

4D attenuation analysis for permeability estimates in hydraulically induced fractures

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ABSTRACT

The effect of wave induced fluid motion between fractures and pores results in complex elastic stiffness coefficients that ultimately gives rise to frequency-dependent attenuation. Therefore, permeability estimates are obtainable through a spectral analysis of the seismic wavefield. In this study, we analyze the attenuation response associated with a time-lapse seismic survey acquired before and after hydraulic fracturing to investigate the permeability within the stimulated zone. The results obtained from the attenuation analysis were in qualitative agreement with microseismic observations and 4D seismic amplitude and travelt ime anomalies, suggesting that a permeable fault diverted the energy from the hydraulic fracture treatment to re-stimulate a specific portion of the reservoir.

INTRODUCTION

- An integrated study to predict and characterize well performance in the Horn River gas shales was conducted by Goodway et al. (2012)
 - “sweet spots” were identified through geomechanical and rock property estimation from 3D seismic
 - Microseismicity associated with the hydraulic fracture treatment and time-lapse (4D) seismic were used to evaluate the extent of the stimulated reservoir volume (SRV)
- In this paper, we provide a more detailed description of the 4D analysis performed to evaluate the permeability of the stimulated zone

SQUIRT FLOW IN MESOSCALE FRACTURES

- Wave-induced fluid flow between open fractures in a poroelastic background was discussed by Brajanovski et al. (2005)
 - The passage of a seismic disturbance consisting of various driving frequencies results in fluid flow characteristics and hence effective elastic properties that varies with frequency
 - This frequency dependence of the elastic parameters ultimately results in velocity dispersion and attenuation of the seismic energy
 - Can be used to provide an indication for the ability of fluids to flow or the permeability within the medium

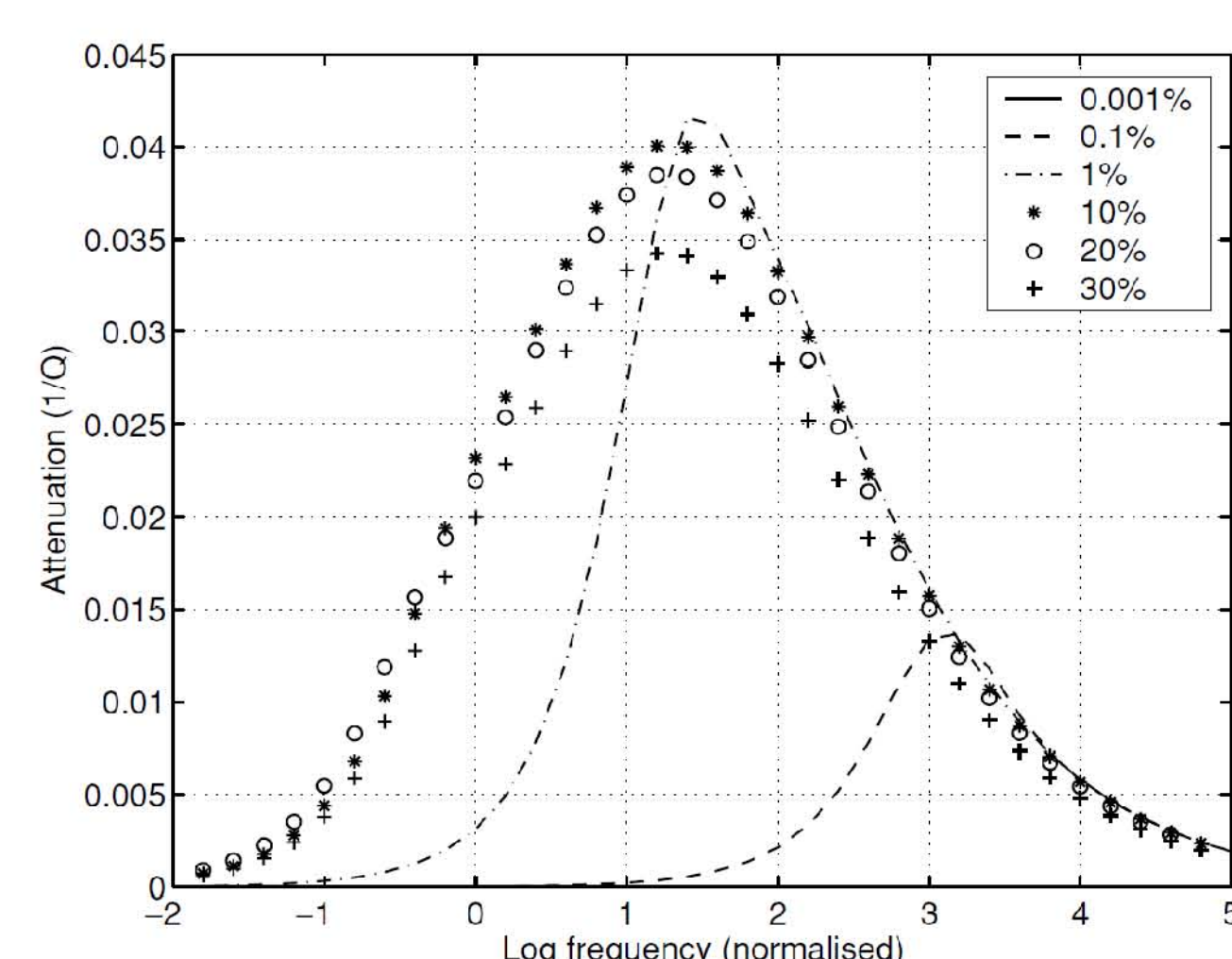


FIG. 1. Attenuation response for mesoscale fractures in a porous background for a constant normal fracture weakness of 0.2 and different background porosity values (From Brajanovski et al., 2005).

MICROSEISMIC AND 4D ANALYSIS

- Low microseismic activity near the fault where the energy was deflected to the toes
 - Re-stimulates NW end of well pad
- 4D amplitude and travelt ime anomalies are consistent for the stimulated interval at the toe of the wells
 - Significantly damaged zone detectable seismically
 - Anomalies bounded by fault suggesting fluid transport through the fault

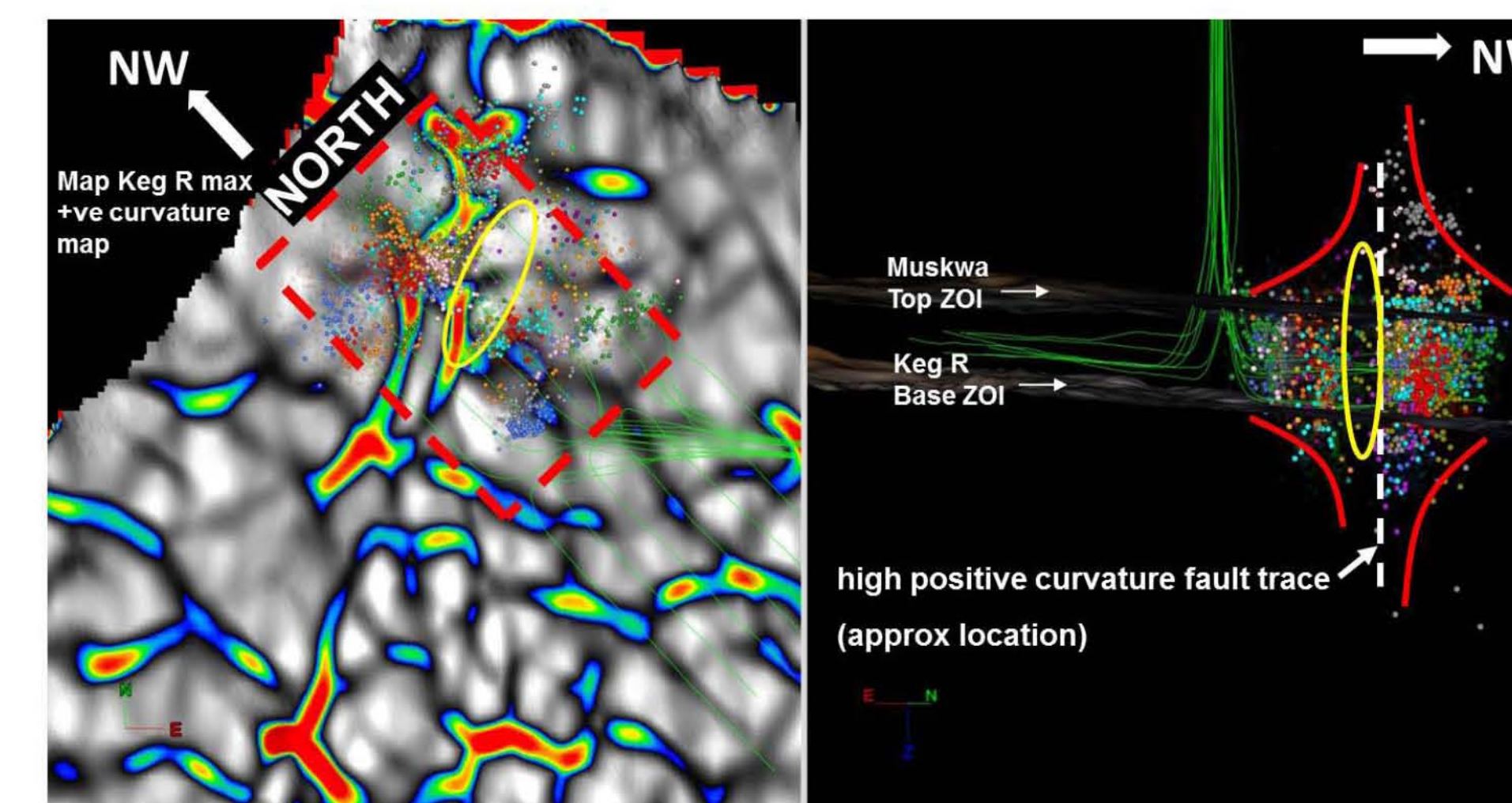


FIG. 2. Microseismic event locations overlaid on a curvature attribute map illustrating the location of a fault cutting through the well pad (From Goodway et al., 2012).

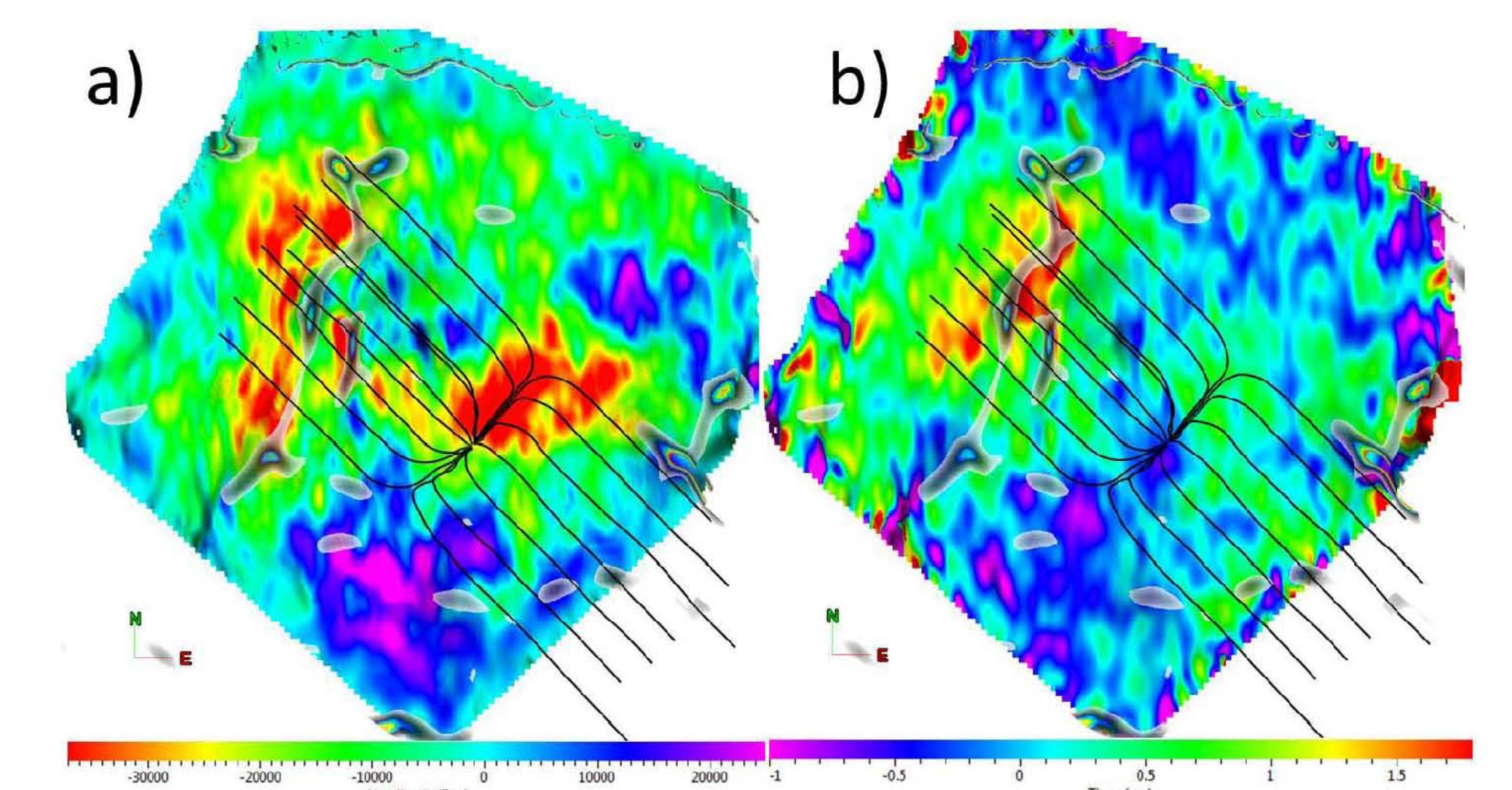


FIG. 3. 4D a) amplitude and b) travelt ime anomalies associated with the hydraulic fracture treatment (From Goodway et al., 2012).

4D ATTENUATION ANALYSIS

- The monitor survey for the 4D analysis was acquired during the completions program where the frac fluid has not yet been recovered
 - Fluid motion produces attenuation effects that can be evaluated using spectral analysis techniques

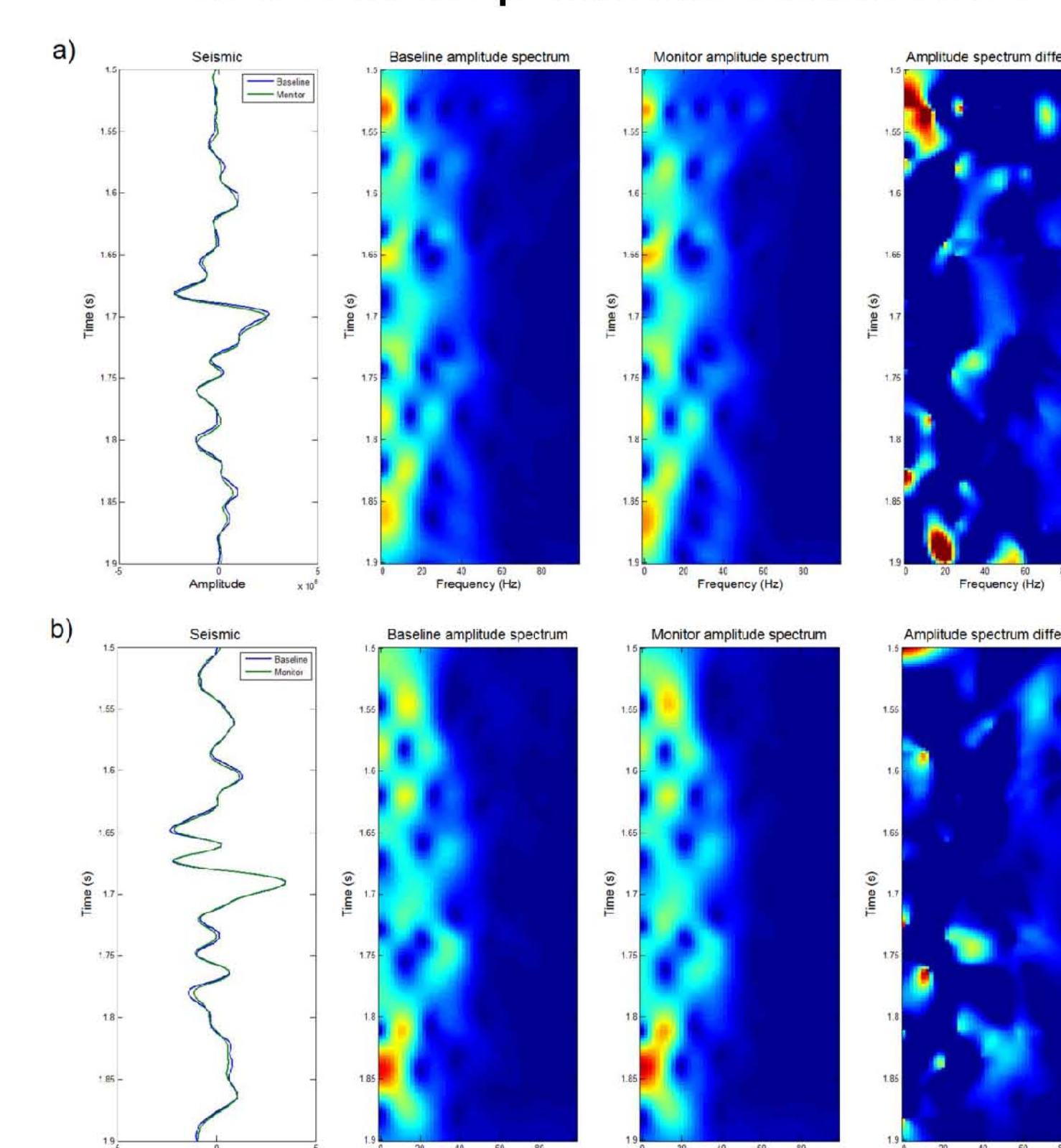


FIG. 4. Time variant amplitude spectrum for an area a) with and b) without stimulation where attenuation effects are observed in a) throughout the reservoir interval.

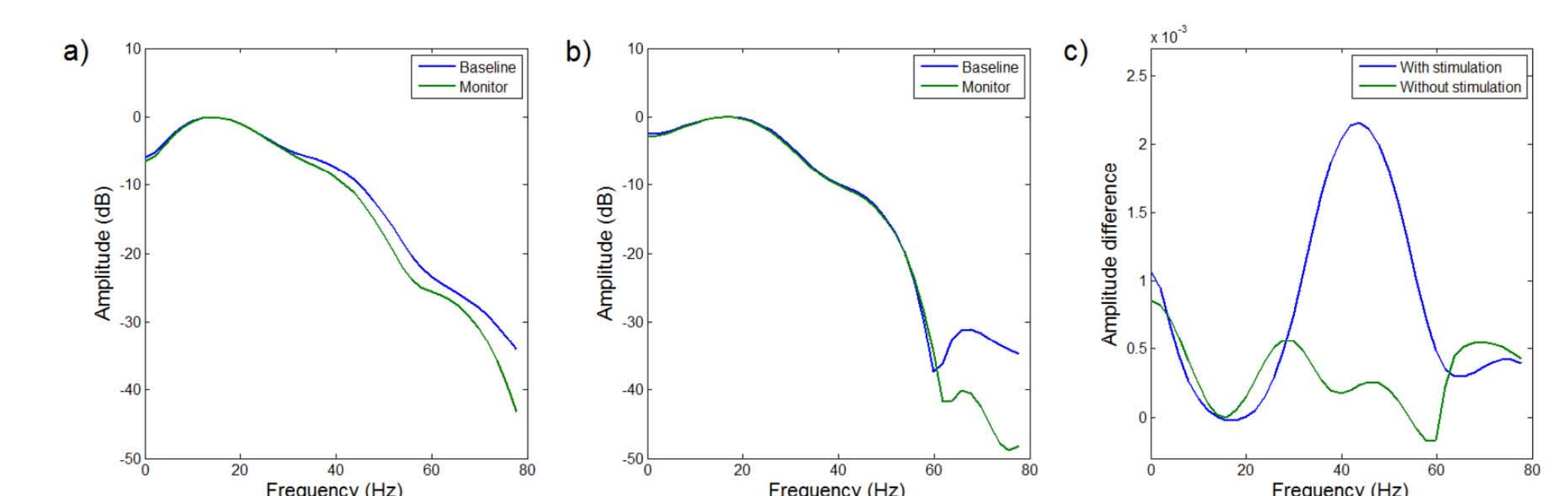


FIG. 5. Time slice through the time variant spectrum for an area a) with and b) without stimulation and c) the amplitude spectrum difference.

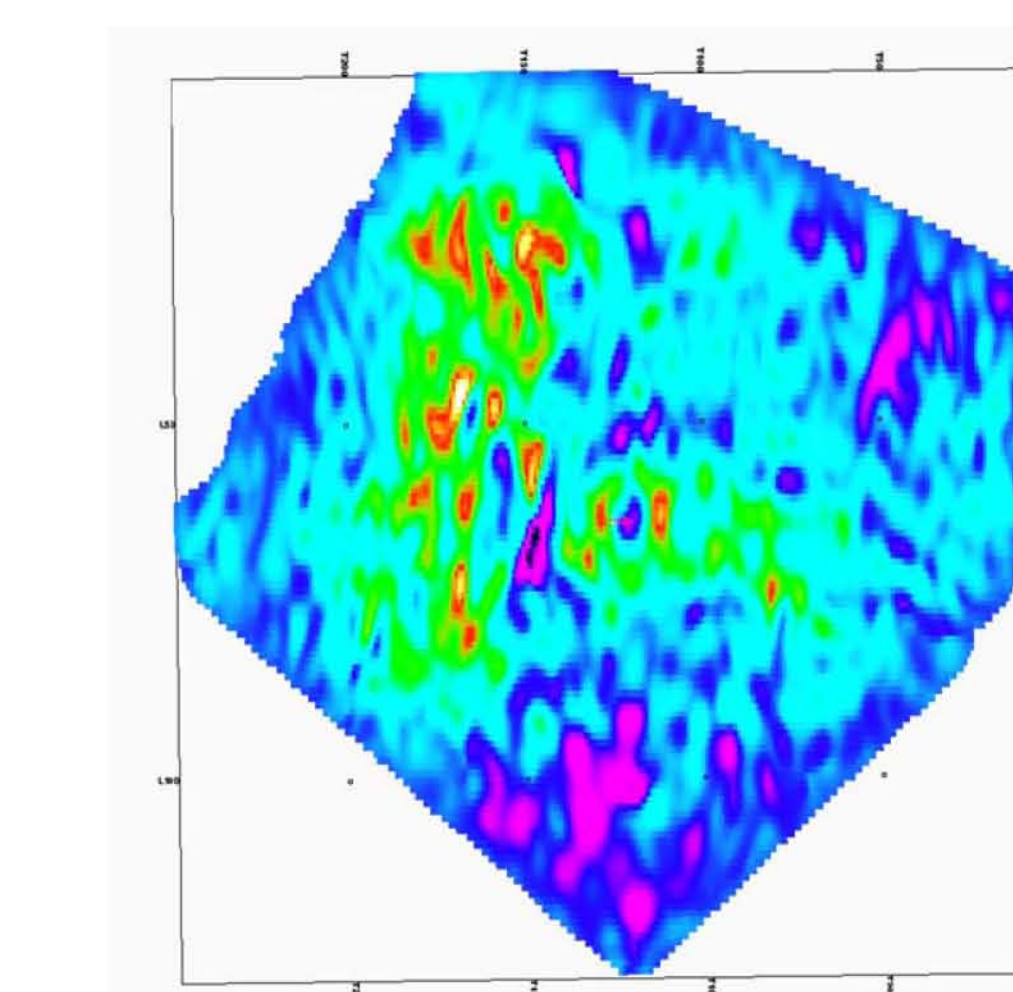


FIG. 6. Map illustrating the areal extent of the 4D attenuation anomalies suggesting fluid mobility in the stimulated zone.

CONCLUSIONS

Estimates of permeability in hydraulically induced fractures were performed through spectral analysis of a time-lapse seismic survey. Estimates are based on theoretical predictions that the effect of fluid mobility results in a frequency dependent attenuation response. Comparison of time-variant amplitude spectra for baseline and monitor surveys shows a bandlimited spectral anomaly consistent with theoretical expectations. The attenuation analysis is consistent with microseismic observations and 4D seismic amplitude and travelt ime anomalies, suggesting that fluid was transported through the fault, diverting energy from the hydraulic fracture treatment to re-stimulate the NW end of the well pad.