Gulf of Mexico Basin Opening (GUMBO): A Seismic Refraction Study of the Northern Gulf of Mexico

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The Gulf of Mexico is a relatively small oceanic basin that formed by rifting between the continental blocks of North America and Yucatan in the Middle to Late Jurassic (165 Ma ago). It is currently unknown how much the margins of the continents stretched and thinned before they separated. After the breakup, seafloor spreading formed volcanic crust in at least part of the central Gulf of Mexico. However, in the Early Cretaceous (140 Ma ago) opening between North America and Yucatan stopped. Since then, subsidence and sedimentation have shaped the Gulf margin that we see today.

Despite decades of seismic exploration in the Gulf of Mexico, its deep crustal structure is not yet imaged in detail. The acquisition of deeply penetration OBS seismic refraction data will help provide new insights in the evolution of the Gulf of Mexico. Currently we only have potential field data and a handful of seismic refraction records to image beneath the top of basement in the Gulf of Mexico. As a result, we do not know how the continental crust of North America tapers towards the central Gulf, and where precisely the transition from continental to oceanic crust can be found. Because of the lack of constraints on the basement, we also do not understand the early depositional setting in which the salt formations developed. A new, comprehensive study of the basement in the Gulf of Mexico would give us insight in the mechanics of continental breakup, and in the role of rift architecture on the post-rift structural development of this margin.

To understand the opening of the Gulf of Mexico we acquired a long-offset seismic refraction line on the northern (U.S.) margin offshore Texas, between Matagorda Island and Alamino Canyon (307 km). The R/V *Iron Cat* provided a powerful airgun source that was recorded by an array consisting of 412 Reftek Texan recorders and L28 4.5 Hz geophones, 12 broadband seismographs (see table), and 43 ocean bottom seismographs, each equipped with a three-component 4.5 Hz geophone and a hydrophone (see figure).

The line is co-located with existing seismic reflection lines to obtain the best possible combined structural models of this rifted margin. Due to deeper penetration, the seismic refraction data will provide crustal thicknesses and much-needed constraints on the nature of the basement. Our main targets are therefore the boundaries of rifted continental crust, possibly exhumed continental mantle and volcanic crust across the margin of the Gulf of Mexico. The new data will subsequently help to improve plate reconstructions of the Gulf of Mexico and to better constrain the thermal history of this economically important basin.

Onshore instrument operations

Broadbands were deployed in June and July 2010 and serviced in mid-October, at which point their sample rates were set to 100 samples/s. Data were recorded continuously.

A total of 418 Texans were deployed over a period of 2 ½ days beginning on the morning of Saturday, November 20, 2010 and ending at noon local time (18:00 GMT) on Monday, November 22. Data were recorded continuously at 100 samples/s. Six Texans failed to record, giving us a final total of 412 independent locations with data recovered.

Elevations were not recorded but varied from 6 m on Matagorda Island to 55 m at the northernmost station. Elevations were interpolated linearly for purposes of data archiving.

The seismic source for this study was an array of airguns operated in the Gulf of Mexico by Reservoir Geophysical's R/V *Iron Cat*. Characteristics of the source are detailed below.

In late morning on Wednesday, November 24 we began to pick up Texans, starting at the far end of the array. We anticipated that the ship would be at offsets greater than 200 km from our closest onshore station at that time, making it more than 300 km from our most distant onshore station. However, due to issues described in detail below, the ship did not reach this distance until many of our more distant stations—and all of the stations on Matagorda Island and smaller islands—had been retrieved. We completed recovery of the remaining stations—those on the mainland but closest to the coast—the following morning (Thanksgiving, November 25). All Texans had been recovered by noon local time on Thursday, November 25.

Gulf Coast Broadbands				Datalogger		Seismometer	
Station	Latitude	Long	Elev (m)	Manufacturer & Model	Serial #	Model	Serial #
GC08	29.0600	-97.2505	45	Reftek 130-01	9655	CMG-3ESP	T3M26
GC09	29.2135	-97.2929	69	Reftek 130-01	962C	CMG-3T	T35441
GC10	29.3485	-97.3376	96	Reftek 130-01	963D	CMG-3ESP	T3L36
GC11	29.4590	-97.4368	80	Reftek 130-01	9657	CMG-3ESP	T3M25
GC12	29.5871	-97.5226	110	Reftek 130-01	9651	CMG-3T	T3877
GC13	29.6690	-97.6274	128	Reftek 130-01	964C	CMG-3T	T36038
GC14	29.7641	-97.7709	142	Reftek 130-01	ACC7	Trillium	482
GC15	29.8579	-97.9316	196	Reftek 130-01	ACC9	Trillium	459
GC16	29.9304	-98.0072	140	Reftek 130-01	963F	CMG-3T	T36037
GC17	30.0323	-98.1602	344	Reftek 130-01	9629	CMG-3T	T36039
GC18	30.1664	-98.2130	437	Reftek 130-01	963C	Trillium	444
GC19	30.2620	-98.3100	350	Reftek 130-01	ACCD	Trillium	426
GC20	30.3099	-98.4044	376	Reftek 130-01	9638	CMG-3T	T36033

Table of broadband seismograph characteristics. Data were recorded continuously at 100 samples/s for this study.

Sound source operations on the R/V *Iron Cat*

During our cruise the R/V *Iron Cat* was equipped with an air gun array composed of five strings. The configuration of guns 1 to12 was identical in each string, each giving us a total of 1800 cubic inches in volume. From back to front, the air-gun capacity for each string was as follows: 1) 100, 2) 100, 3) 150, 4) 150, 5) 300, 6) 300, 7) 150, 8) 150, 9) 100, 10) 100, 11) 100, 12) 100. The air-gun arrays were suspended from linear flotation systems for each array string.

Guns were towed over/under with 1-m vertical separation at 9 and 10 m. The air-gun controller system was the Real Time Systems RTS Big Shot. The compressor system included 8 Price AirMaster 2000 PSI inline diesel-driven air compressors. Each compressor nominally has 200-250 CFM capacity and furnishes air supply to a common distribution system and the air-gun arrays.

Navigation of the sound source was provided by NCS SubSea. Base GPS positions were determined using a differentially corrected C-Nav GPS receiver, and center of source (airgun array) was positioned using a calculated layback from the vessel. NCS SubSea initiated a trigger to the gun controller; shot confirmation from the Real Time Systems Bigshot gun controller was sent to a Novatel GPS receiver which determined the exact time of the shot. Upon completion of each profile, two files were generated:

source data containing shot number, shot time, and shot coordinates; and gun data containing shot number, volume, and pressure. Navigation was also provided for OBS deployment and recovery positions assuming a position near the port side of the OBS lab where operations took place. Profiling speeds of 4.0-4.5 knots could usually be achieved when firing 3 air-gun strings.

Daily logs of ship operations during data acquisition

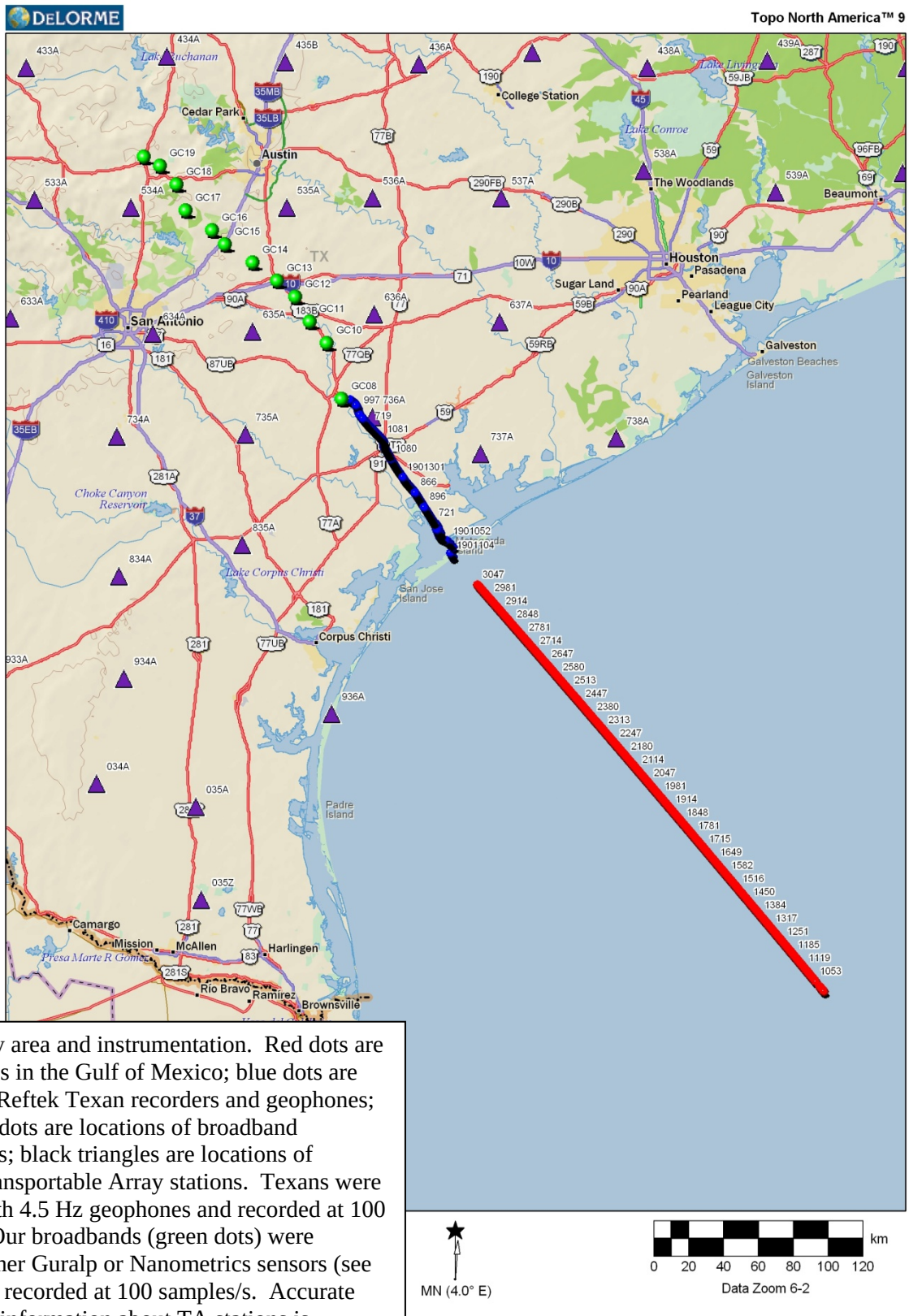
Tuesday November 23 (day 31): At 09:54 GMT the R/V *Iron Cat* was at the north end of GUMBO line 1 for air-gun deployment. The first three gun strings (1, 2, and 3) were out by 13:39, and at 14:52 GMT shooting started with shot 3047. Since we had originally planned to acquire the line from south to north, we were now counting down the shot numbers from the north. All five air-gun strings were in the water by 20:08 GMT, after which we would mostly shoot the three middle air-gun strings (2, 3, and 4). By 24:00 GMT we had reached shot number 2613 at 27.656N.

Wednesday November 24 (day 32): The shooting of GUMBO Line 1 initially progressed well. By 10:00 GMT we informed Jay Pulliam that we would probably have shot 200 km on Line 1 by 16:00 GMT, at which time the land seismic stations could be picked up for data downloads. Although we had certainly acquired enough data on the Texans by that time, it took us much longer than predicted to get to the 200 km mark on our profile. At 16:08 GMT, a prolonged power outage silenced our compressors for a few minutes, so we lost quite a few shots in a row. As we circled back to reshoot this part of Line 1, a half-hour visit of three dolphins at the bow delayed our ramp-up. We took the opportunity to fix a tow rope on air-gun string 2, and string 3 was brought back on deck for repair. We resumed shooting the seismic line by 19:19 GMT with air-gun strings 1, 2, and 4. Due to the worsening sea state we did not re-deploy string 3. By 24:00 GMT we had reached shot 1667 at 26.686N.

Thursday November 25 (day 33): The acquisition of GUMBO Line 1 proceeded steadily, though we slowed down to 3.5 or 3.7 knots to allow the compressors to make sufficient air. At 13:10 GMT we had a large compressor failure that caused us to miss shots 1046 to 1028, but we decided not to circle the ship back to acquire these. The last shot of Line 1 (number 1001) was fired at 14:48 GMT, at 26.000N.

Shot timing. Shots were triggered by NCS SubSea which initiated a trigger signal to the gun controller; the trigger signals were also recorded in the OBS lab. As a test to estimate whether there were any delays between the trigger and the actual shot time we deployed a hydrophone over the side of the ship and ran both the trigger signal and the hydrophone signal through an oscilloscope. The measured time between the trigger and shot as recorded by the hydrophone was 33-36 ms. The estimated distance between the hydrophone position and the center of the gun array was 46 m. With a water velocity of 1500 m/s we would expect it would take 31 ms to travel from the gun array to the hydrophone. Hence, we estimate a shot delay of 2-5 ms between trigger and actual shot, which is within the 5 ms sampling interval of the OBSs.

Volume of seismic source. The R/V *Iron Cat* was equipped with 8 air compressors that were nominally capable of supplying enough air to shoot an air-gun array with a volume of 9000 cubic inches at 2000 psi with a shot interval of 40 to 60 s. Since our project design assumed a 150 m shot spacing, a 60 second shot interval would be sufficient for ship speeds up to 4.5 knots. With this capacity we would be able to shoot all 5 air-gun strings of the R/V *Iron Cat* for the duration of our project. However, we quickly discovered at the start of our operations that the compressors could not meet these specifications, so we had to settle for a smaller air-gun volume. The state of the air compressors generally allowed us to keep 3 air-gun strings shooting.



Map of study area and instrumentation. Red dots are shot locations in the Gulf of Mexico; blue dots are locations of Reftek Texan recorders and geophones; larger green dots are locations of broadband seismographs; black triangles are locations of USArray Transportable Array stations. Texans were equipped with 4.5 Hz geophones and recorded at 100 samples/s. Our broadbands (green dots) were equipped either Guralp or Nanometrics sensors (see Table 1) and recorded at 100 samples/s. Accurate and detailed information about TA stations is available from Earthscope but they typically are equipped with Streckeisen STS-2 or Guralp CMG-3T sensors and record at 40 samples/s. They were not re-programmed for this data acquisition.