Smooth inversion of downhole and refraction survey, with 1D-gradient and constant-velocity initial model :

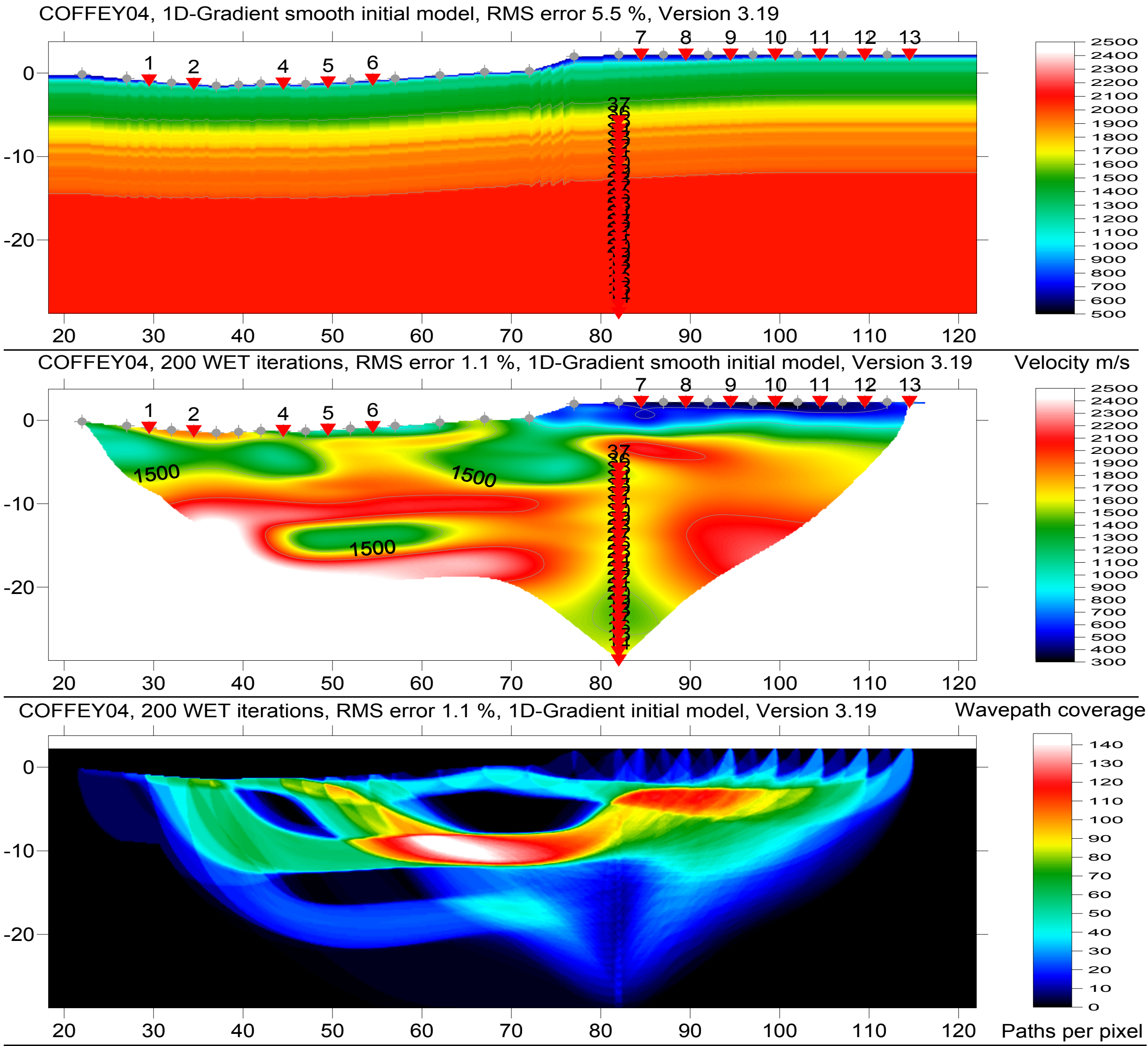

Fig. 1 : Smooth inversion with 1D gradient initial model, 200 WET iterations with *WET wavepath scaling* . Top : 1D gradient initial model. Center : velocity tomogram in m/s. Red inverted triangles are surface and borehole shot points. Grey diamonds are receivers. Bottom : first break energy and wavepath coverage, in paths/grid cell. Horizontal axis is inline offset in meters, vertical axis is elevation above sea level in meters.

Seismic traces were recorded with a hydrophone receiver array, positioned at river bottom for refraction shots 1 to 13 and in borehole for downhole shots. Downhole shots were then gathered by common borehole receiver, to obtain uphole shots 14 to 37. We imported these downhole shots as in walkaway.pdf and exported as in a13r1dm.pdf . To invert the resulting combined data set with version 3.19 of our Smooth inversion method :

- create a new profile database named COFFEY04 with a *Station spacing* of 2.5m. See our manual at http://rayfract.com/help/manual.pdf , chapter 1.1 . Specify *Line type* Refraction spread/line *and Profile start offset* of 22m.
- download the input files from http://rayfract.com/tutorials/coffey04.zip
- copy COFFEY04.ZIP into \RAY32\COFFEY04\INPUT, unzip to obtain ASCII.ASC, COORDS.COR and SHOTPTS.SHO input files.
- import the first breaks and geometry data as described in our manual, chapters 1.2 and 1.11. Specify *Import data type* ASCII column format, and *Input directory* \RAY32\COFFEY04\INPUT. Leave *Default spread type* at 10: 360 channels. Leave all other import parameters at their default settings.
- click on *Import shots* and *Read* to import all refraction and uphole shots. Leave parameters at shown values.

- *File|Update header data|Update Station Coordinates*... with \RAY32\COFFEY04\INPUT\COORDS.COR .
- *File|Update header data|Update Shotpoint coordinates*... with\RAY32\COFFEY04\INPUT\SHOTPTS.SHO
- review traveltimes with *Refractor|Shot breaks* as usual. See our manual, chapter 1.3.
- check *Post*…and *Label*… menu items at bottom of *Grid* menu, to show sources and receivers on tomogram
- select *Smooth invert|WET with 1D gradient initial model* to invert the data. Confirm prompts.
- uncheck *WET Tomo|WET tomography Settings|Disable wavepath scaling for short profile*
- select *WET Tomo|Interactive WET tomography*... and set *Number of WET tomography iterations* to 200 .
- set *Maximum valid velocity* to 2,500 m/s .
- click *button Edit grid file generation*, set field *Store each nth iteration only* to 20 or 50 .
- click buttons *Accept parameters* and *Start tomography processing* . Confirm prompts .

Now run our **Smooth inversion method with constant-velocity initial model**, to determine the influence of the initial model on WET output after 200 iterations :

- select *Smooth invert|WET with constant velocity initial borehole model* to invert the data. Confirm prompts.
- leave *WET Tomo|WET tomography Settings|Disable wavepath scaling for short profile* unchecked
- select *WET Tomo|Interactive WET tomography*... and set *Number of WET tomography iterations* to 200 .
- leave *Maximum valid velocity* at 2,500 m/s
- click on *Start tomography processing* and confirm prompts, to obtain output as shown in Fig. 2 below .

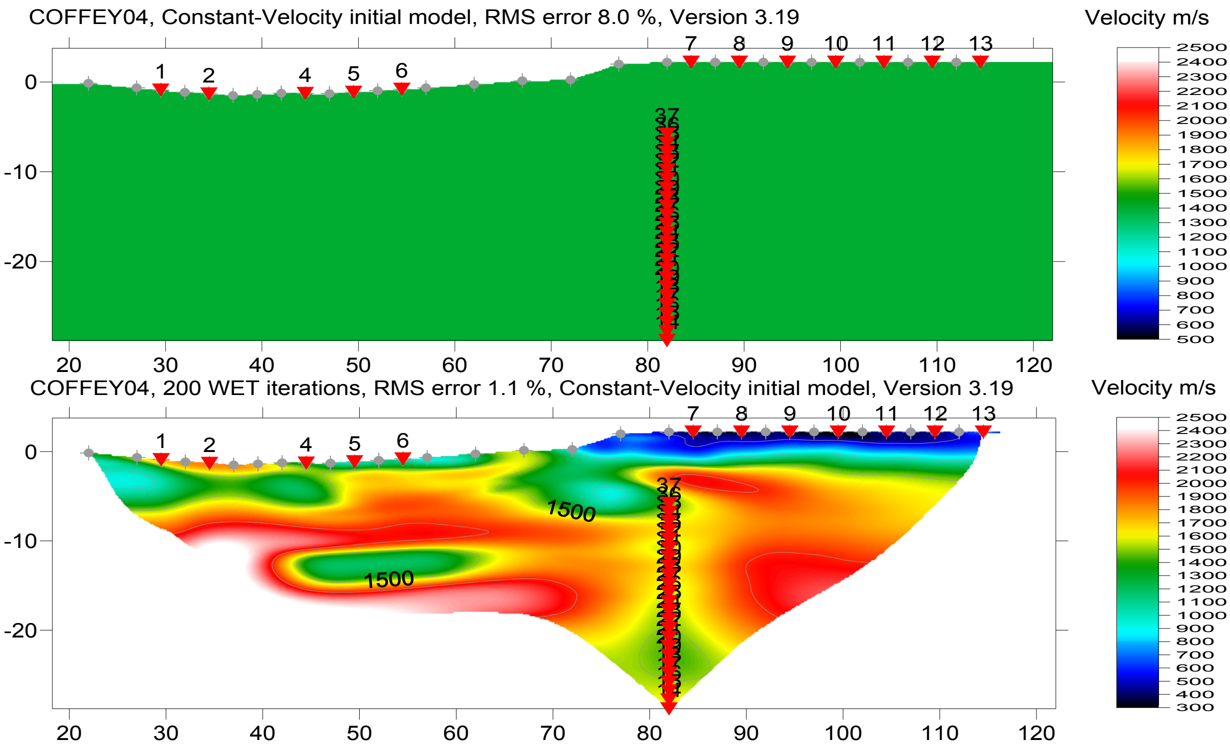

Fig. 2 : Smooth inversion with constant-velocity initial model, 200 WET iterations with *WET wavepath scaling*. Top : constant-velocity initial model. Bottom : velocity tomogram in m/s . Horizontal axis is inline offset in meters, vertical axis is elevation above sea level in meters.

Note the good agreement of velocity shown after 200 WET iterations, between Smooth inversion with 1D gradient vs. constant-velocity initial model. These two interpretations are almost identical.

Also, both tomograms in Fig. 1 and Fig. 2 show a layered subsurface, with a low-velocity layer (at elevation of about –13m) positioned between two higher-velocity layers. These velocity variations may be caused by variation of density and clay content in saturated, medium dense to very dense sand and gravel layers.

These layers are also recognizable in our *Midpoint breaks display* (Common Mid-Point CMP sorted traveltime curves) as shown below in Fig. 3. A steeper dip of a CMP sorted traveltime curve corresponds to a higher apparent velocity. Traveltime curve origin (offset 0, time 0) is at the CMP station number, positioned on the top horizontal axis.

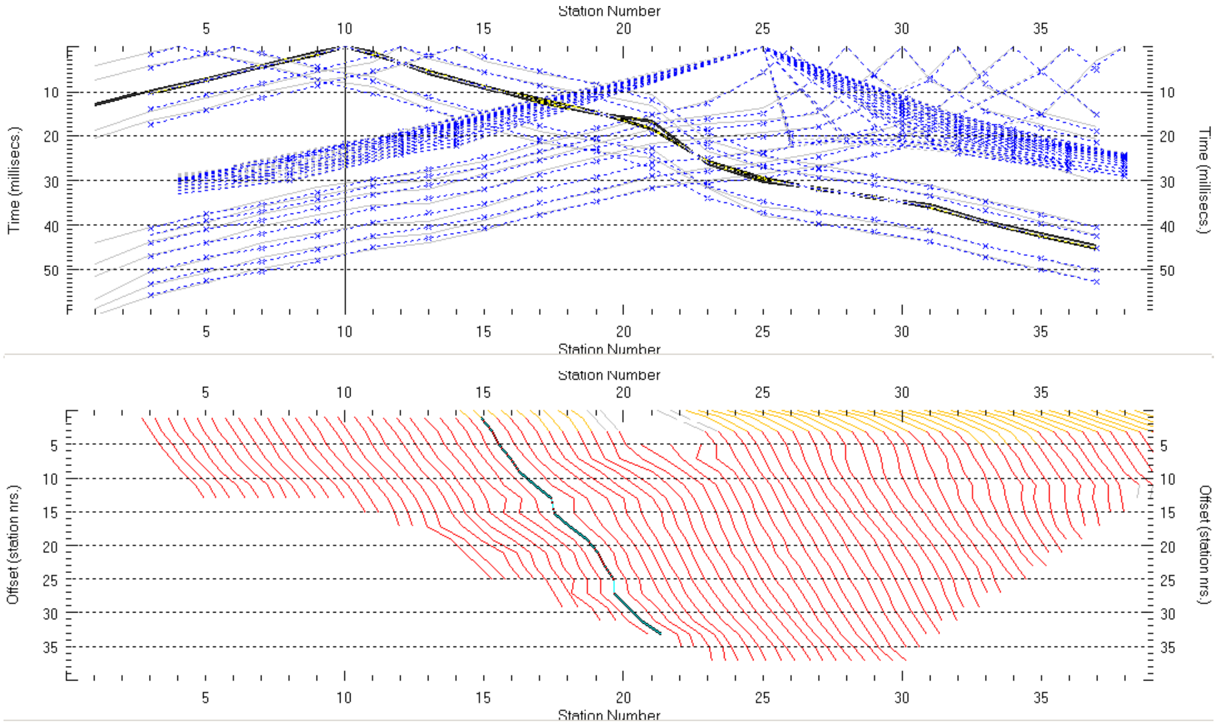

Fig. 3 : Shot sorted and CMP (Common Mid-Point) sorted traveltime curves for line COFFEY04. Top : *Shot breaks display* with shot sorted traveltime curves. Picked curves shown in gray, modeled picks and curves in blue. Bottom : *Midpoint breaks display* with CMP sorted traveltime curves. Yellow is weathering layer, red is first refractor. Horizontal axis is position in station numbers, vertical axis is time in ms (top) and source-receiver offset in station numbers (bottom).

Please note that our software checks if some uphole shots are positioned below bottom of 1D gradient initial model, as computed from surface refraction shots exclusively. If uphole shot points are too shallow, our software will automatically base the Smooth inversion on the 1D gradient model instead of constant-velocity inital model.

Unchecking *WET Tomo|WET tomography Settings|Disable wavepath scaling for short profile* activates *WET wavepath width scaling* with picked time, and *WET filter height scaling* with depth below topography. These two options **improve resolution of the weathering layer** (directly below topography). Use these settings if you have confidence in the first break picks only, and with close enough spacing of shot points and receivers. See http://rayfract.com/SAGEEP10.pdf . Enable this scaling if the default RMS error is less than 2% only, after 20 WET iterations with default settings and 1D-gradient initial model.

Also note possible anisotropy : velocity may be dependent on predominant direction of ray and wave path propagation. This becomes visible directly adjacent to borehole. The imaged velocity structure/layering is blurred out, since wavepaths are propagating from the virtual shot points (reversed borehole receivers) at all angles.

You can **import uphole shots from not just one but multiple boreholes, into the same profile database**. This will further improve angular coverage of the subsurface, with wavepaths. And the inversion of your first break data should become even more robust.

To import reversed VSP shots with arbitrary VSP shot positions along the refraction spread :

- for the refraction profile choose a small station spacing e.g. 0.5m
- round VSP shot points to 0.5m
- define a 1st custom spread type based on above rounded VSP shot points, with one receiver station at every rounded VSP shot point. See our .pdf reference chapter ***Defining your own layout types***.

- define a second custom spread type for surface refraction shots named e.g. "20: every 10th station" with receiver separation string "23*10" for receiver spacing of 5m and 24 receivers per refraction spread
- edit *shot station* and *receiver station* in Microsoft Excel spreadsheet : multiply original station numbers by 10. Export to `ASCII.ASC` .
- import this `ASCII.ASC` with surface refraction shots using this 2nd spread type "20: every 10th station".
- export coordinates via *File|Export header data|Export Station Coordinates* to `...\export\COORDS.COR`
- import .3DD uphole shots obtained by sorting walkaway VSP shots by common borehole receiver as in a13r1dm.pdf into the same refraction profile using above 1st custom spread type
- before import of reversed VSP .3DD shots into the refraction profile first check *File|Import settings|Import horizontal borehole survey or .3DD refraction survey*
- when importing the reversed VSP .3DD shots make sure to increase shot numbers before clicking *Read button* so you don't overwrite already imported refraction shots. Optionally edit and use `.HDR` batch file.
- after import of these reversed VSP .3DD uphole shots reset refraction spread coordinate with *File|Update header data|Update Station Coordinates* and above `...\export\COORDS.COR`
- now edit the shot hole *Depth* in *Header|Shot* for each uphole shot so the *Source elevation* shows elevation of original borehole receiver
- change shot *Type* in *Header|Shot* from `Refraction shot` to `Uphole shot` for these .3DD uphole shots. Uphole shots flagged with this *Type* setting are not used to determine the ***refraction starting model***.
- for complicated survey geometry you may need to edit `ASCII.ASC` with Microsoft Excel with correct station numbers. Copy first breaks column (last column in .3DD) to `ASCII.ASC` via Excel. Then import the `ASCII.ASC` using 1st *custom spread type* as above.
- once you have imported the uphole shots into the refraction profile and reset station coordinates to `...\export\COORDS.COR` : optionally select *File|Export header data|Export shotpoint coordinates...* to generate `SHOTPOTS.SHO` . Now import this into Excel spreadsheet and correct ***holeDepth column***. Set ***correction column*** to 0.01 to mark a shot as an uphole shot. Export spreadsheet to obtain updated `SHOTPTS.SHO` . Select *File|Update header data|Update shotpoint coordinates...* and this updated `.SHO` .

We thank our Australian client Coffey Geotechnics Pty Ltd. for making available this data set. Combining surface refraction with borehole receiver spreads results in better resolution of subsurface velocity variation, and makes it possible to run our Smooth inversion method with a constant-velocity initial model.