#1 : Survey Design for Full Waveform Inversion

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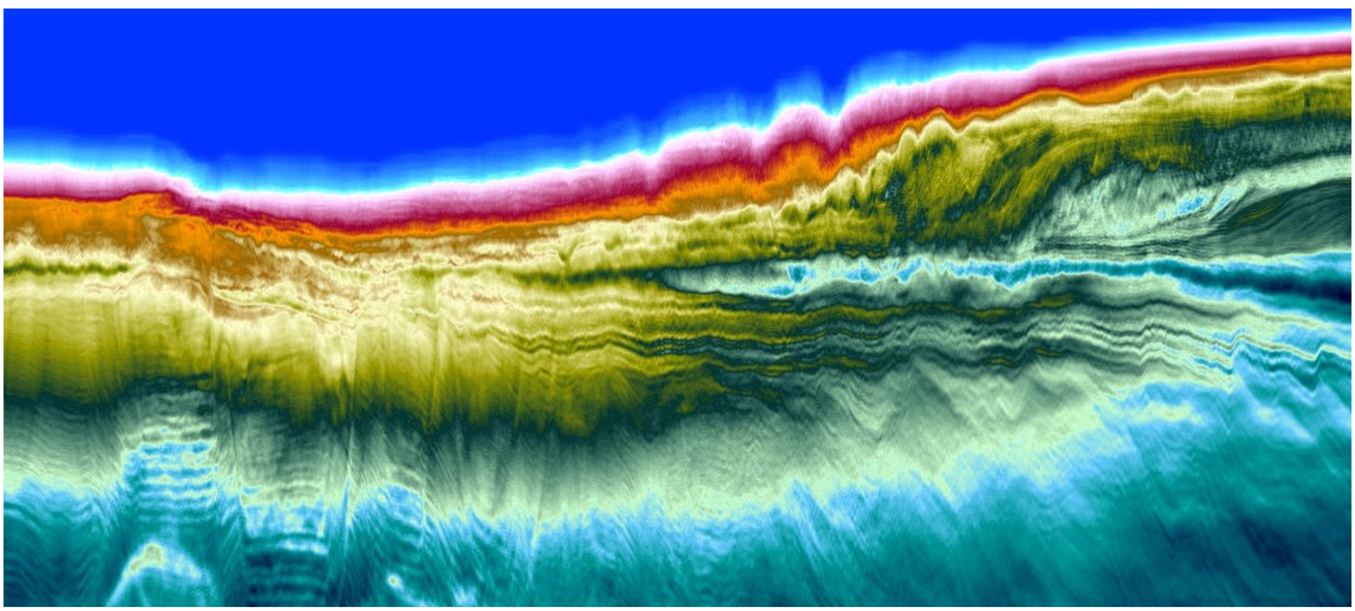


This Full Waveform Inversion shows 100Hz data from 300m to 4,500m. The image was produced by DownUnder Geosolutions. Capreolus data is shown by kind permission of Polarcus

Great imaging requires great data. In this short note, Dave Monk discusses one of the key survey design factors that should be considered when designing a survey for FWI,

Survey Design for Full Waveform Inversion.

Full-waveform inversion (FWI) was invented in the early '80s but it is only recently that FWI has become the preferred tool for estimating complex velocity distributions. So why has it taken this long for the technology to mature? The key factors have been access to sufficient compute power and appropriate seismic data that support the assumptions behind FWI. Compute power limitations have been eroded by the continuing evolution in available hardware performance which increases by an order of magnitude every couple of years. The main barrier to FWI is now the data itself. There are two challenges : geometry (offsets) and bandwidth.

Offset limitations.

Historically seismic acquisition equipment and templates impose limits to FWI. Surveys were typically designed with offset limits designed based on angles of incidence for AVO, or on offsets limited based on moveout stretch factors. The goal was to acquire data for reflection events; with little focus put on the ability to record refractions and diving waves. As a result the offsets acquired were too limited for effective FWI.

Bandwidth limitations.

Until recently, seismic systems generated little low frequency source energy, and were susceptible to low frequency noise (swell noise in marine, and ground roll in land). It was common practice to apply harsh low-cut filters to remove this low S/N data. However, this practice effectively eliminated the low frequencies needed for FWI. Additionally, conventional towed streamer marine data suffers from ghost notches at both source and receiver, which further limit the low frequency spectrum of the resultant data.

Designing surveys for FWI

The introduction of longer offsets (in excess of 8,000 m) and the introduction of broadband seismic have enabled the recording of data with long offsets and low frequencies in the marine environment. Data that are much better suited for FWI than the typical legacy marine dataset.

The bandwidth issue is fairly easily resolved using broadband acquisition methods, but of more interest to the survey designer is the required offset for FWI. But how do we design a survey where we know what offsets will be useful for diving wave examination and FWI? Or alternatively, given a legacy survey how do we quickly determine the depth to which FWI will have an impact on velocity model generation.

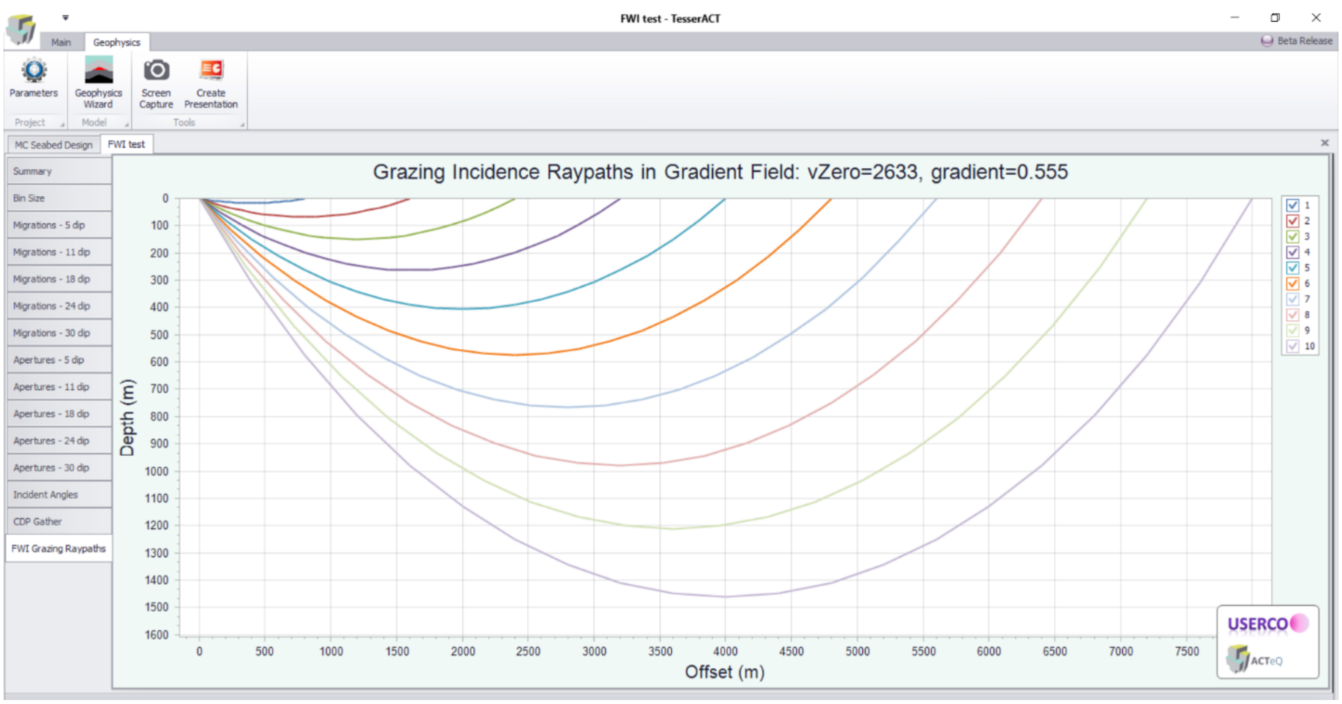
Clearly it is possible to determine the depth of influence by using detailed ray tracing and a complex subsurface velocity model. Industry "guidelines" have also evolved. Data from a dual-sensor towed-streamer acquisition was presented by Zou et al. (2014) in which the authors show that modern streamer data contains refractions that produce good FWI velocity updates to a depth of about a quarter of the streamer length. In these scenarios, FWI relied mainly on recorded diving waves to resolve small-scale geologic features up to the deepest turning point. Others have suggested that a good rule of thumb is that FWI velocities can be determined down to a depth of one third of the maximum offset.

There is however a quick way to estimate the maximum depth of diving wave penetration, using a simple approximation to the subsurface velocity profile. Given a constant velocity gradient of the form

V0+kZ, the form of the curved ray that results is described in Slotnick's "Lessons in Seismic Computing".

Given a constant subsurface velocity gradient (or a subsurface where a gradient can be effectively fitted), it is relatively easy to compute the grazing incidence ray paths as a function of depth or offset. This yields a good approximation to the task of ray tracing through a complex velocity model, and can yield a quick evaluation of whether the offsets are long enough for the requirements of the survey.

In the example shown below, a reasonable starting velocity and gradient have been selected, which yield a result very similar to the ¼ offset rule of thumb suggested by Zou.



Grazing incidence raypaths and offset requirements (Computed by ACTeQ's TesserACT survey design software. Visit ACTeQ.net for more information)

Summary

FWI can lead to a great improvement in the understanding of the velocity profile in the shallow section, and overall improvement of seismic data quality... but only if the required offsets are present in the data.

References

Slotnick M.M. Lessons in Seismic Compyuting Published by the SEG ISBN-0-931830-07-9

Zou, K., J. Ramos-Martínez, S. Kelly, A. A. Valenciano, N. Chemingui, and J. Lie, 2014, Refraction full-waveform inversion in a shallow water environment: 76th Conference & Exhibition, EAGE, Extended Abstracts, http://www.earthdoc.org/publication/publicationdetails/?publication=76285