end	728655	7833072	-19.58419	113.17981	-19 35.052	113 10.788
13 beg	722076	7796241	-19.91755	113.12152	-19 55.053	113 7.291
13 end	728367	7809306	-19.79885	113.17996	-19 47.931	113 10.798