5.2 Multi-Channel Seismic Operations and Preliminary Results

The two primary objectives of the multi-channel seismic survey are to constrain variations in Moho depth and variations in width/depth of an axial magma lens, both as a function of distance from the Galapagos hotspot. In just over eight days of survey, we obtained reflection data over ~86% of the length of ridge axis between ~95.5° and 91.25° W, including 100% coverage east of ~94.5° W. We also obtained ~80% coverage along the ridge flank (parallel to, and 15-30 km north of the axis) between 95.5° and 91.25° W, including 15 across-axis lines, which extended ≥ 10 km north and south of the ridge (see maps in section 6.4.1). The full survey included ~40,500 shots and 24,000 reflection points, which amounted to ~200 GB of data.

The gun and streamer geometry are diagrammed in Figures 6.2.3 and 6.2.4. We shot ten guns with a volume of 4438 cu. in. and deployed two spares. Shooting interval was maintained at 15 s with a 50 ms randomization window to minimize noise from consecutive shots. This shot interval and a ship speed of 4.5 kts yielded ~38 m shot spacing. We used the full 6 km of the Syntrak streamer, recording 10 s of data at a sample interval of 4 ms. The 480 channels with spacing of 12.5 m produced six, 80-fold reflection point gathers every shot.

Acquisition of the reflection data went extremely well. To the credit of the gunning crew, the air guns did not miss a shot over the duration of the survey. Deployment of the streamer went quickly, lasting only 6 hrs, including the replacement of one streamer section. Streamer operation went smoothly over the duration of the survey, with the exception of line GSC-X4 where digitizing canister #38 broke as we passed over the ridge axis (luckily for the second time). Science officer C. Leidhold replaced the faulty canister in ~3 hrs and only 4 hrs of data were missed. Streamer retrieval at the end of the survey took 3 hrs. A final factor that had minor influence on survey operations was a 1-1.5 knot current out of the south east. On several occasions the current slowed our west-to-east lines (ridge flank and along-axis) to ~4 kts and increased our speed on a few north-to-south lines to >4.5 kts. Variations in shot spacing as well as streamer feathering will need to be considered in the final processing of the reflection data; fortunately, both bird compass data and GPS locations of the tail buoy were recorded through most of the survey.

Brute stacks and data copies were produced near real-time, thanks to the diligence of our watch-standers and the technical support and SIOSEIS scripts (used on EW9914, Lau Basin) from P. Henkart. The 3490 field tapes were written in SEG-D format by the Syntrak system approximately and filled every 35 min. After each field tape was written, a watch-stander took it to the Sparc10 Workstation, Heezen and then copied it in SEG-Y format to DLT using the SIOSEIS copy script (section 6.4.3 and 6.4.5). Once the copy was complete, the field tape was read again to produce brute stacks. Half of the streamer was used in the brute stacks to save time and we incorporated the stacking velocities used on EW9914. The copy and brute stack jobs each took ~15 min., therefore the two processes completed in about the same time it took to record each new 3490 field tapes. The Atlantek plotter (using P. Henkart's "Atlantek" script) plotted the stacked traces as they were written to Heezen's hard drive. Often, the traces appeared on the plot within an hour from the time they were shot. These brute stacks were valuable in our choice of way points on some of the along-axis lines (in particular GSC-AA3 and GSC-AA4) and were exciting to see so soon after we collected the data. The brute stack and copy script are in section 6.4.5.

The overall quality of the reflection data is excellent. Calm seas and wind during the survey and adequate streamer balancing kept streamer noise to a minimum, as evident in the shot gather shown in 6.4.4. Immediately apparent in this shot gather is the seafloor reflection (2.2 s on channel 480), the seafloor multiple (4.4 s), and a refracted arrival from layer 2A that immerges before seafloor reflection near channel 210 (offset of ~2800 m). This layer 2A refraction was prominent over most of the survey and will provide valuable constraints on the seismic velocities of layer 2A.

We began the MCS survey near ~95.5° west, where an axial valley morphology is present. The large bathymetric relief generated considerable noise in the records and we did not image Moho or axial magma chamber (AMC) in the initial brute stacks. Our first—though tentative—images of Moho and AMC appeared in our first detailed survey (GSC-S1), located on flat (transitional) axial topography (91.17°-91.3°W). The possible Moho reflector appears as a sharp, flat reflector ~2.0-2.1 s below the seafloor on line GSC-S1e. The possible magma lens reflector is evident on GSC-S1f, ~1.5 s below the seafloor. If this is AMC, then it is deep.

Our more confident images of Moho and magma lens appeared at GSC-X4 (~93.0 W) and further east, where the ridge has a prominent axial high. Two examples of magma lens reflectors are shown in section 6.4.4. The shallowest we imaged AMC was at ~0.75 s. We also imaged AMC at greater times below the seafloor (≤ 1.5 s), though we hypothesize that some in of these sections the reflections may be from the deeper flanks of the AMC or may be from a shallow AMC off to the side of the streamer. We see some correlations between the depth, presence, and absence of AMC with proximity of our ship track to the inferred central accretion zone of the ridge axis. Future analysis will require careful consideration of such correlations. We see no obvious correlation between AMC width or depth with ridge axis depth. The deepest Moho of our survey was observed near 91.5 °W along the ridge flank line GSC-RF6 (Figure 6.4.4). This reflector is, at most, 2.5 s below the seafloor, suggests a crustal thickening of ~25% or 1-2 km from GSC-S1 (~94.3°W). Such a modest increase in crustal thickness implies that a significant fraction of the Galapagos swell is supported by buoyant upper mantle. Thus, our preliminary findings suggest that the depth and width of AMC does not vary systematically with axial depth where the ridge has an axial high, and that the crustal thickness variation is small (25%) over a change in axial depth of almost 1 km.

6.4.2. MCS Line Table

EW0004 MCS Surveys									
	Line #	**Wpt**	**Latitude**	**Longitude**	**J-Day**	**Time**	**File #**	**DLT#**	**Shot #**
Start	GSC-RF1	20	2° 46.04	95° 26.04	100	21:14	1	1	1
End		21	2° 45.28	95° 06.63	101	01:24	7	1	1008
	GSC-X1	21	2° 44.38	95° 06.72	101	01:45	8	1	1010
		24	2° 36.60	95° 10.21	101	06:34	15	1	2150
	GSC-AA1a	24	2° 37.03	95° 09:96	101	06:42	101	1	2200
			2° 36.18	94° 51.27	101	10:56	107	1	3214
	GSC-AA1b		2° 36.18	94° 51.27	101	10:56	108	1	3215
		25	2° 35.17	94° 41.12	101	13:01	111	2	3716
	GSC-X2	25	2° 34.51	94° 41.29	101	13:15	112	2	3750
		28	2° 42.86	94° 43.43	101	18:05	119	2	4908
	GSC-RF2a	28	2° 43.55	94° 42.62	101	18:20	120	2	5000
			2° 42.03	94° 26.66	101	21:57	125	2	5869
	GSC-RF2b		2° 42.03	94° 26.66	101	21:57	126	2	5870
		29	2° 40.49	94° 09.72	102	01:34	132	2	6779
	GSC-S1a	29	2° 40.08	94° 09.14	102	01:55	133	2	6800
		~30	2° 29.47	94° 10.47	102	04:19	136	2	7379
	GSC-S1b	~31	2° 26.55	94° 13.45	102	05:32	139	2	7670
		~32	2° 39.33	94° 13.65	102	08:34	143	2	8394
	GSC-S1c	~33	2° 38.45	94° 15.81	102	09:11	145	2	8540
		~34	2° 27.80	94° 17.25	102	11:35	148	2	9119
	GSC-S1d	~35	2° 27.78	94° 19.72	102	12:11	150	2	9265
		~36	2° 35.71	94° 18.84	102	14:00	152	2	9698
	GSC-S1e	~37	2° 36.88	94° 20.48	102	14:36	153	2	9845
		~38	2° 32.33	94° 07.00	102	18:14	159	2	10714
	GSC-S1f	~39	2° 30.81	94° 08.62	102	18:50	161	3	10860
		40	2° 32.68	94° 21.60	102	21:44	165	3	11547

	Line #	Wpt	Latitude	Longitude	J-Day	Time	File #	DLT#	Shot #
Start	GSC-AA2a	41	2° 33.15	94° 23.54	102	22:16	166	3	11600
End			2° 32.32	94° 07.97	103	01:53	171	3	12469
	GSC-AA2b		2° 32.32	94° 07.97	103	01:53	172	3	12470
			2° 30.88	93° 54.91	103	04:54	176	3	13194
	GSC-AA2c		2° 30.88	93° 54.91	103	04:54	177	3	13195
		42	2° 28.54	93° 44.00	103	07:39	181	3	13849
	GSC-X3	42	2° 28.06	93° 43.65	103	07:46	182	3	13900
		~44	2° 23.47	93° 47.10	103	09:35	184	3	14334
		45	2° 36.51	93° 45.72	103	12:32	189	3	15039
	GSC-RF3a	45	2° 37.25	93° 45.00	103	12:47	190	3	15100
			2° 40.00	93° 29.56	103	16.25	195	3	15969
	GSC-RF3b		2° 40.00	93° 29.56	103	16.25	196	3	15970
			2° 31.01	93° 16.27	103	20:02	201	3	16839
	GSC-RF3c		2° 31.01	93° 16.27	103	20:02	202	3	16840
		47	2° 24.27	92° 58.43	104	01:10	210	3	18042
	GSC-X4a	47	2° 23.98	92° 58.11	104	01:10	211	4	18100
			2° 09.61	92° 58.22	104	04:47	216	4	18969
	GSC-X4b		2° 09.61	92° 58.22	104	04:47	217	4	18970
		50	2°	92°	104		220	5	19368
	GSC-RF4	50	2° 22.83	92° 51.11	104	10:07	222	5	19400
		51	2° 19.16	92° 34.39	104	14:41	229	5	20493
	GSC-X5a	51	2° 17.88	92° 33.38	104	15:00	230	5	20500
			2° 04.64	92° 33.51	104	18:37	235	5	21369
	GSC-X5b		2° 04.64	92° 33.51	104	18:37	236	5	21370
		54	2° 21.54	92° 29.78	104	22:32	242	5	22314
	GSC-RF5a	54	2° 21.87	92° 29.30	104	22:40	243	5	22400
			2° 20.82	92° 13.27	105	02:17	248	5	23269
	GSC-RF5b		2° 20.82	92° 13.27	105	02:17	249	5	23270
		55	2° 20.07	92° 02.50	105	04:43	252	5	23841

	Line #	Wpt	Latitude	Longitude	J-Day	Time	File #	DLT#	Shot #
Start	GSC-S2a	55	2° 19.84	92° 01.77	105	04:45	253	5	23900
End		~56	2° 00.88	92° 02.59	105	09:09	259	5	24914
	GSC-S2b	~57	2° 00.27	92° 00.36	105	09:44	261	5	25062
		~58	2° 12.46	91° 57.58	105	12:46	265	5	25786
	GSC-S2c	~59	2° 10.63	91° 56.53	105	13:22	267	5	25930
		~60	2° 00.03	91° 56.91	105	15:46	270	6	26511
	GSC-S2d	~61	2° 00.47	91° 54.56	105	16:23	272	6	26657
		62	2° 19.01	91° 48.30	105	21:42	279	6	27791
	GSC-RF6a	62	2° 19.01	91° 48.30	105	21:42	280	6	27792
			2° 16.11	91° 32.21	106	01:19	285	6	28661
	GSC-RF6b		2° 16.11	91° 32.21	106	01:19	286	6	28662
		63	2° 13.69	91° 18.82	106	04:21	290	6	29386
	GSC-AA3	65	1° 55.98	91° 16.13	106	11:20	303	6	31050
		67	1° 59.70	91° 33.09	106	15:17	309	6	31983

	GSC-X7a	67	1° 59.17	91° 33.81	106	15:30	310	6	32000
		~69	1° 54.10	91° 31.20	106	17:17	312	6	32434
	GSC-X7b	~69	1° 54.10	91° 31.20	106	17:17	313	6	32435
		72	2° 59.35	91° 28.87	106	21:30	319	6	33442
	GSC-AA4a	72	1° 59.35	91° 29.14	106	21:33	320	7	33500
			2° 03.38	91° 45.02	107	01:11	325	7	34369
	GSC-AA4b		2° 03.38	91° 45.02	107	01:11	326	7	34370
			2° 06.66	92° 00.65	107	04:49	331	7	35239
	GSC-AA4c		2° 06.66	92° 00.65	107	04:49	332	7	35240
			2° 07.88	92° 16.28	107	08:27	337	7	36109
	GSC-AA4d		2° 07.88	92° 16.28	107	08:27	338	7	36110
			2° 11.09	92° 32.90	107	12:04	343	7	36979
	GSC-AA4e		2° 11.09	92° 32.90	107	12:04	344	7	36980
			2° 14.33	92° 49.94	107	15:41	349	7	37849
	GSC-AA4f		2° 14.33	92° 49.94	107	15:41	350	7	37850
			2° 18.33	93° 06.25	107	19:19	355	7	38719
	GSC-AA4g		2° 18.33	93° 06.25	107	19:19	356	7	38720
			2° 23.62	93° 22.17	107	22:56	361	7	39589
	GSC-AA4h		2° 23.62	93° 22.17	107	22:56	362	7	39590
			2° 28.02	93° 38.86	108	02:34	367	7	40459
	GSC-AA4f		2° 28.02	93° 38.86	108	02:34	368	7	40460
		~83	2° 28.90	93° 45.68	108	03:59	370	7	40800

6.4.5 Shipboard MCS Processing Scripts

Tape Copy Script

```
#! /bin/csh

/net/shaka/data/henkart/bin/sioseis << eof
procs segdin diskoa output prout end
segdin
   secs 10
   ffilen 99999   # take all shots (this is the preset!)
   ftr 1 ltr 480  # skip the auxiliary channels - 161-172 and 161-180
   fcset 1 lcset 1 #All channels have same trace length
   offline yes  # eject after the rewind after EOT
   newfile yes  # start a new SEG-Y file on every SEG-D tape
   iunit 43 end
end
diskoa
                                   # write every 50th shot to a "circular" file
    fno 1 lno 999999 noinc 50 rewind 1
    opath /ldata/realtime/shots/latest.shot end
end
output
   ontrcs 480
   rewind 0   # leave the tape alone!
   device /dev/nrst66 end
end

prout
# print the stacked trace number just so the light blink!
 fno 0 lno 99999 ftr 1 ltr 1 end
end

end

eof
```

Brute Stack Script

```
#-----------------------------------------------------------------------------------------------------
#  SIOSEIS Script BSTACK
#
#  Does realtime brute stack.  First done from ew9914
#    segdin-- reads data from 3490
#    prout--  outputs what shots (every tenth) to screen
#    geom--   defines geometry
#    header-- changes water depth to tt-time
#    gather-- generate cmp's
#    diskoa-- write every 50th cmp gather
#    nmo-- moveout correction
#    mute-- zero shallow portion of traces
#    diskob-- write every 50th muted cmp gather
#    stack
#    diskoc-- write stack to file
#    filter-- band pass between 5-40 Hz
#    agc
#    plot--   generate plot file
#-----------------------------------------------------------------------------------------------------
#! /bin/csh
if( $#argv < 1 ) then
    echo "Type line number after call to bstack"
    exit 1
endif
set LINENO = $1

/net/shaka/data/henkart/bin/sioseis << eof

procs segdin prout geom header gather
nmo diskoa mute diskob stack diskoc filter agc plot end

segdin
   ffilen 99999      # take all shots
   ftr 241 ltr 480   # use only closest 240 channels
   fcset 1 lcset 1   # all channels have same trace length
   stime 1.5 secs 5.0          # start time and length of record to process
   offline yes       # eject after the rewind after EOT
   iunit 43 end                # unit 43 is 3490 drive
end
diskin
# take all shots
   ftr 241 ltr 480   #Use first half of streamer
   ipath /net/shaka/data/henkart/data/day346.shot01017 end
end

prout
 fno 0 lno 99999 ftr 479 ltr 479 noinc 10 end
end

geom
  type 2               # increment the shot loction based on the shot number
  fs 1 ls 999999  # all shot have the same parameters (preset)
  gxp 480 -181.65 # dist. to near chan.=181.65
  ggx -12.5        # Used to extrapolate gxp! (channel spacing=12.5m)
  dfls 37.5 dbrps 6.25         # shot and rp spacing
```

```
  smear 6.25         # "distance from a rp in which to look for a trace"
  rpadd 1000 end  # first rp#=1001
end

header
   fno 0 lno 9999999 ftr 1 ltr 9999 #all data
   r50 r54 / 750.    # convert water depth to water time
   end
end
#diskob  #This is now done in tape copy
# write every 50th shot to a "circular" file
#    fno 1 lno 999999 noinc 50 rewind 1
#    opath /ldata/realtime/shots/latest.shot end
#end

gather
#   maxtrs 90 maxrps 500 end
   maxtrs 50 maxrps 250 end            #max. traces (>40) and rp bins (>240)
end
diskoa                  #output every 200th cdp gather, "circular file"
    fno 1 lno 999999 noinc 180 rewind 1
    opath /ldata/realtime/shots/latest.cmp end
end
nmo
# real time nmo, replace interpolation by RP to WB depth in Meters.
# If water depth changes by > 500 m, use previous value. Water-depth
# velocity functions derived from ESP5, interpolation by iso-velocity layering
 vtrkwb 500 stretc 0.50
 fno 1000 lno 1000
 vtp 1500 1.333
     1557 1.414
     1607 1.443
     1789 1.492
     2346 1.645
     2638 1.746
     2900 1.846
     2971 1.872
     3141 1.983
     3150 2.102
     3264 2.362
     4228 3.742
     4343 3.892
     4898 4.393 end
 fno 1500 lno 1500
 vtp 1500 2.0
     1539 2.081
     1574 2.110
     1705 2.159
     2137 2.312
     2379 2.413
     2603 2.513
     2665 2.539
     2827 2.650
     2834 2.769
     2967 3.029
     3939 4.409
```

4053 4.559
4596 5.060 end
fno 2000 lno 2000
vtp 1500 2.667
1529 2.748
1557 2.777
1659 2.826
2012 2.979
2218 3.080
2414 3.180
2468 3.206
2614 3.317
2629 3.436
2761 3.696
3711 5.076
3823 5.226
4351 5.727 end
fno 2500 lno 2500
vtp 1500 3.333
1524 3.414
1546 3.443
1629 3.492
1928 3.645
2108 3.746
2282 3.846
2330 3.872
2463 3.983
2481 4.102
2608 4.362
3526 5.742
3636 5.892
4146 6.393 end
fno 3000 lno 3000
vtp 1500 4.0
1520 4.080
1538 4.110
1609 4.159
1868 4.312
2028 4.413
2184 4.513
2228 4.539
2350 4.650
2368 4.769
2489 5.029
3373 6.409
3479 6.559
3972 7.060 end
fno 3500 lno 3500
vtp 1500 4.667
1517 4.748
1533 4.777
1595 4.826
1823 4.979
1967 5.080
2108 5.180
2148 5.206

```
     2260 5.317
     2279 5.436
     2395 5.696
     3243 7.076
     3346 7.226
     3822 7.727 end
 fno 4000 lno 4000
 vtp 1500 5.333
     1515 5.414
     1529 5.443
     1583 5.492
     1788 5.645
     1919 5.746
     2048 5.846
     2085 5.872
     2189 5.983
     2208 6.102
     2317 6.362
     3131 7.742
     3231 7.892
     3692 8.393 end
 fno 4500 lno 4500
 vtp 1500 6.0
     1513 6.081
     1526 6.110
     1574 6.159
     1760 6.312
     1879 6.413
     1999 6.513
     2033 6.539
     2130 6.650
     2148 6.769
     2252 7.029
     3034 8.409
     3131 8.559
     3577 9.060 end
 fno 5000 lno 5000
 vtp 1500 6.667
     1512 6.748
     1523 6.777
     1567 6.826
     1737 6.979
     1847 7.080
     1958 7.180
     1990 7.206
     2080 7.317
     2098 7.436
     2197 7.696
     2948 9.076
     3042 9.226
     3474 9.727 end
end
mute
   fno 1 lno 999999             #mute outer 20 traces near the seafloor
   addwb yes xtp 200 -.2 1500 -.2 3000 1 6200 2 end
end
```

```
diskob                          #output every 50th muted cdp gather, "circular file"
   fno 1 lno 999999 noinc 180 rewind 1
   opath /ldata/realtime/shots/latest.mute end
end
diskoc              #Write stack file (before filter)
  opath stack.$LINENO end
end
filter                          #band pass filter between 5-40 hz
   pass 5 40 ftype 0 dbdrop 48 end
end
diskoe                          #Not used in current script
   set 3 6 opath /ldata/realtime/cmps/cmps.$LINENO end
end

agc
   winlen .25 center .1 end
end

plot                            #generate plot file
  scalar 1.e-07
  tlines 0.5 1 nibs 7224
  anntyp 5 anninc 15
  def 0.01 trpin 80 wiggle 0
  stime 1.5 nsecs 5.0 vscale 2.5
  opath siopltfil.$LINENO end
end


end
eof
chmod 444 siopltfil.$LINENO
chmod 444 stack.$LINENO
```