Using VwGradient to resolve the near-surface in the presence of velocity inversions.

By Chuck Diggins (DUG), Gary Hampson (DUG)*

Summary

Refractor shingling is a common geophysical response to thin high-velocity layers called "stringers" embedded in the near-surface of many geological basins. Between stringers are low-velocity inversions. Refractor shingling precludes turning-ray tomography which assumes a monotonic increase in weathering velocity from the surface.

This paper introduces a new strategy for creating tomographic models in the presence of refractor shingling. We recommend picking a continuous weathering-velocity gradient that starts at zero time at the surface and follows a continuous velocity until it merges with a deeper refractor. In this way, we pick inside the shingling, picking instead the velocity gradient consistent with a steadily increasing weathering velocity. We call this strategy "VwGradient Picking".

We mathematically model a near-surface stringer in a slow-velocity medium, verifying the existence of the VwGradient in the presence of refractor shingling.

We show various examples of shingling and VwGradient picking in several planes. Stacks with VwGradient-derived turning-ray tomo statics compared to other refraction statics approaches show the efficacy of this novel picking strategy.

Introduction

Many geologic basins around the world that are of interest for hydrocarbon exploration exhibit complex near surface environments. The Delaware Basin, for example, often has embedded high-velocity sills or "stringers" in the shallow section that manifest as "shingling" on shot records. These shingles, which have the appearance of one or more high-velocity events among the refracted arrivals, are difficult to pick consistently and often preclude the generation of a simple refraction statics solution.

We introduce a new approach to computing refraction statics which has general applicability, but also overcomes the problems associated with determination of refraction statics in the presence of shingling. We suggest that the high-velocity shingled events are best ignored as "inconsequential events" in that they have an insignificant impact on the actual weathering layer delays (statics) imposed on our seismic data. Instead, we recommend a picking strategy we are calling "VwGradient Picking", which effectively determines a velocity gradient as if the shingling does not exist. The near-surface models and the resultant statics confirm the efficacy of the approach.

Picking Refractor Shingling

When shingling is observed on seismic shot records, it is usually considered to be "noise" in the sense that the shingles do not contain usable information in the determination of refraction statics. Sun et al. (2018) describe a machine learning approach for automatically recognizing the existence of shingling for the purpose of avoiding using these events in their near-surface solutions!

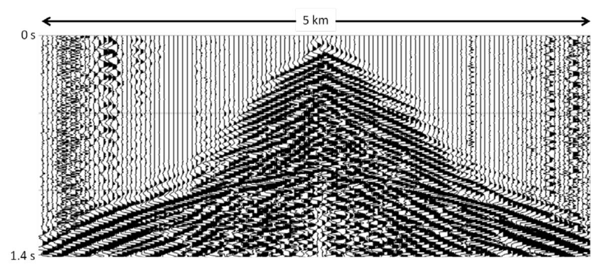

***Figure 1**: Shot record from a jebel in North Africa shows classic "Christmas-tree" pattern of refractor shingles consistent with a thick sequence of alternating high velocity and low velocity layers.*

10.1190/segam2021-3594003.1

These thin beds, sometimes called "*stringers*" or "sills", often consist of basalts (Argentina), limestones or anhydrites (Permian Basin). Because the stringers are underlain by slower velocity layers, there are velocity inversions. Velocity inversions manifest as "*hidden layers*" and are only indirectly visible in refracted arrivals as the gaps between shingles (Banerjee and Gupta, 1975; Cassinis and Borgonovi 1966).

Picking refractor shingles is problematic (Bridle, 2010). There are often many shingled events, making it hard to decide which one to pick as a "first break" (Sun and Zhang, 2013). They tend to fade out with offset, making it hard to determine at what offset to stop picking. Often the shingling is barely visible, making it hard to decide whether one should even pick it at all. Shingling is often spatially inconsistent, so picking strategies will vary within a single seismic survey. And lastly, even when shingling has been picked, there are no algorithms that can convert them into a near-surface model adequate for computing statics.

The most common strategy for computing statics when shingling is evident is to attempt to avoid the shingling by only using a deeper refractor at offsets beyond the shingling. In Figure 2, such a refractor is visible beyond outside the box

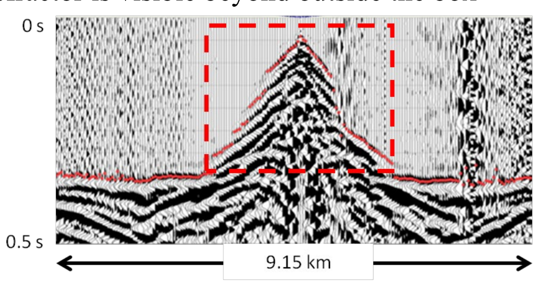

***Figure 2**: A single receiver line from a shot with LMO applied. Offset is plotted above the traces. Shingling appears on the inner offsets in the red box. The inner-offset shingling and the outer-offset deep refractor have been picked. Note the asymmetry of the shingle picks to either side of zero offset with four shingles picked on the left and only two picked on the right.*

Picking the Weathering Velocity Gradient (VwGradient)

We propose a new approach to handling shingling called "VwGradient" picking, where Vw is short for "weathering velocity". In this approach, we pick a velocity gradient "under" the shingles as shown in Figure 3, below.

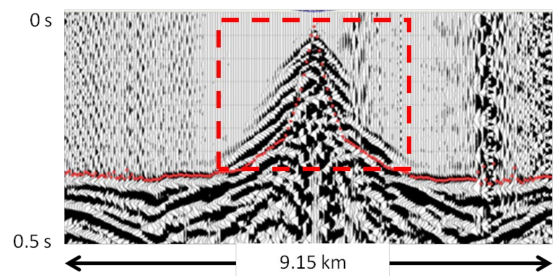

***Figure 3**: The same as Figure 2 except that instead of picking the shingled events, we have picked the VwGradient inside the box. The VwGradient is a continuous picking strategy that starts at (0,0) and connects smoothly with the deep refractor, seen here just outside the box.*

Figure 4 shows another shot record displayed as a function of offset. This is often a better organization of the data for visualizing the gradient. In Figure 4, the shingling is a well-defined series of "first breaks". The weathering velocity gradient beneath the shingling is quite pickable, even though these arrivals are not first breaks.

This technique is consistent with a geological model in which the high-velocity stringers do not significantly impact the time-delay from the surface to the deep refractor. In other words, we pretend the stringers, and therefore their associated shingles, do not exist. Instead, for any given location, we seek to define the smooth velocity gradient that expresses the turning-ray trajectory from surface to the deep refractor. Of course, the timing of the deep event is affected by the shingling. Therefore, turning-ray tomography effectively accommodates the high velocity layers that were not picked.

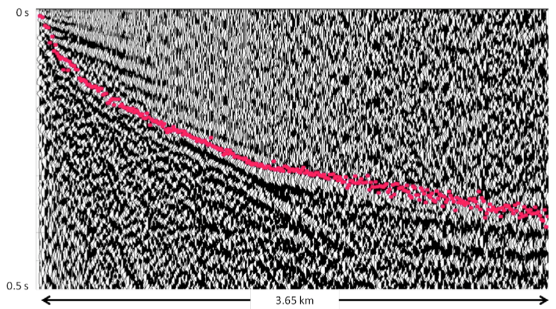

Figure 4: *A shot displayed as a function of offset. Five distinct shingles can be seen on this record. The VwGradient is the smooth curve of picks starting at 0,0 on the left and transitioning smoothly to the deeper refractor about half-way across the record.*

Near-Surface Model Implications

Conventionally, we think of the shingle generating near-surface as a series of high velocity layers interbedded with low-velocity inversions (Sun and Zhang, 2013). This model is unproductive. In many basins, these high-velocity stringers are best ignored. The VwGradient-implied model suggests a near-surface comprising a thick matrix of steadily increasing "slower" velocities, called the "VwMatrix" containing thin higher-velocity beds. Where shingles exist, the VwMatrix provides a more accurate way to conceive of the near-surface.

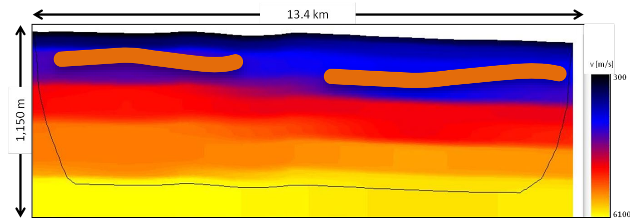

Figure 5 *Shows a slow-velocity layer defined by a velocity gradient from 386 m/s to 6333 m/s at 1067 meters depth derived directly from data in the Delaware Basin. We have inserted two high-velocity thin beds (orange) in different parts of the section.*

Figure 6 shows CMP stacks from the Midland Basin with tomographic statics applied. Note the simpler structure of the VwGradient-derived tomo statics compared to structure on the shingle-derived tomo stack. The structural simplicity is consistent with better long-wavelength statics.

Conclusions

In this paper, we argue that shingled events are often caused by thin high-velocity stringers embedded in a slower near-surface matrix. We further suggest that these events (because they are fast and thin) can be effectively ignored for the purposes of statics derivation and first break picking. These stringers essentially highjack the first breaks and are thus misrepresentations of the near surface velocity structure that are best ignored. We propose a new method for picking through the shingled events to pick the underlying lower background weathering velocity gradient from the surface to a refractor that underlies the weathering layer.

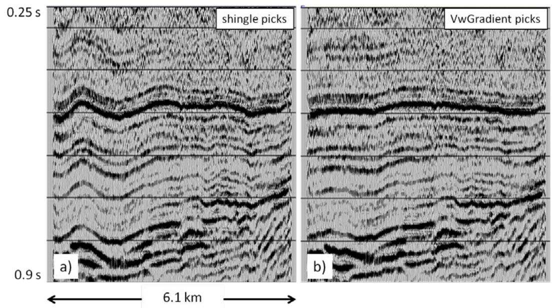

Figure 6 CMP stacks from the Midland Basin. a) Tomographic statics using only shingle picks. b) Tomographic statics using only vwGradient-derived turning ray picks.

VwGradient picking is more interpretive than conventional first break picking. In our evaluation so far, tomographic statics based on VwGradient picks are consistently better than those based on shingled first break picks. Our experience shows that this approach is comparable to delay-time statics in the Delaware and Midland Basins. Because this approach provides significantly better statics solutions than shingle-based picks, we think this new approach produces more accurate near surface velocity models.

It does not escape our attention that more accurate models not only produce superior statics, but they also provide more accurate near-surface models for PSDM and initial models for FWI.

Acknowledgements

Many thanks to DUG and to Geophysical Pursuit Inc for use of their Flying Dutchman data. The input from Adam Searle and Tom VanWagoner of Chevron is much appreciated and we especially thank our colleagues who contributed to this work.

REFERENCES

Bahrain, C. R., and L. Borgonovi, 1966, Significance and implications of shingling in refraction records: EAGE Convention 1966, doi: https://doi.org/10.1111/j.1365-2478.1966.tb02066.x.

Banerjee, B., and S. K. Gupta, 1975, Hidden layer problem in seismic refraction work: Geophysical Prospecting, **23**, 642–652, doi: https://doi.org/10.1111/j.1365-2478.1975.tb01550.x.

Bridle, R. M., 2010, Challenges and strategies for near-surface modelling for static corrections: Geo2010.

Sun, M., and J. Zhang, 2013, Understanding of the first arrivals in the shape of a Christmas tree: SEG Technical Program, Expanded Abstracts, 1843–1846, doi: https://doi.org/10.1190/segam2013-1253.1.

Sun, M., J. Zhang, and Y. Wang, 2018, Recognizing shingling seismic data by unsupervised machine learning: SEG Technical Program, Expanded Abstracts, 2561–2565, doi: https://doi.org/10.1190/segam2018-2995824.1.