A simple and effective method to extrapolate sonic profiles to the surface

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ABSTRACT

The extrapolation of sonic profiles in oil industry is a routine for the geophysicists. A good correlation between geological data in wells and seismic reflectors in a seismic line is necessary to reach good results in oil prospection. If a VSP(Vertical Seismic Profile) is available nearby an exploratory or development well, this routine becomes easy. Commonly the only available information is the sonic log, which in general doesn't starts at the surface. So, the geophysicist begins compiling and integrating technical data from different sources: seismic velocities, geological information, velocity surveys, regional velocity pattern, sonic profiles, etc. Even after a good job, the definition of a velocity to extrapolate sonic data to surface is not an easy task. One usual decision is to use the interval velocity at the beginning of the sonic profile as the interval velocity up to the surface.

In this paper is proposed a simple and effective method to extrapolate sonic profiles: basically it is an interactive computer based application where the user may decide which velocity is good to do this extrapolation. The application creates and integrates velocities starting from the surface that rise exponentially and reach the beginning of sonic profile, then starts integrating the sonic profile. Visually the user may decide: the velocity used to extrapolate is too high, too low or good enough. If this velocity is not good, a visual inspection makes clear that the velocity gradient of the extrapolation doesn't fit the velocity gradient at the beginning of the integrated sonic profile.

INTRODUCTION

One way to compute TxD (time x depth) curves is to use the data from the sonic profile. The sonic time integration and extrapolation gives a complete relation of time with depth, and it may be written as:

$$T(Z) = \sum_{Z=1}^{S-1} 1/Ve + \sum_{Z=S}^{F} 1/Vs , \qquad (1)$$

where T(Z) = time as a function of depth
Ve = extrapolation velocity
Vs = sonic velocity
S = initial depth of sonic
F = final depth of sonic

The key to solve equation (1) is to decide a good value to be used as Ve. Approximated values may be obtained mainly after some interpretation of technical information found in velocity surveys, seismic data, geology and regional velocity pattern of sedimentary layers. Sometimes the definition of Ve is not easy and a bad definition may imply a complete failure of a petroleum industry project. Also, a project can be discarded as no economic when in reality it is economic. Recently, in our company we had an example of this type of situation. An old standby project became attractive due to changes in gas/oil demand and we start a new evaluation. The planning was to drill a wildcat in a new structure nearby an oil/gas field, based on seismic lines. There are no seismic lines over the oil/gas field, due to geographical and environmental constraints. So, the conversion of depths of field wells to time is basic to estimate gas/oil and oil/water contacts in the planned wildcat. At the end we concluded that the project was not attractive due to changes in net-pay, total area and fluid percentage: the project became an oil project and not a gas project, as anticipated in the old evaluation. Mainly those changes were due to a new interpretation of sonic extrapolation velocity of wells from the oil/gas field.

THE METHOD

The velocity gradient of geological layers has an exponential decay with depth: velocities change more rapidly at shallower depths. The use of a constant velocity (Ve) to extrapolate the sonic log disagrees with this property. This disagreement doesn't imply in failures, if Ve is good enough and considering that the target zones as a general rule are below the beginning depth of the sonic profile. Why not to use this property (gradient with a exponential decay) to solve for Ve? The method presented here use this property and give us a nice chance to compute the extrapolation velocity. Basically, it builds a velocity curve starting from a user given value at the surface and an ending value at the beginning depth of sonic survey, rising exponentially. After this, the velocity sonic values are integrated to complete the TxD curve. The complete integration may be written as:

$$T(Z) = \sum_{Z=1}^{S-1} 1/Vi + \sum_{Z=S}^{F} 1/Vs, \qquad (2)$$

$$Vi(Z) = V0*EXP(cZ), \qquad (3)$$

$$Vf(S) = \left\{ \sum_{Z=1}^{S-1} Vi(Z) \right\} / (S-1), \qquad (4)$$

where T(Z) = time as a function of depth
Vi(Z) = interval velocity in the extrapolation zone (computed by application)
Vf(S) = average extrapolation velocity at depth S-1(user defined)
V0 = velocity at surface (user defined)
c = constant value (computed by application)
Z = actual depth
Vs = sonic interval velocity
S = initial depth of sonic
F = final depth of sonic
EXP = exponential with neper constant e

The constant c is computed by doing computer iterations. The definition of an initial value to be V0 is not important, only it must be lower than the average velocity Vf at the end of the extrapolation zone. It is common to use 1500 m/s for Tertiary basins and 2000 m/s for Lower Cretaceous basins as V0 value. Vf must be higher than V0 and this value is obtained after some interactive actions between the user and a Pc (personal computer) graphic application based on equations (2), (3) and (4). The user defines Vf visually, when the extrapolated velocity gradient is similar to the integrated velocity gradient at the beginning of the sonic profile. This will not work very well if the lithology in the extrapolated zone has a velocity gradient completely different compared with the velocity gradient present at the beginning of the zone covered by the sonic. One example of this occurs when the well has clastic sediments in the extrapolated zone and limestones immediately below.

Figure 1 presents an output graphic image of an integrated and extrapolated sonic profile. The green curve was computed extrapolating a velocity function from V0 = 1800 m/s to Vf = 2000 m/s, till the magenta rectangle close to 200 ms and 200 m (x,y). The magenta rectangle gives the position where the sonic profile starts. Nearby this position there is a blue straight line that represents the velocity gradient at the beginning of the sonic profile. Clearly this blue line is moving away from the green line, which means that the velocity gradient defined by the velocity Vf at the end of the extrapolation is different if compared with the gradient of the sonic. Similarly, **figure 2** shows that the blue line is parallel to the green line: the extrapolated gradient is close to the sonic gradient (Vf=2440 m/s). **Figure 3** shows another curve with Vf=3000 m/s and is easy to interpret that the blue straight line is crossing the green curve: in this case the velocity gradient in the extrapolated zone is smaller than that of the sonic profile.

So, we may summarize:

a) A Vf lower than the average velocity at the beginning of the sonic produces an image where the blue curve moves away from the green curve(**figure 1**). Vf may be interpreted as lower than the good one.
b) A Vf higher than the average velocity at the beginning of the sonic produces an image where the blue curve crosses the green curve(**figure 3**). Vf may be interpreted as higher than the good one.
c) A Vf close to the average velocity at the beginning of the sonic produces an image where the blue curve is quite parallel to the green curve(**figure 2**). Vf may be interpreted as being a good velocity to extrapolate the sonic curve.

It is important to mention that the visual selection to define Vf is sensible to changes of 10 m/s, meaning this definition is quite precise.

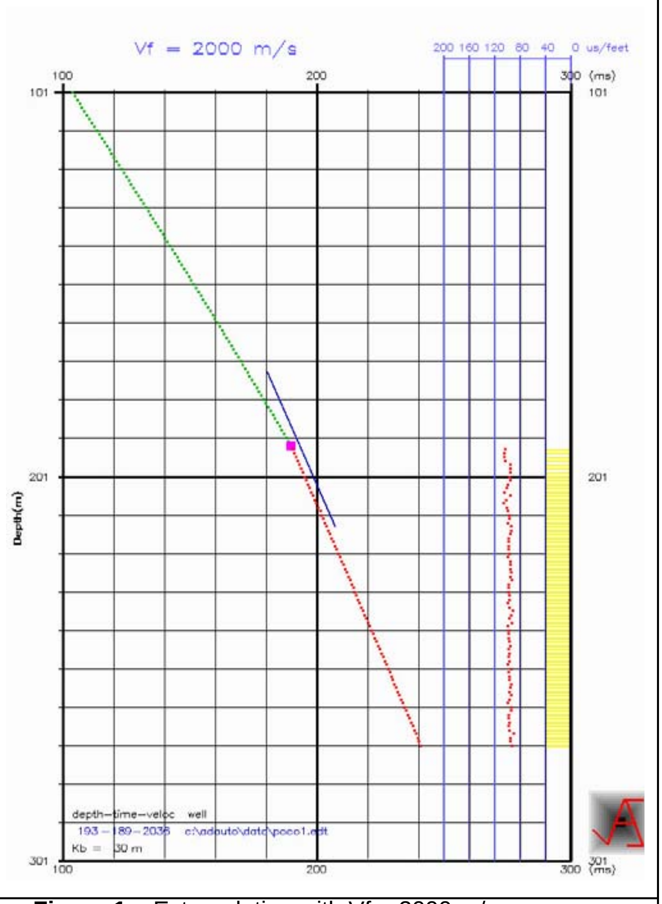

Figure 1 – Extrapolation with Vf = 2000 m/s

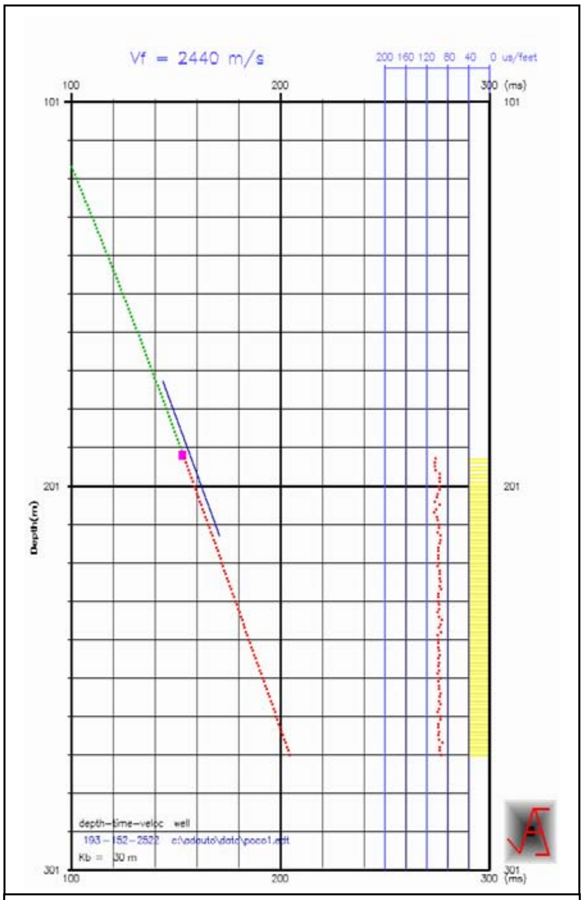

Figure 2 – Extrapolation with Vf = 2440 m/s

Figure 4 presents a final interactive result (complete well) where the interpreter has defined an extrapolation average velocity Vf. In the right hand part of the figure a red curve represents the sonic readings and a colored column represents the lithologies. In the left two curves can be seen: the magenta (average velocities) and the red (interval velocities). In the same figure the green line (TxD extrapolated and integrated) has good fit with some blue boxes, that are data from a VSP survey. An additional output of the computer application is a columnar ASCII file including depths, two-way times, average velocities and interval velocities of the well.

CONCLUSIONS

A simple and effective method to extrapolate sonic curves to surface has been presented. Basically, it solves the problem using the velocity gradient of the geological layers. An exponential decay curve is used to compute and integrate a complete set of interval velocities along the extrapolation zone, where the sonic has no readings. The method is sensitive to variations of 10 m/s in the computation of the extrapolation velocity, what means that it is very precise. A velocity mistake of 10 m/s in a extrapolated zone of 300 m using 2000 m/s as Vf introduces one error of 1.5 ms or 1.5 m. In the example showed in the figures, the average velocity in the first 15 m covered by the sonic is 2959 m/s (depths 224 to 238 m). If the interpreter decides to use this velocity as the one to extrapolate the sonic (Vf), an error of 27 ms will be introduced, assuming that the velocity 2440 m/s is the correct one. You may do some immediate guesses if the length of the extrapolation zone is higher ant the velocities are lower: the error introduced rises rapidly to values higher than 50 ms.

The interpreter must be careful when lithologies in the extrapolation zone are quite different compared with the lithologies in the beginning of the sonic survey: this may result in velocity gradients quite different and the method may not work very well. Anyway, in this case, the method still gives a chance to compute the extrapolation velocity by using additional geological and geophysical information.

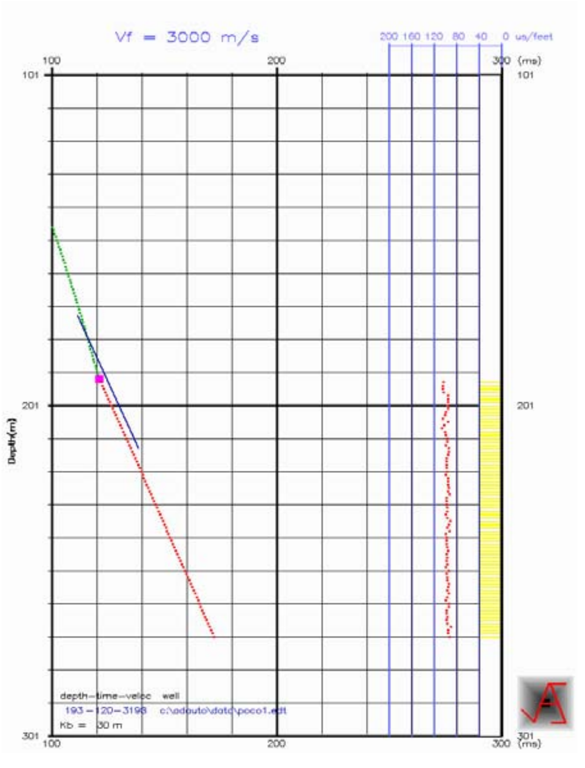

Figure 3 – extrapolation with Vf = 3000 m/s m/s

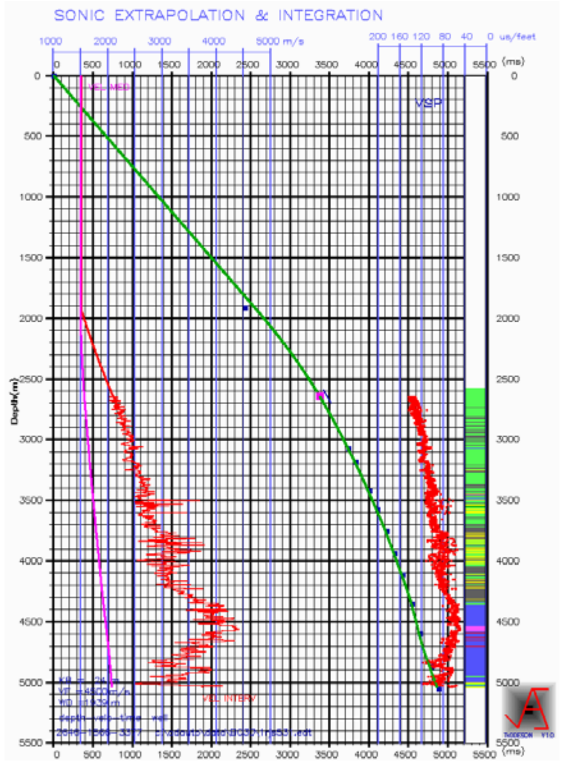

Figure 4 – final graphic output

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