United States Production Operations
Projects

Marathon Oil Company

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November 1, 2007

Karlene Fine, Executive Director
North Dakota Industrial Commission
State Capitol—14th Floor
600 East Blvd. Ave. Dept 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Please find attached to this letter a grant application from Marathon Oil Company to the North Dakota Oil and Gas Research Council requesting $207,550 of matching funds to conduct a surface microseismic study of a simultaneous hydraulic fracture stimulation on two newly drilled, closely spaced Bakken horizontal wells in North Dakota (total cost estimate $415,100). The purpose of this study is to understand the mechanics of a simultaneous fracture stimulation in the Bakken between two parallel horizontal wells (each with a 9000' horizontal wellbore drilled in the Middle Bakken) drilled in the same 1280 acre drilling and spacing unit and compare the results to a microseismic study of a single well stimulation (which your organization is supporting by way of a grant awarded for upcoming Marathon work). This study is directed to identify the effect of artificial fractures that are created between two the drilled horizontal wells. This knowledge will allow for better optimization of the wellbore azimuth in future horizontal Bakken wells and field development. The results will also provide improved future stimulation methods. This knowledge may enhance overall Bakken well productivity, increase ultimate well recoveries, and enhance the economic viability of the Bakken play.

This letter shall form a binding commitment on behalf of Marathon Oil Company to complete a surface microseismic study of a simultaneous Bakken fracture stimulation if the North Dakota Industrial Commission approves the requested grant.

Sincerely,

David L. Brimberry
Bakken Project Subsurface Manager

Attachment

Surface Microseismic Study of a Bakken Simultaneuos Fracture Stimulation

A Grant Application in the Amount of $207,550

To the

North Dakota Oil and Gas Research Council

Made by

Marathon Oil Company

November 1, 2007

Principal Investigators

Ken Dunek, Advanced Production Engineer, Marathon Oil Company

Chuck Meeder, Senior Geoscience Consultant, Marathon Oil Company

Reagan Daniels, Advance Senior Reservoir Engineer, Marathon Oil Company

David Brimberry, Subsurface Manager, Marathon Oil Company

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Section 1.0—Abstract

One of the significant unknowns in the current development of the Middle Bakken horizontal play is the effectiveness of stimulation treatments. A number of stimulation techniques are under investigation. A concept that has not been employed in the Bakken of North Dakota, but has been successful in the Barnett shale gas play of Texas is simultaneous fracture stimulation. This method involves performing a fracture stimulation treatment simultaneously between two parallel horizontal wells in order to increase the amount of fractures created between the two wells thereby increasing contact with the reservoir. That completion method has increased initial production rates in the Barnett by at least 30-50% over wells fracture stimulated individually. The Barnett is analogous to the Bakken in that there is evidence of both transverse and longitudinal fractures and isotropic stress distribution. The proposed study will help determine if similar results can be achieved in the Bakken and if simultaneous fracture stimulation can increase the ultimate recovery of hydrocarbons from the reservoir. The best way to understand what takes place between the wells is to monitor the fracture stimulation resultsand compare it to the results of a single well stimulation. The most cost effective method for monitoring the fracture stimulation is using surface microseismic. Monitoring the simultaneous fracture stimulation is critical to implementing this drilling and completion practice in the Bakken play.

This grant requests funds to conduct a surface microseismic study of a simultaneous fracture stimulation on two of Marathon's wells in Dunn County, North Dakota (tentatively Marathon Grant Carlson 24-31H and Grant Carlson 14-31H, Section 11.) during the first six months of 2008 to map the affect of this unique completion

method. A surface microseismic study consists of laying out an array of geophones on the ground around the target wells (Section 11.2). These geophones measure minute vibrations in the earth's subsurface that occur during the fracture stimulation and represent the cracking of the earth. The surface microseismic technology offers an alternative to the much more expensive and area restricted downhole microseismic technology because it does not require a monitoring well that can cost up to several million dollars to drill. Also, the technology will map a created fracture network between the two wells and over an area of a few thousand acres instead of a restricted 2000' radius around a monitoring well that must be advantageously placed between the two wells. Data from the array will be processed in order to reveal the density of the fracture network between the two wells created during the stimulation and the orientation of fractures away from each well. The results of this study will be compared to surface tiltmeter and microseismic results performed on single wells (Klatt 31-14H and Kevin Buehner 11-18H, respectively; studies for which Marathon has received a grant from the North Dakota Oil and Gas Research Council to conduct) to determine the effectiveness of the simultaneous fracture stimulation. As described above, this information will be applied for better well designs and field development, which will enhance the economic viability of the Bakken play.

Mobilization of the equipment to North Dakota is expected to take three days. Installation of the array will take approximately four days. The fracture stimulation and data acquisition will be completed in one day. Pick up and demobilization of the array from North Dakota are four and three day efforts, respectively. The analyzed results for the job are expected within two weeks of the acquisition. Marathon will participate in the study as the operator, and MicroSeismic, Inc. will be the contractor installing the array and analyzing the data. The total project cost is estimated to be $415,100.

Section 2.0—Project Description

The objective of this study is to conduct a surface microseismic study of a simultaneous fracture stimulation on two of Marathon's wells in Dunn County, North Dakota. The Marathon Grant Carlson 24-31H and Grant Carlson 14-31H are currently the candidate wells, but may change as detailed planning continues. The information gathered in this study will be applicable to wells and field development in the area regardless of which well it is gathered from.

Microseismic geophones are vibration sensitive devices laid on ground between and surrounding the candidate well. The microseismic array will cover an area on the earth's surface with a roughly 10,000' radius around the path of the horizontal wellbores. There will be approximately 14 arms of geophones within this area making up the array. During the fracture stimulation of the well, the geophones will measure minute vibrations of the earth's surface that are caused by shear of rock layers near the wellbores. This data will then be processed in order to determine the orientation and intensity of the fracture created during the stimulation.

A better understanding of created or induced fractures and the comparison to the single well tiltmeter and microseismic results are the primary purposes of this study. Induced fracture orientation at depth is controlled by the direction of the minimum and maximum in-situ stresses in the rock itself. A fracture will propagate in a direction parallel to the maximum principal stress. Using the unrelaxed stress of an area as a control on the fracture stimulation, a higher intensity of induced fractures is expected between the two wells. The higher intensity fracturing is expected to contribute to better production rates and higher ultimate oil recovery for both wells. The production results gathered over time will help to determine the ultimate effect on recovery. The microsiesmic monitoring of the fracture stimulation describe if higher intensity was actually achieved and support for the better oil recovery. Marathon will utilize MicroSeismic, Inc. as a contractor to provide the microseismic array design, installation, data capture and data analysis for this project. MicroSeismic, Inc. specializes in microseismic data acquisition for fracture stimulation and fracture mapping. They have conducted successful microseismic studies throughout the world and in North Dakota with objectives to image fracture stimulations and should be capable to meet the objective of imaging a simultaneous fracture stimulation. In summary, this study will advance several of the purposes of the Oil and Gas Research Council. It will add to the pool of Bakken knowledge that will benefit operators as well as the state and people of North Dakota in several ways, including enhanced oil and gas production rates, increased ultimate well recovery, enhanced well economics, and increased viability of the Bakken horizontal play. These things will result in increased tax revenues, and ultimately can result in the creation of oil and gas jobs and wealth for the state of North Dakota.

Section 3.0—Standards of Success

There are two levels of success that will be measured in this project. The first will be to acquire and analyze the microseismic data to determine the fracture affects of the simultaneous fracture stimulation and its complexity. If the complexity can be measured and compared to individual wells, this level will be considered successful. The second level of success will be if this information can be used by Marathon (and, once it is released to the public, other operators) to improve stimulation design, guide field development and achieve higher production rates and ultimate oil and gas recoveries.

Section 4.0—Background/Qualifications

Marathon Oil Corporation (www.marathon.com) is engaged in the worldwide exploration and production of crude oil and natural gas, as well as the domestic refining, marketing and transportation of petroleum products. Marathon is among the leading energy industry players, applying innovative technologies to discover valuable energy resources and deliver the highest quality products to the marketplace. Marathon is the 4th largest US-based integrated oil and gas company, and has actively drilled for and produced oil and gas since its founding in Ohio since 1887. Business activities of Marathon Oil Corporation have included North Dakota through the years, but most recently in Marathon's entry into the North Dakota Bakken play.

Ken Dunek has 6 years of completion experience with Marathon and has been involved in fracture stimulation design and implementation in various basins in the United States throughout that time. He is currently an Advanced Engineer responsible for Bakken completions in North Dakota, and has been involved with the Bakken since Marathon began drilling and completion operations in North Dakota in 2006.

Chuck Meeder has 27 years of experience with Marathon and has been involved with seismic and VSP acquisition, processing, and analysis around the world. He is currently a Senior Technical Consultant working in the Seismic and System Services section of Marathon's Technology Services Group.

Reagan Daniels has 28 years of experience with Marathon and has been involved in various engineering, engineering management and operations management positions in various basins in the United States. He is currently an Advanced Senior Reservoir Engineer responsible for reservoir engineering tasks associated with Marathon's Bakken development in North Dakota.

David Brimberry has 23 years of experience working a number of United States basins with Marathon and a exploration and production geologist. His current role as Subsurface Supervisor requires him to guide and direct the work pointed at understanding Bakken geology and reservoir engineering.

MicroSeismic, Inc. is an energy industry supplier of two passive seismic imaging technology. Passive Seismic Transimission Tomography (PSTT) uses seismic signals from microearthquakes to construct a velocity image and create a static 3D image of the subsurface similar to conventional 3D seismic. A Passive Seismic Emission Tomography (PSET) images the location of the microearthquakes which are used to map dynamic processes such as hydraulic fracturing operations, active faulting, and reservoir compaction. PSET is distinct from conventional microseismic fracture mapping in that it does not rely on picking first arrival times to determine event locations. PSET uses a beam steering technique to capture and image the microseismic activity. (www.microseismic.com).

Section 5.0—Management

Key milestones in the project will be as follows (not necessarily being completed consecutively—some work can be completed in parallel): 1) Approval of grant from NDOGRC and authorization for work to begin, 2) Completion of microseismic array design, specifying location and pattern of geophones to be installed, 3) Completion of surface landowners notification and subsurface mineral interest where the microseismic array will be installed, 4) Submittal and approval of sundry notices related to the program on the wells involved 5) Installation of the microseismic array, 6) End of drilling of well and wellbore prepared for fracture stimulation, 7) Fracture stimulation with the microseismic data acquisition and 8) Analysis of microseismic data for projected changes.

This project will be managed through consistent communication between the principal investigators, other Marathon employees, and MicroSeismic, Inc., the primary contractor. The fracture stimulation is currently estimated to occur sometime in March or April 2008. The project timetable will be based on this date.

Section 6.0—Timetable—

November 2007 —Project Authorization from Marathon and OGRC

December 2007 —Grant Carlson 24-31H spuds

January 2008 – Grant Carlson 14-31H spud with same rig

January 2008 —Begin notifying surface owners for microseismic installation

March 2008 —Drilling phase of wells finished and completion begins.

March 2008—Microseismic array staking completed and installations

March / April, 2008—Fracture Stimulation

May 2008—Data Analysis Complete

Section 7.0—Budget

- Crew and equipment mobilization and demobilization to North Dakota	$111,300
- Array Installation, maintenance and reclamation	$216,700
- Data Acquisition & Analysis Fee (1 stage)	$ 87,100
Total	$415,100

Marathon will incur significant costs associated with this project to gain the data that include drilling the wells and the fracture stimulations. The fracture stimulation services are $1,200,000 alone. The microseismic study is not the largest expenditure of this project and as such, the fracture stimulation will proceed even without the grant being awarded.

Section 8.0—Tax Liability

Affidavits from Marathon's Tax Organization are attached.

Section 9.0—Confidential Information

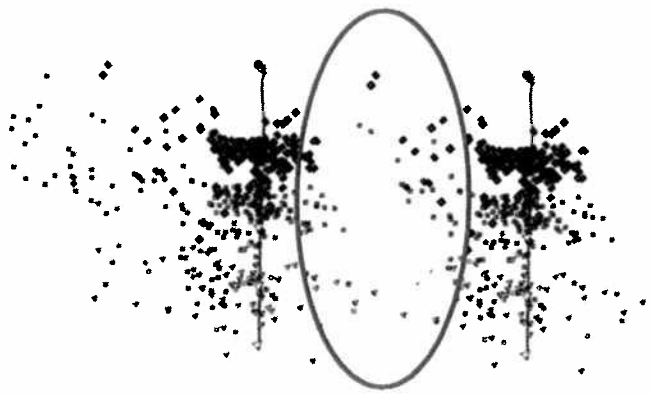
Marathon requests that the results and interpretations of the results remain confidential for a period of 1 year following the release of the "Data Analysis Complete" date to protect Marathon's business interest.

Section 10.0—Patents and Rights to Technical Data

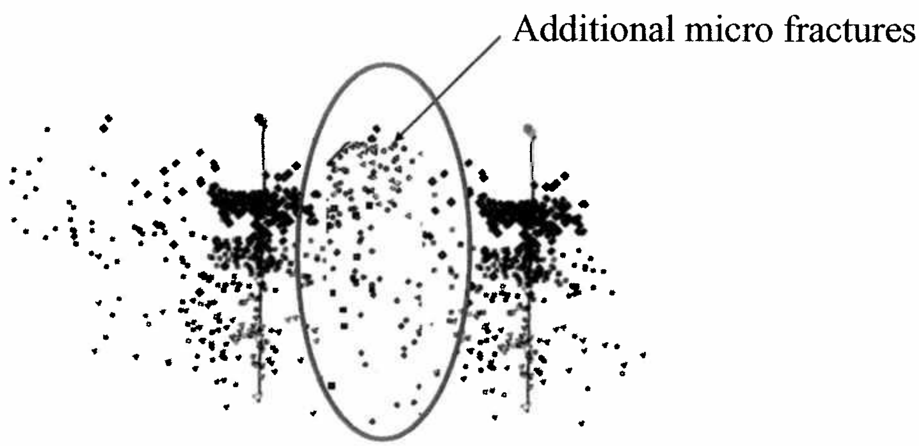
None

Section 11.0—Appendices

11.1a Fracture Pattern Around Two Wells Stimulated Individually

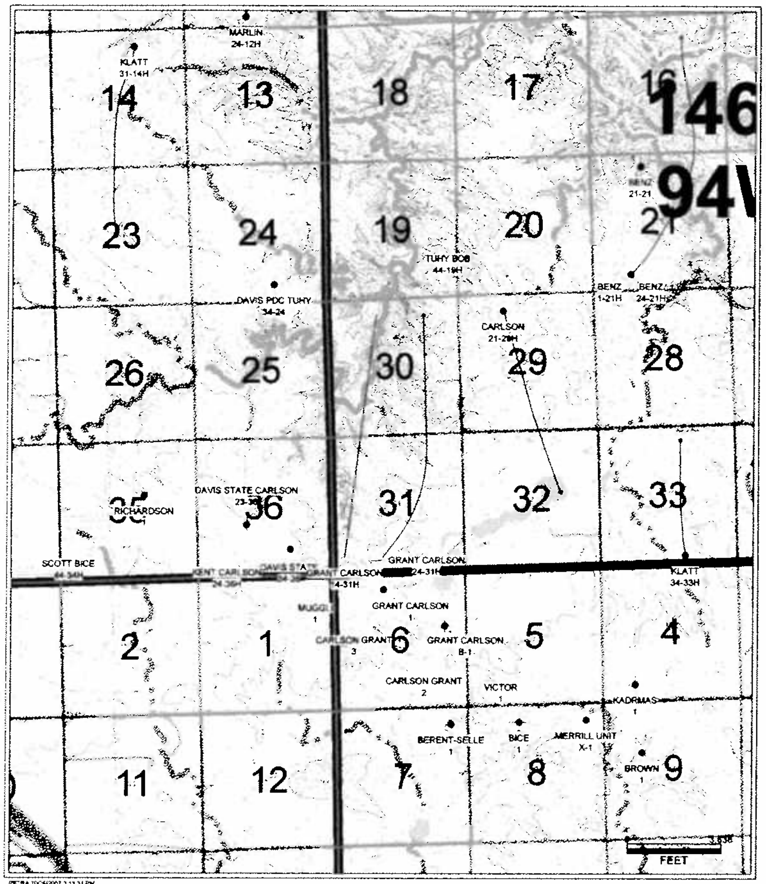


11.1b Fracture Pattern Around Two Wells Stimulated Simultaneously

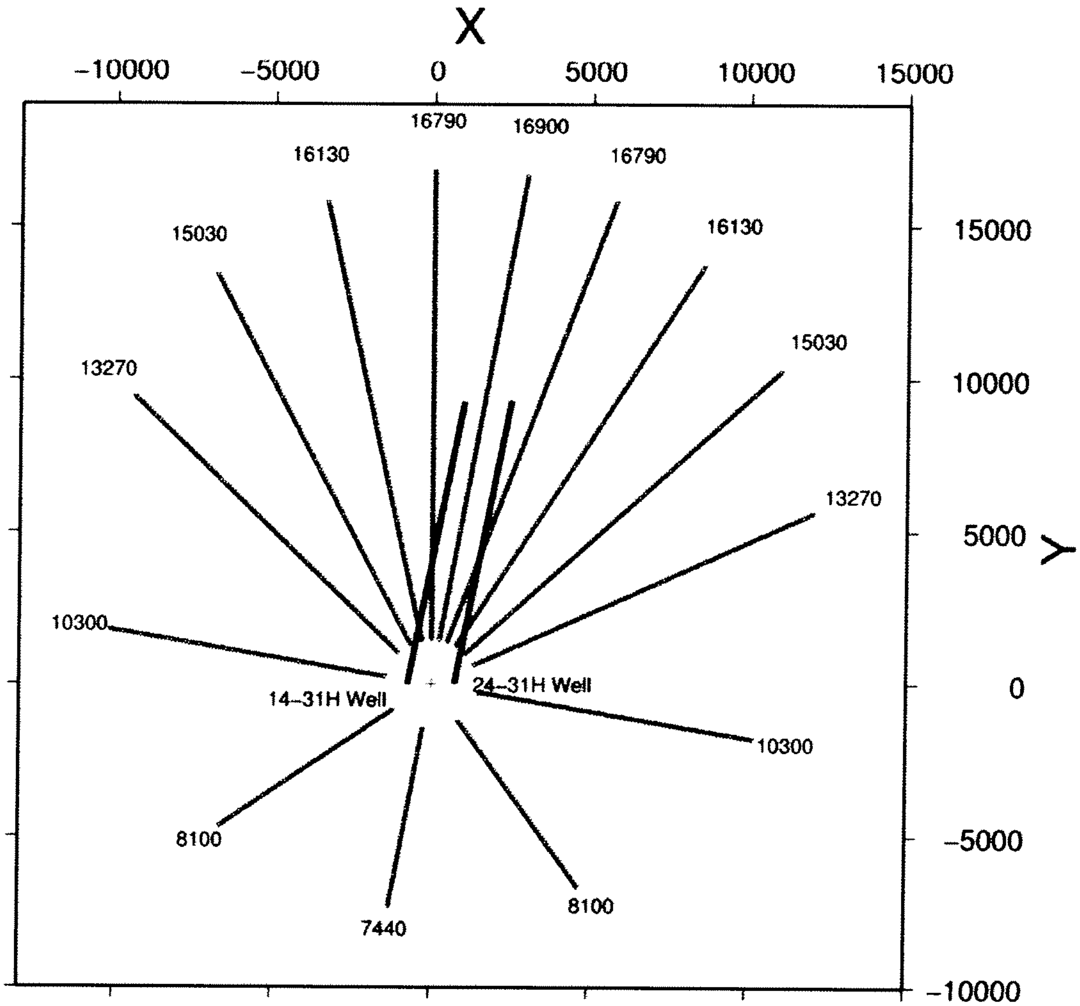


11.2 Proposed Well Paths for Grant Carlson 24-31H and Grant Carlson 14-31

(Section 31 T 146N-R94W)



11.3 Proposed Geophone Array Layout Around Wells (measurements in feet)



11.4 References

P. M. Duncan, Is there a future for passive seismic?, EDGE (European Association of Geoscientist and Engineers) First Break, volume 23, June 2005

JD Lakings, et al, Surface Based Microseismic Monitoring of a Hydraulic Fracture Well Stimulation in the Barnett Shale, Society of Exploration Geophysicist Annual Meeting 2006

Surface Based Microseismic Monitoring of a Hydraulic Fracture Well Stimulation in the Barnett Shale

James D. Lakings, Peter M. Duncan, Chris Neale, MicroSeismic, Inc. and Todd Theiner UTEP*

Summary

Microseismic monitoring of well stimulation by hydraulic fracturing is now an accepted technology. Most such monitoring is achieved with a downhole array of geophones located at or near the reservoir level in a nearby observation well. The need for an available observation well and the limited view such a well provides are impediments to the potential usefulness of the technology. The ability to monitor hydraulic fracture growth from the surface allows for larger array apertures and increases subsurface coverage with while maintaining reasonable resolution and detection limits. Stacking over a large number of stations effectively cancels the surface noise and enables seismic signal detection at levels that are comparable to downhole techniques. More importantly, the surface array is able to detect these comparable signals over a larger subsurface area and shed more light on the extent of the reservoir volume being stimulated.

Introduction

We present a comparison between surface based and downhole microseismic monitoring of the hydraulic fracture stimulation of the Burlington Resources operated well, C. W. "B" 19-H in Wise County, Texas. The seismic energy released by these hydraulic fracture induced earthquakes is typically too weak to be seen on a single station record at the surface. A dense array of geophones is used in order to build up the signal-to-noise ratio using a beam summation technique we refer to as Passive Seismic Emission Tomography or PSET®. Areas of concentrated energy are interpreted to represent the hypocenters of discrete microearthquakes. The objective of the experiment was to validate the observations by making surface passive seismic measurements concurrently with a downhole observation.

The Barnett is a low permeability, naturally fractured shale reservoir that requires fracture stimulation to facilitate production. Directional wells are horizontally drilled perpendicular to the prevailing maximum horizontal compressive stress direction (S_H) and are completed with a hydraulic fracture treatment. Hydraulic fractures are anticipated to propagate in the direction of S_H and intersect and interact with other naturally occurring fractures to form a complex network of connected fractures that enable greater reservoir drainage by enhancing permeability. It is important to diagnose the fracture system in order to optimize the hydraulic fracture treatment, calibrate the fracture model, provide insight on well placement and ultimately improve reservoir production performance.

Method

The surface seismometer array consisted of 97, 3-component stations arranged in a rectangular grid centered on the C. W. "B" 19-H well. All geophones were oriented 3 component seismometers with a natural frequency of 10 Hz. The array covered nearly 2 ½ square miles and was deployed over an area of 6000' by 8000' on a side. The inline spacing was 600' and the crossline spacing was 800'. Near the toe of the well 24 stations were buried 10-18' beneath the surface to test the efficacy of burying the stations to improve the S/N ratios and increase the recorded bandwidth.

The C.W. "B" 19-H well was hydraulically stimulated with a massive single stage completion. A series of perfs were made every 500' along an uncemented liner. The treatment was delivered over an 8-hour period. Periodic sand slugs were introduced during the treatment to control leak off.

The passive surface seismic data were recorded continuously using a Sercel 408 system. Abutting 1 minute records were written to tape at 2ms sample rate. The array was live before during and after the pumping operation.

The data were analyzed using standard seismic data processing techniques. The traces were bandpass filtered and then balanced using a trace by trace AGC. The components were separated into horizontal and vertical component traces. Layered, 1D P- and S-wave velocity models were constructed using a dipole sonic log. The upper and lower portions of the velocity model were extrapolated using expected rock properties. The velocity model was then calibrated by focusing the energy from a small string shot at the heel of the well to the correct location.

A series of records were processed to examine the spatial and temporal distribution of acoustic emission energy. The energy for each cell in a 3D grid was calculated for a series of time periods of one second up to a minute. Horizontal and vertical component beam sum records were analyzed for areas of concentrated energy. The highest energy cells for each time period were plotted and animated to show the relationship between the onset of the activity and the surface pumping pressure.

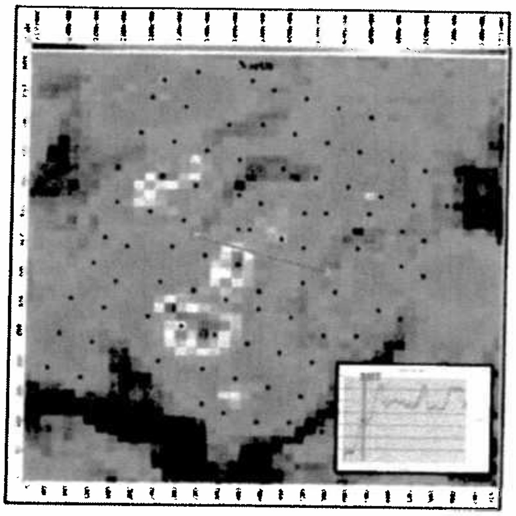


Figure 1. PSET® depth slice at 7800' from surface. Energy summation calculated over a minute period using the vertical component. Distribution of energy values plotted as colored pixels with higher energy values corresponding to warmer colors. Black dots are surface station locations. Brown line traces well deviation. Inset of pressure history curve shows location of minute relative to surface pressure. During this time, the surface pressure dropped rapidly once 3000 psi was obtained. This one-minute period contained the highest seismic energy seen in the early stages of pumping activity. The energy pattern traces out two NE-SW trends with an orientation similar to the inferred S_H. The NE-SW trend offset from the well is suspected to result from the reactivation of a pre-existing hydraulic fracture from another completed horizontal well to the north. The NE-SW energy near the center of the C. W. "B" 19-H appears to be reoriented into an orthogonal direction near the SW tip of the hydraulic fracture. This reorientation is suspected to result from the hydraulic fracture encountering a natural fracture system in the Barnett. The time at the loss of pressure corresponds to the intersection of the hydraulic fracture with the natural fracture system and is accompanied by a large seismic energy release.

A direct comparison of surface based microseismic mapping results to the preliminary downhole microearthquake locations was made for a subset of data during the early stage of the hydraulic fracture treatment. This time period showed the strongest, most dynamic behavior. Picks of high energy events from 5 discrete minute energy volumes were overlaid with the downhole microseismic locations to verify that the high energy locations correspond to seismic energy originating at depth.

Results

Analysis of the surface microseismic data showed the onset of seismic activity within 10 minutes of start of pumping. An initial NE-SW oriented pattern of seismic activity centered on the wellbore propagated bi-directionally, rapidly and orthogonally from the borehole during the first 20 minutes of pumping.

The energy pattern achieved a fracture half-length of ½ mil at which point it was reoriented in a WNW-ESE fashion accompanied by significant microseismic activity (Figure 1). These observations are consistent with the anticipated hydraulic fracture growth direction and interaction with the natural fracture system.

A couple of events were detected and located at the heel of the well. The events appear to link up with another strong lineation directly to the north of the well. The strong energy emission seen in this area is near the location of a previously completed horizontal well. It is suspected that pressure communication from the heel of the well to the hydraulic fracture in the earlier well is reflected by this microseismic activity.

The comparison between the surface based microseismic mapping and the preliminary results provided by the borehole mapping show certain similarities and differences over the short time period analyzed. There is strong spatial and temporal correlation of events from the two data sets in the NE quadrant of the horizontal well (Figure 2).

Discussion

Some of the discrepancy between the exact number of events seen between the two arrays is likely related to the fact that the downhole results provided here were only preliminary results obtained from the field processing and represent only a portion of the total number of events that were recorded and able to be located. That the surface array detected more events to the SW of the borehole is not surprising considering the location of the observation well relative to this seismic activity. The observation well was offset 1500' from the toe of the C.W. "B" 19-H well and events on the southern side of the horizontal are approaching the detection limits of the downhole monitoring technique (Warpinski, et al., 2005).

The locations of the similar events do not correspond exactly and the discrepancy in the location is likely related to the combined errors in the two methods. The surface

Surface Based Microseismic Monitoring

Figure 2. Comparison of preliminary downhole and surface derived locations. Squares are high energy cells from 5 one minute energy volumes. Circles are the downhole locations over the equivalent time period. Large yellow circle is the location of the observation well. There is a strong correspondance of locations to the NE of the well, but many more events to the SW of the well are not seen by the downhole array. The inset shows the time period for which the downhole and surface events were compared.

based locations were mapped on a subsurface grid of 200' on a side, so that lateral resolution less than 200' is not possible. The 200' resolution is controlled by the effective bandwidth used in the processing.

While the surface array is showing more events detected over this time period, there is unlikely to be any exact one-to-one correlation. The process of energy summation over a period of time much longer than the duration of the discrete events, suggests that the hypocenters determined from the energy stacks may be the result of the contribution of multiple sources occupying a single cell during the time period.

The downhole array and the surface array also have different detection thresholds. The downhole array is better suited to discriminating and locating smaller events, especially near the observation well. The detection threshold of the surface array is ultimately controlled by the attenuation of cultural noise at the surface through the data processing and stacking operations. The average ground motion for the Barnett play in this area is on order of 0.5 um/s and varies widely across the array with the buried stations substantially more quiet. For the data presented here, the processing provided a factor 8-10 amplitude increase or nearly a 20 dB boost in signal.. This level of increase in S/N is consistent with the square root of number of stations. The cultural noise and S/N increase show that the detection threshold for locating microearthquake events from the surface is slightly below a local magnitude, M_L = -2.

Conclusions

Surface based microseismic monitoring provides an important and complementary technique to downhole micoearthquake monitoring techniques. Given the S/N at the surface and the array design, events at magnitude levels similar to those seen downhole can be mapped. The frequency content of these events at the surface results in reduced resolution compared to the downhole results. While the detection threshold and location accuracy are not as impressive near the observation well, the fact that the larger surface array is able to detect and locate microseismic activity over a larger area allows greater access to the complexities of hydraulic fracture growth and interaction with the natural fracture system at distances that have not been investigated in the past.

References

Warpinski, N.R., Kramm, R. C., Heinze, J.R., Waltman, C.K., 2005, Comparison of Single- and Dual-Array Microseismic Mapping Techniques in the Barnett Shale, SPE 95568.

Acknowledgements

The authors wish to thank Burlington Resources for permission to show the data presented here.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2006 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Warpinski, N. R., R. C. Kramm, J. R. Heinze, and C. K. Waltman, 2005, Comparison of single- and dual-array microseismic mapping techniques in the barnett shale: 75th Annual International Meeting, SEG, Expanded Abstracts, 1261–1264.