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Well-to-well log correlation: choosing the matching attribute

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ABSTRACT

The geological factor that one wishes to resolve must be the guiding factor for choosing the correlation-attribute in well-to-well log matching. Opting for a smoothed version of the sonic logs leads to the matching of equivalent lithologic units, whereas using an attribute that measures the local relative variability of the logs results in the correlation of iso-chronological events.

INTRODUCTION

Depending on how we approach the problem of well-to-well correlation, we can get different matching results, which can in turn reflect different geological aspects and be related to distinct geophysical images. As observed by several authors (Vail et al., 1977; Sangree and Widmier, 1979), seismic sections represent a chrono-structural image of the earth, whereas the slowness values that are measured in a sonic log are more closely related to lithologic units.

If we choose a smoothed version of the sonic log as the matching attribute, the resulting correlation might be used as a suitable constraint or as an initial model for the tomographic inversion of seismic-traveltime data. However, if we wish to find a correlation between these logs that would correspond to the continuous reflector seen in a surface seismic section, we have to look for an attribute with a chronological (instead of a lithological) meaning. Although synthetic seismograms are the natural attribute candidates for performing the "seismic-reflection correlation" between sonic logs, it is possible to construct other attributes that can better represent the different sequences of events represented in the logs and, therefore, be more suitable for reproducing the "feeling of continuity" of a seismic section.

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CHRONO- AND LITHO-STRATIGRAPHY

During the second half of the 1970s, a controversial debate took place regarding a fundamental concept of reflection seismology, the geological meaning of a continuous reflector. We know that a seismic section represents a view of the contrasts in the seismic velocities and densities. It is also well known that these two physical attributes are controlled by the lithology, degree of compaction, porosity, cementation, fluid content, pattern of micro-cracks, and other, less important factors. Because most of these factors are to some degree related to the lithology and depth, the lithostratigraphic school interprets a seismic horizon (a reflector) as an expression of the boundary between different lithofacies (Harms and Tackenberg, 1972). However, with the support of empirical evidence from bore-hole data (Vail et al., 1977), the chronostratigraphic school interprets the seismic horizon as an isochrone or, equivalently, as the boundary between sediments deposited at different geological times (independently of the lithology). The simple example that follows shows how these two apparently contradictory interpretations can be reconciled.

Figure **??** (center) shows a typical fluvial deposition system, with the transition from coarse-grained to fine-grained sandstone and then to shale, as we move away from the sediment source. A closer look at this transitional layer (bottom) reveals that it includes a thinly-stratified sequence caused by short-period oscillations in the energy level of the transport mechanism. A schematic representation of the velocity profiles in different positions shows that, although the velocities change laterally, their relative vertical changes (which cause the reflections) form a continuous lateral pattern. While locally the reflector represents a lithologic transition, in a more extended view it represents time transitions. If we then consider the same layer from the perspective of a longer time-span (top), we can see that it belongs to a transgressive sequence. The low-frequency components of the velocity profiles clearly delineate different lithofacies, that is, isolated bodies with roughly the same lithology. While the seismic section is an expression of isochrone units, an interval velocity section (derived from tomography or other velocity estimation methods) is a representation of lithologic units. These are complementary descriptions of the subsurface geology. A good illustration of this complementarity can be found in a comparison among a seismic section, a reversed VSP and a cross-well tomographic section presented by Chen et al. (1990). Although the authors emphasize the higher resolution of the tomographic imaging compared to that of the seismic imaging, it is clear from the figures that they are images of completely different geological attributes. They resolve different aspects (derivatives or integrals) of the velocity field.

Making an analogy with the concepts of quantum mechanics, where particles and waves are considered as complementary descriptions of the same phenomenon (light, or subatomic entities), the seismic horizon can simultaneously represent a time boundary or a lithological boundary, depending on the way we look at it.

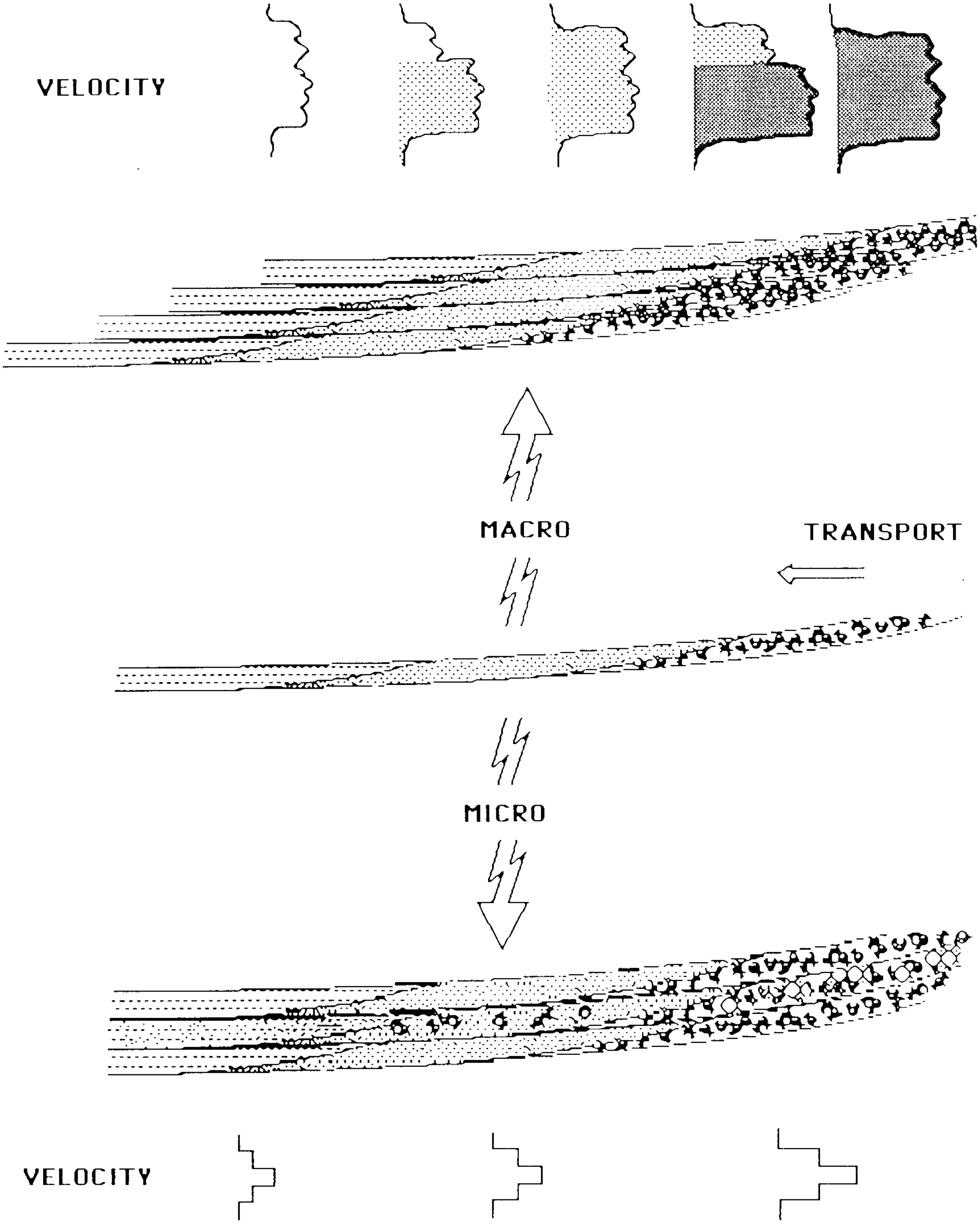


Figure 1: A typical shallow marine depositional system (center) showing the inverse relation between the sediment's grain size and the distance from the source. A detailed view (bottom) shows a thinner stratification caused by a series of transgressions and regressions. From a broader time perspective (top), the layer appears as part of a major transgressive cycle. Lithology is mapped by the low frequency components of the velocity, while isochrones of deposition are mapped by their high-frequency components. carlos2-deposition [NR]

A STRUCTURAL SEISMIC MAP FROM SPARSE SONIC LOGS

Tomograms and seismograms

To make the analysis statistically significant, sixteen wells were selected from the western section of the Gulf of Mexico. The surface location of these wells as well as of a semi-parallel seismic line are marked on the map shown in Figure **??**. The logs were smoothed with a triangle filter, so that the figure represents an averaged version of the subsurface slowness. Figure **??***a* shows the sixteen vertically-smoothed sonic logs. This section represents the major lithologic features, with young, poorly-consolidated sediments at the top, a well-delimited high-velocity layer (white region around 8000 ft.), and a low-velocity zone at the bottom. It can be seen as the result of a tomographic inversion or other type of interval velocity estimation using well-to-well, or surface seismic, data.

Because seismic-reflection structures generally represent isochrones rather than iso-velocity lines, sonic log sections like the one in Figure **??***a* will generally differ from the seismic sections (Figure **??**). There are several ways to transform the information contained in the sonic logs into a log that shows a better correlation with the seismic section. The usual way is to generate a synthetic seismogram using the sonic, or sonic and density, logs. Figure **??***b* shows the synthetic seismograms generated from the original sonic logs by using a very low-frequency wavelet (central frequency of 3 Hz) to avoid spatial aliasing. Although each log correlates well with its corresponding surface seismic trace, the low-frequency synthetic section shows some lateral continuity, but only in localized regions. Likewise, we would find only localized continuity if we selected sparse traces from a very low-frequency seismic section. The next section presents an alternative chrono-attribute that shows a more extensive lateral continuity than the synthetic seismogram.

Instantaneous variation

The partial failure of the synthetic seismogram section to reproduce structural image of the seismic section is caused partly by the presence of unconformities, which limit the spatial extension of major reflectors, and also by the lateral changes in the amplitude and shape of the waveform in a given chronostratigraphic unit. Both the amplitude and temporal separation of the reflectivities associated with this unit can change laterally, but the spatial (depth) pattern is highly uniform, representing the periodic changes in the depositional environment. The impression of extensive lateral continuity in a seismic section comes from the specific patterns in the impedance transitions, not from the values of the transitions themselves.

Figure **??***a* shows two of the selected sonic logs. When looking for similarities between the logs, we can begin by focusing on their low-wavenumber behavior, as illustrated in Figure **??***b*. We than have two options: to match amplitudes or to match shapes, each of which leads to a different result. If we now analyze the behavior of

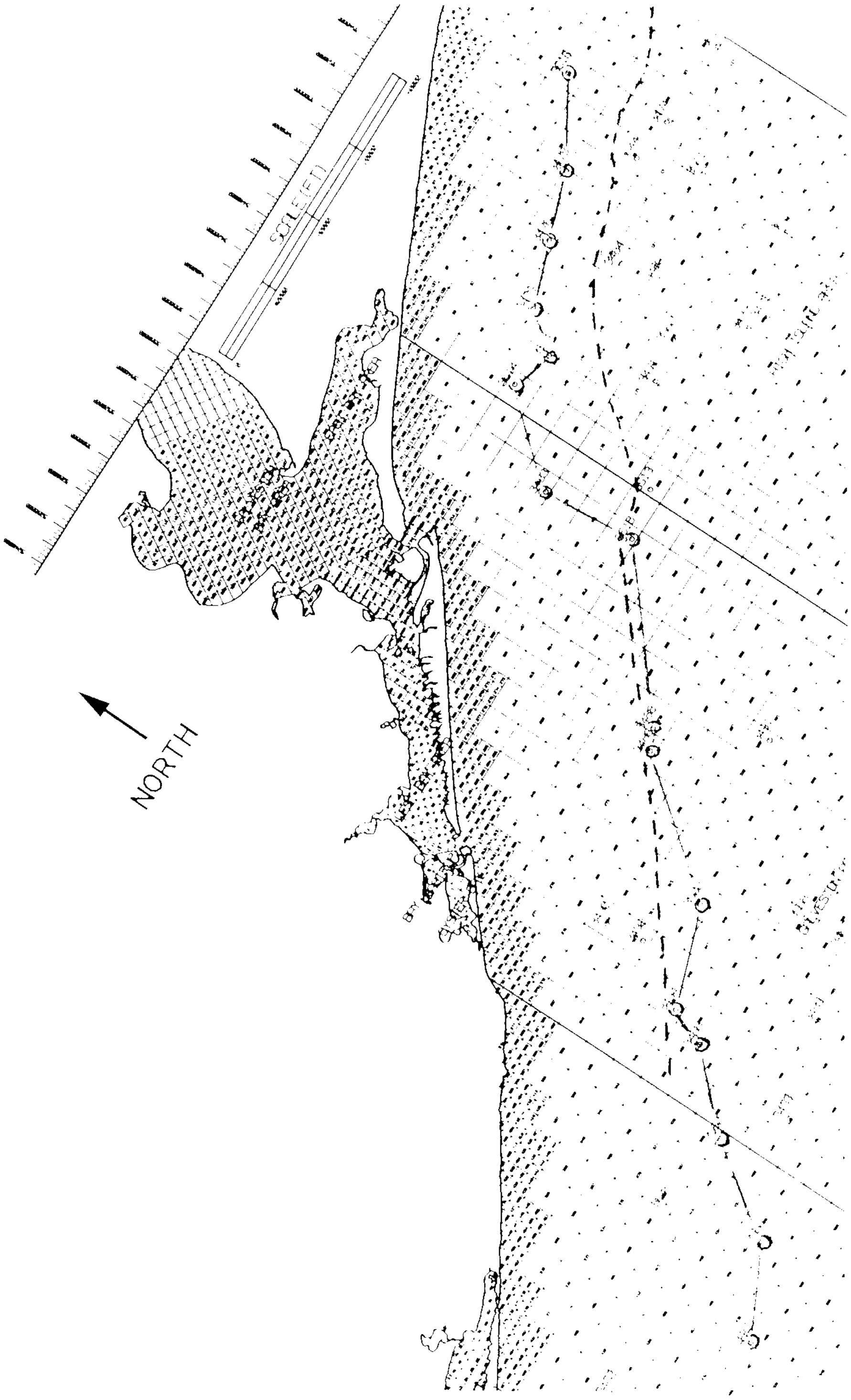


Figure 2: Surface locations of sixteen adjacent wells in the Gulf of Mexico. The continuous line corresponds to the surface locations of the sections derived from the well-logs (Figures **??** and **??**), while the dashed line indicates the surface location of the seismic section shown in Figure **??**. carlos2-map [NR]

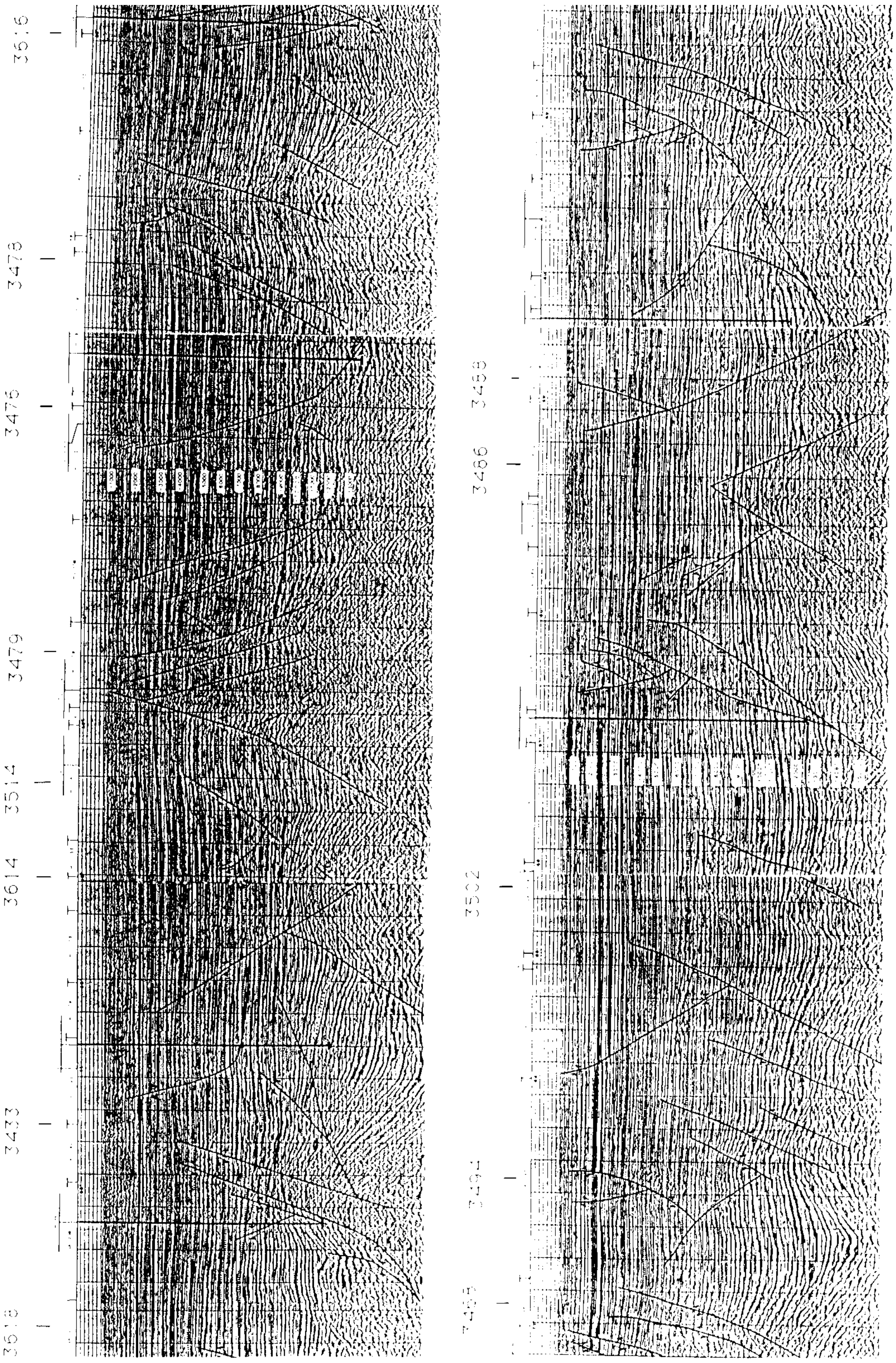


Figure 3: A seismic section from the Gulf of Mexico. The section is semi-parallel to the sixteen selected wells whose locations are shown in Figure ??. The left side of the top section connects with the right side of the bottom section. carlos2-section [NR]

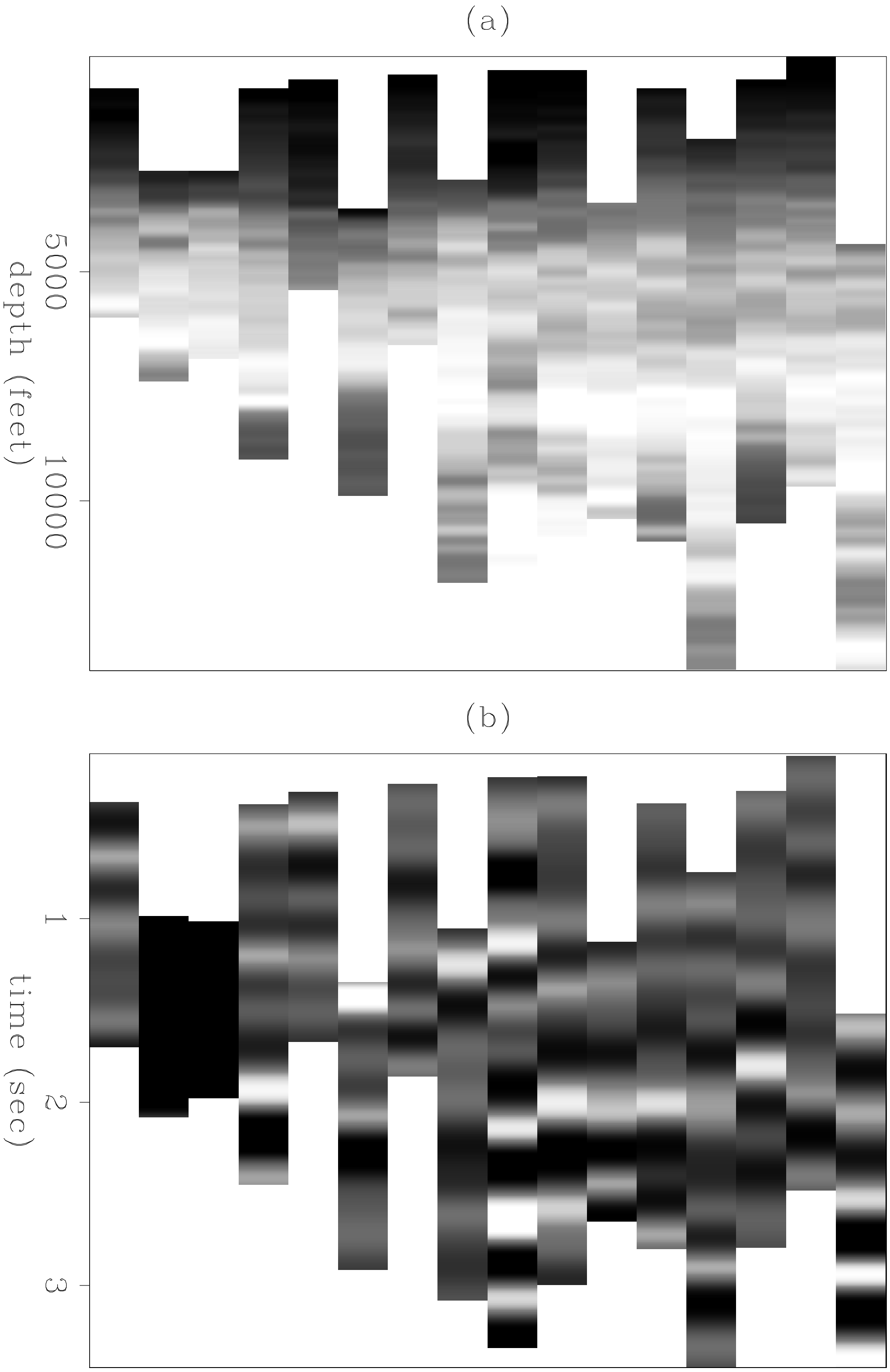


Figure 4: *(a)* The sixteen adjacent sonic logs indicated in Figure **??** after vertical smoothing. *(b)* A low-frequency (3 Hz) synthetic seismogram corresponding to the sonic logs shown in *a*. carlos2-allsmth [NR]

the higher frequency components of the logs (Figure ??*c*), it becomes harder to find a match between the logs. A new look at ??a reveals that there are different patterns in the high frequency behavior, with strong oscillations in some parts, "silent" zones (almost without oscillations), and some parts where the oscillations are predominantly to one side of the median.

To measure the degree of local variability of the logs, I used a filter that has the following form:

$$
\begin{aligned}
y_i &= \sum_{j=i-L/2}^{i+L/2} \frac{|x_j - \bar{x_j}|}{\bar{x_j}} \qquad (1)\\
\bar{x_j} &= \frac{1}{L} \sum_{j=k-L/2}^{k+L/2} x_k .
\end{aligned}
$$

The output is a measure of the relative variation of the input inside a window of length L. To keep a more linear relation between the amplitude of oscillation and the filter's output, equation (1) uses the absolute value instead of the usual definition of variation (difference between squares). Figure ??*d* corresponds to the output of the variability estimation filter applied to the same part of the logs as that represented in ??c. Clearly, the logs in ??d can be correlated better than the logs in ??c.

The same filter (using a larger window to avoid spatial aliasing) was applied to the sixteen wells, the results of which appear in Figure ??*b*. Figure ??*a* corresponds to the smoothing of the original logs with a triangle filter of length equivalent to the the length of the filter applied in ??b. In both cases, the background trend (very low-frequency components) was subtracted from the output to emphasize phase rather than amplitude. The local variability attribute shows a better lateral correlation over the whole interval than both the synthetic seismograms and the smoothed logs.

CONCLUSIONS

There are several possible ways in which well-logs can be correlated. The choice of the matching attribute must be controlled by the geologic feature that one is trying to resolve. A smoothed version of the sonic log is most appropriate for lithologic matching, and can therefore be used as a constraint to a tomographic inversion. In this case, remains the question of whether to match amplitudes or shapes, a choice that can be particularly critical when a strong lateral velocity variation is present. Moreover, if the goal is to find the correlation between chronostratigraphic units that are resolved in a surface seismic section, the usual synthetic seismogram may not be the optimal choice. Extensive lateral continuity in a seismic section is related to the specific patterns in the impedance transitions, rather than to the transition values. As a result, the output of a filter that measures the local variability of the sonic log

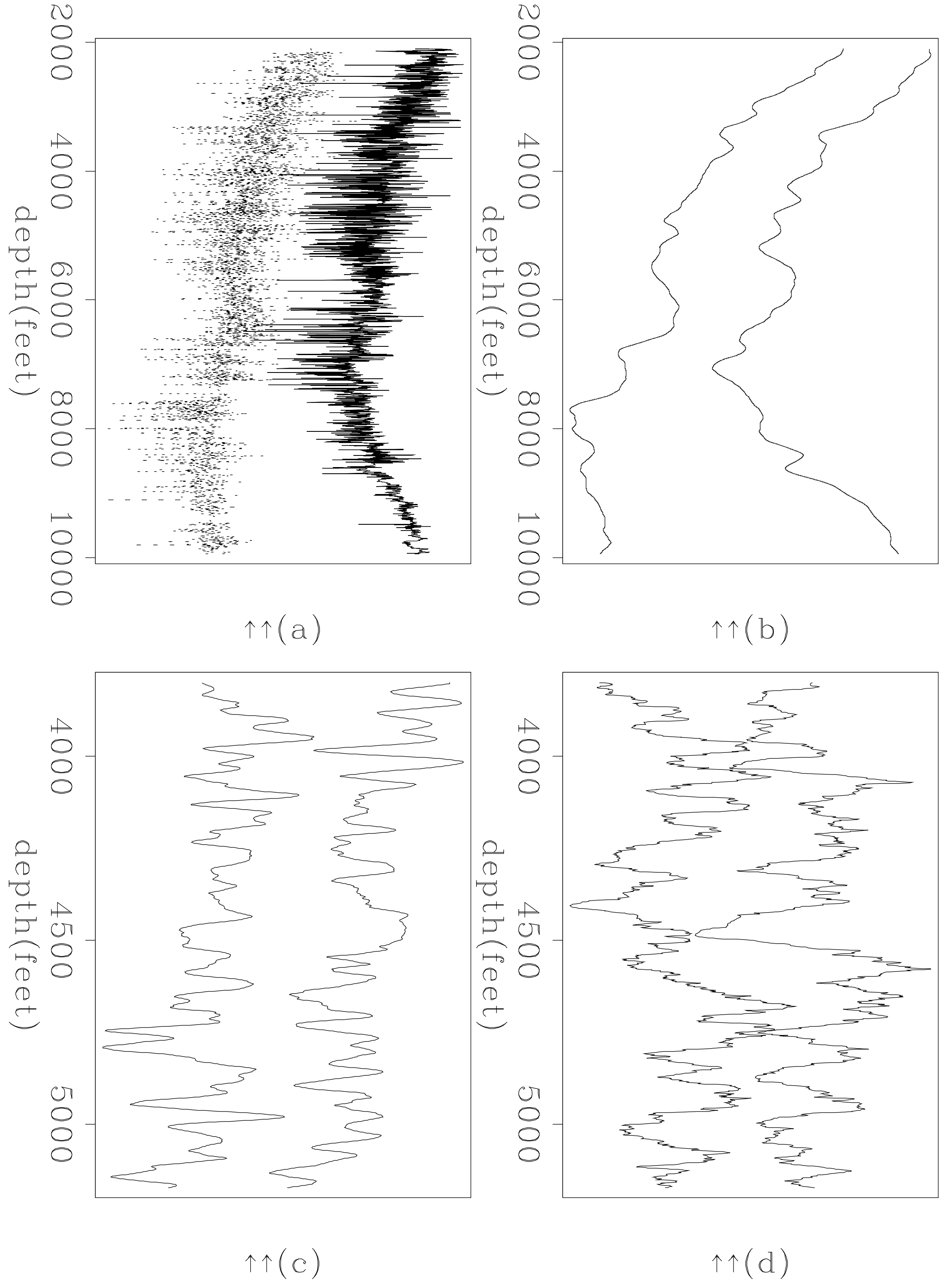
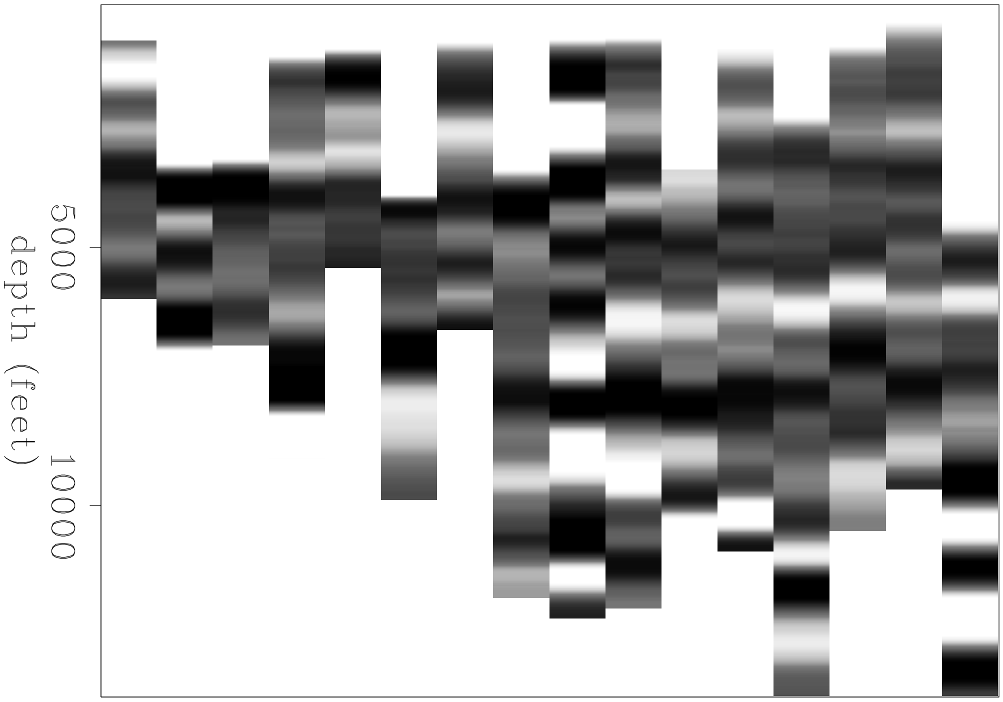


Figure 5: *(a)* Sonic logs of wells 3476 and 3479 of Figure **??**. *(b)* The same logs after smoothing by convolution with a triangle (400 points of length). *(c)* An interval of *a* after weak smoothing (40 points triangle). *(d)* Same interval of *a* convolved with a 40 points wide variability filter. carlos2-four [NR]

(a)



(b)

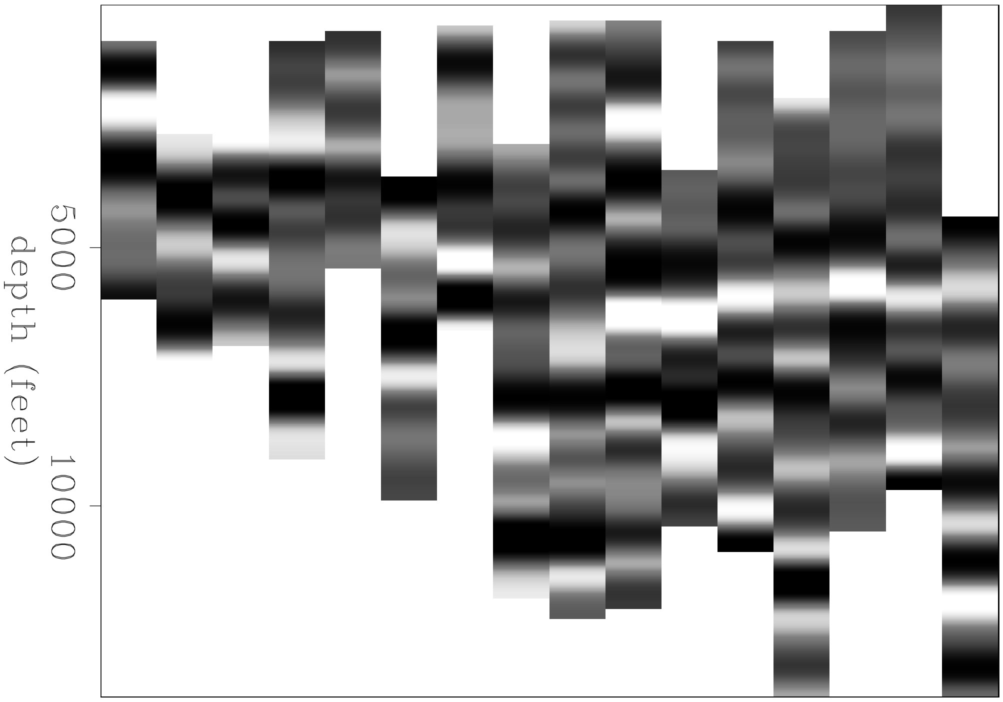


Figure 6: *(a)* The logs shown in Figure **??***a* with subtraction of their strongly smoothed version. *(b)* Local variability estimation applied to the original logs. carlos2-allsv1 [NR]

provides a better chronostratigraphic correlation between wells covering an extensive area than conventional synthetic seismograms.

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REFERENCES

Chen, S.T., Zimmerman, L.J., and Tugnait, J.K, 1990, Subsurface imaging using reversed vertical seismic profiling and crosshole tomographic methods: Geophysics, **55**, 1478-1487.

Harms, J.C., and Tackenberg, P., 1972, Seismic signatures of sedimentation models: Geophysics, **37**, 45-58.

Sangree, J.B., and Widmier, J.M., 1979, Interpretation of depositional facies from seismic data: Geophysics, **44**, 131-160.

Vail, P.R., Todd, R.G., and Sangree, J.B., 1977, Seismic stratigraphy and global changes of sea level, Part 5: Chronostratigraphic significance of seismic reflections. *In* Seismic stratigraphy – applications to hydrocarbon exploration. The American Association of Petroleum Geologists, Memoir 26, 99-116.