MAPPING SEISMIC AND ATTRIBUTE VOLUMES TO A DIFFERENT VERTICAL DOMAIN – PROGRAM surface_driven_data_registration

Contents

Overview

Seismic data volumes acquired over the same area do not always align with each other. Although simple bulk shifts to a common data and wavelet shaping improve the correlations, there may still be differences due to either changes in the acquisition and processing flow, or even the weather, which can change the statics corrections. The most familiar data registration workflows are for matching the reflector times of monitor surveys with the baseline survey in time-lapse seismic analysis and in mapping PS reflector time to PP reflector time in converted wave analysis. For azimuthal anisotropy analysis, a frequent practice is to flatten the azimuthally limited surfaces defining the top or base of the target area, thereby allowing AVAz or impedance variation with azimuth analysis (e.g., Zhang et al., 2013). Here, we provide a means to register the azimuthally limited data across multiple horizons, such as occurs with the multiple targets in the Permian Basin, USA. Finally, the registration workflow is easily modified to provide a simple time-to-depth conversion of time-migrated seismic and attribute data (or correction of depth-migrated data) that is consistent with the depth surfaces honoring the well control that seismic interpreters provide to their engineering partners.

Converting from time to depth

In North American resource plays, the final seismic data volume is most commonly in the time domain, while the engineering data are in the depth domain. In general, the interpreter uses the well control (sometimes hundreds of well tops) and the picked seismic surfaces from the time-migrated data and generates a depth surface that honors the well tops at the well locations but also honors the relative shapes of the picked surfaces (e.g., honoring fault offsets where the fault falls between wells). Perhaps the most common workflow is to use kriging with external drift.

The major goal in resource plays is to (1) identify geologic drilling or production hazards, and (2) if possible correlate the seismic data and attributes to engineering measurements in order to predict future drilling, completion, and production issues. Although well trajectories and measurements can be converted to time (e.g., Guo et al., 2012; Qi et al., 2019) when there are hundreds of wells, a simpler solution is to converted the limited number of attribute volumes to depth. Converting the seismic data to depth also leaves the depths of the wells and perforations in their correct spatial position. The number of well measurements can be many and may include oil production, gas production, water production, proppant volumes, initial pressures, breakdown pressures, temperature logs, flow meter logs, image logs, rate of penetration, number of bit trips and modern fiber optic measurements. Program **surface_driven_data_registration** uses the previously interpreted time surfaces and the corresponding geostatistically generated depth surfaces to map the time domain seismic or attribute volumes to depth. The mapping is simple and assumes a linear mapping from time to depth in each layer bound by two adjacent surfaces (equivalent to a laterally variant but vertically constant velocity in each layer).

Correcting depth-migrated data to honor the wells

Although depth migration provides a more accurate estimate of depth than time migration, the resulting seismic image will still exhibit well tie mismatches. The primary cause is inaccurate migration velocities, which is often due to anisotropy, where tomographic and full waveform inversion methods are more sensitive to the horizontal than to the vertical component of an anisotropic velocity model of the earth. The correction workflow is the same as in the previous paragraph, where the seismic horizons are picked on the depth migrated data volume and then corrected using kriging with external drift to honor the true depths measured by the wells.

Registering azimuthally limited volumes for AVAz analysis

Even for the most carefully migrated data volumes, there may be some misalignment of reflectors seen on the azimuthally limited migrated volumes. In order to apply amplitude variation with azimuth (AVAz) analysis, we must first register or align the prominent reflectors. Here, the interpreter picks the same key horizons on the fully stacked volume and each of *N* azimuthally limited volumes. Then each azimuthally limited volume is registered, one-by-one with the target (e.g., fully stacked) volume, and hence with each other.

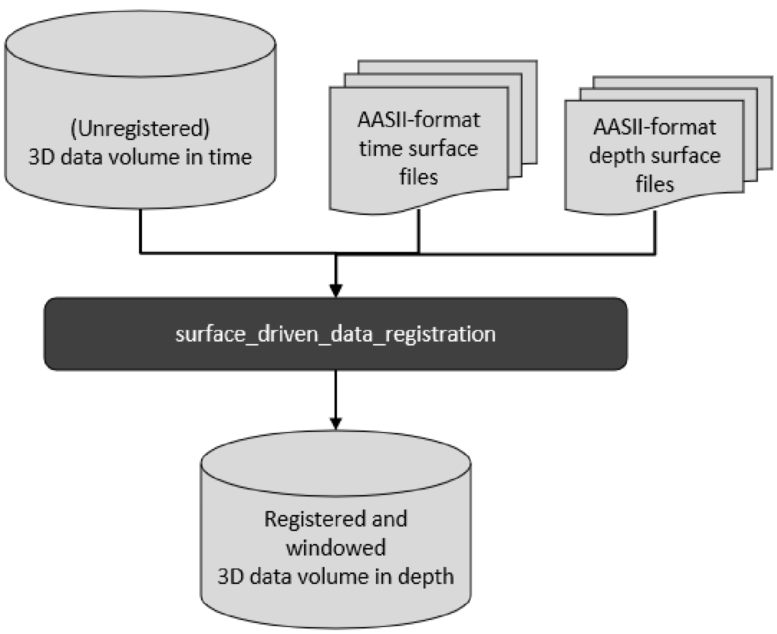
Registering PS data to align with PP data

Because the S-wave velocity is slower than the P-wave velocity, converted (PS) wave sections will be stretched with respected to the PP section. Surface-driven data registration is perhaps the most commonly used method to align the two data volumes, where now, the goal is to map to

PS volume to PP time. Here the data between each pair of PS surfaces are mapped to the time interval between the corresponding PP surfaces.

Registering time-lapse seismic monitor volumes with the base survey
Production of oil and gas and the injection of water, CO2, and other fluids change not only the amplitude of the reflectors, but also their position due to changes in velocity. While changes in temporal thickness (velocity) are a valuable tool in time-lapse seismic analysis, measuring changes in amplitude requires aligning the same stratigraphic reflectors in the multiple surveys. Such alignment is again a data registration process where the target time or depth surfaces are typically those of the baseline survey.

Computation flow chart



The flow chart is simple. In this example, the (unregistered) input data volume is in time, whereas the desired (registered) output data volume in in depth. To do the conversion we must provide corresponding surfaces in each of two volumes. In time to depth conversion, we use well control to map each of our picked time surfaces to depth. In registering azimuthally limited data volumes, we will pick the same horizons on each of the volumes as well as on a target volume (e.g., the stacked volume or the “best” of the azimuthally limited volumes). Because the surfaces may have been generated using different software and have different formats, we require that all surfaces be converted to AASPI format using program **surface_import**. Program **surface_import** will also convert the units of the surfaces to those of the corresponding input and output data volume. (e.g., changing an ASCII text format surface in ms or ft to an AASPI-format surface in s or kft). Along with the task of either converting time surfaces to depth surfaces or picking multiple versions of the same surfaces for data registration, this latter step is the most tedious part of the time-to-depth conversion process.

Output file naming convention

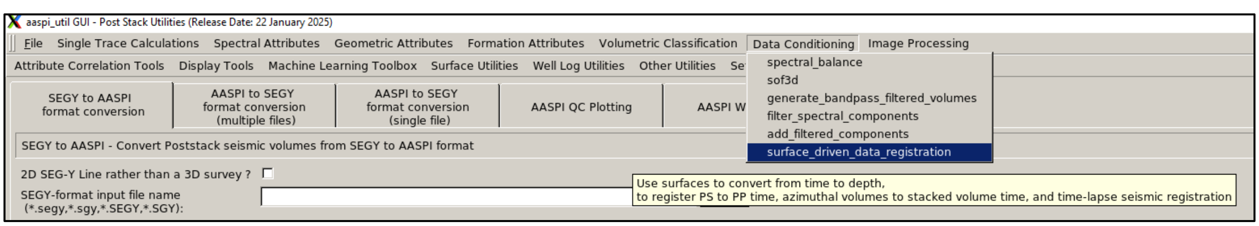
Program **surface_driven_data_registration** will always generate the following output files:

Output file description	File name syntax
Program log information	surface_driven_data_registration_unique_project_name_suffix.log
Program error information	surface_driven_data_registration_unique_project_name_suffix.err
Output surface file name	registered_old_input_surface_file_name.H

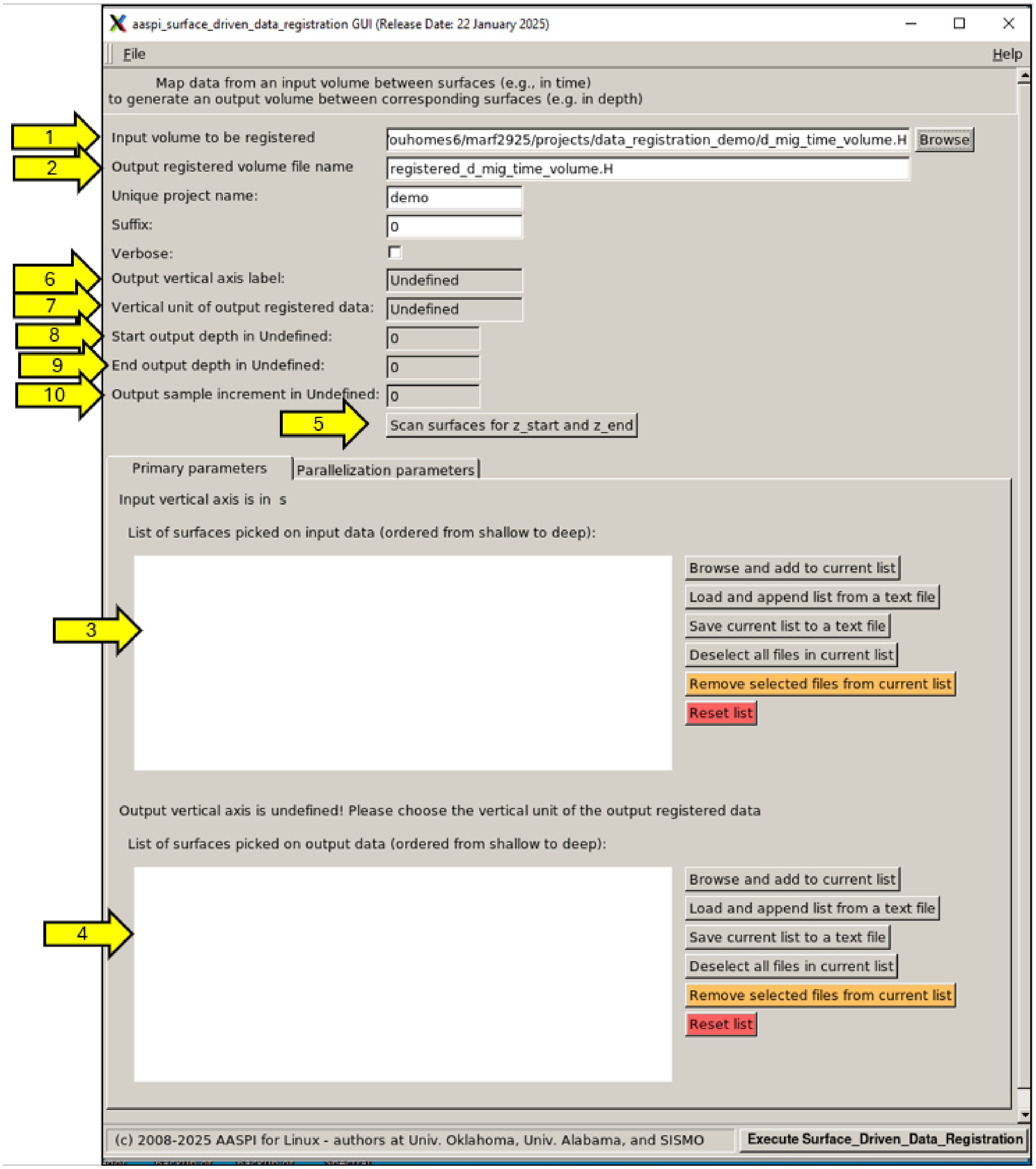
where the values in red are defined by the program GUI and the values in blue are related to the input file names. Errors, much of the input information, a description of intermediate variables, and any software trace-back errors will be contained in the **.log* file. More common errors and program completion messages will appear in the **.err* file and appear in a pop-up window upon program completion or termination.

Invoking the surface_driven_data_registration GUI

To convert an AASCI-format surface to AASPI-format, click the *Data Conditioning* tab in the **aaspi_util** or **aaspi_main** tab and drop down and select *surface_driven_data_registrationl*:



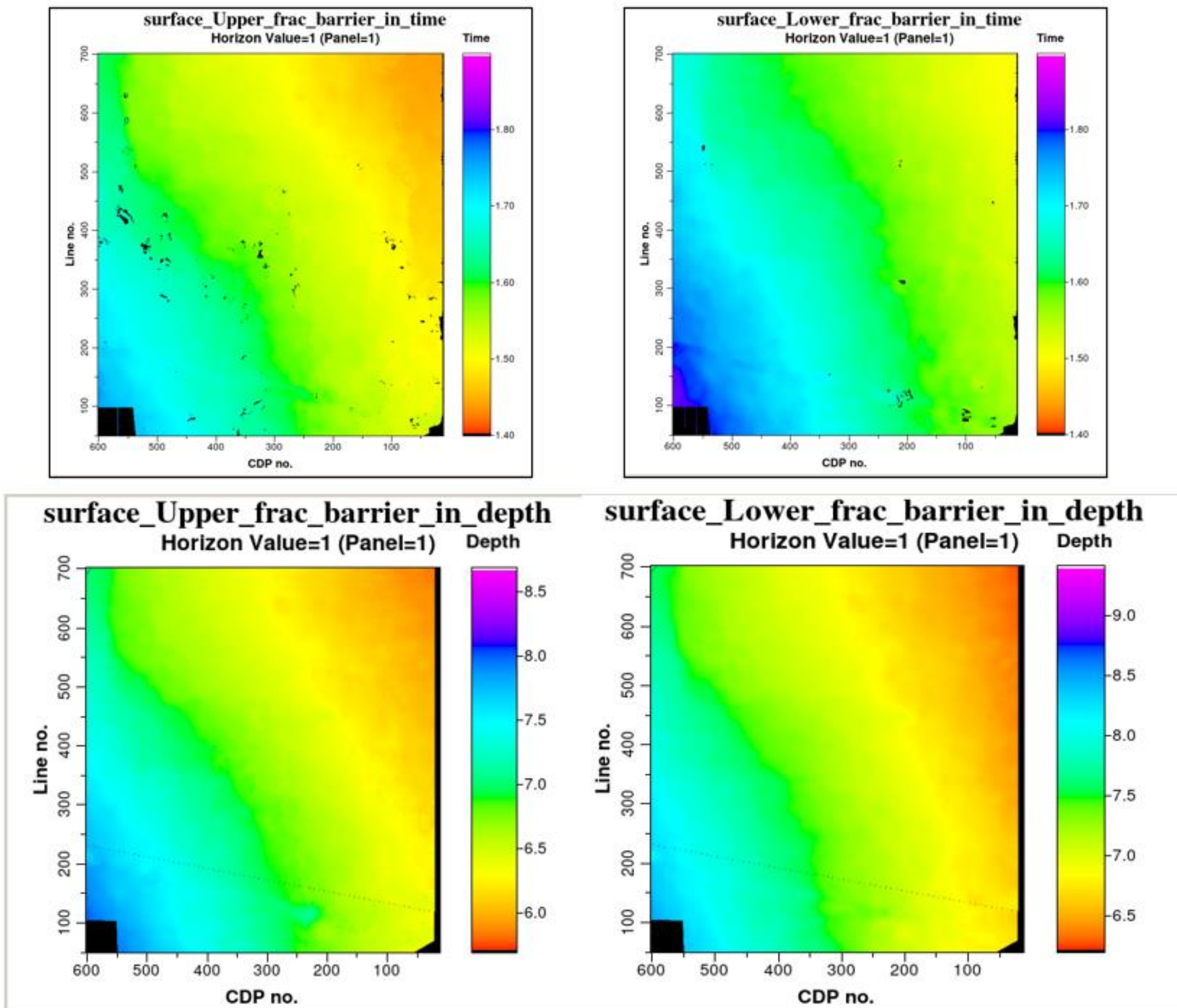
The following GUI appears:



The first step is to (1) choose the seismic volume that will be registered. In the following example, it is a time-migrated data volume that I wish to convert to depth. In a different application, it could be a monitor survey that I wish to register with the base survey, or the 30° azimuthally limited data volume that I wish to register with the stacked data volume. The (2) output registered data volume file name will be automatically generated but the GUI allows you to modify the name to suit your needs. At this point, items (5)-(10) are disabled, so drop down where you will enter your (3) list of surfaces picked on the input data volume, and (4) your list of surfaces that correspond to the output volume to be generated. For time-to-depth conversion, there are no data to pick, so the surfaces will be generated using kriging with external drift or some other process. For PS to PP conversion, time-lapse seismic applications, or registration of azimuthally limited volumes, you would pick the surfaces on the data volume with which you wish to register the input data volume (e.g., the PP, base survey, or stacked data volumes).

Ordering and one-to-one correlation of the input and output surfaces

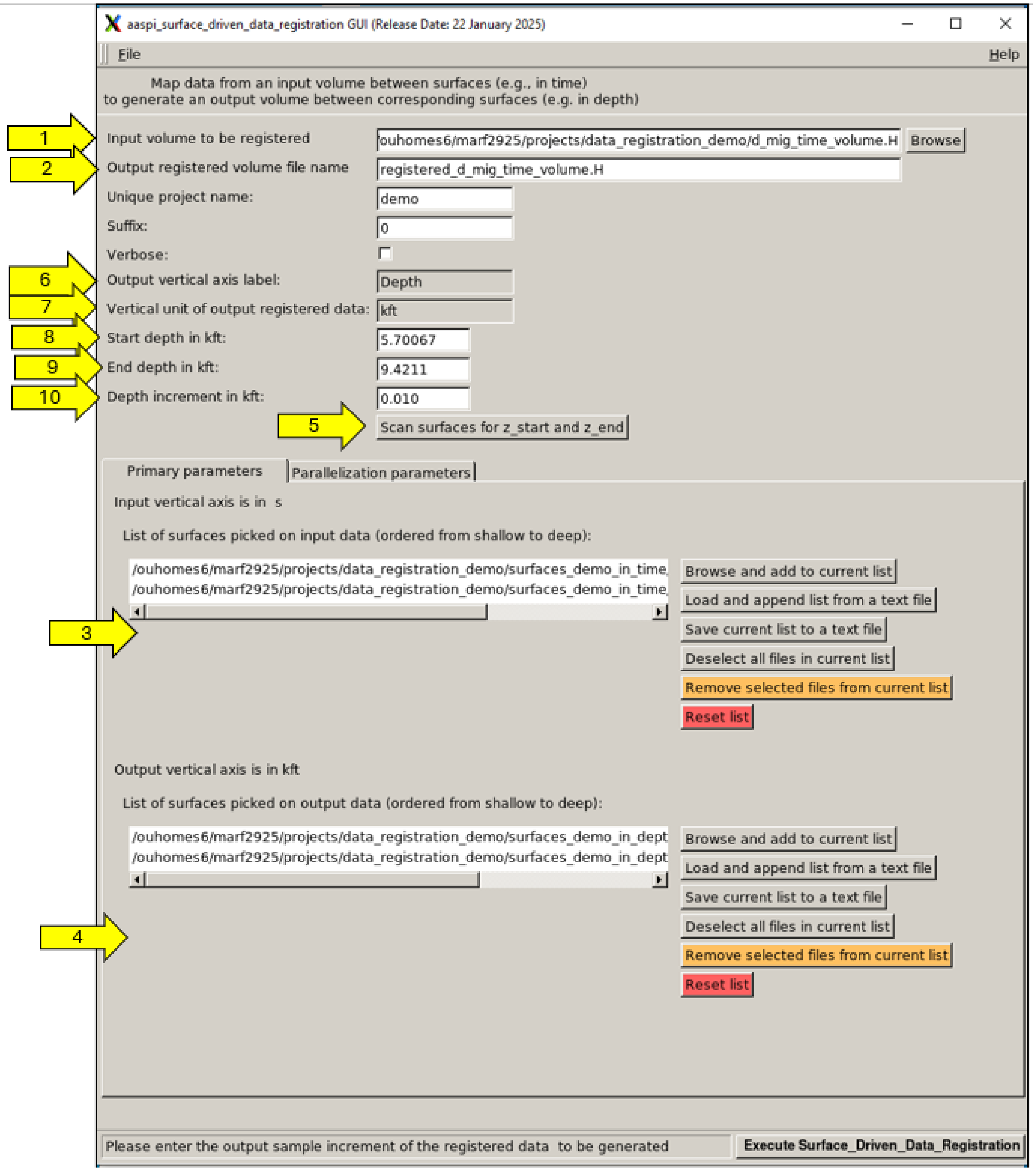
The (3) input and (4) output surfaces need to be ordered from shallow to deep. They also need to correlate one-to-one with each other. In general, the extent of the surfaces may be different; In the surfaces below, you will see that the surfaces converted to depth do not honor the no-permit and poor data areas of the picked time-domain surfaces. Data will be registered only when all surfaces are defined for a given trace location.



Example: Converting from time to depth between frac barriers

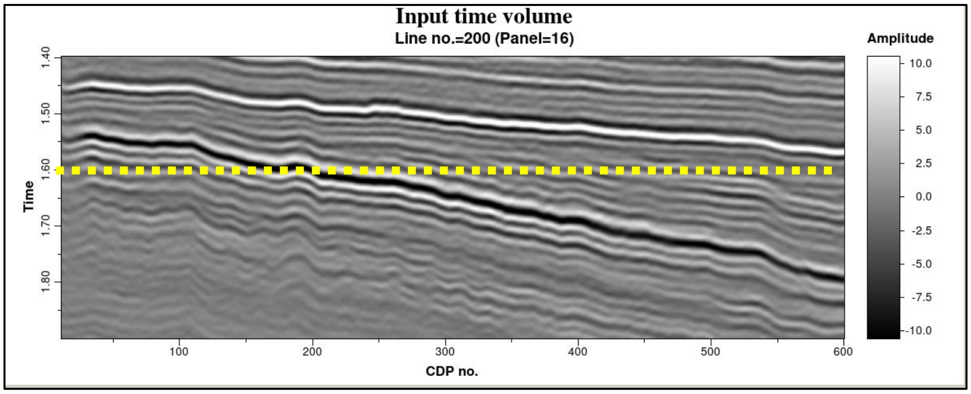
The following example is from a resource play in the Midcontinent, USA. Only two surfaces have been picked in time. Note the no-permit (black) areas in the figures shown previously. Both surfaces have been converted to depth using a geostatistical method.

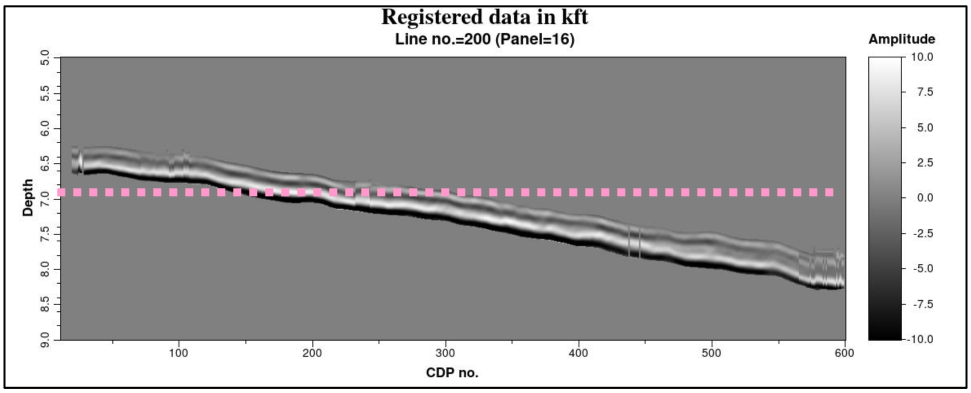
After having selected the (4) output surfaces items (6)-(10) become active in the GUI. In this example, the GUI reads from the AASPI-format surface files and finds that the (6) *Output vertical axis label* is in depth and the (7) *Vertical units of the output registered data* will be kft. If I click (5) Scan surfaces for *z_start and z_end*, it will read the minimum and maximum value of each AASPI-format surface (stored as *min_amplitude* and *max_amplitude* in the AASPI-format surface files) and display them in (8) *Start depth in kft* and (9) *End depth in kft*. You can modify these values to include a larger or smaller vertical window.

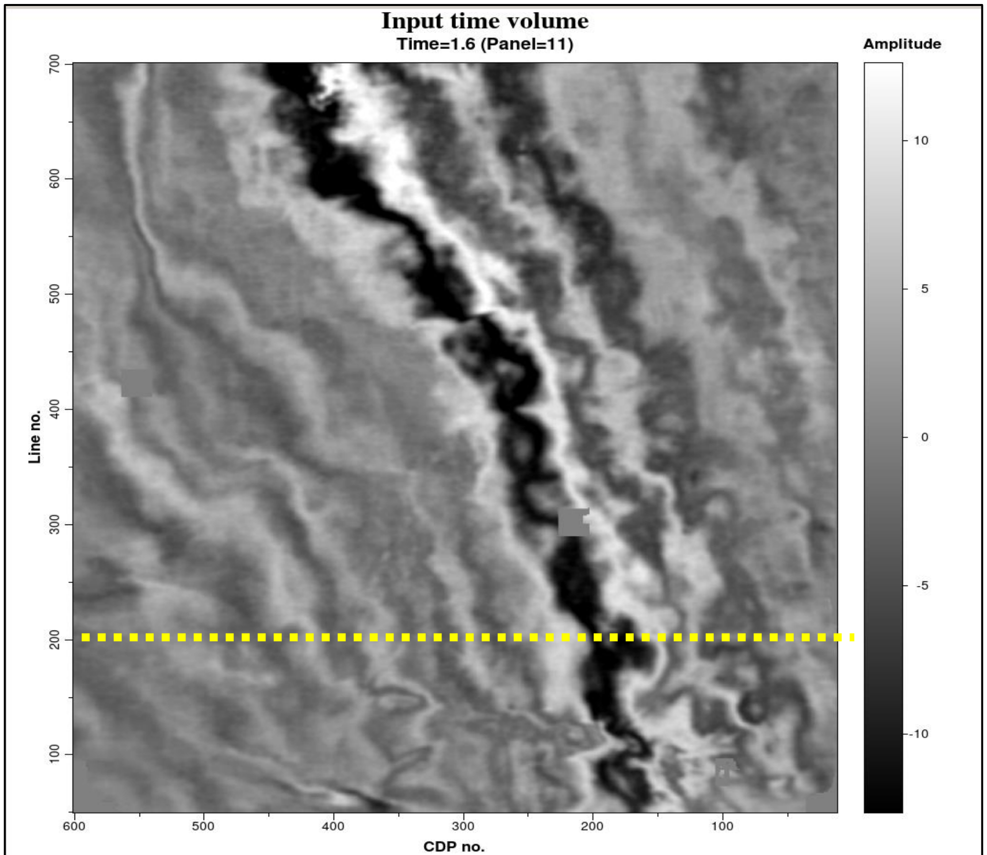


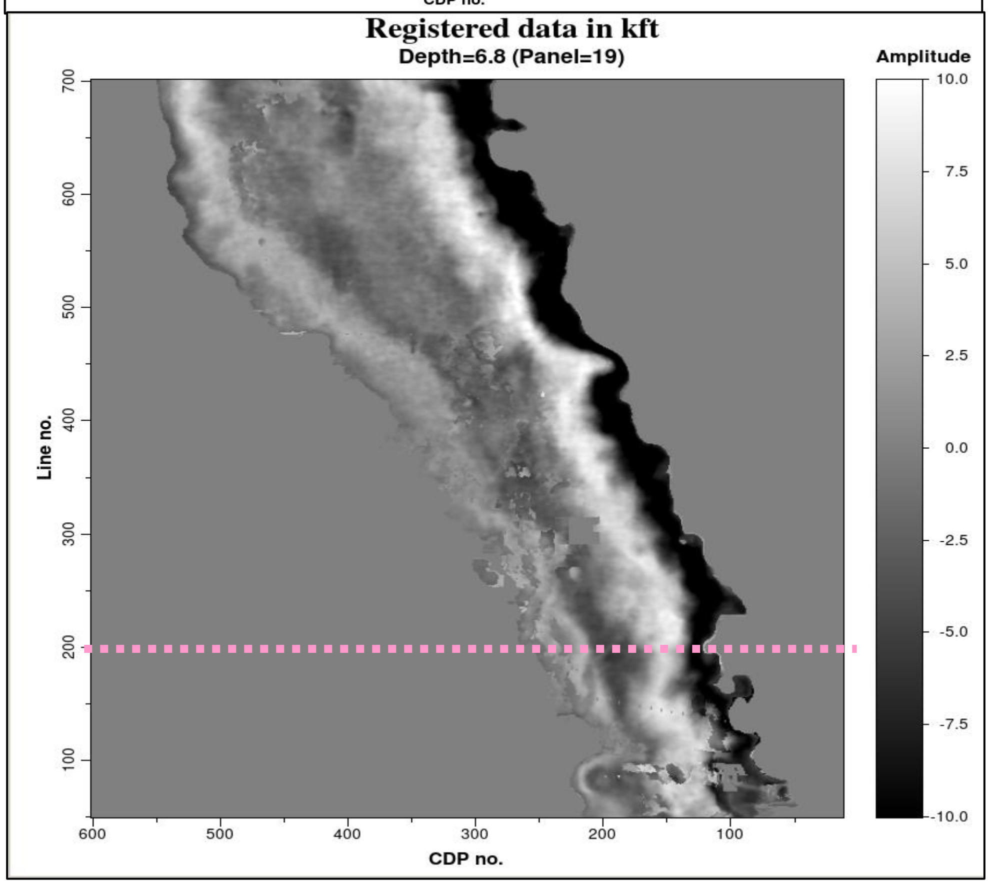
The final parameter to choose for this example is the (10) *Depth increment in kft*. The output data are in kft because the output surfaces were told to be in kft in AASPI program **surface_import**. In this example, I entered a depth increment of 10 ft which is 0.010 kft. Modify your parallelization parameters if needed and click *Execute Surface_Driven_Data_Registration*.

A vertical slice through the input and output data looks like this, where the yellow line corresponds to a time slice and the magenta line a depth slice in the following two figures:


Input time volume
Line no.=200 (Panel=16)
Amplitude
Time
CDP no.


Registered data in kft
Line no.=200 (Panel=16)
Amplitude
Depth
CDP no.


Input time volume
Time=1.6 (Panel=11)
Amplitude
Line no.
CDP no.


Registered data in kft
Depth=6.8 (Panel=19)
Amplitude
Line no.
CDP no.

This example is simple and used only two horizons. In general, multiple horizons can be used, so long as they are ordered from shallow to deep and exhibit a one-to-one correspondence from the input to the output data volumes.

References

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Qi, X., J. Snyder, T. Zhao, K. J. Marfurt, and M. J. Pranter, 2019, Correlation of seismic attributes and geomechanical properties to the rate of penetration in the Mississippian Limestone, Oklahoma, in G. M. Grammer, J. M. Gregg, J. O. Puckette, P. Jaiswal, S. J. Mazzullo, M. J. Pranter, and R. H. Goldstein, eds., Mississippian Reservoirs of the Midcontinent: AAPG Memoir 122.

Zhang, K., Y. Guo, B. Zhang, A. M. Trumbo, and K. J. Marfurt, 2013, Seismic azimuthal anisotropy analysis after hydraulic fracturing: Interpretation, 1, SB27-SB36.