Seismic acquisition tests in Cook Inlet, Alaska
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Summary

Cook Inlet in south-east Alaska is a known hydrocarbon province with significant proven reserves of oil and gas, but in recent years has been an area of low exploration activity. The low activity levels are in part due to the difficulties of acquiring seismic data in this harsh regulatory and physical environment; Cook Inlet is the critical habitat for the endangered Beluga Whale and home to the second-highest tidal range in the world, with a mean tidal range of 30 feet in places, and seismic operations are impacted by the currents that result.

In March and April 2011, Apache successfully carried out a 2-D seismic acquisition test program to investigate the feasibility of a regional multi-mode 3-D seismic program to image the deep geological structures beneath Alaska’s Cook Inlet.

Introduction

Previously, the majority of 2-D and 3-D surveys recorded in and around Cook Inlet had been designed to image shallow gas plays in the area, were relatively small, had been acquired in a single season, and had only collected a limited range of offsets and azimuths due to limitations of time, equipment and project size (LaFehr et al., 1990).

To meet imaging requirements, a method was required that would collect long-offset, full-azimuth data throughout the year, in all of the prevailing environments and climatic conditions, and with enough flexibility to manage operations while complying with the regulations set by the many state and federal agencies with jurisdiction in Cook Inlet.

Acquisition tests were carried out along an 18-mile 2-D line in Redoubt Bay on the west side of Cook Inlet, immediately south-west of the West Foreland as shown in Figure 1. The line spanned the four environments that would be encountered in a regional survey; upland, coastal plain, tidal mudflat transition zone (TZ), and marine, as can be seen in Figure 2.

Objectives

The objective was to understand the regulatory environment for Cook Inlet seismic operations and verify that a seismic survey could seamlessly image deep targets in this area across all four operating environments in all four seasons. Operating year-round would allow larger areas to be covered more quickly, and would virtually eliminate the high cost of standby or repeated mobilization and demobilization that would be incurred with multiple smaller campaigns.

Figure 1 - Cook Inlet, showing test line location

Figure 2 - Test line location detail

In addition, we wanted to investigate source and receiver performance and evaluate the effectiveness of recently-
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developed nodal seismic recording equipment in this environment.

Operations overview and timeline

Crew operations began on February 18, 2011 with the first land survey stakes set out using GPS packs. Shot hole drilling started on February 23rd using heli-drills and Nodwell tracked drills in the coastal plain and was completed March 13th. Mobilization and rigging of the marine fleet began in Homer in early March and was complete by March 12th. Layout of land recording equipment began on March 10th, and was completed on March 15th. There was then a waiting period of one week until a high-tide, coupled with a change in the wind direction, floated the near-shore sea ice and drove it away from the test area. In the days that followed both the cable and node lines were laid offshore and positioned, ready for the recording start on March 25th. Shooting the land and marine tests continued until April 1st, after which all marine equipment was retrieved by April 4th with complete crew demobilization on April 5th.

Recording system comparison

Two recording systems were deployed along the entire test line, a cable-telemetry system and a nodal system, both shown in Figure 3. An additional nodal recorder was deployed on a one mile section of line as a system test and to look at the performance of geophones laid out as linear and as bunched arrays.

The standard receiver point interval for both systems was 165’ along the line, except for the onshore nodes which were deployed at 82.5’ intervals to address point-receiver concerns relative to strings of sensors.

The cable-telemetry system was composed of land stations with single strings of six geophones per station onshore and submersible 2-component (hydrophone + geophone) stations in the TZ and offshore. This system was deployed and connected as a single line to a recorder housed in an onshore recording cabin.

Two types of continuously-recording nodes were deployed on the complete nodal line; self-contained, single-sensor land nodes shown in Figure 3 above the high-tide line, and four-component (hydrophone + 3-component geophone) marine nodes, shown in Figure 4, capable of operation in water up to 700 meters deep in the inter-tidal and offshore zones. Timing information to allow the “shot-slicing” of the continuous recorded data into individual record-length receiver gathers was captured by both the land shot-firing and airgun control systems.

Both systems recorded data suitable for our needs. However, the submerged cable system was never 100% operational due to leakage and line faults in the water. The nodal system was the preferred system for future work due to the flexibility of operation, the freedom from physical connection between land and marine systems, and the expectation of 100% up-time in the absence of submerged electrical connections.

Source Test – Land

The majority of recent onshore seismic surveys in Cook Inlet had been acquired using 2 kg explosive charges in shot holes drilled to 25 feet. With deeper targets and longer-offset goals than many of these surveys, a test was carried out using eight different combinations of hole depth and charge size as shown in Figure 5 to establish the effect of larger charges in deeper holes.

Figure 3 - Nodal and conventional recording equipment onshore

At each shot location seven single deep holes and a pattern of shallow holes were drilled and loaded as shown in Figure 5, and this test was repeated every 660’, or four receiver stations, along the line as can be seen in Figure 6.

The test concluded that a 4kg charge at greater than 25’ offered better signal penetration, but drilling to depths greater than 35’ rarely permitted loading to depth, leading to the selection of 4 kg at 35’ as the optimum source parameters for future work.
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Source test - Marine

A shallow-draft jet-driven gunboat was equipped and mobilized as the source vessel for all tests. The offshore portion of the test line was shot multiple times with two basic source array types configured with five different source volumes. These ranged from a 440 in$^3$ ultra-shallow water array to a combination of two 1,200 in$^3$ arrays for a 2,400 in$^3$ array, all operating at 2,000 psi.

The results of the test, when the data was stacked and compared, showed that for the deeper targets of the program there was a definite correlation of array volume to signal penetration, and thus the largest array was selected for use in future 3-D acquisition.

Tidal noise evaluation

Prior offshore and TZ surveys in Cook Inlet had limited recording operations to slack-tide periods in order to eliminate current noise from receivers on the sea floor, limiting recording operations to 3 or 4 periods a day each of about 3 hours. There was a major operational and economic benefit to be had if it could be shown that final processed data were not adversely affected by current noise.

Two of the seven deep-hole shots in each onshore shot test set were programmed to be shot at times of high current noise, in addition to airgun lines that were acquired during these times. During the test period, Cook Inlet’s strongest currents, which can exceed six knots, did not occur; consequently data was only collected in currents up to about four knots. These periods were predicted from tide tables, and the noise monitored in real-time by the cable-telemetry system laid out offshore.
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When these data were processed no adverse effects from the current noise were observed, thus opening up the time windows in which recording should be possible. The Inlet’s strongest currents are however still expected to limit layout, retrieval, and gunboat operations.

**Receiver comparison**

Along a one mile section of line, two additional receiver types were deployed alternately at 165° intervals to allow evaluation of point receivers versus arrays, three versus six geophones per station in linear arrays, and bunched arrays of 3 geophones. Despite the theoretical signal to noise improvement of all the multi-sensor combinations, data recorded by the point-receiver self-contained node was comparable to that of the other systems, which when combined with the operational benefit of its form and weight, made it the ideal choice for future surveys.

**Conclusions**

The test program was a success in that it answered all the initial objectives set:

i. Permits required for the acquisition of the 2-D seismic line were acquired from the controlling agencies,

ii. The subsurface was successfully imaged across the four environments encountered along the test line as shown in Figure 7,

iii. Comparison of all the test datasets allowed the selection of optimum onshore and offshore source parameters for a future 3-D survey,

iv. Regional multi-year 3-D survey operations were considered feasible using the nodal recording system as tested.

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![Figure 7 - Migrated stack of 2-D test line](image-url)