CHAPTER 10 – REFLECTION SEISMIC STUDY OF A LOWER PALEOCENE COAL DEPOSIT, WABAMUN, ALBERTA

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INTRODUCTION

In the last decade, increased use of the reflection seismic method has been made for seismic exploration of targets within the top few hundred metres of the subsurface (e.g. Ziolkowski and Lerwill, 1979). In Canada, shallow coals are widespread in Alberta and in southern Saskatchewan (Steiner, et al., 1972; Irvine, et al., 1978) and high resolution reflection seismic surveys are applicable in the development of these deposits for mining. In this study, the reflection seismic method was used in a detailed investigation of a shallow coal deposit near Wabamun, Alberta.

Interpretation of seismic data collected over shallow coal deposits involves examining the continuity and coherency of the reflections from the coal zone and assessing reflection character, i.e. variations in amplitude, phase and frequency of individual events. The coal deposit under study is less than 25 m deep, and is thinly stratified, with thicknesses of most seams an order of magnitude less than the seismic wavelength used. Under these conditions, individual interfaces are not resolvable, and modeling was carried out to determine whether correlation could be achieved between reflection seismic character and stratigraphic variations in the coal zone.

GEOLOGIC SETTING

This study was focused on the Whitewood coal deposit in central Alberta (Fig. 10.1). The deposit belongs to the Scollard Fm (Edmonton Gp) and is underlain by the Battle Fm (Gibson, 1977).

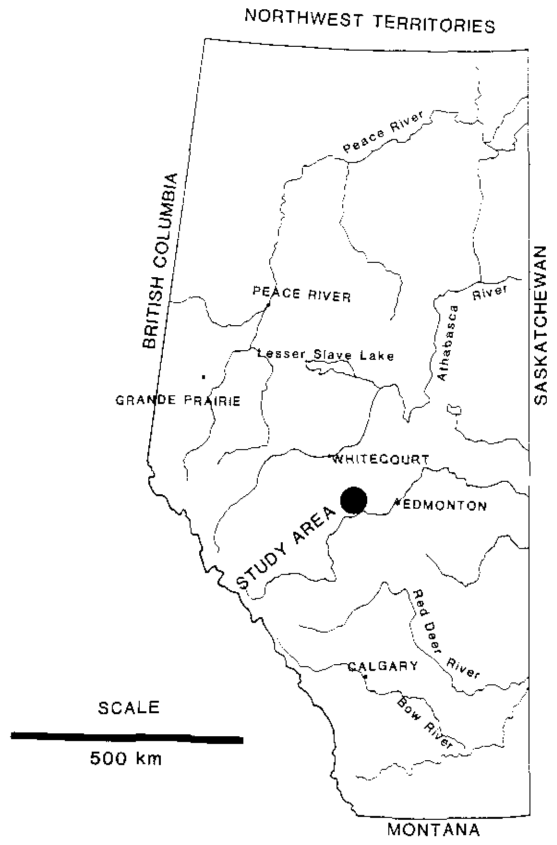

Figure 10.1. Location of the study area in Alberta.

The Cretaceous-Tertiary boundary occurs immediately at the base of the coal deposit (Demchuk, 1987; Sweet and Hills, 1984).

The coal-bearing interval, which is 20 m thick, consists of six major seams, of which seams 1 and 3 are the thickest (up to 3.5 m). Seams are separated by bentonitic interburden. Inorganic clastic sediments including abundant fluvial sands overlie the coal zone, with several metres of glacial till occurring at the surface. The coal zone occurs at a depth of 15 to 20 m below surface and is locally disturbed as a result of glacio-tectonic deformation (Fenton, 1987). Most of the structuring is confined to the uppermost seams since the anelastically deformable interburden serves as a partial detachment zone.

DATA BASE

Two seismic lines from the area (Fig. 10.2) were examined, the objective being a quantitative geological interpretation. Previously, interpretation of high-resolution reflection seismic data has been limited to establishing simply the presence or absence of coal, or locating faults within the coal zone (e.g. Peace, 1978; Ziolkowski and Lerwill, 1979; Ruskey and Lepper, 1979; Schlicker and Böning, 1981). Attempts to interpret the stratigraphy of a coal zone have been made by Fry and Orange (1982) and Lawton (1985).

The data used in this study, were acquired by Geo-Physi-Con Co. Ltd. and processed by the authors at the University of Calgary. Twenty-four channel, split-spread receiver geometry was used in the field, and both the group interval and the near offset were 5 m. A shot, consisting of 10 gm of primacord at 1 m depth, was fired at every station, with the data recorded at a sampling interval of 1/4 ms. A refraction statics correction was applied to field data to eliminate the effects of topography and glacial till. Signal-to-noise ratio of the data was improved by frequency-domain deconvolution with a 32/48-200/240 Hz passband. Examination of shot gathers showed degradation of near-offset data by ground roll and only the 35 to 60 m source-receiver offset window was used for CDP stacking. This approach to the processing of shallow seismic data was favored by Varsek and Lawton (1985), although it reduced the subsurface coverage to 600% from the 1200% recorded (Lyatsky, 1988). Post-stack processing involved a correlation statics correction,

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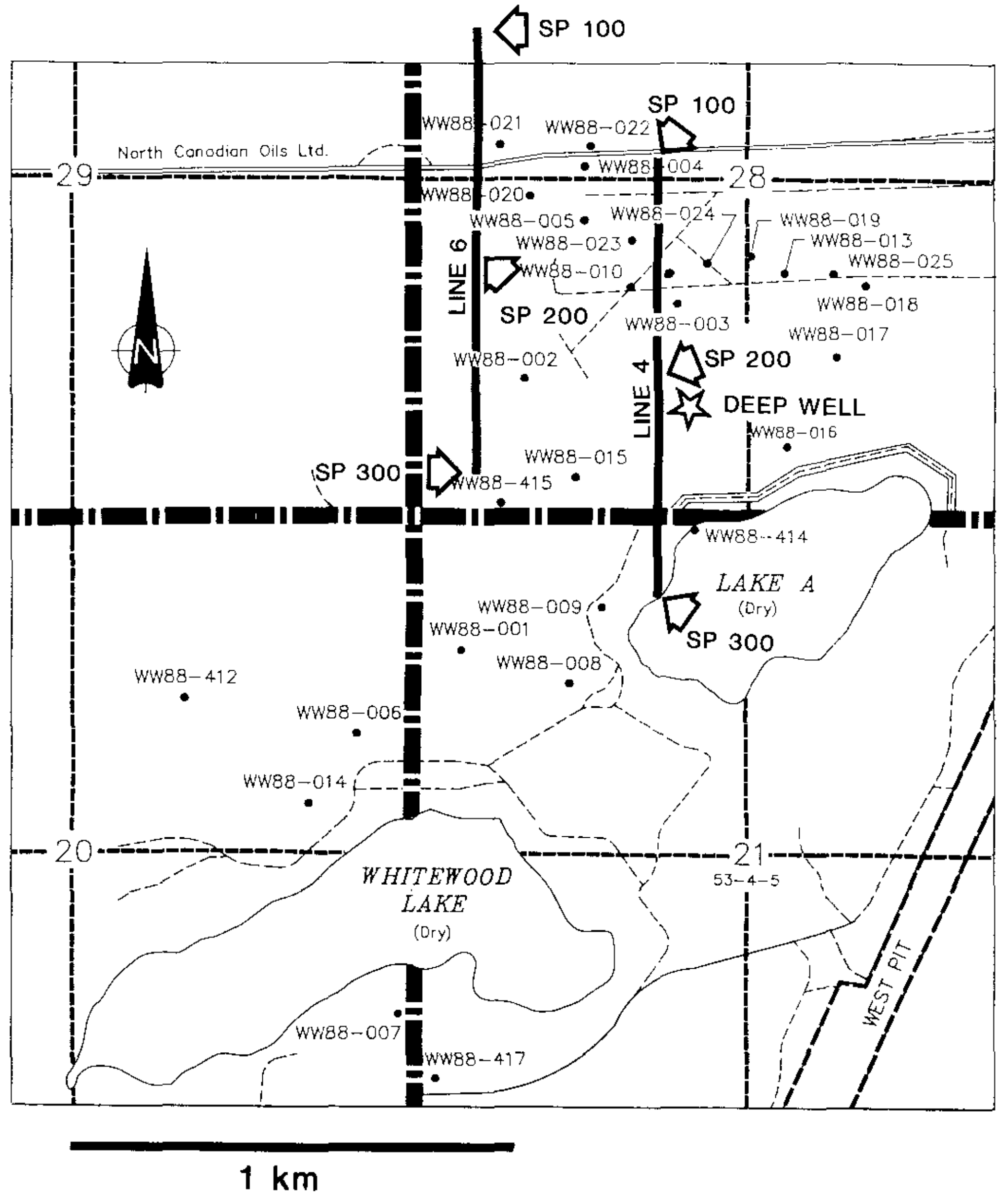

Figure 10.2. Location map of Lines 4 and 6, the deep well, and the 1988 drilling program at Whitewood (Courtesy TransAlta Utilities Corporation).

and frequency-wave number filtering to enhance subhorizontal events. Geologic control was provided by drill-hole data.

LINE 4 INTERPRETATION

The processed seismic section for Line 4 is displayed in Figure 10.3A. This is a structural section, obtained using a standard processing sequence, although particular attention was paid to refraction and correlation statics. However, residual static errors remaining introduce uncertainties in the inferred depth to the coal zone in the section. The interpretation was aided by the reflection from the top of the Horseshoe Canyon Fm (hereafter referred to as the Horseshoe Canyon Marker, or HCM). This marker represents a conformable and locally isochronous geologic surface and is the most consistent reflection in the seismic section. A depression is found between shot-points (SP) 230 and 140, and its existence was confirmed by drilling. As the coal-related event, where it is observed, follows the trend of the HCM, the deformation must post-date the deposition of the Scollard coal.

For the analysis of stratigraphic variations in the coal zone, the seismic section was flattened on the HCM (Fig. 10.3B). Stratigraphic control of the interpretation was provided by a well (WW-87-015) at SP 210 (Fig. 10.2), which penetrated below the HCM. A 1-D synthetic seismogram, based on this well, is included in Figure 10.4, where the central portion of the seismic line is reproduced. This seismogram was generated by assuming a constant velocity (2000 m/s) for the entire modeled interval and using the density log to compute the reflectivity sequence. This approach was justified since it had been discovered that reflectivity in the coal zone is a result of density contrasts between coal and interburden, with velocity variations playing only a minor role. The coal-related event and the HCM can be easily correlated between real and synthetic data. The strong peak observed in the synthetic seismogram, just after the coal-related event, is interpreted to be from a sandstone body (Fig. 10.4) at the base of the Scollard Fm. The high-amplitude event found in the 1-D model after the HCM corresponds to a deep coal zone in the Horseshoe Canyon Fm. This horizon is poorly resolved in the field data due to either lack of energy penetration resulting from too small a charge size, or from velocity variations at this depth which are unaccounted for in the modeling.

The coal-zone stratigraphy at the south end of Line 4 is illustrated in Figure 10.5. The generalized density log shown was constructed from drillhole data, and care was taken to include even relatively thin coal and bentonite beds into the model. Seam 1 is absent from the section, and the coals represent seams 2 to 6. The synthetic seismogram based on this log is included in Figure 10.6. It is dominated by a peak-trough pair with a half-period of 4 ms, preceded by another, smaller peak. This character is contributed mostly by seam 3. Seams 4 to 6 are thin and contribute little to the coal-related event. A similar character is observed on the south end of Line 4 (Fig. 10.3B), confirming that seams 2 to 6 are present there. Although, near SP 200, the small early peak disappears, the main peak-trough pair persists, with interruptions and minor variations, as far as SP 160. The loss of the side lobe preceding the coal reflection may be due to interference arising from the thinning of the interval between the uppermost coal and the base of glacial till. At SP 202, a strong event appears after the coal reflection. This is interpreted to be a result of a sandstone body in the lower Scollard Fm or Battle Fm, as noted above.

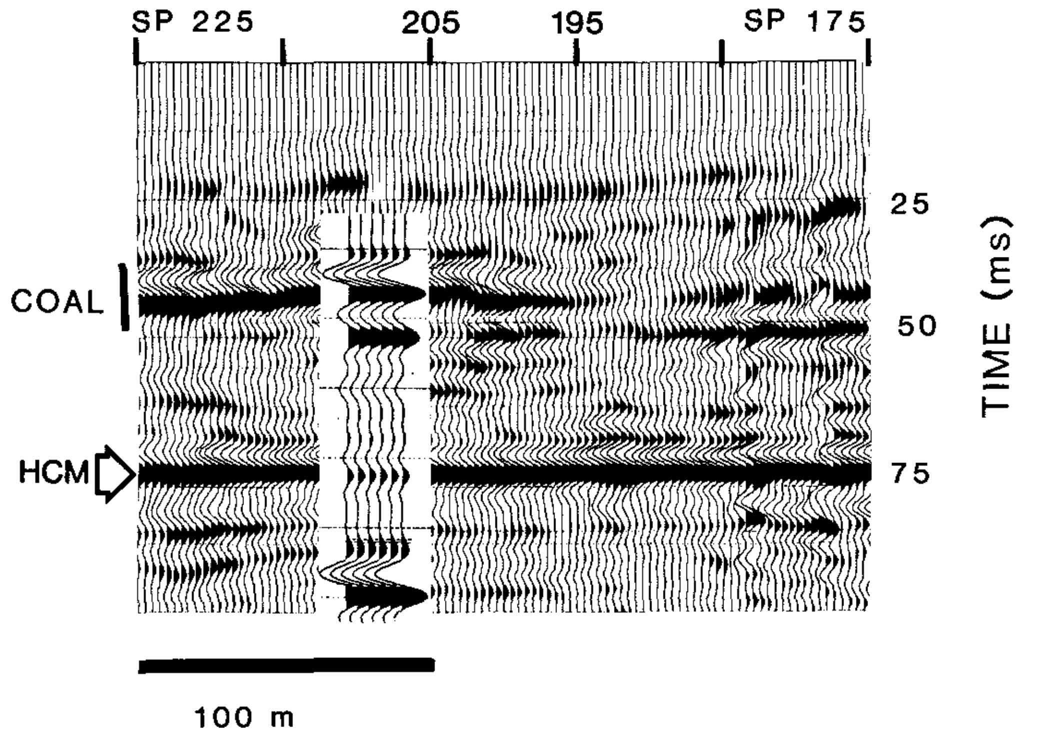

Figure 10.4. Central portion of Line 4 (flattened on HCM), with a synthetic seismogram based on well WW-87-015.

A local change in the character of the coal-related event occurs between SP 200 and 190 (Fig. 10.3B), where this reflection loses amplitude or disappears completely. A similar anomaly is found between SP 160 and 140 (Fig. 10.6). Both anomalies are similar to those expected from fluvial channeling. However, drilling has revealed that the coal zone is continuous across these anomalies, although it is fractured, and seam 3 is sometimes thinned. One-dimensional modeling showed that the amount of thinning of seam 3 is probably insufficient to produce the observed loss of reflection, suggesting that these seismic anomalies may be a response to changing petrophysical properties of the coal, particularly local fracturing from glacio-tectonic deformation where the coal zone is very shallow.

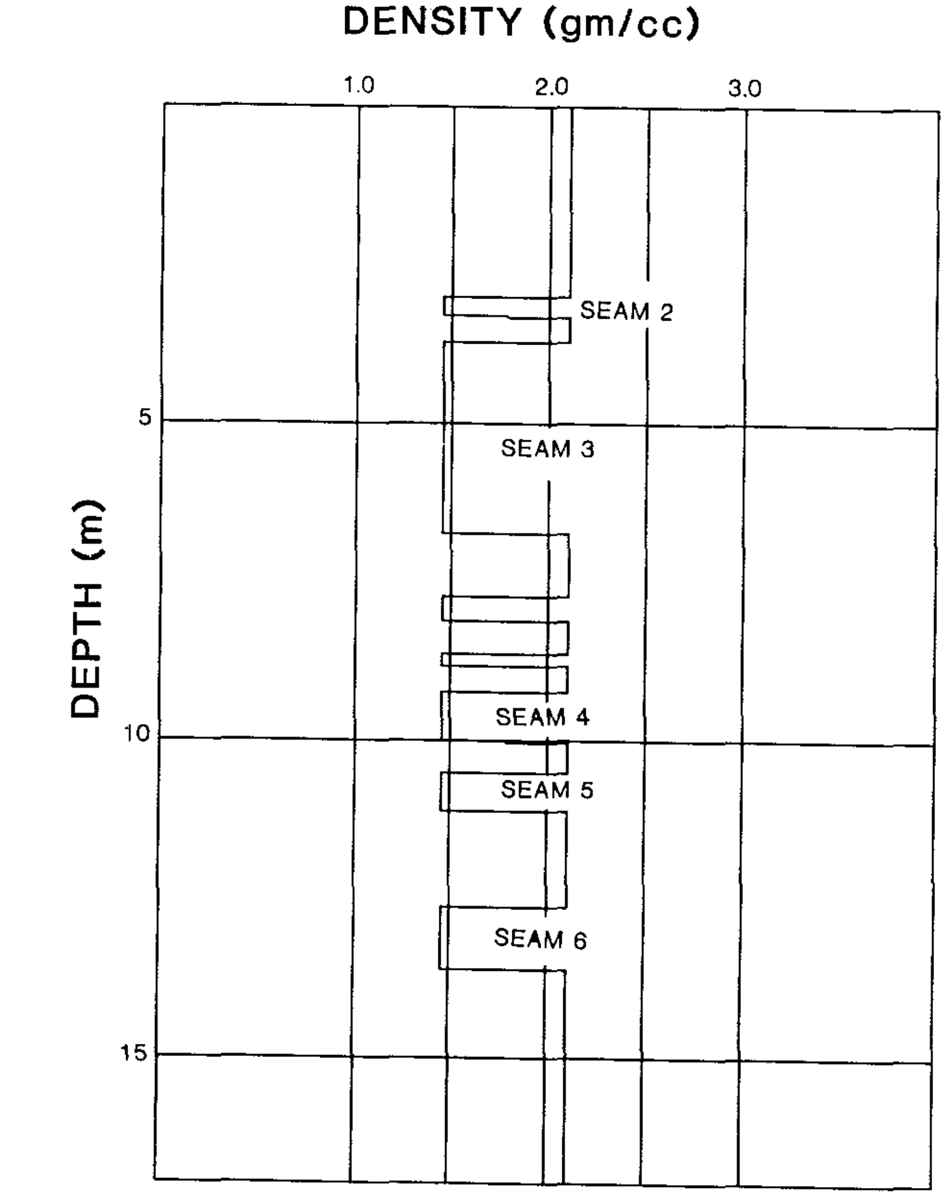

Figure 10.5. Synthetic density log with Whitewood seams 2 to 6.

Near SP 140, the zone of interest acquires a double peak-trough character at 40 to 60 ms (Fig. 10.6). This character can be correlated to that observed in the synthetic seismogram based on the log in Figure 10.4, although the sand-related event now dominates the data. The low amplitude of the coal reflection could be explained by structural deformation of the coal zone, although no seam 3 subcrop occurs. However, any interpretation remains speculative due to a lack of well-control on the north end of Line 4.

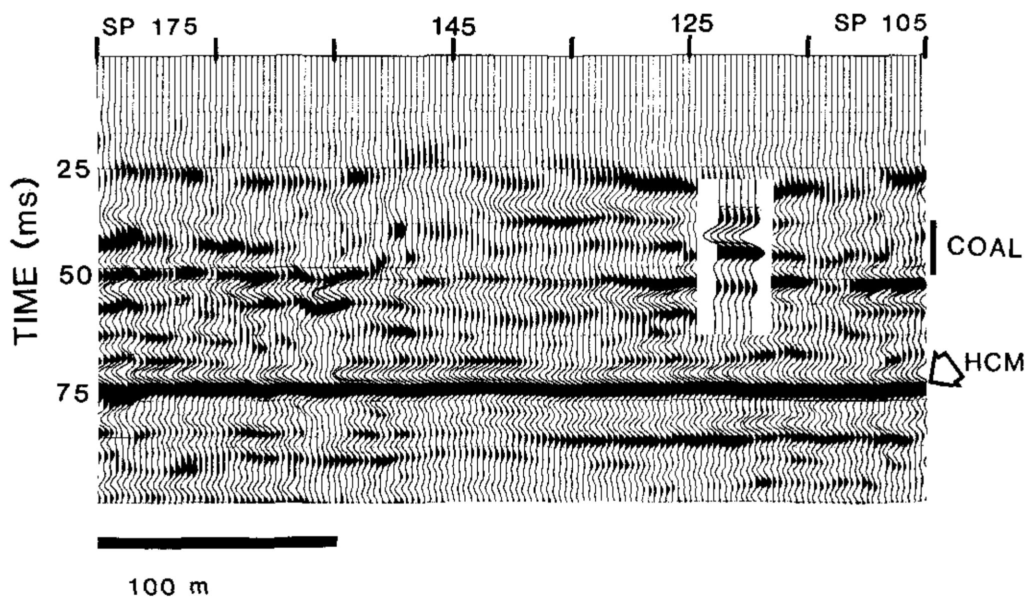

Figure 10.6. North end of Line 4 with a synthetic seismogram based on the log in Figure 10.5, assuming an average interval velocity of 2000 m/s.

Figure 10.3C shows a summary of the preferred interpretation of the data from Line 4, based on the modeling studies discussed above.

LINE 6 INTERPRETATION

Analysis of Line 4 allowed us to attempt an interpretation of the seismic data along Line 6, which is both structurally and stratigraphically more complex than Line 4. Drillhole information revealed a structural situation different from the one imaged in Line 4. The dip of the coal zone is highly variable: northward in the south and southward in the north. The most prominent long-wavelength structural feature is a deep (10 m) depression in the middle of the section.

The seismic expression of this structural style is shown in Figure 10.7A. It is masked by residual static anomalies in the central and northern portions of the seismic line. However, at the south end of the line (SP 235 to 275), a northward dip is evident in the data. The apparent structure between SP 120 and 140 is considered most likely to be a long-wavelength static anomaly.

As with Line 4, seismic structural analysis was aided by reference to the HCM. Although the coal reflection generally mimics the structure of the HCM, the time difference between them is not constant. Near SP 175 and 140, the coal-HCM isochron thickens abruptly. If glacio-tectonic faulting is the cause, these disruptions could be easily misinterpreted on the basis of drillhole data alone, creating the appearance of a depression with two smooth flanks.

Examination of well data revealed a similarity in the distribution of coal and interburden along Lines 4 and 6. Therefore, the density log in Figure 10.5 and the modeling undertaken in the previous section are also relevant to the interpretation of this profile.

Figure 10.7B shows the seismic section from Line 6 flattened on the HCM. The coal zone is present at 50 ms on the south end of the line. Off-line well data suggest that the till-coal interval here is thicker than in Line 4. The event at 35 ms in Line 6 may represent a reflection from the base of glacial till. It is sufficiently earlier than the coal reflection so as not to interfere with it.

The coal-related event starts as a doublet on the south end of the line (Fig. 10.8) but rapidly changes into a peak-trough pair similar to that in Line 4. The doublet is interpreted to indicate the presence of seam 1 at the south end of the line. Such an interpretation is supported by 1-D modeling of a thickened coal zone, with the synthetic seismogram included in Figure 10.8, along with the seismogram from Figure 10.6 for comparison. Incorporation of seam 1 into the coal-bearing interval gives the data a peak-trough-peak character similar to that observed on the south end of Line 6. This interpretation is further supported by drilling south of Line 6.

The coal-related event loses its continuity between SP 230 and 190. This is interpreted to represent either the removal of some or all seams, or structural deformation of the coal zone. It has been found (Lyatsky, 1988) that the area of degradation of the coal reflection coincides with a zone of large weathering static anomalies, suggesting considerable glacio-tectonic deformation in this area.

Between SP 215 and 200, two high-amplitude reflections appear at 40 to 60 ms. These events represent either locally undisturbed coal or the presence of erratic material within the glacial till.

Extensive deformation ends near SP 180, and an undisturbed coal-zone reflection is again observed. This part of the seismic section is shown in detail in Figure 10.9A. The coal-related event is now represented, not by a peak-trough pair, but by a more complex reflection pattern. In explaining this character change, several factors have to be considered:

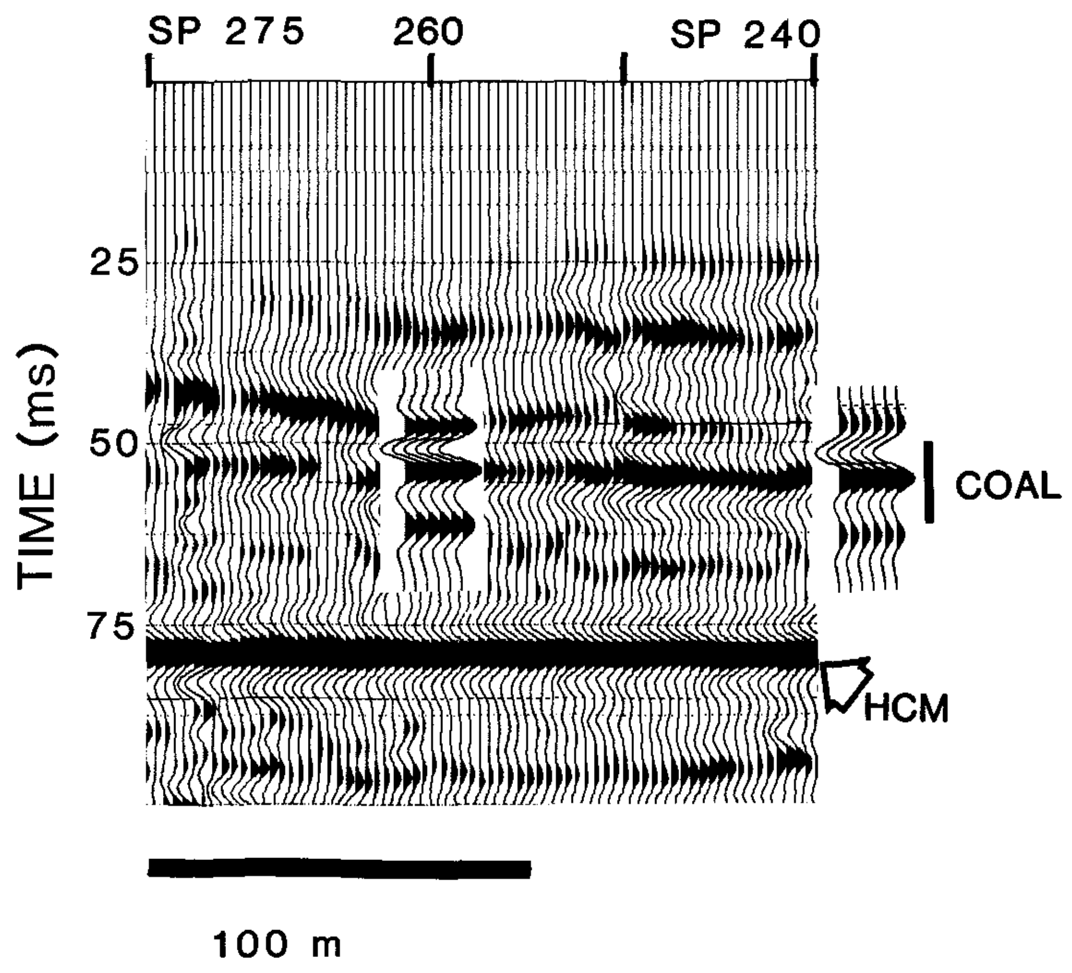

Figure 10.8. South end of Line 6, with synthetic seismograms representing seams 1 to 6 (center) and seams 2 to 6 (right).

1) The top peak (at 35 ms) may represent the reflection from the bedrock surface (base of till). Reflectivity within the till-coal interval or within the till is also possible, accounting for the high amplitude of the peak at 40 ms;

2) The high amplitude of the 40 ms peak may be a result of remnants of seam 1. Combined with the event at 50 ms, this peak forms a reflection configuration similar to that on the south end of the profile in Figure 10.8;

3) The onset of anomalous character coincides approximately with the possible structural deformation noted in the previous section. Faulting of the HCM is possible, with the north side downthrown. However, this scenario is unlikely since no major disruptions of the HCM are observed in the structural section (Fig.10.7A);

4) The deformation may be caused by glacio-tectonic thrust faulting. Such faulting is known to exist in the area (Fenton, 1987). Since the ice advanced generally from the north, a northward dip of the fault plane is expected; and

5) The character change may mark the end of the zone of extensive weathering-static anomalies, and the restoration of the undisturbed coal-bearing interval.

Details of the north end of Line 6 are shown in Figure 10.9B. At SP 160, the coal reflection is weakened, possibly due to interference with the base-of-till reflection. The anomaly at SP 145 is due to either pre-glacial faulting of the HCM or, more likely, glacio-tectonic thrust faulting of the coal zone.

The anomaly between SP 140 and 120 is similar to those observed in Line 4. In a Monenco interpretation of drillhole information near SP 135, faulting was postulated within the coal zone, which occurs less than 1 m below the glacial till. This confirms the interpretation of similar seismic anomalies proposed in the discussion of Line 4.

The preferred interpretation of Line 6 is shown in Figure 10.7C. It shows the possible structure and stratigraphy of the coal zone as well as areas interpreted to contain glacially excavated or thickened coal.

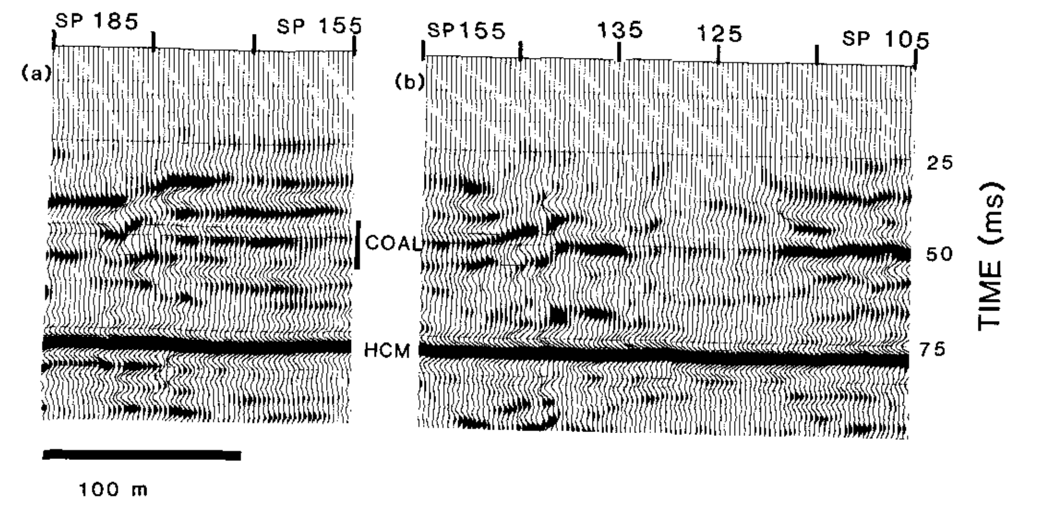

Figure 10.9. Seismic anomalies in the center (a) and at the north end (b) of Line 6.

DISCUSSION

This study illustrates the application of reflection seismic profiling in shallow coal exploration. The greatest success can be achieved when seismic studies are incorporated into an integrated exploration program, and drilling can be used to provide control for the seismic interpretation. This study also shows that the coal zone should not be considered alone, whether seismically or geologically. Reflections from interfaces above and below the coal-bearing interval can interfere with the coal-related reflection, and structural deformation may cause degradation of coal. This study indicates that seismic techniques can be applied successfully in shallow coal fields in the Plains of Western Canada.

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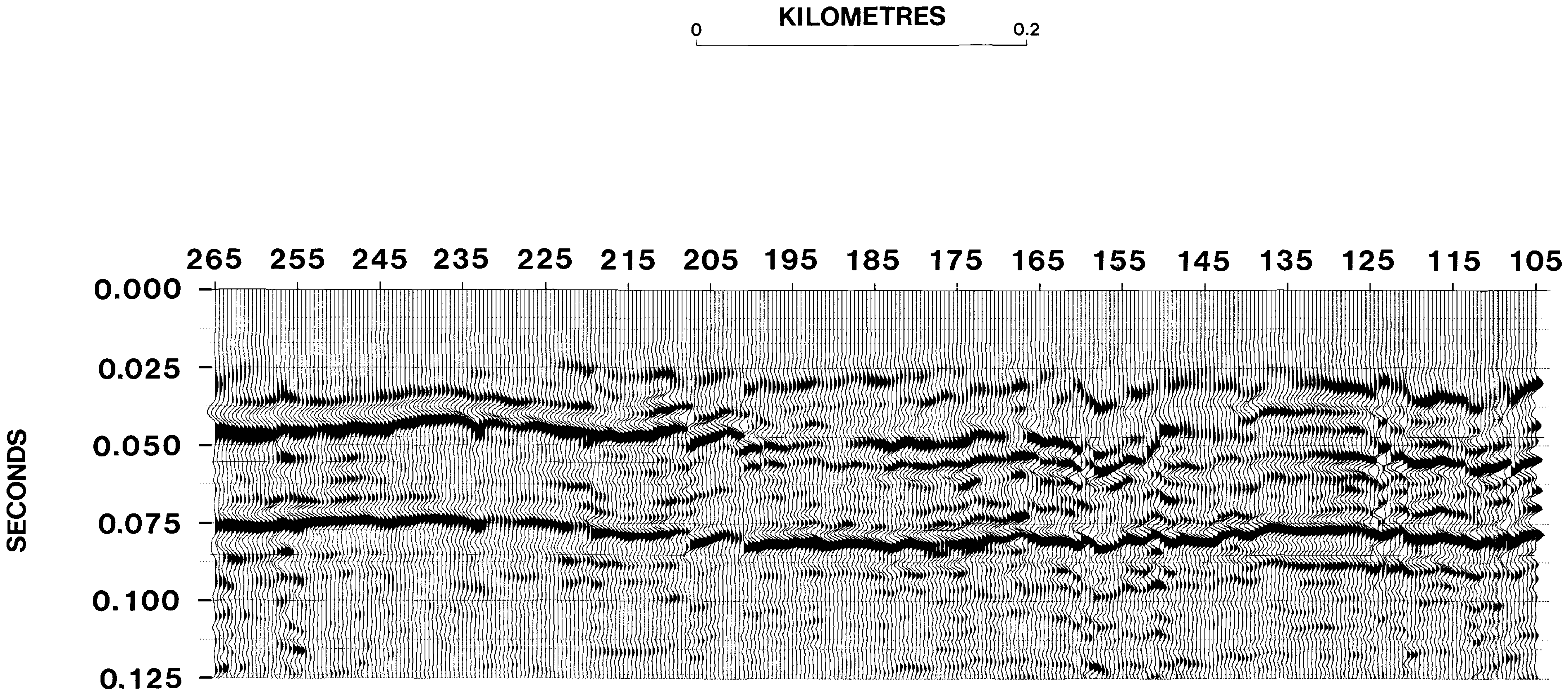

Figure 10.3A. Field stacked section from Whitewood Line 4.

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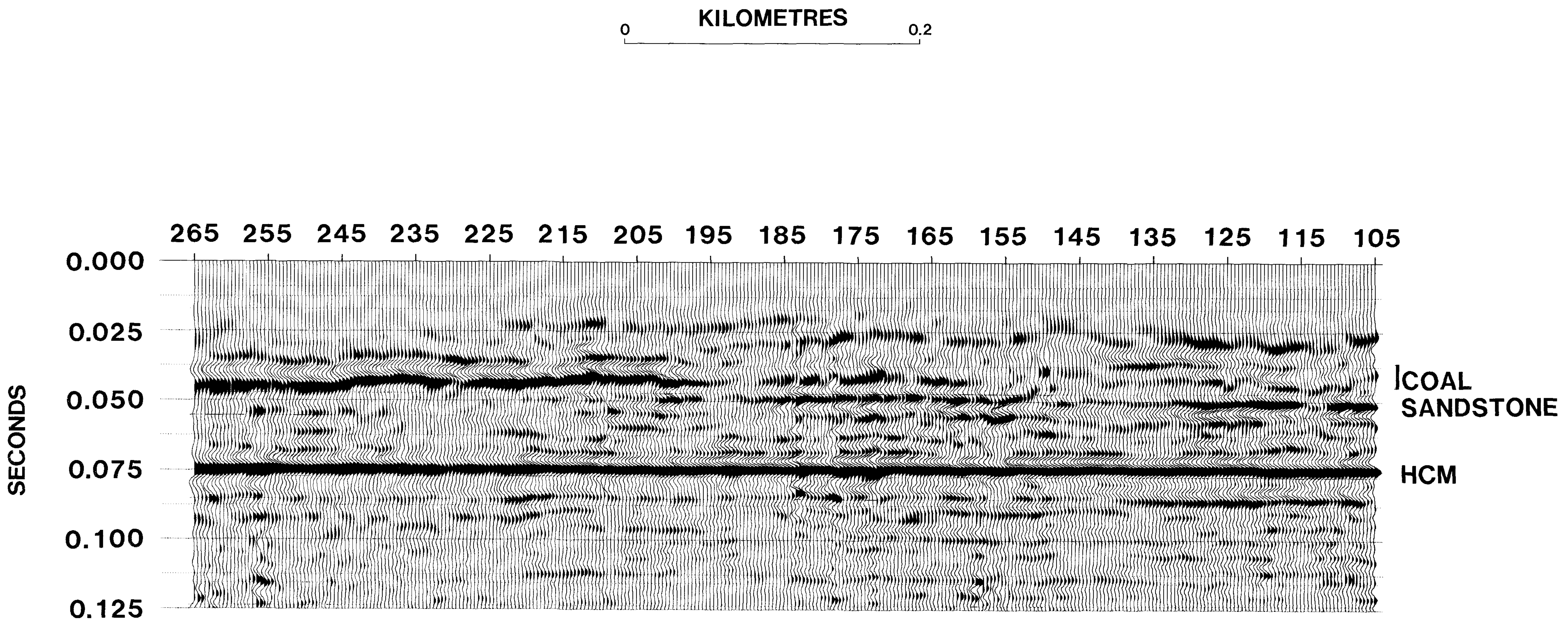

Figure 10.3B. Stacked section from Whitewood Line 4, flattened on the Horseshoe Canyon marker (HCM).

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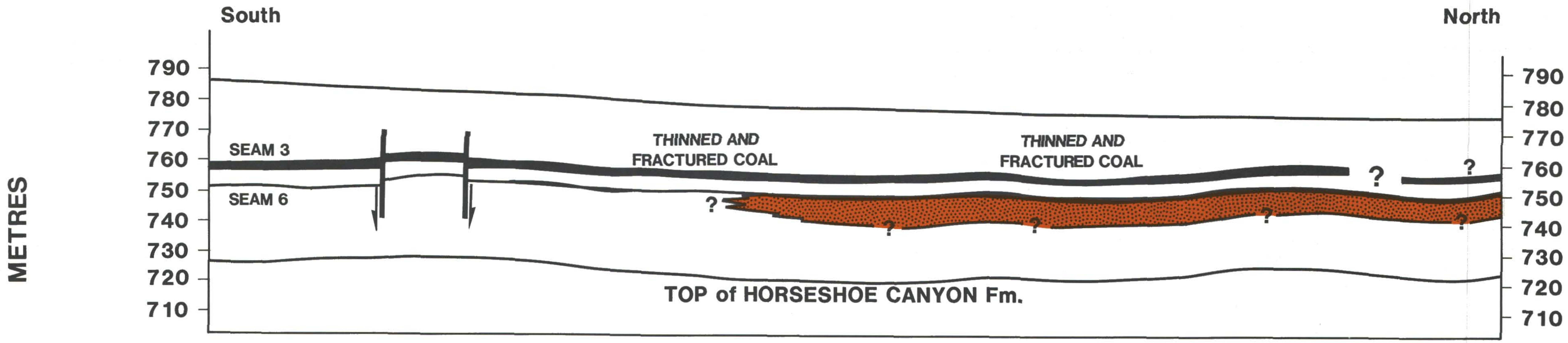

Figure 10.3C Final interpretation of Whitewood Line 4.

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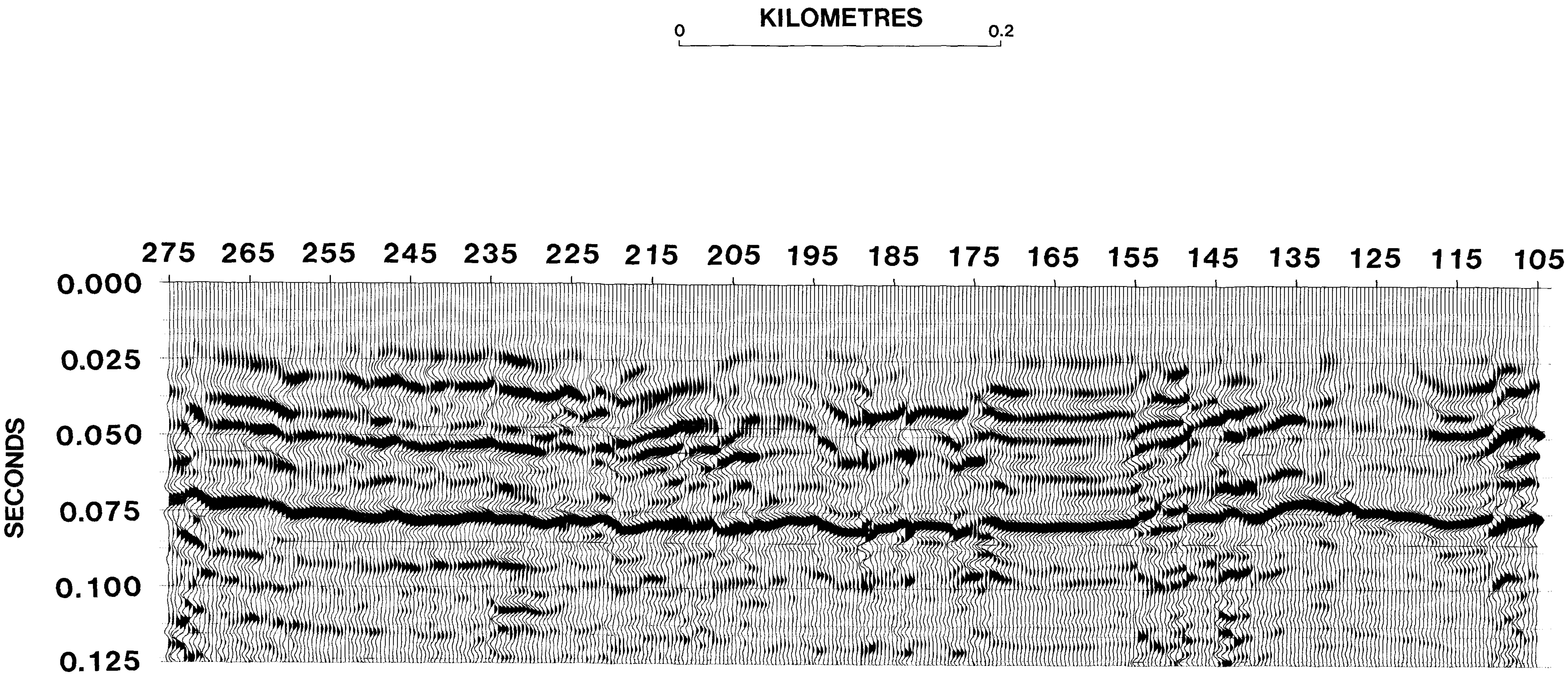

Figure 10.7A. Final stacked section from Whitewood Line 6.

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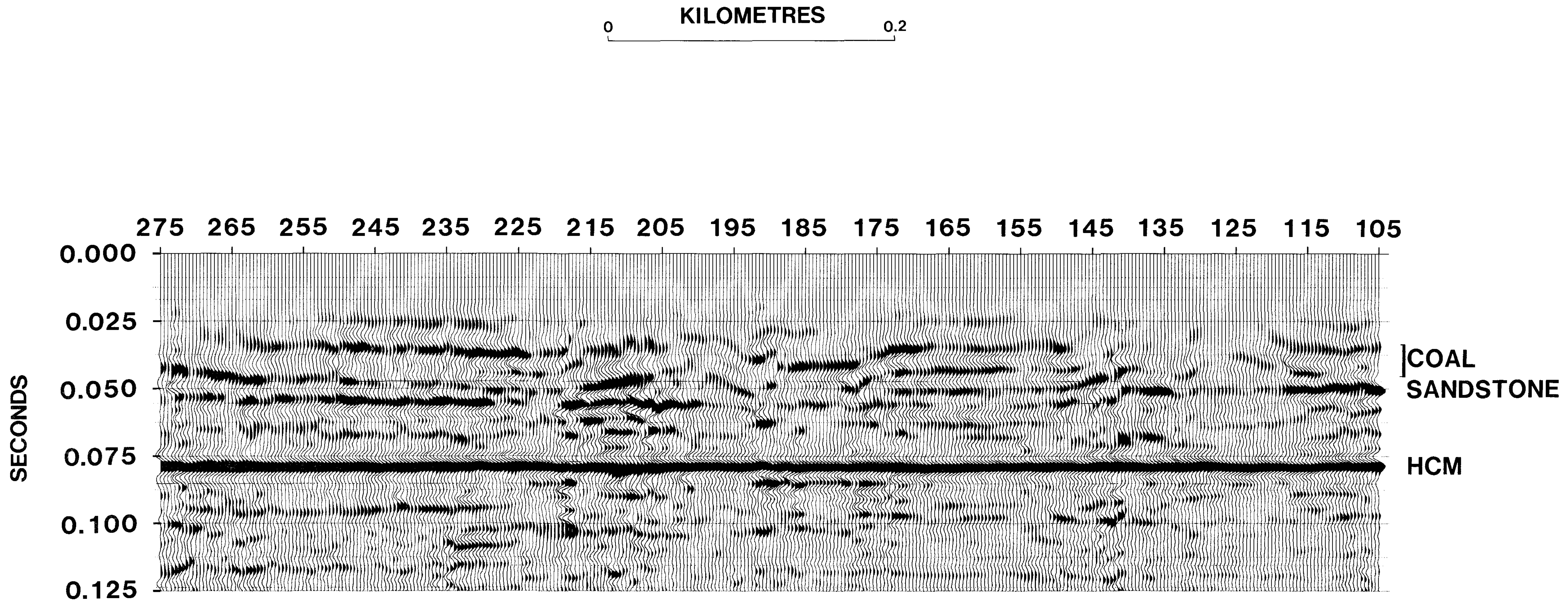

Figure 10.7B. Stacked section from Whitewood Line 6, flattened on the Horseshoe Canyon Marker (HCM).

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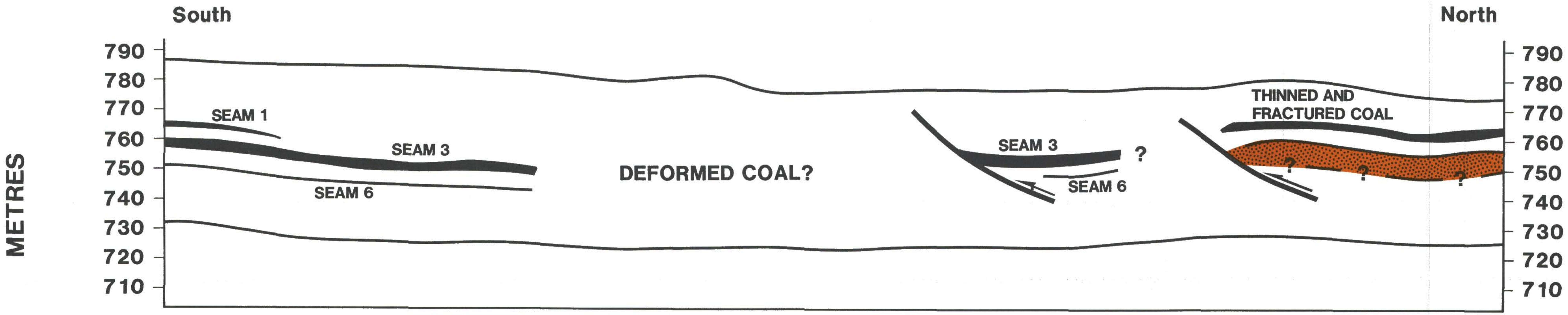

Figure 10.7C. Final interpretation of Whitewood Line 6.

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