Smooth 2D inversion compared to conventional Wavefront interpretation of Palmer Mt. Bulga data set:

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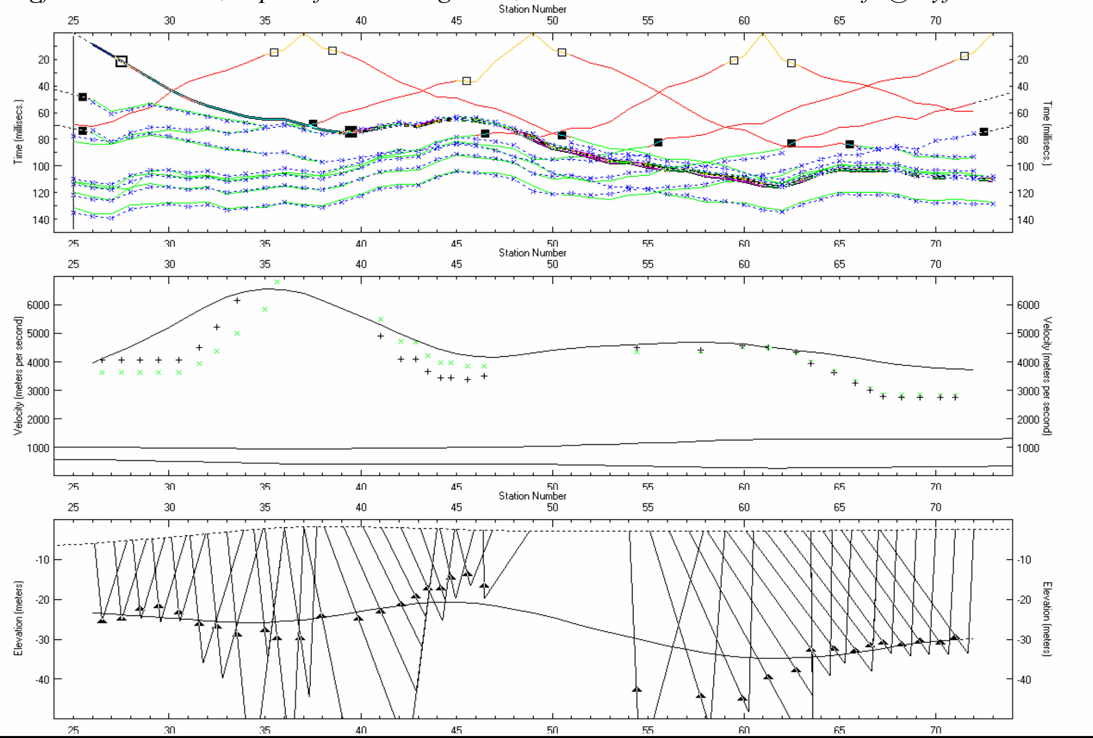

Fig. 1 Wavefront method interpretation (Jones and Jovanovich 1985), of Palmer Mt. Bulga data (Palmer 2003). Download from http://rayfract.com/tutorials/mtbulga.zip. Station spacing 5 meters. Top: map first breaks to refractors. Center: velocity, m/s. Bottom: refractor depth (m) below topography. Dashed line is weathering bottom. Triangles outline second (basement) refractor.

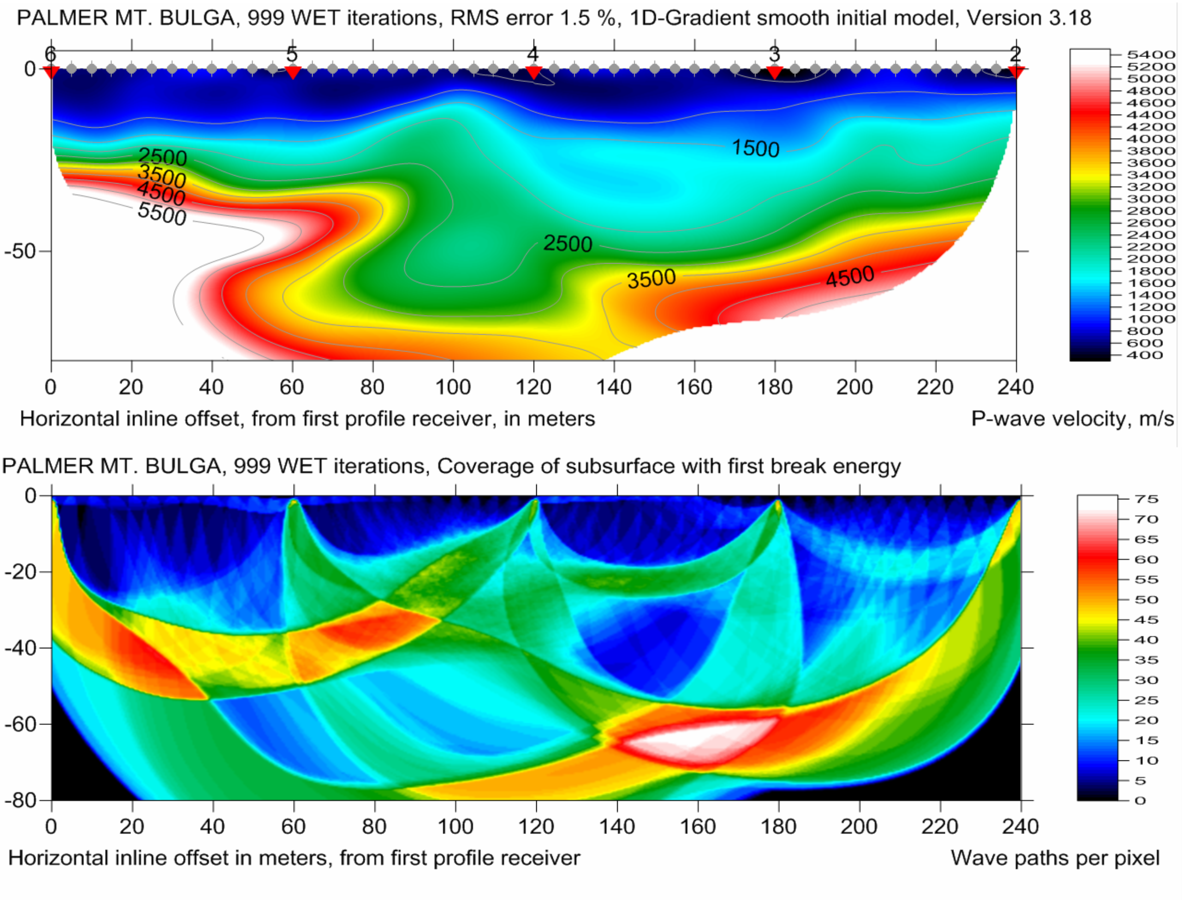

Fig. 2 Smooth 2D inversion version 3.18, 999 WET iterations (Schuster and Quintus-Bosz 1993), default parameters. Top: velocity. Bottom: wave path coverage . Note strong lateral velocity variation and velocity inversions in overburden. There are no laterally continuous refractors. Far-offset shots not regarded. We recommend to record shots with overlapping receiver spreads.

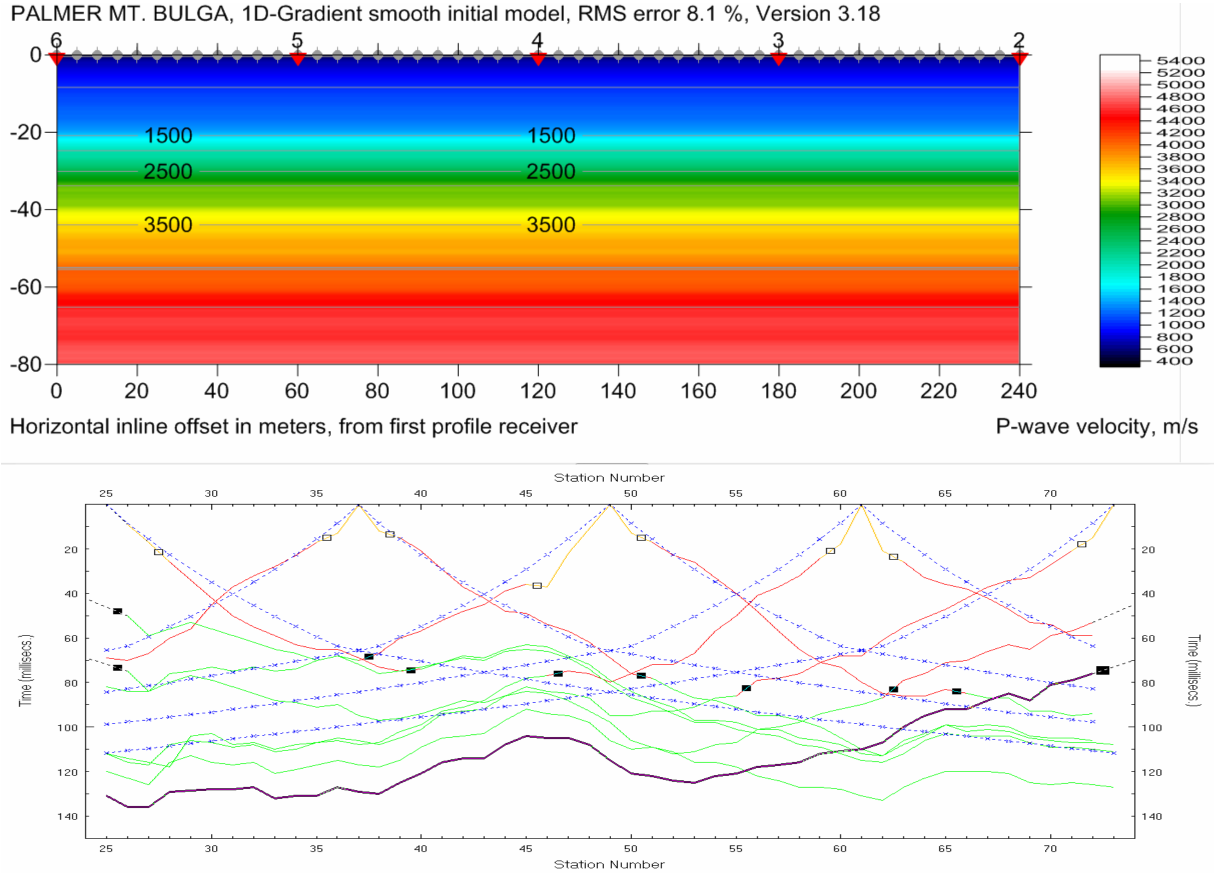

Fig. 3 Top: 1D-gradient initial model, determined with Delta-t-V method and default parameters. Bottom: fit between picked times (solid colored curves) and times modeled with Eikonal solver (dashed blue curves), for this 1D-gradient initial model. RMS error is 8.1 percent. Far-offset shots are not regarded.

Note the good correlation of basement depth, between the Smooth inversion (Fig. 2) and Wavefront interpretation (Fig. 1). For my Smooth inversion interpretation, I assume that the 2,500 m/s velocity contour represents the basement top. Below inline offset 0 meters to 80 meters, both methods show a basement depth of 25 to 30 meters. Also, both methods show a maximum basement depth of 45 to 50 meters, below inline offset 150 meters to 175 meters. Above shot spacing of 12 receivers is too wide for reliable Smooth inversion. We recommend an average shot spacing of 3 receivers or closer, see http://rayfract.com/tutorials/fig9inv.pdf and http://rayfract.com/SAGEEP10.pdf . Palmer (2003) uses the term “main refractor”, with the same meaning as my usage of “basement”. Smooth inversion does not regard far-offset shots positioned outside profile. Since four out of nine shots in this data set are far-offset shots, this may contribute to difference between Smooth inversion and GRM interpretation. We recommend overlapping receiver spreads. See http://rayfract.com/help/overlap.pdf .

In (Palmer 2003, Fig. 1) Dr. Palmer states that the line crosses a known major shear zone. His final interpretation (Palmer 2003, Fig. 4) shows a subvertical zone. I show a zone dipping to the left (Fig. 2). At a depth of 20 meters, we both agree on a zone centered at inline offset of about 150 meters. Obviously Dr. Palmer has decreased WET smoothing and wavepath width, and only run a few iterations, in (Palmer 2003, Fig. 3 to 5). Such poor settings effectively cripple WET, and resulting output will be very similar to the initial model. Default WET smoothing and wavepath width will give output with fewer artifacts (Fig. 2). We recommend to run at least 50 to 100 WET iterations, instead of the default 20 iterations. When I proposed to Dr. Palmer to drill a hole at the center of the profile, he replied that he did not remember the exact location of the line, and there would be a lot of trees now. For a synthetic fault model study showing imaging of a similar dipping low-velocity anomaly see http://rayfract.com/tutorials/thrust.pdf .

Resolution of WET and seismic refraction tomography in general decreases with increasing depth. See e.g. http://rayfract.com/tutorials/thrust.pdf , D.J. White 1989 Two-Dimensional Seismic Refraction Tomography and J.G. Hagedoorn 1959 The Plus-Minus method of interpreting Seismic Refraction Sections Fig. 1 .

Whiteley and Leung (2006) compare their VIRT interactive ray tracing interpretation to my Smooth inversion output, for above data set. They obtain similar depths and velocities, that compare well with the extensive drilling, carried out earlier, to explore the Mt. Bulga ore body.

For a systematic evaluation of our Smooth inversion method, see Sheehan et al. (2005a). Smooth inversion is based on a 1D gradient initial model (Fig. 3) as determined with our Delta-t-V inversion (Gebrande and Miller 1985, Winkelmann 1998), to avoid velocity artefacts. This initial model is refined iteratively with true 2D Wavepath Eikonal Traveltime inversion WET (Schuster and Quintus-Bosz 1993). While the Delta-t-V method is similar to the tau-*p* method (Diebold and Stoffa 1981; Barton and Barker 2003), Delta-t-V automatically detects and models velocity inversions (Winkelmann 1998: XTV method). While it may not always be possible to image velocity inversions, Smooth inversion output correctly shows the averaged velocity trends (Sheehan et al., 2005b). Delta-t-V detects and models layer internal constant velocity gradients (linear increase of velocity with depth). Velocity may jump discontinuously at layer boundaries.

In our experience, WET true 2D tomography processing requires a simple initial model which shows a good fit between picked and modeled traveltimes (Fig. 3). Otherwise WET may get stuck in a local minimum of the traveltime misfit function (Schuster and Quintus-Bosz 1993, eqn. (1)), especially if the initial model and grid are too shallow. Our WET implementation will not increase the depth of a too shallow initial grid.

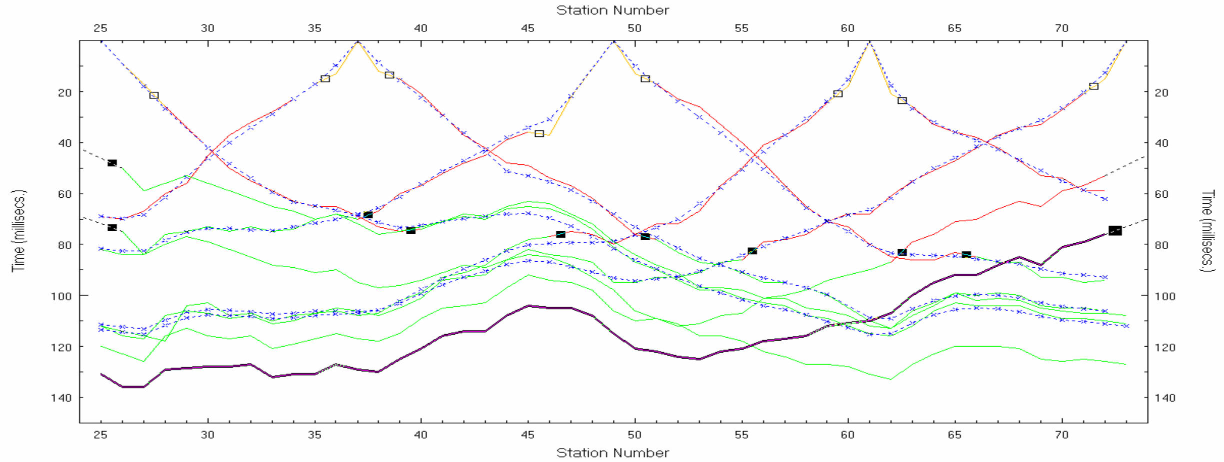

Fig. 4 Fit between picked traveltimes (solid colored curves) and modeled times (dashed blue curves), after 999 WET iterations. The RMS error is 1.5 msec. Hollow squares separate direct wave (yellow) from 1st refractor (red). Filled squares separate 1st from 2nd refractor (green). Assignment of traces to refractors is not required for Smooth inversion and WET.

As shown by Sheehan et al. (2005a, 2005b), Smooth inversion and Seismic Refraction Tomography in general vertically blur the basement top. But conventional methods such as Wavefront (Jones and Jovanovich 1981) and Generalized Reciprocal Method GRM (Palmer 1981) are based on the often unrealistic assumption that the subsurface can be modeled with a few laterally continuous layers with no vertical velocity gradient. Such layers are mathematically idealized refractors, with constant layer-internal velocity below constant inline offset. These conventional methods suppress a common basement-internal, positive velocity gradient (Fig. 3 and 4, highlighted shot) and project the average basement-internal velocities to the basement top. So these methods typically give a too high estimate, for the seismic velocity at the top of the basement.

Also, faults, velocity inversions, local velocity anomalies, pinchouts, outcrops and vertical velocity gradients within layers often make the interactive assignment of first breaks to laterally continuous idealized refractors difficult and ambiguous. See Fig. 3 and 4, e.g. shots located at station number 49 and higher. Delta-t-V does not require the user to carry out such a subjective assignment, while conventional methods such as GRM and Wavefront do. Mechanical and chemical weathering cause the rock quality and seismic velocity to decrease the closer the rock or sediment unit is to the surface. In other words, rock quality and seismic velocity tend to increase with increasing burial depth. See e.g. (B. Murck 2001), chapter 6 (Weathering and Erosion) : joints, exfoliation and frost wedging.

Leung (1995; 2003) and Sjögren (2000) describe the non-uniqueness inherent in the determination of the optimum XY value, as required for the GRM (Palmer 1981). GRM assumes that the XY value is constant for the whole profile. In case of strong lateral velocity variation, a too short estimated XY value may then result in a too low derived overburden velocity, and too shallow imaged basement. Our Wavefront method automatically determines a laterally varying XY receiver separation. See Jones and Jovanovich (1985), Brueckl (1987) and Ali Ak (1990). Wavefront considers local emerging wavefront angles. A critically refracted ray is represented by first break and emergence angle at a receiver. Each reverse ray is combined with a matching forward ray, such that both rays surface from an approximated common refractor location.

We thank Dr. Palmer for making available this interesting data set. You can download the original data from http://rayfract.com/tutorials/mtbulga.zip .

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