DEEPA

Deep Probe Refraction Experiment 1995:

Field Acquisition and Preliminary Data Processing Report

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Summary

The 1995 Deep Probe experiment was an active source seismic experiment conducted in collaboration with the Canadian Lithoprobe project along a line extending from southern New Mexico to Great Slave Lake, a total distance of 3000km (Figure 1). The experiment was designed to investigate the crustal and upper mantle structure to depths of up to 400km beneath the line, which encompasses tectonic environments ranging from Phanerozoic orogenic belts in the south to Archean cratonic regions north of Wyoming. Ten shots at seven different shotpoints, with sizes ranging from 2400kg to 17500kg and located from 33° N to 61° N were recorded into two arrays of 750 portable seismographs. The seismographs were deployed along a north-south line from central Alberta to northwestern New Mexico with a station spacing of 1.25 km in the US and 2 km in Canada.

Participants in the experiment included scientists and technical support personnel from Rice University, University of Texas at El Paso, Purdue University and University of Oregon in the USA, from the Universities of British Columbia, Alberta, Saskatchewan, and Victoria in Canada and several institutions in Europe as well as from the Geological Survey of Canada, *LITHOPROBE*, the United States Geological Survey and the Incorporated Research Institutions for Seismology Program for Array Seismic Studies of the Continental Lithosphere (IRIS PASSCAL.)

Preliminary results from the experiment are published in *Deep Probe Working Group* (1998) and *Snelson et al.* (1998).

This report starts by providing a summary of the survey rationale, goes on to detail the field procedures used prior to and during the acquisition of the refraction data set, and concludes by summarising the post-experiment steps that were required to merge the data collected into a useable form.

1. Introduction

Two controversial aspects of continental geodynamics are:

1) the mechanical and chemical nature of the part of the Earth which lies below the continental crust and above the asthenosphere, and

2) the role of this layer in vertical motions that intermittently influence the interiors and margins of continents (Ross and Kanasewich, 1992).

3) The role that preexisting lithospheric structure plays in determining large-scale tectonics.

In physical terms this layer can be referred to as the sub-crustal lithosphere, or in chemical terms as the upper mantle. The purpose of the Deep Probe refraction seismic experiment is to gather and interpret direct physical information on the properties of the deep (~50 - 450 km) sub-crustal lithosphere from two specific zones of interest in western North America: the Medicine Hat Block in southern Alberta and the Colorado Plateau / Southern Rocky Mountains. The complementary crustal-scale Southern Alberta Refraction Experiment (SAREX), probes shallower (<50 km deep) regions.

1.1 Regional Tectonic Settings

In southern Alberta, Canada, the hydrocarbon-rich Western Canada Sedimentary Basin has been deposited over a crystalline basement which is a subsurface extension of the Canadian Shield. It has become possible to subdivide this basement into distinct domains through the use of potential field data (Figure 1), U-Pb geochronology of basement drill cores recovered during petroleum exploration, and geochemical studies of crustal xenoliths (Ross *et al.* 1989; Villeneuve *et al.* 1993).

The current interpretation of the domainal structure of the basement is shown in Figure 2. Three main Archean provinces are identified: Rae, Hearne, and Wyoming. In northwestern Saskatchewan on the exposed Canadian Shield, the Rae Province is separated from the Hearne Province by the Snowbird Tectonic Zone. In north-central Montana, the Hearne was thought to be separated from the Wyoming Province by the Great Falls Tectonic Zone, but the more significant boundary now appears to be the Vulcan tectonic zone. As a group, these three provinces are separated from the Superior Province to the east by the Proterozoic Trans-Hudson Orogen. To the west, the Hearne and Wyoming Provinces abut the Eastern Cordillera. However, the nature of the autochthonous basement domains west of the Front Ranges is difficult to determine due to the masking effects of the Cordillera.

The Hearne Province itself has been subdivided into several units (Figure 2). Centred in the southeastern corner of Alberta, the Medicine Hat Block (MHB) is characterized by a NNW-trending fabric of narrow positive and negative aeromagnetic anomalies of moderate intensity. The boundaries of the MHB can be clearly seen The areal extent of the MHB corresponds closely to that of an overlying paleogeographic feature in the sedimentary section named by Deiss (1941) as Montania. The 1.5 billion year sedimentary record deposited on the MHB shows persistent differences from the sediments deposited on the adjacent domains and indicates that the region has behaved as a paleotopographic high with respect to the surrounding crust. In addition, there is strong evidence for reactivation in the bounding structures to the north (the Vulcan Low) and the south (the Great Falls Tectonic Zone) (O'Neill and Lopez 1985; Hoy 1982).

To the south of the Wyoming province the Cheyenne Belt separates Archean crust from Proterozoic accreted terranes interpreted as island-arc sequences. There is also a significant mantle boundary between high velocity to the north, and low to the south and a transition between relatively low elevations in northeastern Wyoming and high elevations in western Colorado and to the south-west as can be clearly seen in Figure 1. The Colorado plateau in particular is an intriguing feature in that it has been uplifted 1 - 2 km compared with its pre-Laramide elevation but remains essentially undeformed and has crust that is too thin to explain the topography. Low-angle subduction of the Farallon plate during the Laramide orogeny may have had an impact in removing part of the previous mantle lithosphere beneath the Colorado plateau thus providing extra buoyancy for the uplift. If this is the case then the profile may sample upper mantle emplaced as young as Cenozoic times beneath Colorado, compared with Archaean lithosphere to the north.

1.2 SAREX and Deep Probe Refraction Seismic Experiments:

In July and August 1995, *LITHOPROBE*, in conjunction with other university and governmental institutions (see Appendix 1) carried out the complementary SAREX and Deep Probe seismic refraction experiments to gather information on the structure of the crust and upper mantle. A location map for the experiments is shown in Figure 3 and statistics on the shot points and instrumentation used are provided in Appendices 2 and 3. The principal investigators of the active source component of the Deep Probe study are:

Purdue University	Larry Braile
Rice University	Alan Levander
University of British Columbia	Ron Clowes and Bob Ellis
University of Texas at El Paso	Randy Keller

SAREX was a crustal-scale refraction survey centred on the Medicine Hat Block. Ten source points ranging in size from 800 to 2400 kg of explosives (see Appendix 2) were positioned evenly along a north-south line from 49 N to ~53 30' N. 661 portable seismographs were deployed along the line at a 1 km station spacing in Canada and 1.25 km in the USA. The recording line extended 320 km into the USA but no shot points were located there.

Deep Probe, which is a collaborative effort between scientists and institutions in Canada and the USA, aimed to gather information on the sub-crustal lithosphere from two geographical foci: the Medicine Hat Block and the lithosphere below the Colorado Plateau / Southern Rocky Mountains. Deep Probe involved two deployments of 756 portable seismographs. Five shots ranging in size from 3000 to 25,000 kg and located from 33 N to 61 N were shot into each of the deployments (see Table 1). The seismographs were deployed along a north-south line from central Alberta to northwestern New Mexico with a station spacing of 1.25 km in the US and 2 km in Canada. This provided source-receiver offsets of up to 3000 km, and focussed the bottoming points of seismic rays at increasing depths beneath the zones of interest. An earthquake source component of the US Deep Probe study was recently completed in the Colorado-Wyoming border region.

Taken together, the SAREX and Deep Probe experiments are arguably the largest refraction study ever undertaken in North America. They involved more personnel (>100) and more instruments (756 field seismometers) than any other survey in the past. A total of approximately 126 tonnes of explosives were detonated at 20 shot points that spread out over 3100 km (8% of the Earth's circumference.)

Figure 1: Map of experimental layout with topography and state boundaries. The blue line shows the receiver array, with stars marking shotpoints.

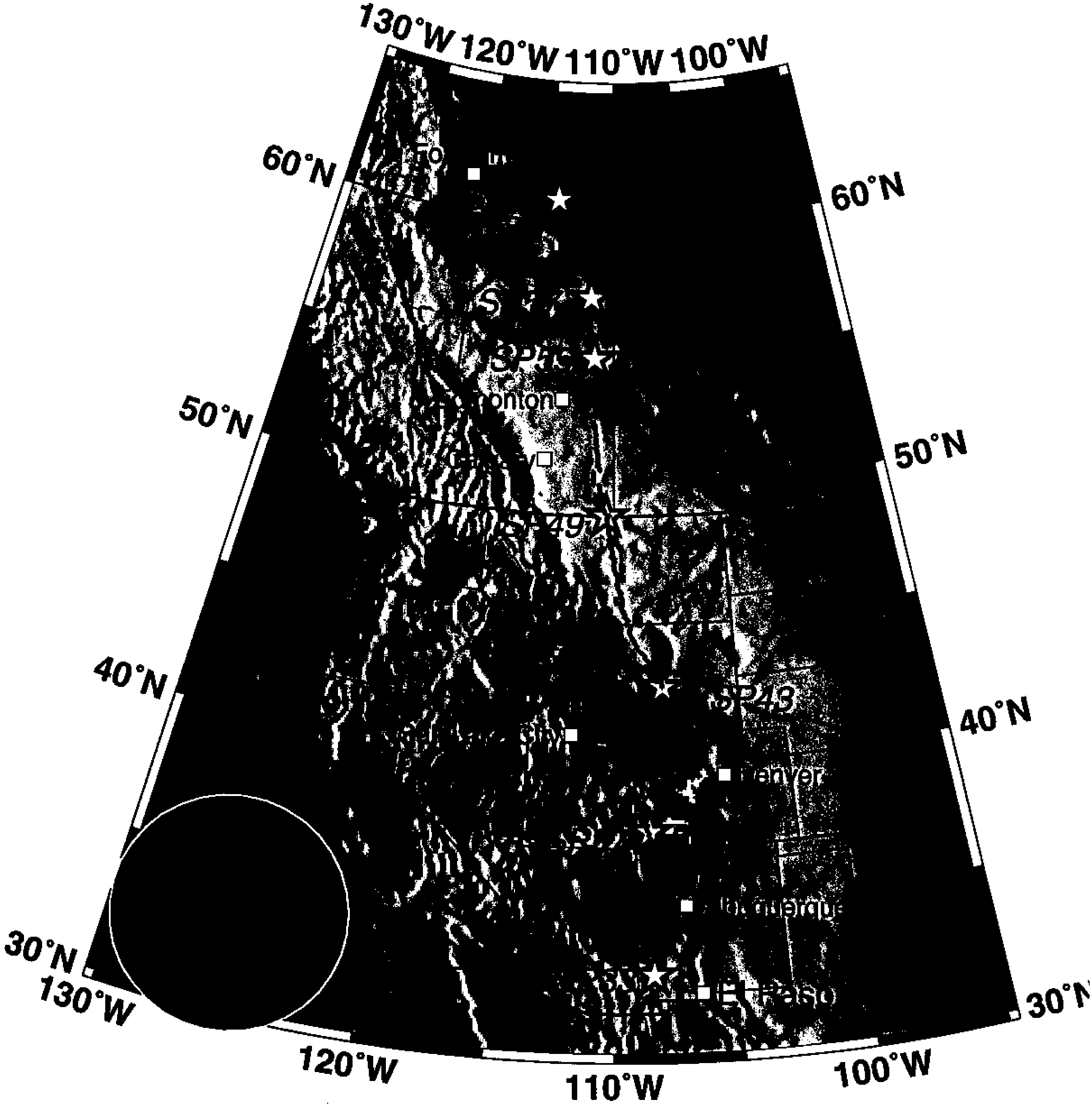
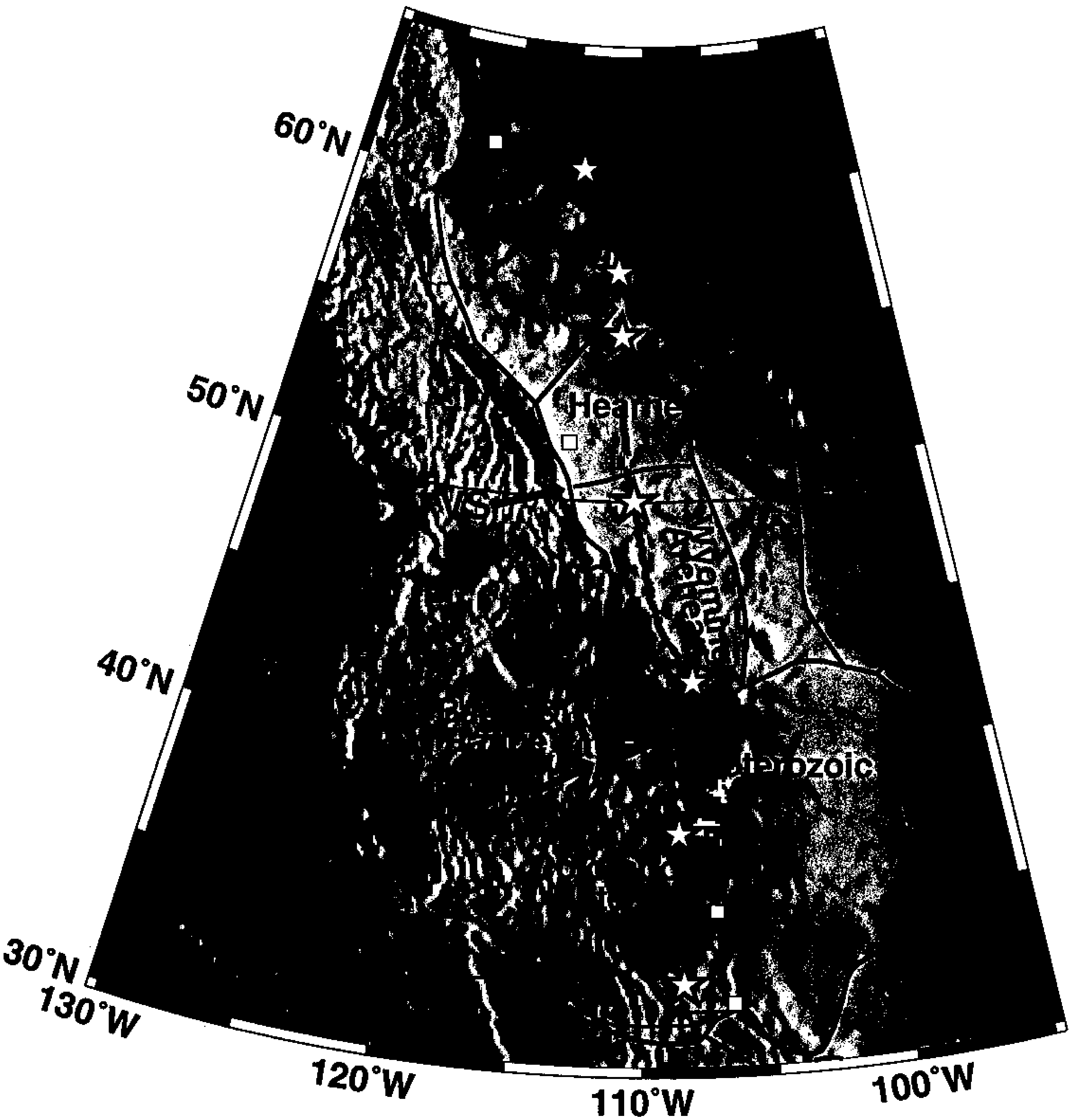


Figure 2: Experimental layout with boundaries between the main tectonic elements sampled in the experiment. VS: Vulcan structure, CB, Cheyenne belt.



2. Preliminary Field Procedures

In the months preceding the acquisition of the Deep Probe and SAREX refraction data, an immense amount of preliminary work was required. The principal investigators and other interested parties met in Calgary, Alberta on 12 April 1995 to establish operational and technical plans. With many of the initial procedures already underway, a second oganisational meeting was held in Salt Lake City, Utah on 20 and 21 June 1995 to finalise arrangements.

The nature and scale of this international experiment required that much of the preparatory and post-experiment work be done separately in Canada and the United States. This report chronicles the work done on both sides of the border.

2.1 Initial Source and Receiver Site Selection

The trajectory of Deep Probe and SAREX was initially laid out to cover the main blocks of the Archean Hearne and Wyoming provinces which underlie the Western Canada Sedimentary Basin and the equivalent sedimentary deposits in the western United States. When the support of the American partners in Deep Probe was established, the trajectory was shifted slightly to the east to avoid the Yellowstone Hot Spot. In addition, the length of the profile was extended to cover more of the southwestern United States.

The final plan called for two deployments of seismographs running along a line from Great Slave Lake, Northwest Territories to Southwestern New Mexico (see Figure 3.) The northern half of the Deep Probe line investigates the Archean part of the North American craton, while the southern half examines tectonically active Proterozoic and younger crust.

2.2 Final Source and Receiver Site Selection / Permitting of Private Lands

After a proposed trajectory was established for the Deep Probe line, source point locations were scouted. In the autumn of 1994, Peter Carroll of *LITHOPROBE* and others visited Alberta and the Northwest Territories to look for suitable sites. The same was done by representatives of Rice University and the University of Texas at El Paso (UTEP) along the American portion of the line.

Canada

Most of the scouted locations were located on private land with the exception of a few located on military bases (Canadian Forces Bases Suffield and Cold Lake) and one on a federal Ministry of Agriculture research ranch. In the spring of 1995, the final selection of shot point locations was made (see Appendix 2.) Landowners were contacted directly and formal permits were drawn up. These permitted sites were surveyed using the same GPS system that was used for positioning seismometer stations along the line.

USA

The three shot point locations in the United States consisted of one privately held active mine, one abandoned mine on public lands, and a small area within a National Forest.

The southernmost shot point location (shot points 133 and 233) in southern New Mexico was located within part of a currently active mine, where Precambrian basement rocks had been exposed by mining operations. Permitting was carried out with the mine owners and the State of New Mexico.

For shot point 237 in the San Juan National Forest in southwestern Colorado, Steve Harder contacted the local Forest Service office in Dolores. Prior to meeting with a forest ranger, a reconnaissance of the area was made to locate possible shot points in areas where the water table might be close to the surface. Two possible locations were determined in consultation with the ranger, one of which was later rejected by the Forest Service on the basis of an archeological survey. A permit was issued for the preferred site.

For the Wyoming shot point location (shot points 143 and 243), a search of abandoned open pit mines was made. Most open pit mines are unusable because they either have no water or the water supports aquatic life. However, the Day Loma Pit in central Wyoming is an abandoned uranium mine with 150 ft. of water in the bottom and virtually no aquatic life, making it an ideal shot point. The Day Loma Pit is on Bureau of Land Management (BLM) land and a permit was applied for and received from the BLM.

2.3 Environmental Permitting

A substantial amount of time was required to obtain all the necessary environment approvals needed for the experiment. Once shot locations were finalised, these positions were submitted to the Albertan, Northwest Territorial and Canadian governments in Canada, and to the appropriate agencies in the USA, as required by the laws of both countries. Obtaining approval in Alberta was especially convoluted due, in part, to the bureaucracy which is entrenched there to deal with petroleum industry exploration. For future experiments, this procedure should be started more than a year in advance of going to the field.

Permits and licences that were received included the following.

Alberta Environmental Protection: Client and Field Services Exploration Licence No. 5089
Science Institute of the Northwest Territories: Scientific Research Licence No. 12765N
Indian and Northern Affairs Canada: Land Use Permit N95X367

Numerous restrictions are routinely placed on drilling shot holes for safety and environmental reasons. In particular, in southern Alberta a zoologist, Dawn Dickinson, was hired to search for endangered prairie species such as the burrowing owl and swift fox in the vicinity of proposed locations. None was found.

In the USA, there were two specific environmental concerns. First, as previously mentioned, during the selection of shot point 237 in the San Juan National Forest in southwestern Colorado, an archeological survey was required to ensure that any indigenous American archeological sites were left untouched. Second, at the Wyoming open pit mine site, it was noted that raptors nested in high walls of nearby abandoned mines. No nests were found in the high walls of the Day Loma Pit. Other permits required in the US included the National Forest Service, the Bureau of Land Management, state Highways Departments (Montana, Wyoming, Colorado and New Mexico), the New Mexico Department of the Environment, and the Bureau of Indian Affairs.

2.4 GPS Surveying of Source and Receiver Locations

Starting at the end of May 1995, source and receiver locations were positioned using the **Global Positioning System** (GPS). The GPS hardware and software package used by both Canadian and American surveyors was the **Trimble Pathfinder** system. The Canadian system was provided by the Geological Survey of Canada and the American system by IRIS / PASSCAL. Stakes were set up at each receiver location and annotated with the station number. Road logs were constructed so that instrument deploying teams could locate the stations easily from their deployment vehicles.

Using the Trimble Pathfinder system, approximately 40 to 50 stations could be positioned by a single survey team each day. Four to five minutes of GPS readings were recorded at each location (about the time it took to hammer in the stake and update the road log on the field PC.) The field GPS unit was a six-channel system running in 3-D mode which means that it required information from four GPS satellites at all times. Readings were recorded every 5 seconds. Each evening, the measurements were downloaded from the field *polycorder* computer to a PC and backed up on disk. A separate GPS base station provided survey information at known geographic locations so that differential processing could be applied to the data to improve the accuracy of the measurements (see Section 4.1.) Once differential processing was complete, the accuracy of the recorded position should nominally be within 5 m horizontally and 10 m vertically.

Stations surveyed by UTEP and Rice were located using a GPS field system which included rover recorders and a base station system that could be temporarily installed within the survey region. The base station location is then obtained by long-term (7-14 day) averages of GPS locations or from USGS 1:24000 topographic maps. In this study base station locations from the two methods typically agreed to within 30 m laterally and 10 m vertically. Following the merging of the survey data quality control included large scale plots of station locations and elevations.

The complete set of geographical location data is located in Appendix 8. Receiver locations in the 1000 - 2999 range were surveyed by UBC, 3000 - 4999 by UTEP and 5000 - 5999 by Rice. 9000 series stations correspond to the like-numbered 1000 series stations, but lie along the west side of Canadian Forces Base Suffield instead of through the middle of the base. They were also surveyed by UBC.

2.5 Drilling and Loading of Source Locations

Canada

The drilling and loading of source positions started well in advance of the deployment crew's arrival in the field. Numerous companies were involved in the drilling. The companies involved were:

Garrity and Baker Drilling, Edmonton, Alberta
Camfield Drilling, Lethbridge, Alberta

In most cases, holes were drilled to a maximum of 50 m by conventional drill trucks, similar to those that would be used for drilling water wells. Depth depended in part on the amount of explosive that would be inserted into the hole and also on the diameter of the drill used. In most cases 10 inch bits were feasible. PVC piping was used at many locations to case the upper part of the hole to prevent collapse.

The explosives contract was awarded to Western Explosives of Calgary, Alberta. The low density (1.3 g/cm3) explosive, Blastex, produced by Dyno-Nobel of Salt Lake City, Utah, was delivered to the site in 20-kg sausage-shaped bags. These were lowered one by one into the hole until the required charge size was reached. Under optimal conditions, these bags of explosives should all be in contact with each other. They are all linked using Cordtex (40 grains/foot) explosive cord with four or five 1-lb booster charges (Trojan Cast Booster) attached along the length of the explosive.

It is now known that in several instances, this method for loading the holes was not as successful as it should have been. At several shot points (particularly Deep Probe shots 257 and 261) it is known that there was not complete detonation of all the explosives.

USA

At shot point 133 and 233 in southern New Mexico, ground conditions in the vicinity of the shot point were extremely variable due to differences in fractures and weathering. The ground surface was saturated with water flowing from some of the fractures, and from a number of test wells drilled by the mine. Shot holes were drilled with a diameter of 8 inches to a nominal depth of 150 ft, but locations and final depths were determined by the local conditions. Water was encountered in a number of the wells at inconsistent depths; wells were cased using PVC as required. Shot 133 consisted of 15,000 kg in 15 holes, and 233 of 17,000 kg in 17 holes. The holes were filled with an ammonium nitrate-fuel oil slurry.

At shot point 237, three 8 inch holes were drilled to a nominal depth of 150 ft. Water was encountered at approximately 30 ft and the upper 20 ft of each hole were cased with steel casing. Holes were drilled in a line perpendicular to the Deep Probe trajectory with a 60 ft spacing. The holes were each loaded with 1200 kg (total 3700kg) of emulsion, a slurry of ammonium nitrate and fuel oil. After the shot was detonated, the holes were back filled with drill cuttings and plugged with bentonite.

In Wyoming, at the location for shot points 143 and 243, a shot was planned to coincide with the SAREX deployment in Canada and Montana. This shot failed. The explosive was delivered in 25kg bags of emulsion which were then packed into larger bags totalling 200 kg each with boosters and detonating cord. A total of 12,000 kg were packaged in this way. Each bag was then carried by helicopter from the edge of the pit and dropped into water in an array as closely as the pilot could manage. Two problems were identified with this method, the expense of the helicopter and the fact that the detonating cord did not deploy properly from all bags. This first batch of explosive was insensitive to the high explosive boosters and therefore did not detonate.

For shot points 143 and 243 a second batch of emulsion was ordered, this time it was delivered in bulk and was pumped directly into the larger bags in which boosters and detonating cord were placed. The bags, containing up to 1100 kg of emulsion each, were suspended from a large inner tube and loaded in the water. The inner tube and bag were towed to the desired location, the bag was released from the inner tube and the detonating cord was played out from the tow boat. This method was less expensive and faster than the helicopter method. Both shot charges of 7000 kg each were loaded in the way.

Emulsion from the first batch is still on the bottom of the pit. Recent water samples from the pit indicate there are elevated levels of nitrates in the pit. Since there is no aquatic life in the pit this is not seen as an environmental problem. Clean up at the pit consisted of skimming the water for plastic remains of emulsion bags and buoys.

2.6 Public Relations

In Canada, public relations for the experiment were handled by ***LITHOPROBE***'s public relations consultant, Horst Heise of Calgary, Alberta. In addition, general information was distributed to the major daily and weekly newspapers in Alberta and the Northwest Territories, and also to the main radio and television stations in the province. Several articles appeared in the print media and a television news segment was produced in Medicine Hat.

In the United States, public relations were handled by Rice and UTEP. The local media were often interested in the experiment and interviews with our scientists appeared in numerous newspaper articles. Positive stories included the Washington Post, Boston Globe, Billings Gazette, and the Los Angeles Times. Adverse publicity appeared in the Santa Fe New Mexican

2.7 Other Administrative Concerns

The headquarters for the experiment were determined and set up well in advance of the arrival of the deployment teams. Excellent facilities were found in each of the four towns or cities that acted as our headquarters.
Specific concerns that needed to be addressed with the headquarters included finding facilities that could accommodate all the necessary equipment and personnel with adequate access and electrical power capabilities. The following table lists the facilities that were used.

Town / City	HQ Location	Accommodation
Medicine Hat, AB	Medicine Hat College	Medicine Hat College Residences
Billings, MT	County Fair Grounds	Airport Metra Inn
Rock Springs, WY	Rock Springs High School	Inn at Rock Springs
Grand Junction, CO	West Middle School	The Peach Tree Inn

Additional accommodation was occasionally used during the actual deployment of the seismometers by teams that were working a long distance from the headquarters location.

3. Data Acquisition

SAREX and Deep Probe data were acquired during the period of 28 July to 14 August 1995. Appendix 7 outlines the daily schedule of the experiment.

3.1 Seismometer Deployment

Six different field instrument systems were used to record SAREX and Deep Probe. They came from a variety of sources and each type had its own idiosyncrasies (these are discussed in section 3.2.) Each of the deployments of SAREX and Deep Probe required two support locations (headquarters) due to the distances that deployers needed to travel.

In the morning of deployment day, the programmed seismographs were picked up at the headquarters and driven in vans or trucks to their preassigned locations. The procedure for setting up a temporary seismograph station in the field differs depending on the instrument type, but the main steps were:

1) locate the survey stake corresponding to the desired station number.
2) select a position within a few metres of the stake where the seismograph instrument box can be positioned free from natural and man-made hazards.
3) record identification numbers of all instruments left at each station in a field log.
4) dig a hole or holes to bury the geophone(s). A depth of at least 50 cm or a location on bedrock is optimal.
5) position and level the geophones in the holes and attach them to the instrument box.
6) carefully bury the geophones to ensure good coupling with the ground.
7) tidy up the site to ensure that it will not be disturbed by animals or people during the period of data collection.

The instruments were deployed either by single deployers or by teams of two people. The number of people required depended on the instrumentation type being used and safety considerations. Most of the stations were located on public rights-of-way or ditches along secondary roads. Between 20 and 40 stations were deployed by each deploying unit during the day.

All shots were fired in the night (or at sunrise in the case of the shots in New Mexico and Wyoming) in order to minimise cultural noise (cars, trucks, trains, other human activity.)

The following morning, the deploying units returned to the field to pick up the instruments. These were brought back to the headquarters where the information was collected.

3.2 Timing Corrections

Chronometers are an integral part of the field instrumentation used for refraction seismology. Both the seismometers and the shooter boxes contain very accurate clocks that are set using satellite information before they are deployed in the field. However, in the few hours that these clocks remain in the field, their accuracy may start to degrade. This inaccuracy often is in the order of several milliseconds per day. It is therefore vital that the instruments be returned to the headquarters as quickly as possible to estimate the error that is present in the recordings. This is generally done by assuming a linear drift in the degradation of the timing.

Both shot time corrections and seismograph clock drift must be accounted for in order to have accurate timing information for the data. Both the shot time corrections and the seismograph clock drifts are applied in the SEG-Y headers of the data. In the case of the seismograph clock drifts, this can be done:

by modifying the start time of the trace to reflect the clock drift.
by including the clock drift as a defined header word which can be utilised later.

For this experiment, all seismograph clock drifts have been incorporated into the trace start time shown in the headers. The drift time used for each instrument is stored in trace header word cor (bytes 217-218). This is for informational purposed only and no further processing is required.

3.3 Field Instrumentation

Six different types of instruments were used during these experiments. These are briefly described below.

3.3.1 PRS-1 Number Used: 182 Owner: GSC

The **Geologic Survey of Canada** developed these *Portable Recording System* instruments specifically for use in large scale refraction surveys. The field unit is programmed by one of several PC's running LithoSEIS software in the field headquarters and then attached to a geophone at the deployment site. For these experiments, L-4 1Hz geophones from *Mark Products* were used. The PRS-1 instruments record only one channel (the vertical component) of data in solid state memory. The recorded information is uploaded to the save field PC that programmed it once it is returned to the field instrument centre. The data for all the PRS instruments is then compiled in SEG-Y format and archived on exabyte tapes.

3.3.2 **PRS-4** Number Used: 34 Owner: GSC

These instruments extend the abilities of the PRS-1 instruments by including the ability to record three components. They also have a triggering ability which enables them to be used in earthquake seismology experiments.

3.3.3 **RefTek** Number Used: 260 Owner: IRIS-PASSCAL

These instruments are manufactured by *Refraction Technology Inc.* (hence the name) and have been provided by the **Program for Array Seismic Studies of the Continental Lithosphere** (PASSCAL) of the **Incorporated Research Institutions for Seismology** (IRIS). The field units are programmed by a palmtop computer at the HQ and then attached to a three-component geophone at the deployment site. Some of the RefTek units contain GPS receivers and are therefore capable of avoiding clock drift problems. All the RefTek units recorded GPS pulses at the time of deployment and recovery, minimising the period over which clock drift may occur. (At the time of the experiment, the software was not yet available which would let the unit calculate an accurate geographic position.) L-28, L-22, S6000 and S6000CD geophones were used. Note that the L22, S6000 and S6000CD are 2Hz geophones, whereas the L28 is a 4.5Hz phone. The location of instruments with particular geophones was chosen to maximise response coherence through the recording array. The RefTeks record their data on disk, which enables long recording times. When the instruments were returned to the field headquarters, the information was uploaded to a Sun Sparcstation for compilation processing. Data were archived to exabyte tapes.

3.3.4 **SGR** Number Used: 185 Owner: Stanford

These *Seismic Group Recorders* were provided by the **United States Geologic Survey**. The SGRs were developed by Amoco and built by Globe Universal Sciences, Inc. They have an overall frequency response of 2 to 200 Hz and a theoretical dynamic range of 156 dB. The deployment process is similar to that of the PRS instruments. L-4 and L-28 geophones from *Mark Products* were used with these instruments. Data are recorded in digital format on specially designed tape cassettes that are removed from the instrument and read into a Everex System 1800 microcomputer upon return to the field headquarters. The compiled data are archived on 9-track tapes.

3.3.5 **SCR** Number Used: 75 Owner: USGS

The **United States Geologic Survey** also provided the *Seismic Cassette Recorder* instruments. Again, the deployment process is similar to that for the PRS instruments, although more manual work is required in selecting settings on the boxes. The SCR system passes the output from the geophone through three parallel amplifiers, each with a separate manually adjustable attenuation setting. L-4 geophones from *Mark Products* were also used with these instruments. The data are recorded in FM analogue format on conventional audio cassette tapes. After the experiment, the data were digitised and compiled at the USGS office in Menlo Park, California for further display and processing. They were archived and distributed on exabyte tapes.

3.3.6 PDAS   Number Used: 20   Owner: GFZ-Potsdam

These *Portable Data Acquisition System* instruments were provided by **GeoForschungsZentrum Potsdam,** Germany. They are manufactured by *Teledyne Brown Engineering* (formerly Teledyne Geotech) and record in solid state memory and an on additional hard disk. The geophones used by the PDAS instruments were *Mark Products* L-4C-3D. The clocks in the instruments are TCXO temperature compensated crystal clocks which were synchronised by GPS every four hours. These data were compiled at GFZ-Potsdam and made available via the internet.

3.4 SAREX

(For information only - these data are archived separately)

The Southern Alberta Refraction Experiment (SAREX) had headquarters in Medicine Hat, Alberta and Billings, Montana. To simplify the procedures involved with crossing the international boundary, deploying teams did not cross the border. (*i.e.*, deploying teams in northern Montana were based in Billings even though they were geographically much closer to Medicine Hat.)

Early in the morning of 2 August 1995, the ten SAREX shot points were detonated in southern Alberta (see Appendix 2.) These were located at approximately 50 km intervals along the line from the Canada - USA border (49 N) to the North Saskatchewan River (~ 53 30' N). Due to land permitting problems, shot point 007 had been cancelled in the weeks before the experiment.

The University of Saskatchewan and *LITHOPROBE* provided the personnel for firing the shots. Each shooter had two or three shots assigned to him. All of the shots were successful electronically initiated, chronometer controlled detonations. Weather conditions on the night of the shot were good, although isolated thunder storms did occur.

UTEP attempted to detonate three small charges at a mine site near Riverton, Montana for recording by the SAREX array. These shots were unsuccessful.

Of the 661 stations deployed, 622 stations were successful in recording data, representing a success rate of 94.1%.

3.5 Deep Probe

3.5.1 Deployment 1

This first deployment of the Deep Probe experiment used the same headquarters locations as SAREX. However, some of the personnel who had been stationed in

Medicine Hat for SAREX moved to Billings for Deployment 1. Only the PRS instruments were deployed north of the Canada - USA border during Deployment 1. Early in the morning of 9 August 1995 the five Deployment 1 shot points (100 series shots) were detonated (see Appendix 2.) The last two digits of the shot point number correspond to the approximate latitude of the shot.

Weather conditions in southern Alberta and northern Montana on the night of the shots were quite poor. Wind speeds were very high along several hundred kilometres of the line. The increase in wind generated noise is noticeable when compared to the SAREX data and deployment 2.

Of the 756 stations deployed, 706 stations were successful in recording data, representing a success rate of 93.4%.

3.5.2 Deployment 2

For the second deployment of Deep Probe, the headquarters locations were moved south to Rock Springs, Wyoming and Grand Junction, Colorado. Ground conditions in Wyoming, Colorado and New Mexico in general were much rockier; digging holes to bury geophones was an arduous task. To compensate, two days were set aside for preparing site locations prior to the actual deployment day.

Early in the morning of 17 August 1995 the five Deployment 2 shot points (200 series shots) were detonated (see Appendix 2.) Again, the last two digits of the shot point number correspond to the approximate latitude of the shot.

Weather conditions along the line for this deployment were generally good, with the isolated sites showing background ground velocities of less than 10nm/s. Unfortunately, the two most northerly shot points (257 and 261) had incomplete detonations and as a result, the signal strength from these two points was reduced.

Of the 733 stations deployed, 699 stations were successful in recording data, representing a success rate of 95.4%.

3.6 Clean-up

Post survey clean-up was undertaken wherever our activities affected the surrounding countryside. At all shot point locations, except those located in active mines and on military bases, it was a condition of the permit that clean-up be done. This involved filling any resulting holes or craters and removing any debris (such as PVC piping) ejected from the shot hole. In some cases, contractors were hired to perform this reclamation work. At seismograph station locations, geophone holes were refilled and any visible signs of the experiment (*e.g.*, stakes and flagging) were removed.

4. Post-Experiment Procedures

The procedures detailed in this section are those that were used by Rice University. Merging of field data sets was done using the ProMAX softare from Landmark Graphics The field data were also merged independently at University of British Columbia using the PLOTSEC software. The procedure followed there mirrored that which was done at Rice, but is not specifically discussed in this report.

4.1 Finalisation of Geographical Survey Information

The first step completed after returning from the field was to create a final geographical survey file for all the source and receiver locations used. In most cases, Global Positioning System (GPS) information was used to position field locations (see section 2.4). In order to increase the accuracy of the GPS measurements, base stations were recorded at known geographical locations so that differential calculations could be conducted. This resulted in reduced values for the geographical locations that are deemed to be accurate to within 5 m horizontally and 10 m vertically. The data are all reduced using the standard North American Datum of 1983 (NAD '83.)

The software used to reduce the survey data is included in the Trimble Pathfinder software (PFINDER) that was provided, along with the instrumentation, by the GSC. For the data recorded by the UBC team, the Alberta Department of Transportation GPS Base Station, located in Red Deer, Alberta was used.

See Appendix 4 for a summary.

4.2 Merging of Seismic Data Sets

The lengthy process of combining the different datasets is described in detail below. The major steps were to:

read the various field tapes into the *ProMAX* environment.
update and correct the file header information for each instrument type.
update and correct the trace header information for each trace.
merge various time windows created due to limitations in the various field instruments and recording formats.
merge the data from each instrument type into a single SEG-Y file.

4.2.1 *ProMAX*

Five different types of instruments were used in the field, each with slightly different capabilities, and different raw data formats based on the Society of Exploration Geophysics standard known as SEG-Y. Although intended for processing of conventional reflection data, the ProMAX software is sufficiently flexible to cope with this task.

The overall aim of the processing was to reach a common trace format with a trace length of 600s starting at the true shot instant, to give maximum flexibility in analysis of the data. This breaches many implementations of SEGY, which typically assume a SEGY trace can be described by a short (2-byte) integer, hence the data were split into shorter traces during field reduction. A common sample interval of 8 ms was also selected, in some cases requiring resampling from the field records. This affected the data from the different instruments in the following ways.

Reftek: originally recorded at 8ms with a continuous window: broken into consecutive segments during the field data reduction and recombined in ProMAX.

PRS: originally recorded at 120 samples per second (approx. 8.3333 ms), with files segmented during the field reduction process.

SCR: digitised from analogue field tapes at a 5 ms sample interval, and a variable recording start time.

PDAS: originally recorded at a 10 ms sample interval, supplied as short traces with reduction applied.

SGR: recorded multiple windows of 50-96s length for each shot, with start times determined by distance from the shot, padded and combined in ProMAX.

Some inconsistency is present in the actions of the different field reduction software packages when data are not present for a given recording window. This is particularly true of the SCR and SGR instruments which were more likely to complete only part of the recording program; traces in the merged dataset reflect these differences, and in a few cases data from any given recording station may be present only for a subset of the shots.

4.2.2 Gain

Final gain corrections have not been applied to these data. Each instrument - geophone combination results in a different amplitude being recorded. Corrections have been applied during processing for the different preamplifier gains used in the field, but not for the individual geophone motor constants. For the PRS, SCR, and PDAS instruments the motor constants are applied as part of the field data reduction process, and the data already nominally give ground motion in nm/s.

Instrument type	Geophone type	Motor constant to apply
PRS	L-4	1
RefTek	L-22	$1.136\ 10^7$
RefTek	L-28	$3.289\ 10^7$
RefTek	S6000	$5.556.\ 10^6$
RefTek	S6000CD	$3.571.10^6$
SGR	L-4	$1.90464\ 10^7$
SGR	L-28	$3.289\ 10^7$
SCR	L-4	1
SCR	L-28	1

PDAS	L-4C-3D	1

Some gain concerns remain and will be evident in the data. The locations of L-4 and L-28 geophones within the SGR deployments for Deep Probe are not known. However, most (>90%) are L-4 phones. Empirical observations show amplitudes that are 4 to 10 times larger than those expected in some instances. The reason for this has not been determined and for this reason, true amplitude plots should be treated with suspicion for these traces. A similar problem seems to affect the 20 PDAS instruments. Although the data should have a similar amplitude to those from neighbouring instrument types, they seem to be approximately one order of magnitude greater than what is expected. Again, the reason for this has not been ascertained, but empirical observation suggests that they are all scaled by the same amount. Particular problems with amplitude inconsistency are seen in the horizontal components due to a combination of equipment and deeployment issues.

4.2.3 Updating SEG-Y Headers

The final data are all saved using the PASSCAL extensions to the SEG-Y header definitions. Appendix 5 details the nature of each header word as used specifically in this experiment.

The major updates from the field information that were required globally were:

shot and receiver survey information. These data were compiled in SEG-P1 format files that could be accessed by FORTRAN code written to interface with the ProMAX geometry database. The geometry was calculated assuming an equatorial radius of 6371km, and ratio of polar to equatorial radius of 0.9932315. Latitude and longitude are contained in the trace headers in units of 0.01 arc-second, with offset in m. A CDP number was also defined as the location of the midpoint in km north of SP33. Stations to the south of a shot have a negative offset.

correction of taper information the SEGY definition is ambiguous on the nature of how trace start times and trace full amplitude times (the headers ProMAX refers to as TLIVE_S and TFULL_S) and their equivalents at the end of the traces should be handled. Typically these have different meanings on different processing systems, and both start times were set to 0, with end times set to the full trace length.

4.2.4 Merging Data and Creating Final Data Sets

Once all the headers from the various instrument types were updated, the data were merged into a single file (shot point gathers). At this point the data contain all the data recorded for a specific shot point and deployment. SEG-Y files were created from these final data sets in several different formats, including raw files containing the full trace length, and files with either reduction and time-windowing, or with additional subsampling to 32ms to allow the most important parts of the data to be accessed using trace lengths within typical implementations of the SEGY standard.

These final tapes are available through the *LITHOPROBE* Seismic Processing Facility at the University of Calgary and the IRIS Data Management Center in Seattle. Appendix 7 lists the specifications of the available files.

5. Acknowledgements

The Deep Probe and SAREX experiments were undertaken with the generous help of numerous volunteers, scientists, academic and governmental institutions. Primary funding for the study came from the National Science Foundation Continental Dynamics program and the Air Force Office of Scientific Research in the US, and from the National Science and Engineering Research Council in Canada.

The initial concept for these experiments was proposed by Ernie Kanasewich at the University of Alberta and Gerry Ross at the GSC - Calgary. Much of the preliminary organisation and permitting was conducted by Peter Carroll of the *LITHOPROBE* Secretariat at UBC. The selection and permitting of shot point locations were handled by him, and the frustrating burden of obtaining environmental approvals often fell into his lap too.

Preliminary survey work was conducted with the assistance of Shawn Rastad from UBC. The GPS system used was borrowed from the GSC and after a few initial hiccoughs, worked very well. Don Smith, at the Alberta Department of Transportation office in Red Deer, provided base station information. Michael and Jackie Gorman and Jane and Richard Galway in Calgary provided numerous nights of free accommodation and meals. In the US additional survey work was carried out by Peeter Akerberg, Satish Pullammannapallil, Steve Harder and Cathy Snelson using the IRIS/PASSCAL GPS system.

Source location drilling and explosives loading in Canada were monitored with the assistance of Tim Cartwright of *LITHOPROBE* and Don Smith of the GSC. The assistance of numerous farmers whose lands were used for the shot points is greatly appreciated. In the US, Ed Criley, Tom Burdette, and Grey Jensen of the USGS, Steve Larkin of Rice, and Steve Harder of UTEP were primarily responsible.

Countless people were of assistance to us at the four headquarters locations that we occupied. In Medicine Hat, a special thanks goes out to Judy Reid, Aileen Lesley and Carol Montane who helped us set up headquarters and accommodations at Medicine Hat College. The motel staff in Billings, Rock Springs and Grand Junction are also owed much thanks.

The field personnel from the GSC (Isa Asudeh, Tim Cartwright and Blake Wright), the USGS (Tom Burdette, Ed Criley, Don Farrel, Gray Jensen, and Will Kohler) and IRIS-PASSCAL (Marcos Alvarez, Bill Koperwhats, Steve Michnik, John Webber, and Anthony Wei) did a great job of co-operating with each other and organising the various deployment groups. Theirs is often a thankless task, but their technical know-how and experience are vital in an experiment such as this.

Lastly, a great thank you goes out to all the volunteers from various academic institutions in North America and Europe who gave of their time to dig holes in the prairies, mountains and deserts of western North America This great research effort could not have been undertaken without you. We have attempted to list all of these people in Appendix 1; if we have missed any, our apologies.

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Appendix 1
Deep Probe Personnel

Canada (44)

University of British Columbia (20)

Ron Clowes
Bob Ellis

Peter Carroll*
Dave Daird
Scott Dodd
Charly Bank
Christine Erbe
Andrew Frederiksen
Andrew Gorman
Phil Hammer
Brad Isbell*
Costas Karavas
Kevin Kingdon
Denise Long
Holger Mandler
Reingard Mandler
Wendi Milner
Shawn Rastad
Weimin Zhang

* *LITHOPROBE* Secretariat

University of Alberta (6)

Bill Briskie
Michael Burianyk
Jeremy Gallop
Neil Hibbard
Len Tober
Lei Wei

University of Saskatchewan (8)

Zoli Hajnal
Alex Bezdan
Brad Carr
Hendrick Holmes
Chris Milne
Balazs Nemeth
Tim Prokopiuk
Pal Redly

University of Victoria (5)

George Spence
Bernard Desmons
Joe Henton
Jeff Whittsell
Tianson Yuan

Geological Survey of Canada (Ottawa) (3)

Isa Asudeh
Tim Cartwright
Blake Wright

Lithoprobe Seismic Processing Facility (University of Calgary) (2)

Kris Vasudevan
Arie van der Velden

USA (50)

IRIS - Passcal Consortium (5)

Marcos Alvarez
Bill Koperwhats
Steve Mitchnick
John Webber
Anthony Wei

University of Oregon (2)

Dennis Fletcher
Randy Palmer

Purdue University (3)

Larry Braile
Mark Davidson
Mohammed Sufi

Rice University (6)

Alan Levander

Peeter Akerberg
Tim Henstock
Lisa LaFlame
Steven Larkin
Satish Pullammanappallil

Stanford University (2)

Brian Hicks
Curt Holden

University of Texas at El Paso (21)

Randy Keller
Steve Harder
Kate Miller

Allison Bruce
Dave Bruner
Jesus Chavez
Brian Darby
Paul Dial
Alex Duran
Bashir Durrani
Jose A. Granillon
Bill Keller
Fiona Kilbride
Graeme MacKenzie
Carlos Montana
Terry O'Donnell
Silas Simiyu
Bill Smith
Kathy Snelson
Aloyce Tesha
Julie Whitelaw

United States Geological Survey (8)

Tom Burdette
Mike Carpenter
Ed Criley
Don Farrel
Edward Gray Jensen
Tilo Kaspar
Will Kohler
Walter Mooney

Others (3)

Tom Eckman (No Affiliation)
Tom Jefferson (No affiliation)
Frank Lorenz (GFZ-Potsdam, Germany)

Total Field Personnel: 94

Appendix 2
Shot Point Information

Date	Shot Point	Location	Latitude	Longitude	Elevation (m)	Julian Day	Shot time	Charge Size (kg)		
9 August 1995										
	133	Tyrone, NM	32 ° 37 ' 56 . 57 " N	108 ° 23 ' 16 . 1 " W	1850	221	11:00:00	16329	32.632381	108.38778
	143	Riverton, WY	42 ° 43 ' 50 . 81 " N	107 ° 40 ' 2 . 85 " W	1931	221	11:30:00	6804	42.730781	107.66746
	149	Canada/US Border	49 ° 1 ' 3 . 84 " N	110 ° 25 ' 38 . 48 " W	855	221	7:00:00	2400	49.017733	110.42736
	155	CFB Cold Lake, AB	54 ° 54 ' 54 . 91 " N	111 ° 14 ' 12 . 66 " W	740	221	7:40:00	5000	54.915253	111.23685
	157	Fort McKay, AB	57 ° 11 ' 18 . 65 " N	111 ° 33 ' 49 . 45 " W	276	221	7:20:00	10000	57.188514	111.56374
17 August 1995										
	233	Tyrone, NM	32 ° 37 ' 56 . 57 " N	108 ° 23 ' 16 . 1 " W	1850	229	11:00:00	17237	32.632381	108.38778
	237	Delores, CO	37 ° 34 ' 36 . 11 " N	108 ° 26 ' 39 . 31 " W	2309	229	7:00:00	3629	37.576697	108.44425
	243	Riverton, WY	42 ° 43 ' 47 . 60 " N	107 ° 39 ' 55 . 76 " W	1932	229	11:30:00	6804	42.729889	107.66549
	257	Fort McKay, AB	57 ° 11 ' 32 . 27 " N	111 ° 33 ' 10 . 30 " W	279	229	7:30:00	18000*	57.192297	111.55286
	261	Pine Point, NT	60 ° 52 ' 53 . 49 " N	114 ° 14 ' 7 . 94 " W	207	229	9:00:00	25000**	60.881525	114.23554

* actual size of source ~ 14 000 kg

** actual size of source ~ 16 000 kg

Appendix 3
Instrument Deployment Summary

Instrument	Number of Instruments	Site # (first)	Site # (last)	Trace # (first)	Trace # (last)	Comments
Deployment 1						
PRS-1	182	1120	1482	1	182	
PRS-4	34	1484	1550	183	216	
SGR	186	1551	1736	217	402	
RefTek	259	1737	1995	403	661	
PDAs	20	1996	2015	662	681	
SCR	75	2016	2090	682	756	
Sum	**756**					
Deployment 2						
SGR	185	1911	2095	1	185	
SCR	16	2096	2111	186	201	
SCR	54	3000	3077	202	255	
RefTek	21	3078	3098	256	276	
SCR	5	3099	3103	277	281	
RefTek	104	3105	3208	282	385	
RefTek	128	5000	5134	386	506	skip 5084-5087 and 5113-5115
PRS-4	34	5135	5168	507	540	
PRS-1	182	5169	5527	541	722	skip 5239, 5240, 5276, 5277, 5423, and all even stations above 5405
Sum	**729**					