Current and planned VSP capabilities within CREWES

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ABSTRACT

Datasets donated by industry and seismic field equipment currently available to the CREWES Project are the basis of its VSP research capabilities. Analysis of sponsor-donated VSP data from various geological settings by CREWES staff and graduate students has led to the development of new ideas and algorithms. In addition, access to modern seismic instrumentation has given CREWES the ability to conduct research-scale field surveys efficiently. Existing hardware suitable for VSP acquisition include hydrophone arrays, three-component downhole geophones, various recording systems, and the recently commissioned EnviroVibe vertical vibrator. Planned projects to enhance VSP capabilities within CREWES include the drilling of a shallow test well somewhere near Calgary, and the evaluation of a downhole vibrator source for shallow reverse VSP data acquisition.

INTRODUCTION

The CREWES Project has engaged in research connected with vertical seismic profiling (VSP) research from its very beginning (Labonte and Stewart, 1989; Geis et al., 1990; Parry and Lawton, 1993; Lawton et al., 2002). Over the years, this research has led to advances in data analysis and to improved field data acquisition. Datasets donated by industry from a variety of geological settings have provided staff and students opportunities for addressing a wide range of processing and interpretational issues. These datasets help to focus VSP research within CREWES so that it continues to address topics that are of immediate concern to the industry (for example, converted-wave/AVO analysis, and VSP-CDP imaging in time-lapse investigations).

CREWES possesses or has access to field equipment that gives it the capability to conduct VSP data acquisition on a research scale. Suitable existing hardware includes hydrophone arrays, three-component downhole geophones, various recording systems, and the recently deployed EnviroVibe vertical vibrator. As for the near future, we plan to add to our VSP capabilities by drilling a shallow well (200 to 300 meters deep) somewhere near Calgary for testing VSP and well logging equipment. This well will be an important teaching facility for use in the geophysical field school conducted by the University of Calgary Department of Geology and Geophysics. We will also evaluate the suitability of a downhole vibrator as a source for shallow reverse VSP applications

DATASETS AND ANALYSIS

Since the early 1990's, CREWES has used and processed VSP datasets donated by its sponsors for research and teaching purposes. In processing these datasets, listed on Table 1, staff and students have developed valuable expertise in all aspects of VSP analysis. A search of the CREWES archive with VSP as a keyword reveals a long list of publications, reports, and graduate theses, involving topics such as VSP/CDP migration, Q estimation, anisotropy, time-lapse surveying, three-component (hodogram) analysis, and converted wave AVO. Some of the results may be found in the references listed on Table 1.

Commercial software packages such as VISTA and PROMAX (made available by vendors free of charge on a continuing basis) play an important role in this research, but new ideas and algorithms addressing specific VSP issues also have been developed in-house and made available to sponsors and the seismic industry in general.

Table 1. Sponsor-donated VSP datasets.

Location	Source	Sensor	Reference
Rolling Hills, Alberta	Vibrator	3C geophone	Geis et al., 1990
Joffre, Alberta	Airgun	3C geophone	Zhang et al., 1994
Blackfoot, Alberta	Dynamite	3C geophone	Stewart and Zhang, 1996
Pike's Peak, Sask.	Vibrator	3C geophone	Osborne and Stewart, 2001
White Rose, Nfld.	Airgun	3C geophone	Jaramillo et al., 2002
Ross Lake, Sask.	Vibrator	3C geophone	Xu and Stewart, 2003
Red Deer, Alberta	Vibrator	3C geophone	Richardson and Lawton, 2003
Violet Grove, Alberta	Dynamite	3C geophone	Coueslan et al., 2006

EXISTING FIELD EQUIPMENT

Through the University of Calgary Department of Geology and Geophysics, CREWES has available field equipment that enables its staff to conduct VSP field surveys for research and teaching purposes (Table 2).

Sensors suitable for deployment in shallow wells (less than 300 meters deep) include a 48-element hydrophone array, an eight-element hydrophone array with FM multiplexing, and a single level, borehole-clamping three-component geophone. At Violet Grove, three-component geophones have been cemented in a well for long-term time lapse acquisition (Coueslan et al., 2005, 2006). Other three-component geophones targeted for retrievable deployment in a well await the addition of suitable clamping mechanisms.

Surface sources available for research-type VSP surveys include sledge hammers, accelerated/dropped weights, Betsy and buffalo guns, blasting caps, and dynamite. The recently commissioned EnviroVibe vertical vibrator belonging to the University of Calgary Department of Geology and Geophysics is an important addition to the seismic sources available to CREWES. Because it is a controlled source that does not damage shot locations, it is ideal for time-lapse VSP surveys for which repeatable source-generated waveforms are crucial.

Recording equipment include a 60-channel engineering seismograph, five 24-channel GEODE modules, the 600-channel ARAM/Aries System which supports the vibrator owned by the University of Calgary, and several options for PC-based digital acquisition.

Table 2 summarizes field equipment owned by or easily accessible to CREWES. More detailed descriptions of the EnviroVibe vibrator and the ARAM/Aries system are given by Bertram et al. (2005), and by Lawton and Bertram (2006).

Table 2. VSP Equipment within CREWES.(* recently purchased).

Sensors	
48- hydrophone array	100-conductor cable, 200 meter long.
8-hydrophone array (multiplexed)	4-conductor cable, 300 meter long.
Single borehole locking 3C geophone *	7-conductor cable, 100 / 500 meter long.
Surface Sources	
EnviroVibe *	Swept frequency vibrator.
Betsy, Buffalo gun	Shotgun-type source.
Large EWG	Accelerated weight-drop source.
Small EWG	Accelerated weight-drop source.
Recording Instruments	
ARAM/Aries *	600-channel seismic acquisition system.
Geometrics R60	60-channel digital seismograph.
Geometrics GEODE *	24-channel acquisition module (5 units).

CLAMPED GEOPHONES VERSUS HYDROPHONES

Although 3-C clamping geophones when properly designed and operated give the best and most complete VSP information, in many situations hydrophones are a more practical alternative. Hydrophones are fluid-coupled and need not be in contact with the borehole wall to respond to seismic vibrations. Consequently, compared to clamped geophone tools, hydrophone arrays are simpler and less costly to engineer and more efficient in field operation (Gulati and Stewart, 1998). They are attractive when only first arrival times are required, as in check shot applications or determination of near-surface velocities for statics corrections.

When reflections are the primary interest, the utility of hydrophones for borehole seismic acquisition is limited by their extreme sensitivity to tube wave energy, a limitation not faced by properly clamped geophones. Datasets acquired with hydrophones often contain strong tube wave arrivals which mask coherent reflections. However, tube wave events have consistent characteristics that are significantly different from those of VSP reflections. On common source gathers of borehole seismic records, tube waves have linear moveout velocities near that of the velocity of sound in water (1480 m/sec), and along this linear moveout, the tube wave trace-to-trace coda are very uniform. Exploiting these characteristics, Marzetta et al. (1988) demonstrated that velocity and bandpass filtering can remove tube waves very effectively from gathers of hydrophone VSP records. The filtered gathers revealed reflection events with clarity similar to that seen in data recorded in the same well with clamped geophones.

We show an example of tube wave removal in Figures 1 and 2 (Gulati and Stewart, 1998). Figure 1 is a common receiver gather of raw hydrophone data recorded in a well from the Blackfoot area. The hydrophone receiver is fixed at a depth of 98 meters in the well, while the source points on the surface are located at 20m intervals. Notice the strong tube wave arrivals with linear down-going moveout. Figure 2 shows the gather after the tube waves have been largely removed by a combination of predictive deconvolution and f-k velocity filtering. Reflections that were totally obscured by tube waves are clearly visible and unambiguous.

FUTURE DEVELOPMENTS

1. CREWES and the University of Calgary Department of Geology and Geophysics intend to have a shallow test well (200 to 300 meters deep) drilled on university property. Possible locations are at the Rothney Astronomical Observatory near Priddis, and the Biological Field School in Kananaskis. A surface seismic survey has been done at the Rothney Observatory site using the EnviroVibe source and the ARIES/ARAM system. Figure 3 is an example of a common source gather from that survey. The data will be analyzed to determine whether or not suitable geological structure exists in the upper 200 to 300 meters for a shallow test well. The test well will provide a facility within easy reach for testing and demonstrating VSP and geophysical logging equipment. It will play an important role in the teaching functions of the Department, and will support research by CREWES in borehole geophysics. It may be feasible to drill the well with a horizontal extension to increase its utility. Planning is in the initial stages, and input from sponsors concerning various aspects is welcomed.

2. The Department has a number of three-component geophones designed for insertion into wells up to 300 meters deep. These geophones are already on downhole cables, and can be connected easily to our surface recording instrumentation. We will combine eight of these geophones with a clamping

system based on hydraulic packers, and so obtain an eight-level, retrievable geophone array suitable for multi-component VSP research studies.

3. CREWES will investigate the feasibility of doing reverse VSP surveys in near-surface environments for gathering seismic data to assist in statics analysis. Reverse VSP, with a borehole source shooting into surface geophones, can be more efficient than standard VSP because it is much easier to deploy many three-component geophones on the surface than it is to deploy them in a well. Blasting caps have been used successfully for shallow VSP, but they are dangerous and inefficient. We will investigate the suitability of the CORRSEIS downhole vibrator (Wong, 2000) for use as a shallow reverse VSP source. To this end, a collaborative effort with JODEX Applied Geoscience Limited will be undertaken by CREWES to modify and optimize the present design of the CORRSEIS vibrator (Wong, 2006).

CONCLUSIONS

This overview of VSP capability within CREWES and the University of Calgary Department of Geology and Geophysics has acknowledged the importance of datasets donated by the sponsors of CREWES from industry. CREWES staff and graduate students continue to develop and implement innovative ideas that contribute to VSP processing, and the data from real-world geological settings play a valuable role in guiding and promoting the research. In addition to relying on industry-donated data, CREWES and the Department have the capability to independently conduct research-scale VSP surveys. Both groups jointly own or have access to equipment for conducting VSP surveys efficiently: downhole seismic sensors, different types of surface sources, and several modern digital seismic acquisition systems. Active research in VSP analysis includes 3 component processing, VSP-CDP imaging, Q and anisotropic studies, and time-lapse investigations. Plans to enhance VSP capabilities within CREWES include developing a test site near Calgary with one or more shallow (200 to 300 meters) boreholes, and the design and construction of a vibrator suitable for shallow reverse VSP acquisition

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REFERENCES

Bertram, M.B., Lawton, D.C., Gallant, E.V., and Stewart, R.R., 2005, New seismic reflection and other geophysical equipment available to CREWES: CREWES Research Report, **17**, 1.1-1.7.

Couelsan, M.L., Lawton, D.C., and Jones, M., 2005, Baseline VSP processing for the Violet Grove CO_2 Injection site: CREWES Research Report, **17**, 42.1-42.22.

Couelsan, M.L., Lawton, D.C., and Jones, M., 2006, Time-lapse monitoring of CO_2 EOR and storage with walkaway VSPs: 76th Annual International Meeting, SEG, Expanded Abstracts, 3130-3134.

Coulombe, C.A., Stewart, R.R., and Jones, M.J., 1990, Amplitude-versus-offset using the vertical seismic profile: CREWES Research Report, **2**, 27.1-27.13.

Geis, W.T., Stewart, R.R., Jones, M.J., and Katapodis, 1990, Processing, correlating, and interpreting converted shear waves from borehole data in southern Alberta: Geophysics, **55**, 660-669.

Gulati, J.S., and Stewart, R.R, and Hoffe, R.H., 1998, Hydrophone cable acquisition and imaging: CREWES Research Report, **10**, 8.1-8.18.

Jaramillo, J.S., Stewart, R.R., and Emery, D.S., 2002, Interpretation of well-log, VSP, and streamer seismic data from the White Rose oilfield, offshore Newfoundland: CREWES Research Report, **14**, 57.1-57.15.

Lawton, D.C., Margrave, G.F., Richardson, S., and Stewart, R.R., 2002, A 3C-4D surface seismic and VSP program for a coalbed methane and CO_2 sequestration pilot, Red Deer, Alberta, CREWES Research Report, **14**, 64.1-64.1.

Lawton, D.C., and Bertram, M.B., 2006, New seismic and other geophysical equipment at the University of Calgary: CSEG Recorder, **31**, No. 6, 26-31.

Labonte, S., and Stewart, R.R., 1089, Modal separation, mapping and inverting three-component VSP data, CREWES Research Report, **1**, 14.1-14.21.

Marzetta, T.L., Orton, M., Krampe, A., Johnston, L.K., and Wuenschel, P.C., 1988, A hydrophone vertical seismic profiling experiment: Geophysics, **53**, 1437-1444

Osborne, C.A., and Stewart, R.R., 2001, Analyzing the Pike's Peak Multi-offset VSP dataset: CREWES Research Report, **13**, 48.1-48.14.

Parry, D.G., and Lawton, D.C., 1993, Analysis of direct wave arrivals in a shallow multi-offset reverse VSP: CREWES Research Report, **5**, 8.1-8.16.

Richardson, S.E., and Lawton, D.C., 2003, PP and PS imaging and reflectivity the Ardley coal zone, Red Deer, Alberta: CREWES Research Report, **15**, 53.1-53.17.

Stewart, R.R., and Zhang, Q., 1996, 2D and 3D VSP interpretation: Blackfoot field, Alberta, CREWES Research Report, **8**, 41.1-41.13.

Wong, J., and Stewart, R.R., 2006, Development of a vibratory source for shallow VSP applications, CREWES Research Reports, this volume.

Wong, J., 2000, Crosshole seismic imaging for sulfide orebody delineation near Sudbury, Ontario, Canada: Geophysics, **65**, 1900-1907.

Xu, C., and Stewart, R.R., 1999, Preliminary processing and analysis of the Blackfoot walk-away VSP experiment, CREWES Research Reports, **11**, 27.1-27-11.

Xu, C., and Stewart, R.R., 2003, Ross Lake 3D-3C seismic survey and VSP, Saskatchewan: a preliminary interpretation, CREWES Research Reports, **15**, 58.1-58-12.

Zhang, Q., Sun, Sun, Z., Brown, R.J, and Stewart, R.R., 1994, VSP interpretation from Joffre, Alberta, CREWES Research Reports , **6**, 33.1-33.17.

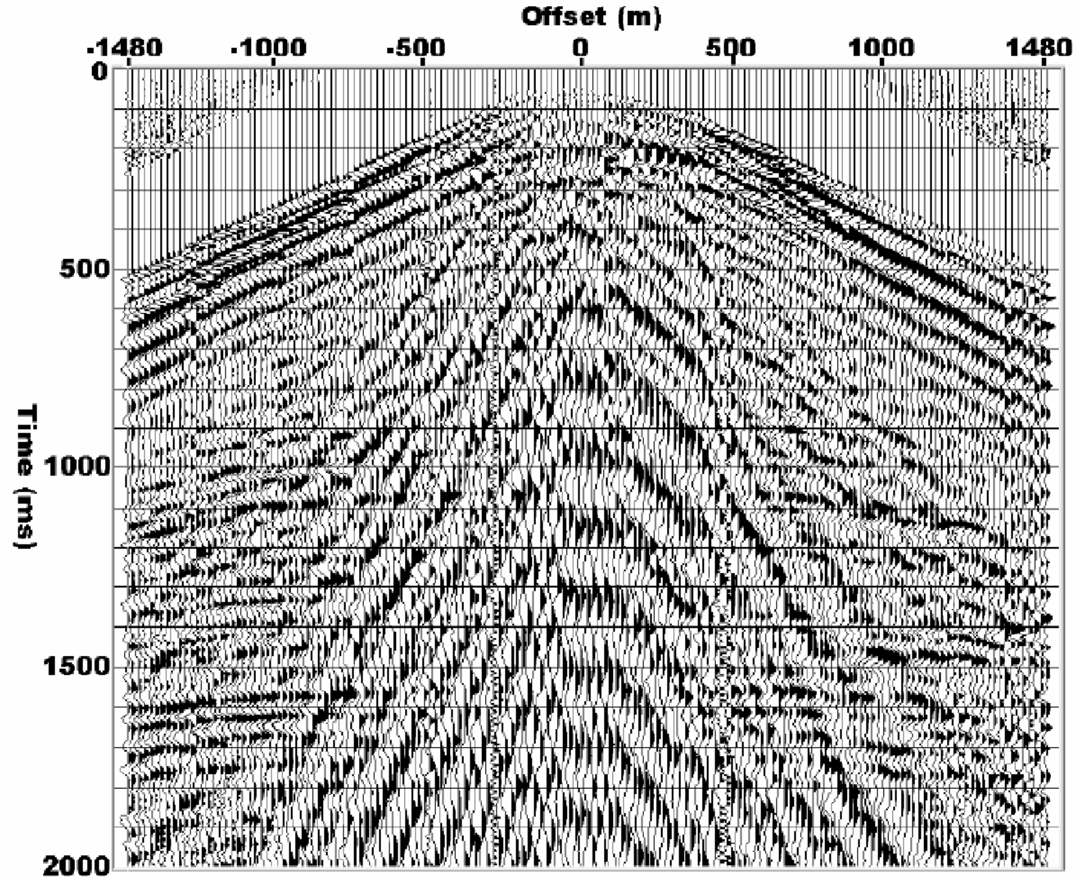

FIG. 1. Common receiver gather of raw hydrophone data. The hydrophone is fixed at a depth of 98m. Surface source points are located at 20m intervals (from Gulati and Stewart, 1998).

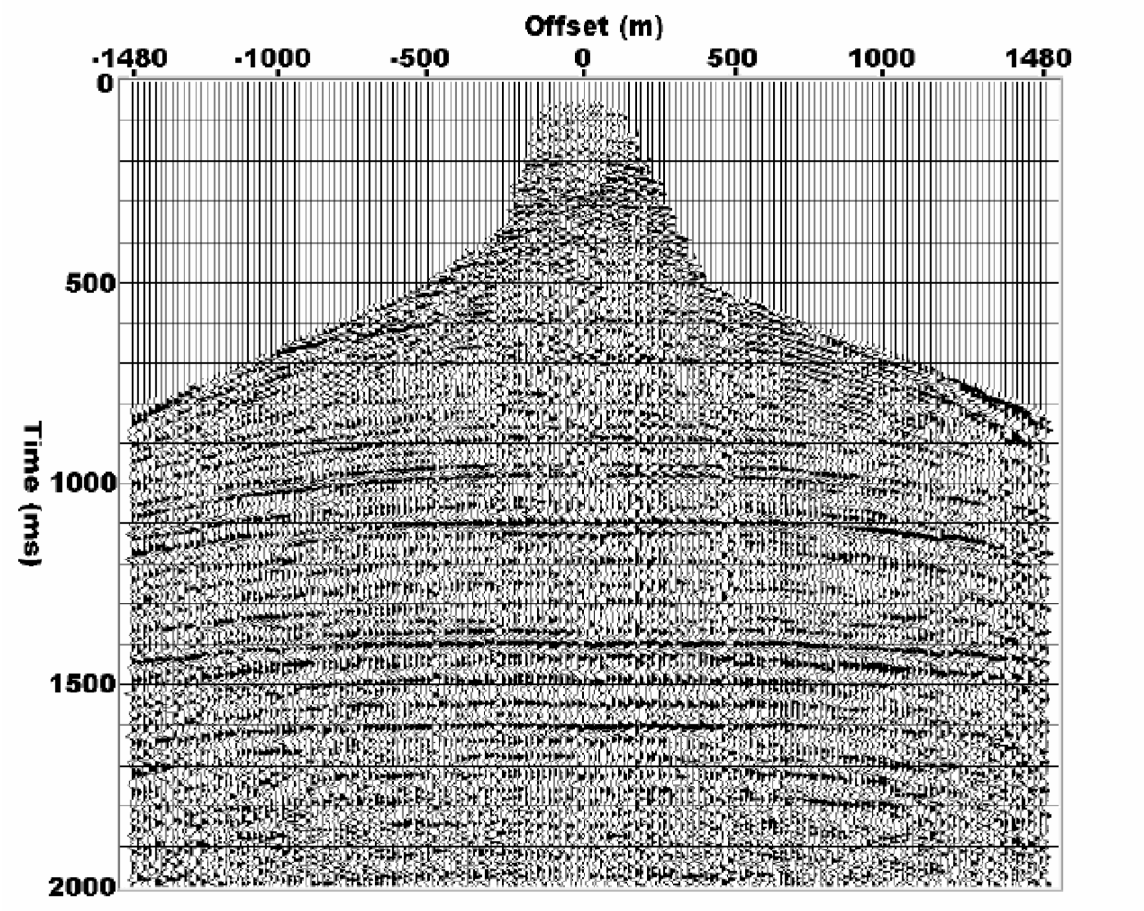

FIG. 2. Common receiver gather of Fig. 1 after predictive deconvolution and f-k velocity filtering to remove tube waves (from Gulati and Stewart, 1998).

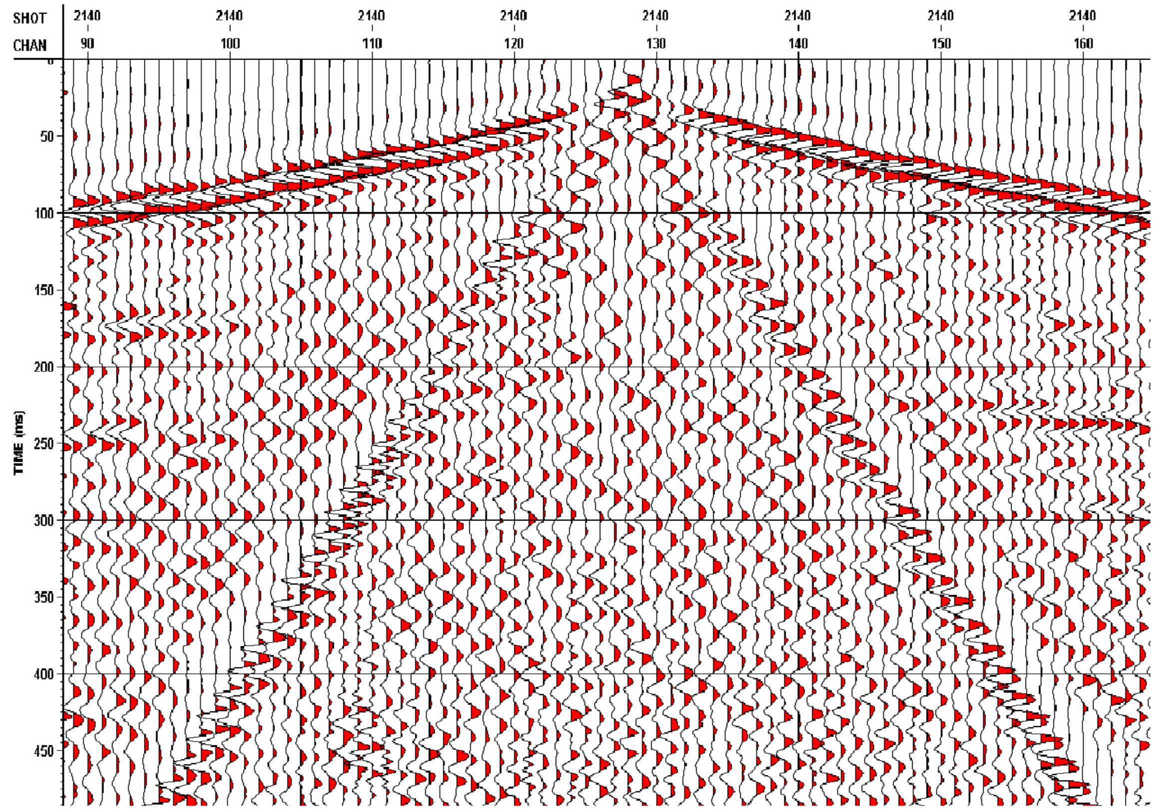

FIG. 3. Common shot gather from Rothney Astronomical Observatory site. Raw traces are displayed with an Ormsby filter (40-50-150-200) and AGC. Spacing between channels (receivers) is 5 meters.