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Research Article

Seismic Exploration and Mine Planning, Comox Coal Field

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Background

In 1997 Tsable River Coal Company owned the Raven Coal Project in Vancouver Island, British Columbia. In 2006 Compliance Energy owned the Raven Coal Project. The seismic portion of the geologic investigation for both companies was conducted by Emerald Exploration Consultants, Inc. (EMEX). It consisted of a series of high resolution seismic reflection lines totaling 43 km. The goal of both programs was to characterize the coal beds and any subsurface features such as folds, faults, and stratigraphic variations that might affect the planned underground mine plan. In 2008 Compliance Energy formed the Comox Joint Venture which was made up of Compliance Energy which controlled 60% and the remaining 40% was owned by IComox Coal Inc. (a subsidiary of Itochu Corporation of Japan) and by LG International Investments, Canada Ltd. (a subsidiary of consumer sector giant LG International Corp. of Korea). The Comox Joint Venture was to receive up to $500,000,000 in funding from the minority partners. In 2009 additional core drilling was undertaken to fully characterize the area, and this data was reviewed by EMEX in 2010. In 2016 after spending over $25,000,000 and failing to obtain the necessary permits Compliance Energy and partners paid off all debts and dissolved the joint venture and the company.

Location

The Quinsam Mine and the Raven Coal Project are in the Comox Coal Field which is located on the east coast of Vancouver Island, British Columbia. The Quinsam Mine is 20 km southwest of Campbell River. The Raven Property is 20 km south of Courtenay and due west of Buckley Bay. The area is mostly heavily forested and was being logged by Island Timberlands. The Raven Coal Project contains several haul roads for local logging operations.

Figure l is the location map showing all the seismic lines involved, with emphasis on those being discussed. Specific topographic features, well locations, and roads are also shown. The topography depicts a series of linear northwest trending ridges that indicate bedding plane dip to the northeast. The course changes in the various creeks are felt to be indicative of a complex fault pattern.

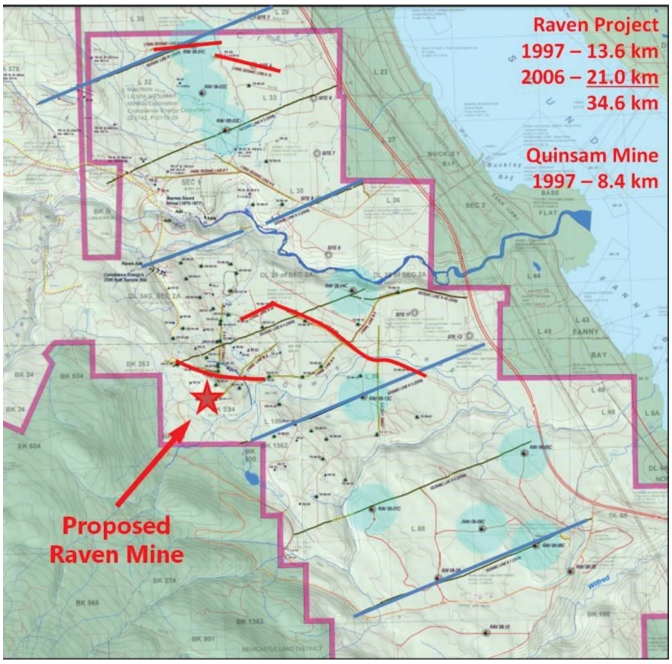

Figure 1: Location Map.

Seismic Data

In 1997 the acquisition and on-site processing and interpretation of 13.6 km of high resolution seismic reflection data in a series of ten (10) lines was accomplished and similarly in 2006, 21.0 km of high resolution seismic reflection data in a series of seven (7) parallel lines was accomplished. All lines were optimized for the upper 100 to 500 m of geologic strata, depending upon the depth to the coal seams. To accomplish this objective acquisition and on-site processing was performed in a conventional stepwise approach, followed by a detailed interpretation of all available data. Associated geologic data were evaluated on a regional and site-specific basis to help in the determination of optimal parameters and aid in the interpretation. The evaluation of the borehole data allowed for accurate reflection identification. Synthetic seismograms indicate that the various seams produce reflections of variable amplitude and character based upon coal seam thickness, partings, and possible changes in floor and or roof quality.

In 1997 the complexity of the geology at the Raven Coal Project led to the acquisition of a test line at the Quinsam Coal Mine over known geology. These tests clearly showed that the seismic data was correctly portraying the known geology. Four (4) additional lines of 8.4 km were obtained at the mine to locate suspected faults and to assist in developing the future mine plan.

The details of seismic data acquisition and processing are beyond the scope of this paper. However, it should be noted that in 2006 appropriate extra shots were taken to ensure that continuous

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reversed refraction data were available on all lines. The data along each line was reviewed at the first and last shot of each cable so that the effects of elevation and dip could be averaged. The results in terms of overburden and bedrock velocity, and overburden thickness are discussed below. It should also be noted that the building of fold with time is an important consideration when viewing the very shallow information. This increase of fold with time is variable dependent upon the shallow velocities but is generally 30 ms for this data. The variation in fold at line ends and in areas where loss of fold was due to topographic and physiographic restrictions is another important consideration when viewing these lines. The quality of the data, which relies on the statistics of full fold, is degraded in areas in which loss of fold (either horizontal [lateral] or vertical [time]) are encountered and should be viewed with caution.

Geology

The Raven Coal Project is at the south end of the Comox Coal Basin. The coal is steeply dipping to the northeast. Overburden thickness was originally thought to preclude surface mining, but in 2006 one area was found to exist where surface mining may be practicable. The existence of faults in the subsurface as observed in the seismic data was suspected because of regional geology, large displacements observed in borehole data, and surface expressions normally related to faulting.

The coals are contained in the Cumberland and Dunsmuir Members of the Late Cretaceous Comox Formation which overlies the volcanic basement rock of the Triassic Karmutsen Formation. Surface glacial till is generally from 2 m to over 100 m thick. The surface geology and generalized stratigraphic section are from Bickford and Hoffman, [1]. Analysis of the cuttings from the auger holes lead to a map showing surface rock type. The refraction data led to mapping the thickness of the overburden, and the velocities of the overburden and the bedrock.

The Cumberland Member contains the chief economic coal seam (Seam 1) and consists of a 30 to 90 m sequence of alternating dark gray siltstone, carbonaceous shale, and minor sandstones. The overlying Dunsmuir member is generally about 60 m thick and contains thick bedded medium grained arenites, medium to coarse grained sandstone, and minor dark gray shale and mudstone. It contains Seam 3 that generally has two plies and is overlain by hard, dense, massive sandstone. The silty shales of the Trent River Formation overlie the Dunsmuir.

The Cougar Smith Creek and the western portion of the Tsable River generally overly cross faults that separate the Raven Coal Project into northern, central, and southern blocks. Seismic lines 1 and 2 portray the northern block; seismic lines 3, 4, and 5 portray the central block; and seismic lines 6 and 7 portray the southern block. The structural contour map of the coal surface was based primarily upon the seismic data and to some extent on the well log information. It indicates both complex thrust faulting and northeast dip. In the northern block the presence of a repeat section of subthrust coal is noted. To the south the presence of a repeated section is not ascertained but the tear fault separating the central and southern blocks has moved the southern block further to the east compared to the central block. The complexity of faulting in the subsurface is based upon the limited amount of seismic data; making the map very conjectural in areas away from the seismic data.

Synthetic Seismograms and Geologic Correlation

A common pitfall in seismic interpretation is to see variations in time on the seismic section and attribute these variations to structural variations. [1] and many other authors point out that a flat time horizon may have apparent structural variations caused by variations in velocity, and conversely that an undulating time horizon may actually be flat with the apparent time undulations being caused by variations in velocity. For this data, assume a reflector caused by an interface at a depth of 500 ft occurs at a two-way time of 0.100 sec and the velocity is 10,000 ft/sec. If a 5 ms time variation is encountered it can be caused by either a 25 ft structural variation with no change in velocity, or a 500 ft/sec velocity variation with no change in structural configuration, or some indeterminate combination of effects. Both scenarios appear to be geologically plausible.

Typically, in petroleum exploration, the above scenario presents little problem since the magnitude of the changes are relatively insignificant compared to the size of the target structures. For coal projects the above scenario presents a large problem and is significant, although virtually irresolvable. To obtain absolute accuracy in depth one must calibrate to well log information with the seismic data, preferably several times along the line. This has been done, with the qualifications that the sonic logs, where available, did not always start at the surface, and virtually none had check shots for calibration. Within the upper 100 ft of geologic strata the measurement of the near surface velocity with continual refraction analysis along each seismic line had the effect of minimizing this irresolvable problem.

The geologic correlation of seismic reflectors was made by comparing the character and amplitude of synthetic seismograms to the observed seismic character and amplitude. As an aid in the interpretation synthetic seismograms were computed from 115 wells. Figure 2 depicts a sample of four synthetic seismograms. In 2010 all

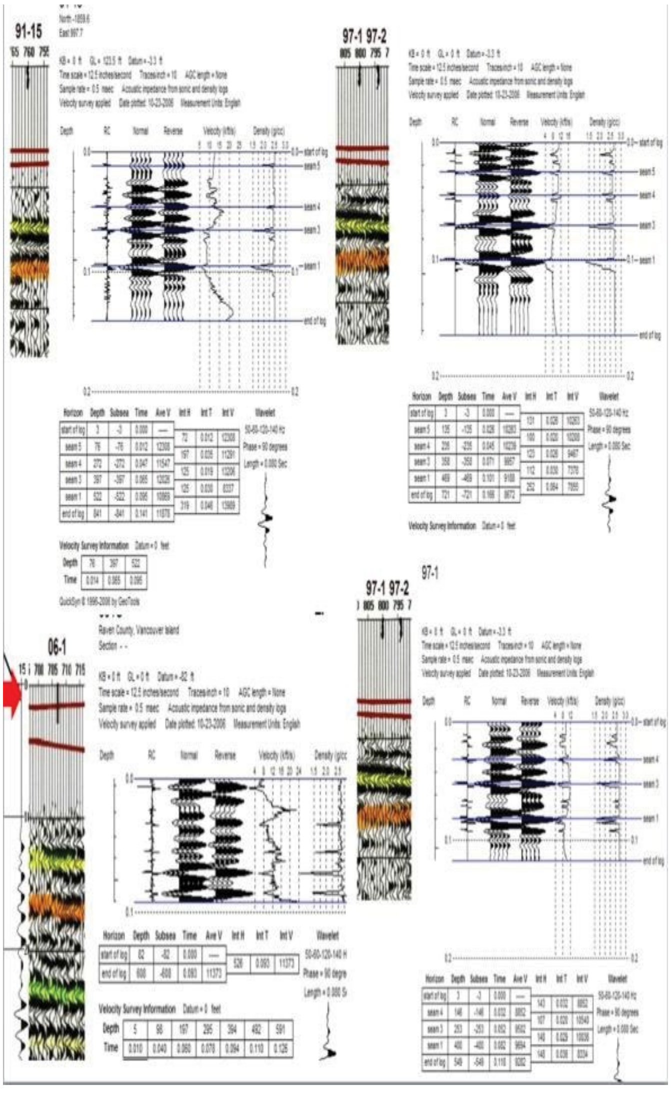

Figure 2: Sample Synthetic Seismograms.

well, log information was reviewed in a "post completion analysis" to determine if there were any "significant errors" in the prior interpretation. None were found.

There were no calibrated sonic logs available until we recorded three (3) check shot surveys in 2006. Without check shots the absolute time tie becomes interpretive. In an attempt to overcome this problem, the procedure was to utilize refraction data for near surface information. A time versus depth plot of all sonic logs verified that the refraction velocities were consistent with the well log information. A cross plot of density versus velocity established the conversion if only density logs were available. Hence, if there was no sonic log, the density log was used. If there was no density log the refraction data was used. And the refraction data was used to establish the overburden thickness and velocity.

Mismatch was encountered in time zero of the synthetics and the seismic data. The observed time mismatches were within the anticipated range considering the highly variable overburden thickness and velocity. A correspondence of strong reflections to coal seams is clearly the case. The various coal seams produce high amplitude reflections which are accentuated through simple tuning, with the amplitude related to the thickness of the seam and the nature of the partings. Typically, a thin coal produces a weaker reflection than a thick coal.

Local thickness variations between seam 3 and seam 1 are observable in both the drill hole and seismic data, therefore erosional changes related to removal of strata and/or depositional changes related to thickening, thinning, and variations in the stratigraphy are present in the seismic data that lead one to infer that the depositional basin was to the west of the present structural basin. At the level of seam 3 and seam 1 faulting and flexures are clearly present. Most faults that intersect the coal zone appear to be continuous to the base of the glacial till and related to regional thrusting.

A generalization from this data is that the seam 1 reflection is generally a bit stronger (thicker) than the seam 3 reflection. The well data indicate the average thickness of seam 1 is 2.5 m or 8.2 ft, and for seam 3 it is 1.6 m or 5.3 ft. Therefore, the well data support the observed generalization. Another generalization from this data is that both the seam 4 and seam 5 reflections are generally weak and intermittent being observable only on a very local basis. The well data indicate the average thickness of seam 4 when present is 0.99 m or 3.3 ft, and seam 5 when present is 1.20 m or 3.9 ft. To the west the interval between seam 3 and seam 1 thins.

The agreement of the character of the synthetic seismograms to the seismic data is beyond dispute and makes the identification of geologic layers indicated in the seismic data justifiably secure. Coal seam interpretation was based on recognizable reflection character and continuity on an individual line basis. The lateral extent of the seams 1 and 3 was clearly evident on each line and the correlation from line to line was also evident. Figure 3 shows example seismic data.

From the surface to seam 3: The upper part of this sequence is the overburden. Beneath the overburden this interval contains interbedded sandstone, siltstone, mudstone and occasional thin coal stringers in addition to seams 5 and 4. For the most part the section immediately above seam 3 is massive sandstone. In the seismic data over the western, shallow area much of this section is missing and shows a general lack of lateral continuity. In the seismic data over the eastern, deeper area the data does contain some reflections that lack lateral continuity. These reflections come from seams 4 and 5 and a few rock/rock interfaces. Reflections from seams 4 and 5 are clearly not as continuous and uniform as the reflection from seams 3 and 1.

Seam 3: Seam 3 appears as a high amplitude reflection that generally exhibits good reflection amplitude and continuity. The average thickness of seam 3 indicates that it should produce a "tuned" reflection.

Between Seams 3 and Seam 1: Geologically this interval contains interbedded sandstone, siltstone, mudstone and occasional thin coal stringers of seam 2. Within this interval seam 2 is too thin to produce a reflection, or significantly alter the reflection complex produced from the thicker seams 3 and 1. Seam 2 is observed in several wells but the synthetics do not show any observable effect of this thin seam. In the seismic data the thickness of this interval varies on a local and regional basis and indicates that the original depositional basin did not coincide with the present day structural basin. In the area to the east this interval is approximately 20 ms thick.

In the area to the west it is approximately 30 ms thick.

Seam 1: In the seismic data seam 1 appears as higher amplitude reflection than seam 3, and generally exhibits excellent continuity that is variable locally. The overall thickness of seam 1 indicates that it is a "tuned" reflection.

Beneath Seam 1: Geologically this interval contains interbedded sandstone, siltstone, mudstone and occasional thin coal stringers as floor conditions at the base of seam 1.

The well logs and synthetic seismograms that encounter basement indicate that there is virtually no difference in rock properties at this interface. This is an ambiguous zone with occasional reflections of low amplitude and limited continuity.

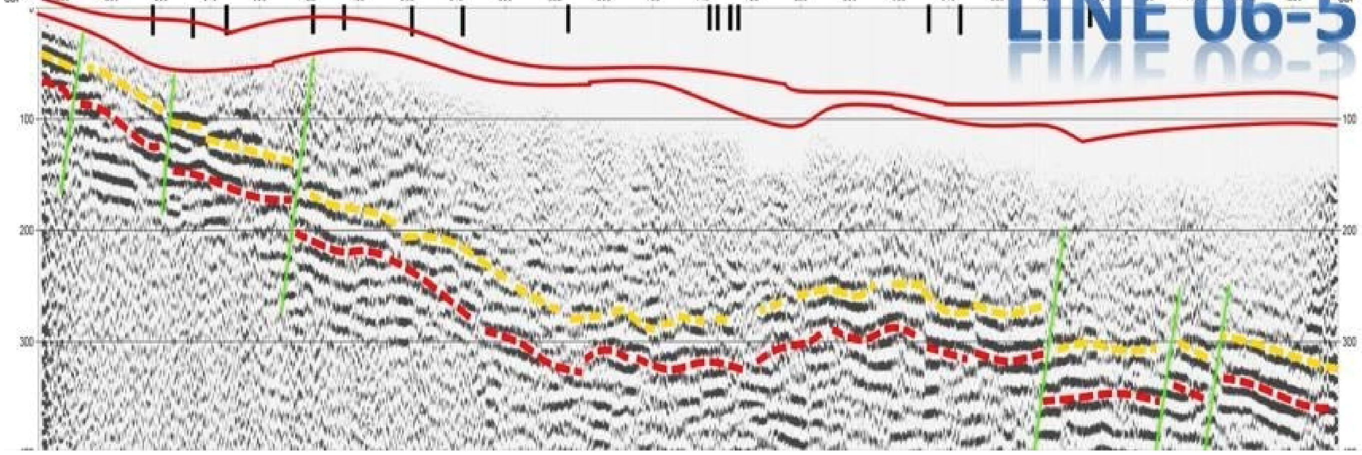

Figure 3: Seismic Line 06-5

Conclusions

The reflectors are interpreted to be caused by coal/rock interfaces with reflections from rock/rock interfaces being infrequent. The data indicates the presence of thick seam 3 and seam 1 coal, their depth, configuration, and faulting with beds dipping regionally to the northeast. Erosional surfaces and lithologic changes related to thickening, thinning, and variations in the coal zone are present. The presence of several sonic logs makes correlation of the seismic reflectors to specific coal seams clear cut in those area and more conjectural in others. Based upon all the available seismic data in the Raven Coal Project there is evidence for complex thrust faults in the coal zone in some areas while other areas are virtually free of faulting, as shown in the interpretation of the various seismic lines.

The interpretation characterized faults that might be present and might affect future surface and/or underground mining operations in the area. The presence of shallow coal amenable to strip mining is noted. The seismic data is clear cut and easily interpretable. Mining should be initiated, the seismic data shows thick coal seams, their depth, configuration, and thickness variations, and faults where present, and other stratigraphic features. It should be used to guide the coal mining in these areas.

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