Seismo-Acoustics Signature Analysis of Temperature and Pressure Dependent Porous Rocks

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SUMMARY

Seismo-Acoustic signatures of temperature and pressure dependence of geothermal reservoir rocks, two samples of volcanic rocks (Iceland), have been investigated using laboratory experiment measured at in-situ conditions. The analysis of the seismo-acoustic signatures has been employed using the acoustic waveform recorded during laboratory experiment in terms of their P-P and P-S-wave velocities, instantaneous frequency and phase. In accordance to the systematic change of velocities with the temperature rise and down, the instantaneous frequency and phase of the acoustic waveform have shown systematic change with the temperature change.

EXPERIMENTALS

The measurement system was equipped with an electrical heating and sealings made of heat-resistant materials for withstanding temperatures up to 250 ºC. It consists of syringe pumps that control the hydrostatic confining pressure (up to 70 MPa) and the pore fluid pressure (up to 50 MPa), electrodes for electricity measurements and P- and S transducers. A 500 kHz resonance frequency for the piezo shear and compressional transducers was used to generate S and P acoustic waves, respectively. To investigate the seismo-acoustic behaviour of temperature dependent rocks three kinds of experiments have been performed:

- P-P acoustic measurement, i.e., "P-P" means generating P wave at source and recording using P receiver;
- P-S acoustic measurement with the same meaning to P-P, i.e. P wave at source and S receiver; and
- P-P acoustic measurement by keeping temperature constant and slowly decreasing the fluid pore pressure (damped experiment).

More details on experimental work and setup are given in the work of Bruhn et al. (2007) and Kulenkampff et al. (2005). Due to the available and meaningful data obtained in the experiment, only P-P and P-S acoustic wave have been used for the analysis of seismo-acoustic signatures of investigated sample rocks.

SAMPLES

The cores came from Icelandic geothermal wells. Some properties of the measured core samples are summarized in Table 1. Note, for more complete description of the samples refer to the work of Flovenz et al. (2005) and Bruhn et al. (2007).

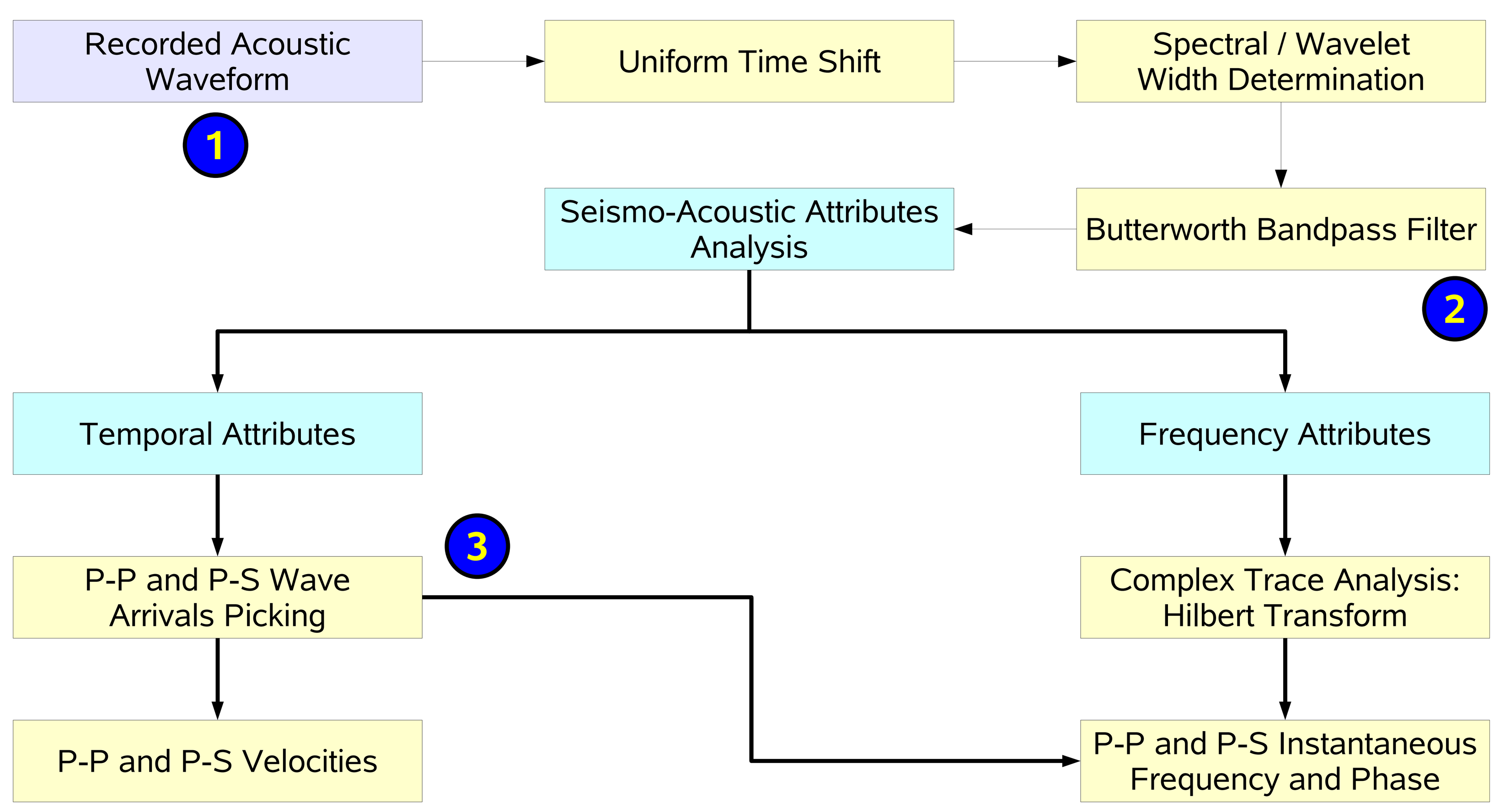
Table 1

Sample Description	Sample ID 58	Sample ID 3A
Depth (m)[1]	187	795
Material[1]	Basalt	Hylaloclastite
Alteration zone[1]	Smectite	Chlorite
Present in-situ temperature (ºC)[1,2]	160	200
Sample length (mm)[3]	40	40
Sample diameter (mm)[3]	30	30
Estimated in-situ fluid conductivity at 25 ºC (µS/cm)[1]	780	808
Porosity (%)[3]	20.0	20.7
Pore volume (cm^3)[3]	5.6	6.0
Density (g/cm^3)[3]	2.37	2.15

[1] The data from Flovenz et al. (2005)
[2] The data bank of National Energy Authority and Iceland GeoSurvey
[3] Measurements made by Erik Spangenberg at GFZ Potsdam, Germany

DATA PROCESSING

The analysis of seismo-acoustic signatures of temperature dependent rocks has been employed by using the emission acoustic waveform recorded by the pair of P-P or P-S transducers. In the liquid-steam transition experiment only P-P acoustic waves were available for the investigation. The data processing flow is shown in the diagram below:



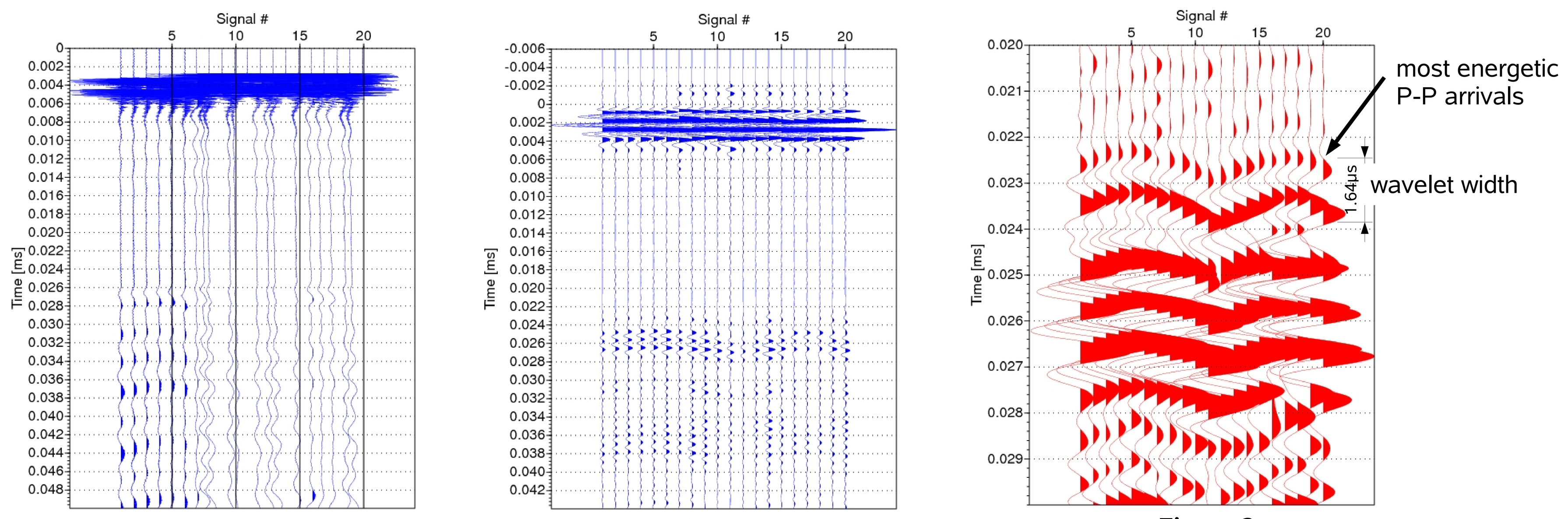


Figure 1 Figure 2 Figure 3

Figure 1 shows the original recorded P-P waves (for the sake of illustration, only P-P acoustic wave of the sample 58 was shown) at step 1 indicated in the processing flow diagram. Note the very-low and high frequency noises are evident in this record. Figure 2 depicts the P-P waveform after employing a uniform time shift, wavelet width determination and Butterworth filter of 3rd order (step 2). After these spectral width selection and bandpass filtering, the most energetic P-P arrivals responsible for the P-P velocities computation are clearly seen in Figure 3 (step 3).

DATA ANALYSIS

Plotting the recorded waveform in a style of the standard seismic section may help to interpret the data qualitatively. Figures 4 (a-c) show an example of a P-P "section" of the sample 3A, and its corresponding instantaneous frequency and phase sections. In these figures the horizontal axis indicates the temperature cycle used in the experiment; the vertical axis shows the recorded time in miliseconds. The same representation can also be made for P-S waveform and its corresponding instantaneous attributes. The systematic change of P-P or P-S arrivals with the temperature cycle describes the P-P or P-S wave velocity change with the temperature, respectively. Figure 5 summarizes the final result for P-P, P-S and P-P (damped) velocities and instantaneous attributes for both samples 3A and 58.

DISCUSSION

The P-P and P-S velocity decrease with temperature increase indicates that pressure (stress generally) and temperature work under competing behaviour affecting the elastic wave velocities in an opposite way. It is important to note the analogy between mechanical stress due to the applied differential pressure (the different between confining and pore pressure) and the thermal stress due to the temperature increase. As the temperature change from its reference state is applied to the sample the rock will expand. The expansion due to the temperature rise is responsible for a volumetric strain in the rock. In this case the intrinsic effect of temperature is able to re-open the old or to create new cracks at a certain state of differential pressure resulting in the decrease of elastic velocities.

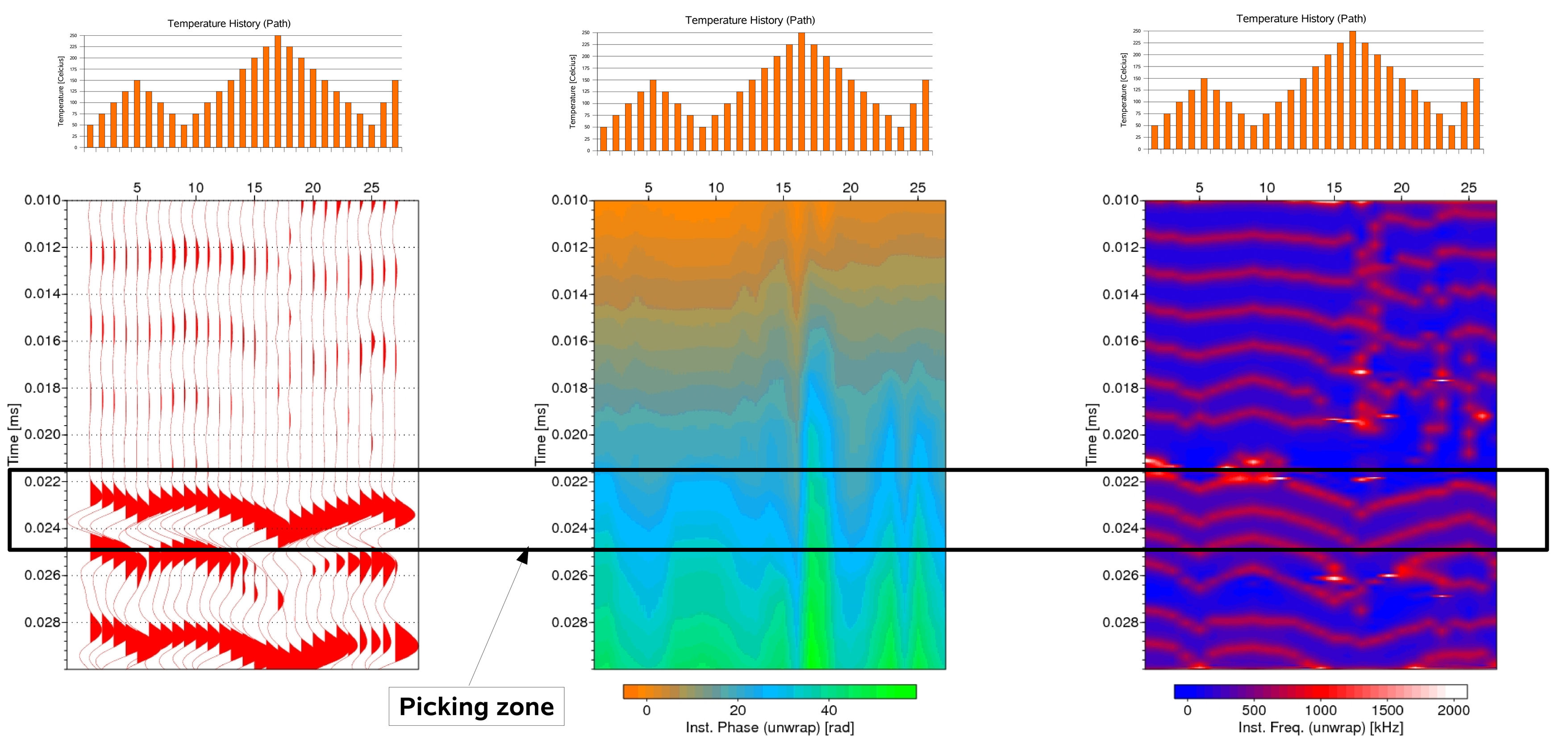


Figure 4a Figure 4b Figure 4c

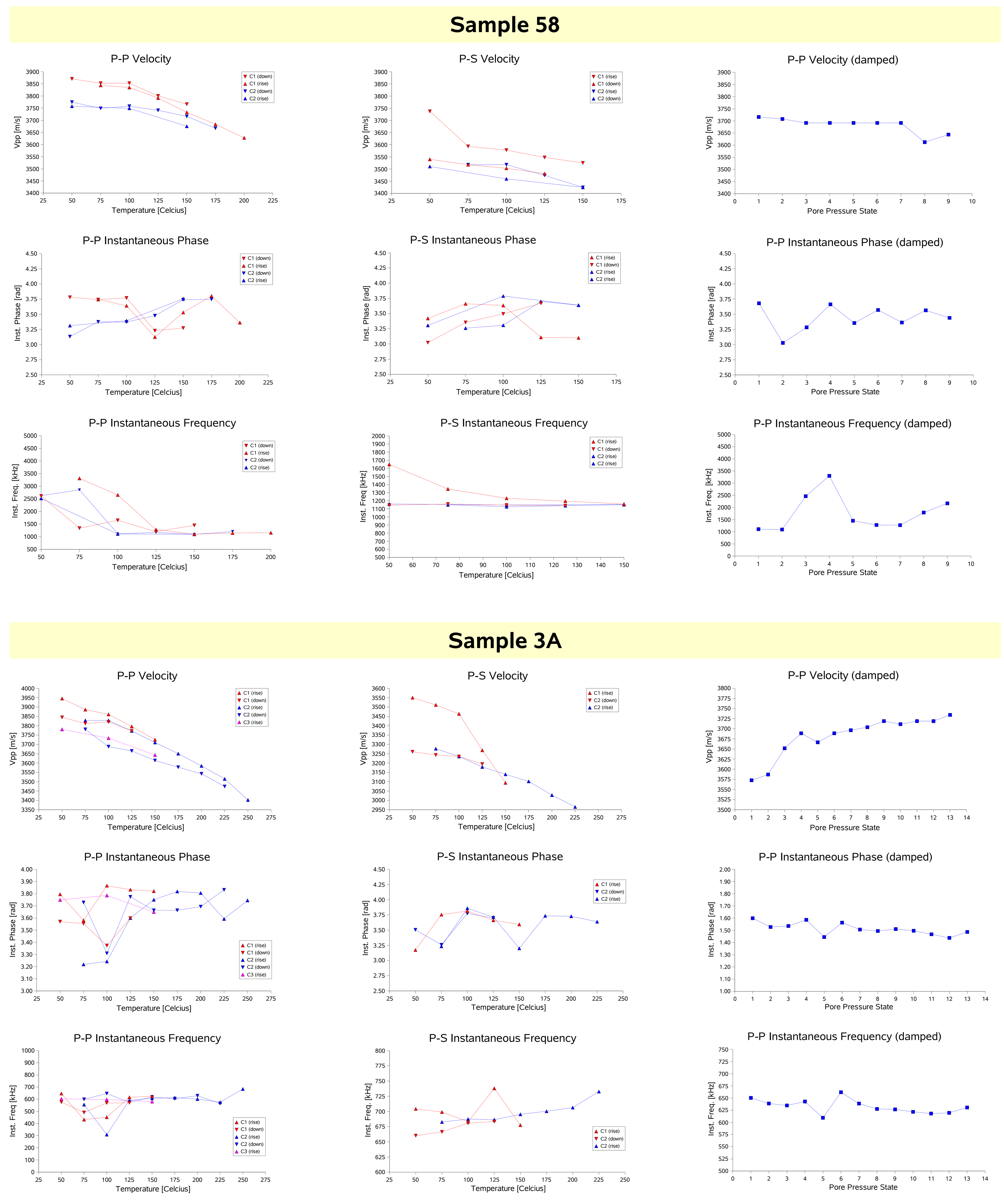


Figure 5

References

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