Time Lapse Monitoring – Foster Creek SAGD Project

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Introduction

Canada's oil sands represent the world's largest single hydrocarbon resource with 2.5 trillion barrels of bitumen in place, though it is estimated that only 12 percent of these reserves are recoverable given today's technology *(AEUB, 2000)*. This has driven research into new technologies to exploit those bitumen deposits that are buried too deep for surface mining to be cost effective. Geophysics is playing a significant role in understanding how some of these new technologies are performing and in establishing successful development projects.

In 1995, AEC initiated a pilot project to assess the economic viability of Steam Assisted Gravity Drainage (SAGD), a process originally developed by AOSTRA at the underground test facility (UTF) *(O'Rourke et. Al., 1991)*. As part of the development a 3D seismic program was acquired to assist in the delineation of the reservoir and provide a baseline survey for future Time Lapse Monitoring (TLM) surveys. By 1999 three horizontal well pairs were on production and the first TLM survey was acquired to evaluate the steam chamber progression. Results of these repeat surveys have demonstrated that, through careful attention to detail in both the acquisition and processing stages, TLM images of the steam chamber can provide engineers with valuable additional data in monitoring the SAGD process and resulting reservoir development.

Geology

The bitumen resources in NE Alberta are primarily trapped in Cretaceous aged sediments, which outcrop in the vicinity of Fort McMurray but are buried at depths of about 450m in the Primrose area, the location of AEC's Foster Creek pilot. In 1997 the pilot commenced bitumen production from the McMurray formation, within which the reservoir is comprised of a series of stacked channel sands deposited by a northward flowing river system.

SAGD

With bitumen viscosities in the range of 500,000cp, 9-10.5api, it is necessary to develop procedures to reduce this viscosity to a level where the bitumen can be produced in-situ. One method is to apply steam to the bitumen saturated reservoir, this effectively reduces the bitumen viscosities into the 5cp range which is easily produced. Cyclic steam is the methodology applied successfully by Esso where they alternatively pressure up their reservoir with steam and then produce the wells *(Eastwood et. al., 1994)*. SAGD utilizes two horizontal wells, the upper well injects steam at near reservoir pressure while the lower well is used to produce the bitumen. The SAGD process has proven to be very successful with individual well pairs capable of sustained production of over 1000bbls/day.

Time lapse monitoring is ideally suited to these types of steam projects as there are major changes in the reservoir and fluid properties associated with the processes which result in significant impedance changes between the baseline and monitor surveys *(Jack 1997, Matthews 1992)*. With the cyclic steam process one must be aware of where you are in the pressure cycle in order to be sure that your TLM results will be comparable *(Eastwood, 1997)*. For SAGD this is not an issue as pressures are maintained at as close to reservoir pressure as possible and TLM timing can be dictated by the needs of the production and reservoir engineers.

Acquisition

The design of the base line survey factored in the complex nature of the reservoir, TLM requirements and operational challenges associated with the area. To define the reservoir in sufficient detail high resolution seismic data with smaller bins (10x10m) is recommended. As traditional surface sources in this muskeg dominated area had achieved frequencies of only 100hz, it was determined that small dynamite charges would be more effective. For repeatability and reduced environmental impact, both the source and receiver lines were cut using new low impact line cutting equipment and single geophones were buried at a depth of 8m.

The baseline survey was acquired in 1996 and provided the necessary imaging to help guide the pilot well development. A time lapse survey was acquired in 1999 over a portion of the original survey which covered the three horizontal pilot wells. With the exception of the geophones the baseline survey parameters were duplicated as close as possible. Facilities construction affected the placement of a number of shots and receivers, Fig. 1 which would have to be handled in the processing flow Fig. 2.

Time-Lapse Processing

To enable reliability and accuracy of time lapse measurements, seismic data processing needs to be consistent. Appropriate corrections should account for all field acquisition differences between the two surveys *(Harris and Henry, 1998)*. Differences in fold, azimuth, offset distribution and spectral content are just a few factors that determine a successful repeatability study. Fig.3. Gathers display geometry differences between the two surveys. The baseline survey was shot prior to the SAGD facility construction. The fold coverage was not possible to duplicate Fig.4. A high-resolution surface consistent processing flow addressed the differences in noise levels, wavelet stability, resolution, and consistency of amplitudes. Pre-stack and post-stack noise attenuation was obtained with signal preserving projection filters. Cascading surface consistent deconvolutions resulted in a high resolution and stable wavelet. Amplitude fidelity was maintained through surface consistent amplitude treatment.

As predicted with reservoir heating, a significant reduction of the p-wave velocity was observed in the monitor stacking velocities. Trace-trace cross equalization, which is a common practice to match time-lapse surveys was avoided. Matching QC tools ensured coherence attributes were confined to the signal component of the data. This robust processing flow resulted in an average static difference of 2 ms and a phase difference of 10 degrees. Only a global correction to match minor spectral and static differences was needed. Fig.5 is a comparison of the final migrated stacks for the baseline and monitor surveys. The images illustrate the quality and repeatability of the data. Fig. 6 shows the differences in monitor and baseline statics after automatic surface consistent 3D statics. Minor static changes are attributable to construction of the SAGD facility, roads, and pipelines. Additional passes of residual statics and a trace-trace phase consistent static match were applied prior to differencing. Fig.7 is a time slice from the difference cube over the reservoir zone. The location of the three horizontal well pairs are easily identified by the changes in amplitude on the difference cube slice.

Conclusions

When a project has the potential for TLM work, significant data quality improvements can be achieved if TLM requirements are considered from the initiation of the project. By documenting all acquisition and processing procedures along with ensuring that any changes that have occurred are understood in terms of their impact on the data, very high quality TLM results can be achieved in a time efficient manner. Future TLM surveys benefit from these procedures with reduced cycle times and more consistent attributes.

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References

Alberta Energy and Utilities Board (AEUB), May 2000, Alberta's Reserves 1999 (Statistical Series 2000-18), pp2-6

Eastwood J, Lebel P, Dilay A, Blakeslee S,1994, Seismic monitoring of steam-based recovery of bitumen, The Leading Edge, pp242-251

Eastwood J, 1997, 3D Seismic Monitoring for Enhancing Thermal Recovery, Time-Lapse Seismic in Reservoir Management, SEG, Tulsa, Oklahoma, pp9-54 to 9-65

Harris PE, Henry B, 1998, Time lapse processing:-A North Sea case study: 68th Ann. Internat. Mtg.,SEG, Expanded Abstracts, pp 1-4

Jack Ian, 1997, Time-Lapse Seismic in Reservoir Management, SEG, Tulsa, Oklahoma

Matthews L, 1992, 3-D Seismic Monitoring of an In-Situ Thermal Process, Athabasca, Canada, Reservoir Geophysics, SEG, pp 301-308

O'Rourke JC, Bohme CG, Edmunds NR, Kovalsky JA, Luhning RW, Suggett JC, 1991, AOSTRA's Underground Test Facility (UTF) in the Athabasca Oil Sands of Alberta, 5th Unitar et al Heavy Crude & Tar Sands Int Conf (Caracas, Venezuela, 8/4-9/91), Proc V 1, pp 487-508

FIGURE CAPTION

Figure 1. 3D acquisition differences between monitor and baseline. (P) is the SAGD facility. Shots are north - south, geophones are east - west.

Figure 2. Simplified post-stack cross-equalization flowchart. At each key-processing step, difference checks minimized uncertainties in statics, bandwidth, amplitude and phase.

Figure 3. Gathers display geometry differences between the two surveys. The monitor survey was shot prior to the SAGD facility construction. The fold coverage was not possible to duplicate.

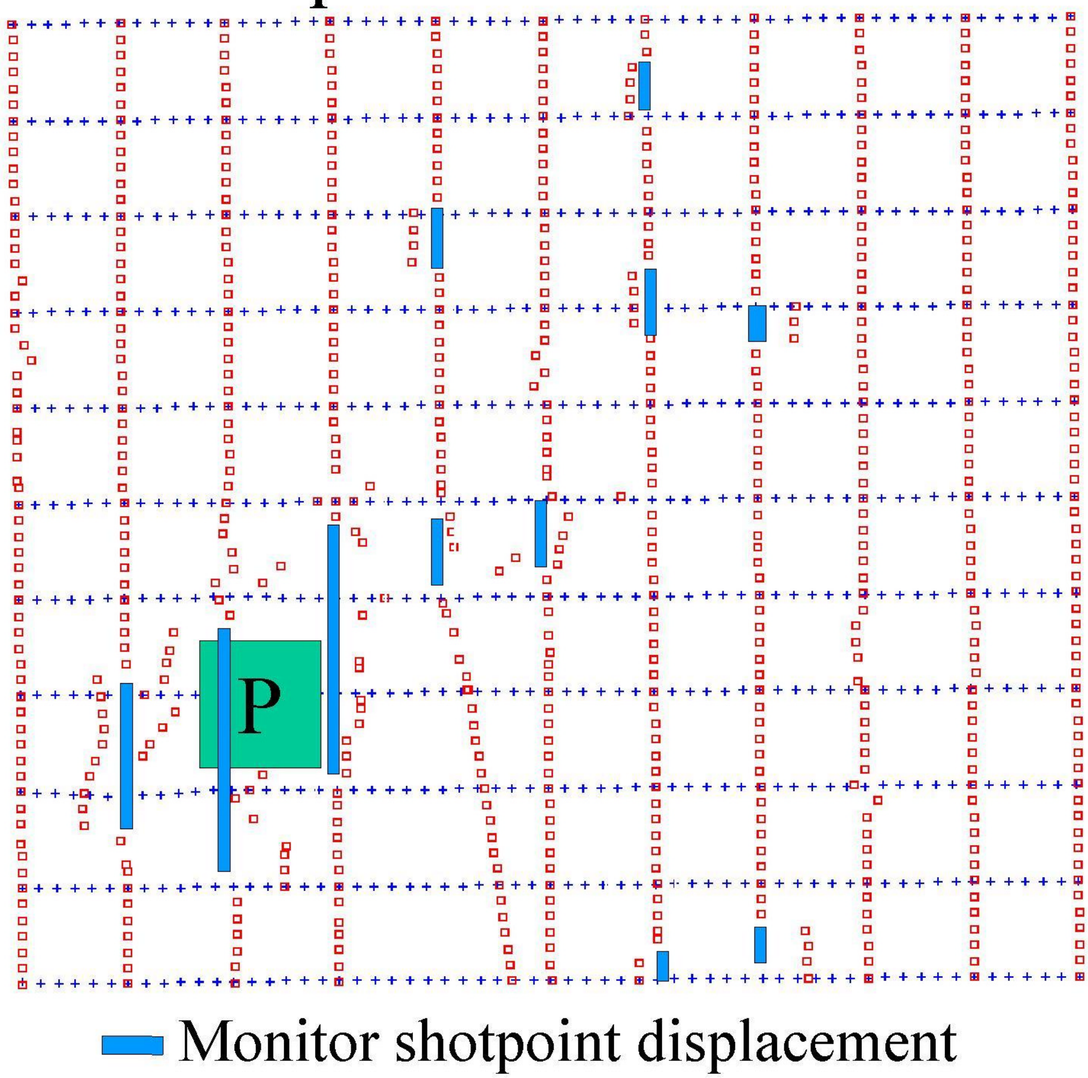
Figure 4. Matching the fold, offset, and azimuth distributions. The Monitor (M) and Baseline (B) fold. B^1 is the baseline survey with offset distribution matched. Prestack fold is critical to quantify differential amplitude changes observed.

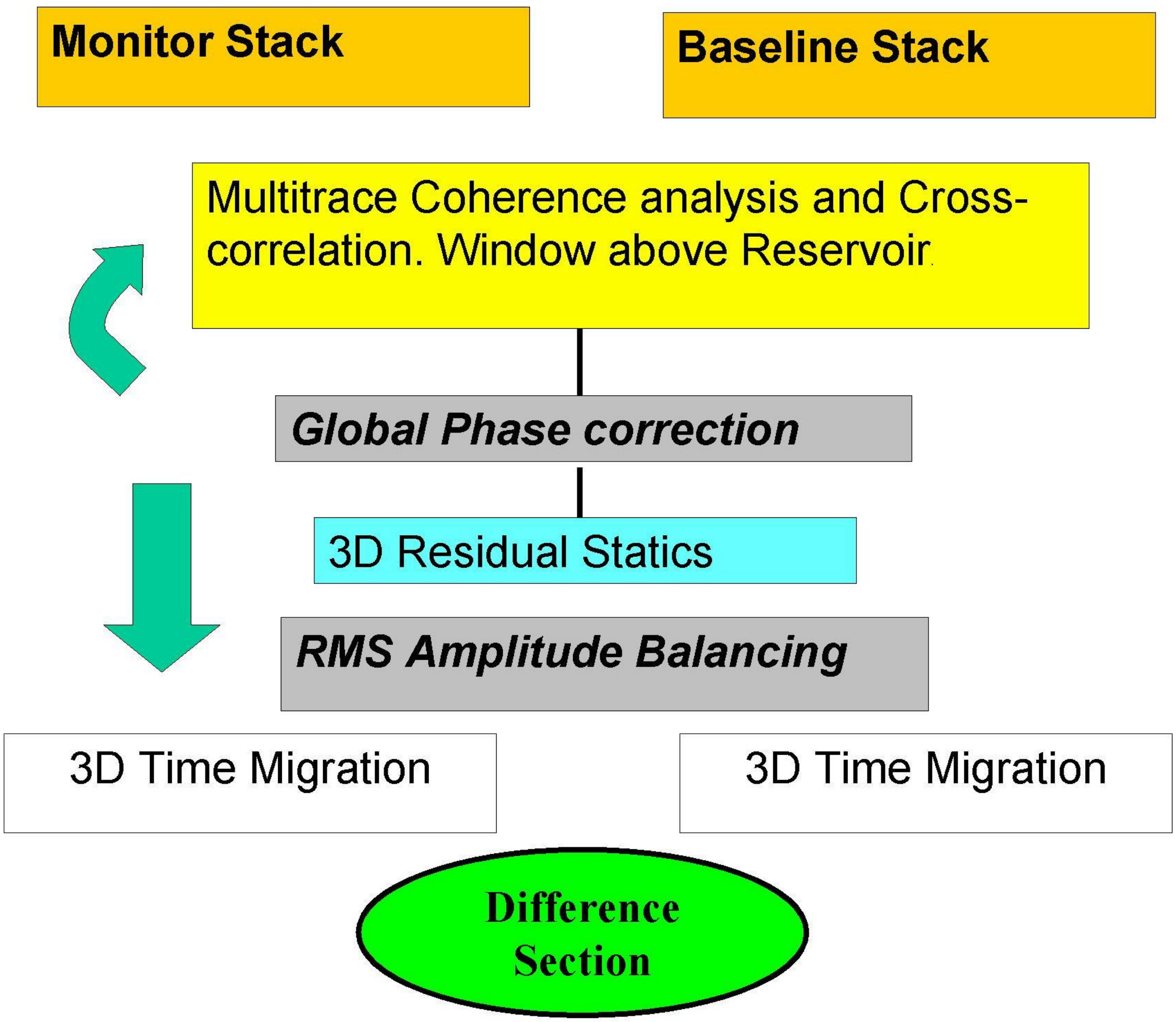
Figure. 5 Comparison of the final migrated stacks for the baseline and monitor surveys. The images illustrate the quality and repeatability of the data.

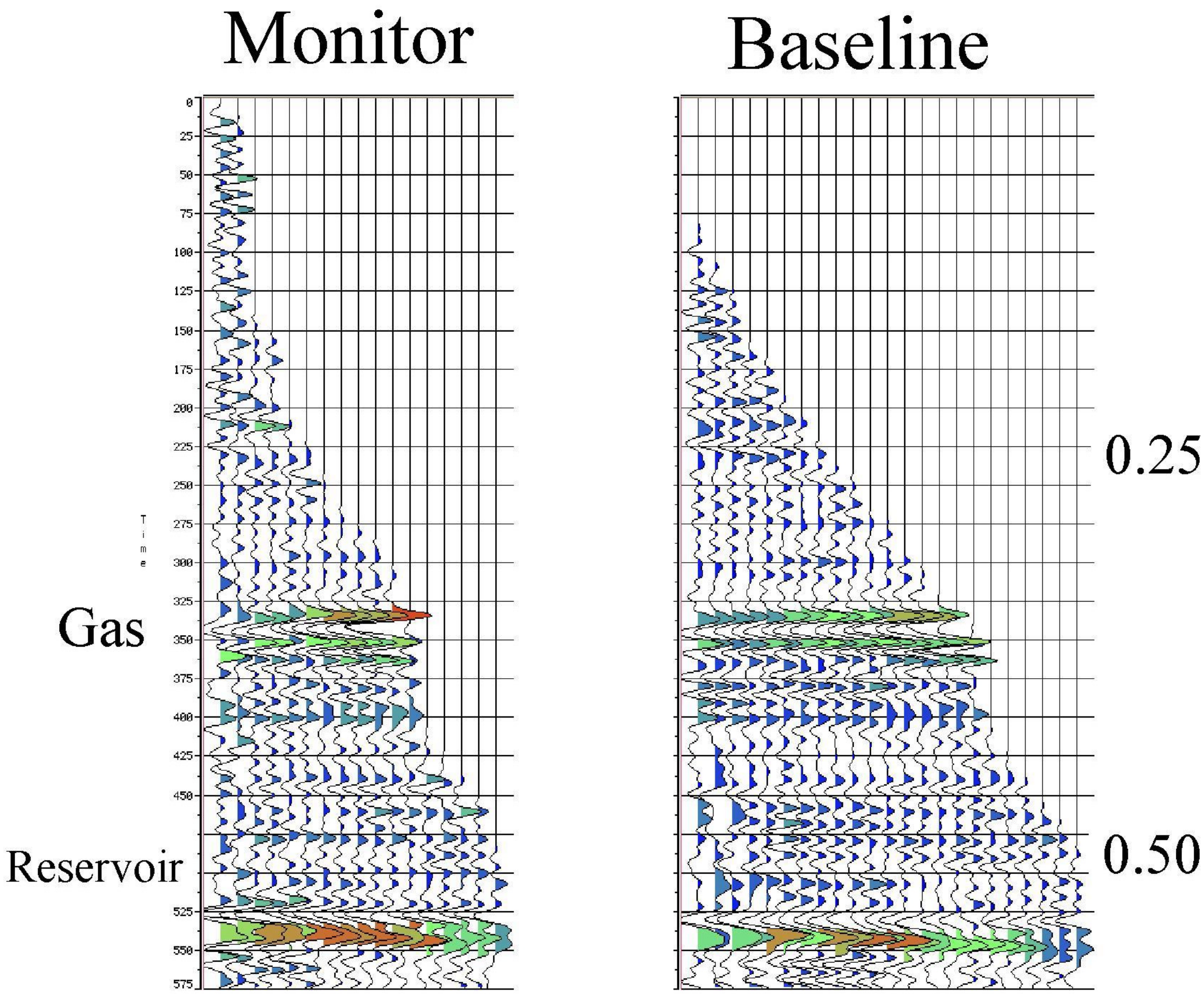
Figure 6. Differences in monitor and baseline statics after automatic surface consistent 3D statics. Minor static changes are attributable to construction of the SAGD facility, roads, and pipelines. Additional passes of residual statics and a trace-trace phase consistent static match were applied prior to differencing.

Figure 7. Difference time-slice (506ms) from the reservoir zone, which illustrates the amplitude effects that would be expected at the heated zone.

3D Acquisition Differences




Monitor Stack
Baseline Stack
Multitrace Coherence analysis and Cross-correlation. Window above Reservoir
Global Phase correction
3D Residual Statics
RMS Amplitude Balancing
3D Time Migration
3D Time Migration
Difference Section


Monitor
Baseline
Gas
Reservoir
0.25
0.50
Time
0
25
50
75
100
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150
175
200
225
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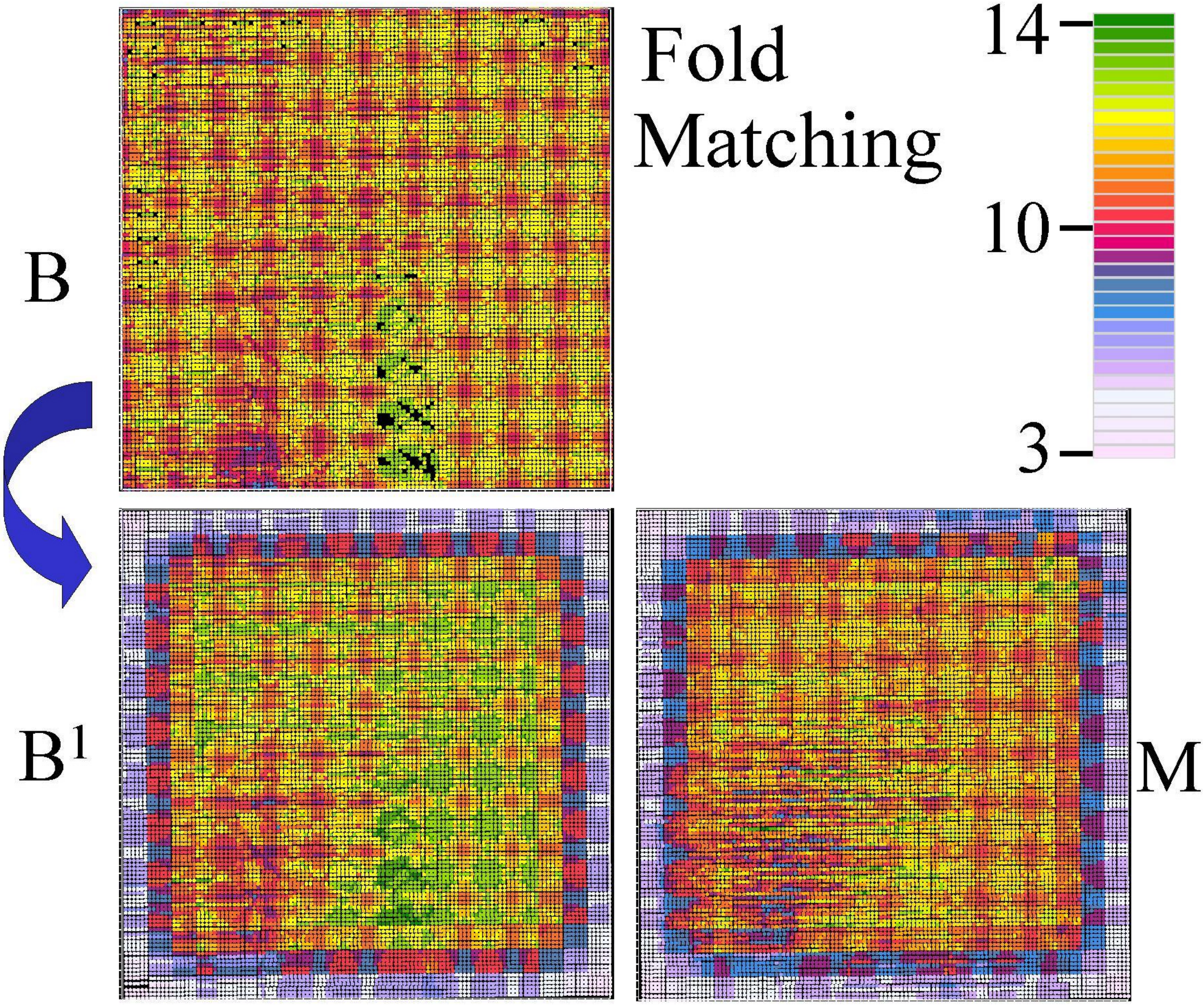
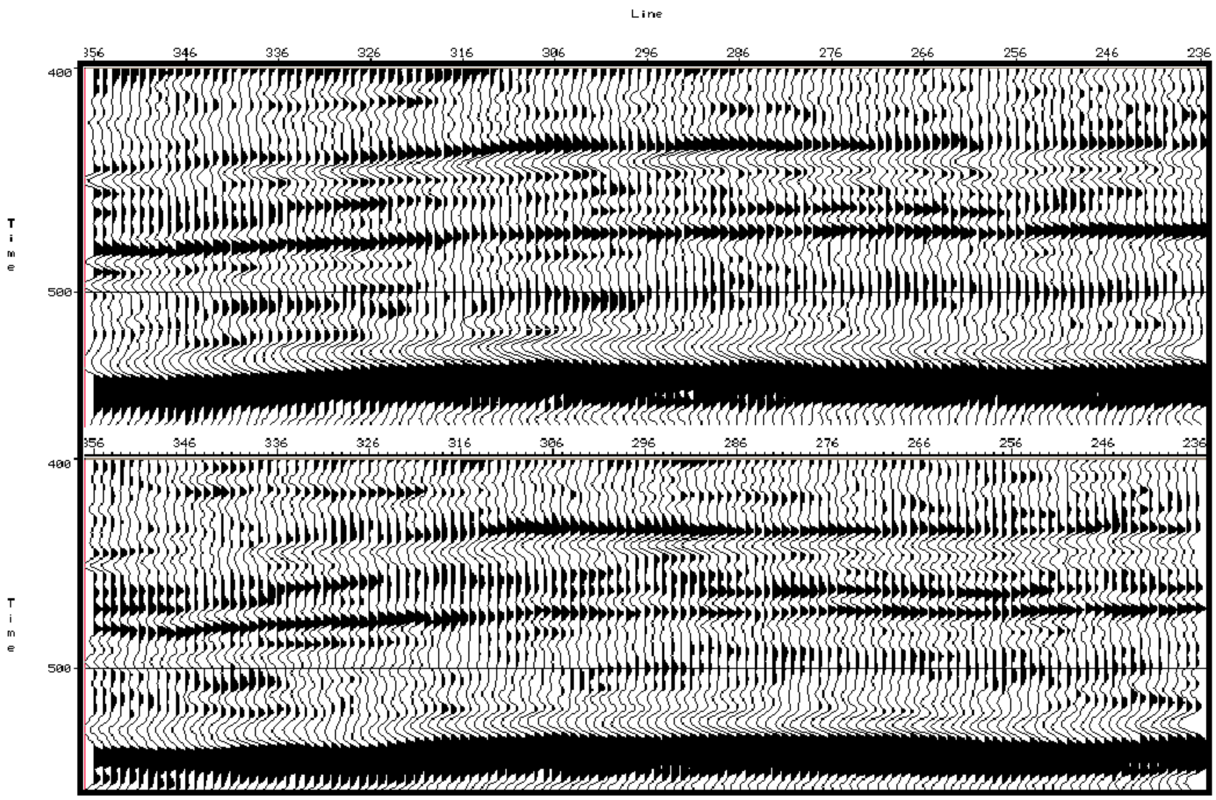
575


Fold Matching
14
10
3
B
B1
M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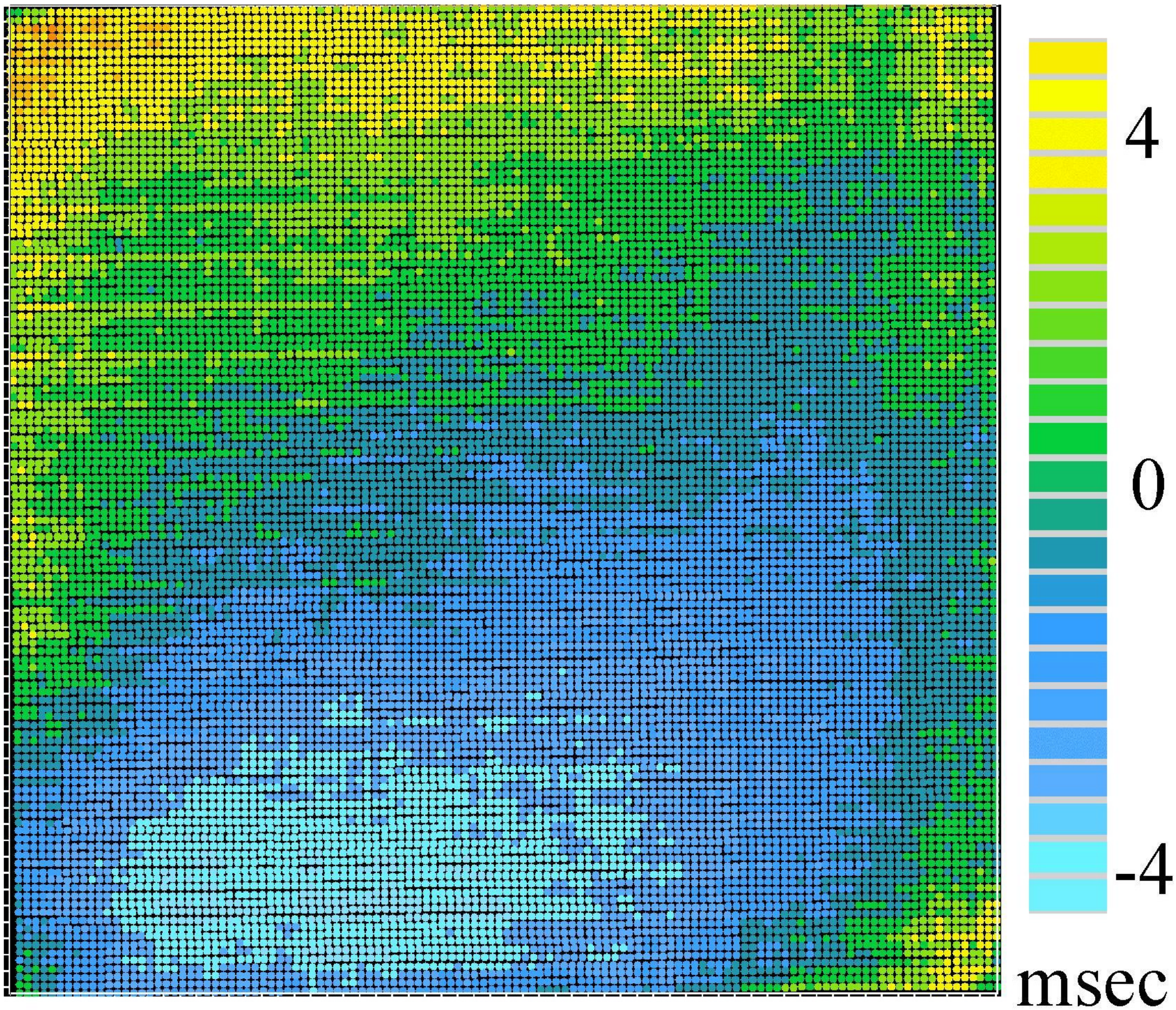
236
400
Time
500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