TONSTEINS AND BENTONITES IN NORTHEAST BRITISH COLUMBIA (93O, P, I)

By W. E. Kilby

INTRODUCTION

Tonsteins are presently considered the most reliable coal seam correlation tool available (Stack, *et al.*, 1982). Such ancient volcanic ash bands in coal-bearing and adjacent strata of northeastern British Columbia were examined during the 1983 field season as the preliminary phase of a study documenting these time lines throughout the coalfield. Altered ash bands also were noted and studied by previous workers; Stott (1968), Duff and Gilchrist (1983), and Spears and Duff (in press).

In this paper the terms tonstein and bentonite will be used to broadly group all the types of altered volcanic ash encountered. Tonsteins have a distinct tuffaceous texture and are confined, in this study, to the coal-bearing formations. Bentonites, on the other hand, are generally restricted to marine formations and have the greasy feel and conchoidal fracturing common to bentonite. Montmorillonite-illite and mixed-layer (smectite) group clay minerals are more prominent in the bentonites; kaolinite is the major component of both groups (*see* accompanying table). Generally, a particular band is consistently a tonstein or a bentonite throughout the studied area, but exceptions exist and are very significant. Tonsteins and bentonites examined in this study are the alteration products of volcanic ash. Controversy over the origin of these materials has continued for decades but the last 10 years has seen a general acceptance of their volcanic origin (Stack, *et al.*, 1982). It will be seen that the only plausible explanation for many of the intervals studied here is that they represent volcanic ash. The depositional environment dictates the resulting textures and possibly the mineral assemblages, which are distinctive between the two major groups. Tonsteins-bentonites have been examined in outcrops, trenches, and drill cores. Core obviously provides the best exposure but to obtain an accurate description of the ash characteristics tonsteins within coal seams must often be removed with the coal. For this reason, the search for tonsteins in old core is often frustrated. In contrast, bentonites in Moosebar mudstone were readily identified in core and bands with widths down to several millimetres showed up distinctly. Exploration companies active in the area have been noting these 'tuffaceous' bands for the last several years; company personnel were extremely helpful during the field season allowing examination and sampling of their newly obtained core and pointing out occurrences on their properties.

Initially investigation was concentrated in the Pine Pass area where the majority of exploration activity was occurring. Examination of company trenches and fresh core in this area led to the identification of two readily correlatable tonstein zones in the upper Gething Formation. The latter part of the season's study was completed at the Charlie Lake core facility in Fort St. John examining Gething, Moosebar, and Gates core from Peace River to the Alberta border along the foothills belt. Virtually all ash bands encountered were sampled and are undergoing petrographic, X-ray diffraction, and chemical analyses. Some preliminary results are presented here.

Tonstein-bentonite occurrences are limited to the few sedimentary environments favourable for their preservation. Obviously, any environment with more than a minimal energy level will obliterate ash falls. Thus, tonsteins-bentonites preferentially occur in low-energy marine and coal-swamp settings. Ash falling into marine settings tends to be clean, with only minor bioturbation. Tonsteins preserved in the coal-swamp environment are much more susceptible to organic and detrital contamination. The various degrees and types of contamination provide information for determining the detailed environments at a particular location in the swamp and, potentially, the overall swamp morphology. Some thick (>5 centimetres) bentonites provide recognizable geophysical responses which can be correlated considerable distances (*see* Duff and Gilchrist, Fig. 7), but thin bentonites (3 millimetres to 3 centimetres) are not picked up on a normal suite of logs (detailed gamma might delineate some of these bands but they are seldom used over non-coal intervals). Detailed logs are run over coal intervals, therefore tonsteins can often be recognized. However, contamination or masking by oppositely responding strata usually result in logs that are not distinctive but are recognizable if tonsteins can be seen in the core. Tonsteins-bentonites usually have a high gamma count and a density reading similar to that of mudstone or siltstone. For these reasons, at present, visual inspection is the most reliable means of detecting all the tonsteins-bentonites in a section.

Tonsteins have been grouped into coal and non-coal tonsteins by previous workers in both Europe and British Columbia (Price and Duff, 1969). At this preliminary stage in our study this distinction has not yet been made; it will likely be used when more analytical data is available. Tonsteins, if clean, are easily recognized in core and outcrop. They generally weather medium to light grey in outcrop but may have a rusty appearance (Plate III). In core they tend to be medium grey with sharp contacts. In hand sample tonsteins have a distinctive appearance due to platy kaolinite crystals (Plate IV) and plant fragments often parallel bedding planes. This granular appearance has often resulted in these bands being logged as siltstone or sandstone. They are predominately non-calcareous and can be scratched with a fingernail. The speckled appearance results from development of vermicular kaolinite (Plate V). Stack, *et al.* (1982, page 161) contains an electron micrograph of one of these vermicular structures. Usually, devitrified glass shards or angular crystal fragments are common in these tonsteins (Plate V) confirming their volcanic origin. Mineralogically, tonsteins are kaolin rich; they often have quartz as a secondary constituent (*see* accompanying table). Contamination by organic and detrital material greatly alters the physical appearance of these rocks but detailed examination reveals the distinctive speckled appearance. Organic-rich tonsteins (usually coal tonsteins) are greyish brown in colour; they often contain coal spar.

Plate III. Fisher Creek Tonstein zone exposed in trench outcrop. Arrows mark the three tonstein bands. The measure is 2 metres.

23 24 25 26 27 28 29 31 32 33 34 35 36 37 38 39

Plate IV. Hand sample of the lowest tonstein in the Fisher Creek sequence. Note carbonaceous fragments and freckled appearance. The freckled appearance is due to vermicular kaolinite.

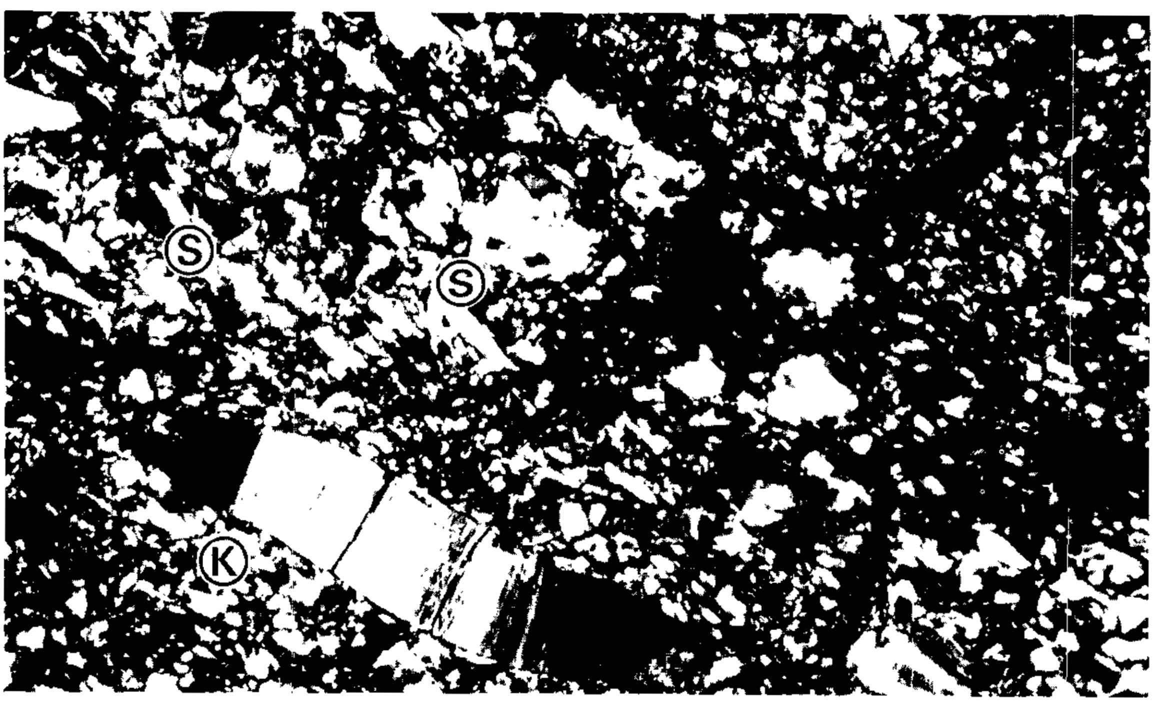


Plate V. Photomicrograph, under-crossed nicols, of tonstein from the Number 1 Seam on the Willow Creek property. This sample may be correlative with the Fisher Creek Tonstein zone. The large 'kaolin worm' is about a millimetre in length. Note devitrified glass shards (S) and a rare form of vermicular kaolinite (K).

SAMPLE	FORMATION	X–RAY DETERMINATION
R82– 1	Moosebar	QUARTZ > KAOLINITE ≥ Fe-rich DOLOMITE
2	Moosebar	KAOLINITE > QUARTZ > minor amounts of PYRITE, illitic mixed-layer clay, Fe-rich DOLOMITE and APATITE (?)
3	Moosebar	KAOLINITE ≫ minor amounts of PYRITE, QUARTZ and APATITE
4	Moosebar	Fe-rich DOLOMITE > KAOLINITE > QUARTZ > minor amounts of PYRITE, CAL–CITE and APATITE
5	Moosebar	KAOLINITE with a very small amount of QUARTZ
6	Gething	KAOLINITE ≫ QUARTZ > a small amount of illitic mixed-layer clay
7	Moosebar	KAOLINITE > QUARTZ > minor amounts of PYRITE, CALCITE, APATITE ± Fe-rich DOLOMITE
8	Gething	KAOLINITE ≫ QUARTZ > SIDERITE
9	Gething	KAOLINITE > QUARTZ > Fe-rich DOLOMITE ≈ PLAGIOCLASE > a minor amount of illitic mixed-layer clay
10	Gething	KAOLINITE > Fe-rich DOLOMITE ≥ QUARTZ > small amounts of ILLITE, CHLOR–ITE, and Fe-rich MAGNESITE
11	Moosebar	KAOLINITE ≈ Fe-rich DOLOMITE ≫ trace amounts of QUARTZ and CALCITE
12	Gething	QUARTZ > illitic mixed-layer clay ≈ DOLOMITE > minor amounts of KAOLINITE and PLAGIOCLASE
13	Gething	ILLITE > QUARTZ > Fe-rich DOLOMITE > KAOLINITE > trace amounts of MONT–MORILLONITE (?) and APATITE (?)
14	Gething	KAOLINITE > Fe-rich DOLOMITE ≈ QUARTZ > trace amounts of ILLITE, PLAGIO–CLASE, and APATITE (?)
15	Gething	KAOLINITE > QUARTZ ≥ Fe-rich MAGNESITE ≥ illitic mixed-layer clay ≥ PLAGIO–CLASE
16	Gething	KAOLINITE ≈ QUARTZ > Fe-rich MAGNESITE > PLAGIOCLASE ≈ illitic mixed-layer clay
17	Gething	KAOLINITE ≈ QUARTZ > ILLITE > Fe-rich DOLOMITE
36	Moosebar	KAOLINITE > ANKERITE/Fe–DOLOMITE ≫ minor QUARTZ > trace APATITE, CALCITE, GORCEIXITE, ILLITE, and CHLORITE ± PYRITE (?)
37	Moosebar	KAOLINITE ≫ QUARTZ > minor PYRITE > ANKERITE/Fe-DOLOMITE > trace APATITE, ILLITE, K–FELDSPAR ± GORCEIXITE (?)
38	Moosebar	ANKERITE/Fe–DOLOMITE > KAOLINITE > QUARTZ > CALCITE > trace PYRITE and ILLITE ± APATITE
39	Moosebar	QUARTZ ≥ KAOLINITE > ANKERITE/Fe-DOLOMITE > PYRITE > trace CALCITE
40	Moosebar	QUARTZ ≥ KAOLINITE ≥ ANKERITE/Fe-DOLOMITE ≫ PYRITE > minor ILLITE > CALCITE
R83– 81	Gething	KAOLINITE > ILLITE–MONTMORMILLONITE (mixed-layer clay) ≫ minor QUARTZ PLAGIOCLASE
82	Gething	QUARTZ ≈ KAOLINITE ≫ minor ILLITE–MONTMORILLONITE (mixed-layer clay), PLAGIOCLASE and DOLOMITE
83	Gething	KAOLINITE > QUARTZ > PLAGIOCLASE > Fe-rich DOLOMITE > trace ILLITE–MONTMORILLONITE
87	Gething	KAOLINITE ≫ QUARTZ ≫ trace ILLITE–MONTMORILLONITE (mixed-layer clay)
90	Gething	QUARTZ ≫ ANKERITE > ILLITE–MONTMORILLONITE ≥ KAOLINITE ≈ CAL–CITE > SIDERITE
151	Moosebar	MONTMORILLONITE ≈ KAOLINITE ≫ minor QUARTZ > trace SIDERITE ± ALLO–PHANE
152	Moosebar	CALCITE > ANKERITE > SIDERITE > QUARTZ ≈ KAOLINITE ≫ trace ILLITE
155	Moosebar	KAOLINITE ≈ MONTMORILLONITE ≥ QUARTZ ≥ SIDERITE ± ALLOPHANE
177	Moosebar	Fe-rich DOLOMITE > KAOLINITE ≫ trace QUARTZ and PYRITE ± GORCEIXITE
178	Moosebar	Fe-rich DOLOMITE ≈ KAOLINITE ≫ minor QUARTZ, PYRITE, GORCEIXITE, ± APATITE
179	Moosebar	KAOLINITE ≥ Fe-rich DOLOMITE ≫ QUARTZ ≫ minor PYRITE
182	Gething	KAOLINITE ≫ QUARTZ ≫ trace CHLORITE, APATITE (?) ± DOLOMITE
183	Gething	KAOLINITE ≫ QUARTZ
184	Gething	KAOLINITE ≫ QUARTZ > Fe–DOLOMITE ≫ trace APATITE
185	Gething	KAOLINITE ≫ QUARTZ > Fe–DOLOMITE > ILLITE > trace APATITE (?)

Bentonites are even more readily recognized in core and outcrop than tonsteins. The material tends to be light grey to greenish grey, consists of clay size material, and has a conchoidal fracture. When weathered at surface the band usually develops the classic 'popcorn' texture common to these swelling clays. Depending upon outcrop conditions the band may become completely softened. Due to swelling and light colour, bands as thin as 3 millimetres can be apparent on a clear outcrop surface. In hand sample this material is greasy when wet and breaks into 'poker chip' or cuspate fragments. Although usually non-calcareous, some bands have been subjected to late carbonate replacement. Where found in the marine Moosebar Formation the bentonites often display well-preserved bioturbation. At one location a bentonite in the glauconite portion of the 'Bluesky' is slightly glauconitic. In marine settings the bentonites are usually free of contamination other than that introduced by bioturbation; occasionally they are interlaminated with the surrounding mudstones. Kaolinite predominates in the bentonites, but montmorillonite-illite clays are also important (*see* accompanying table).

At present the only means of correlating various tonsteins-bentonites are their approximate stratigraphic position, thickness, and relationship with one another. Petrographic and chemical correlation techniques will be applied as analyses become available.

The 'Fisher Creek Tonstein' zone was initially recognized in exploration trenches on Crows Nest Resourses Ltd.'s Pine Pass property. Early correlations were based on the presence of a thin 1 to 2-centimetre coaly band near the middle of a thick (20-centimetre) tonstein. Better exposures revealed several thinner tonsteins in the overlying few metres of strata (Plate III). With familiarity, this series of tonsteins became recognizable in core and outcrop. Figure 36 contains a series of sections through the Fisher Creek Tonstein zone. Note the variations in inter-tonstein lithology and thicknesses. This zone is located approximately 45 metres below the Bluesky unit (Moosebar-Gething boundary) (Fig. 38a and b); at present it has only been recognized in the Pine Pass area (Fig. 37) due in large part to a lack of detailed investigation outside this area.

The 'Number 2 Tonstein' is located about 20 metres stratigraphically below the Fisher Creek Tonstein zone or about 65 metres below the Bluesky (Fig. 38a and b). It is usually clean and consists either of one thick band (20 centimetres) or a large band and a series of thinner tonsteins all within a short stratigraphic interval. This tonstein is present in the middle of the Number 2 Seam on David Mineral Ltd.'s Willow Creek property. So far, it has been recognized mainly in the same sections as the Fisher Creek Tonstein zone.

From Peace River to Onion Creek bentonites were located in core in the lower portion of the Moosebar mudstone. Two prominent bentonite bands ('Twin Bentonites') were noted by Duff and Gilchrist (1983) and tentatively correlated over much the same area as this study. These two bentonites are readily seen on geophysical logs and are obvious in outcrops of the lower Moosebar. In the Bullmoose and Mount Spieker areas they are located about 4 metres above the Bluesky; the bands, which are about 10 centimetres thick, are 3 to 5 metres apart. In the Monkman area the Twin Bentonites are 30 metres above the Bluesky and 3 metres apart. In the Peace River area they are about 140 metres above the top of the Gething but this interval contains the Moosebar Lower Silty Member which is not present south of Sukunka River. In addition to these two prominent bands (shown on Duff and Gilchrist, Fig. 7), a zone of several thinner bentonites is usually present a short distance below the Twin Bentonite bands (Fig. 38a and b). Correlation of these thinner bands has not yet been accomplished over any significant distance but they have helped to solve one stratigraphic anomaly and have potential for documenting the relationship between the Moosebar Mudstone Member and the Moosebar Lower Silty Member. A recent visit to the Grande Cache area of Alberta revealed at least four thin bentonite bands in the lower Moosebar mudstones of that area.

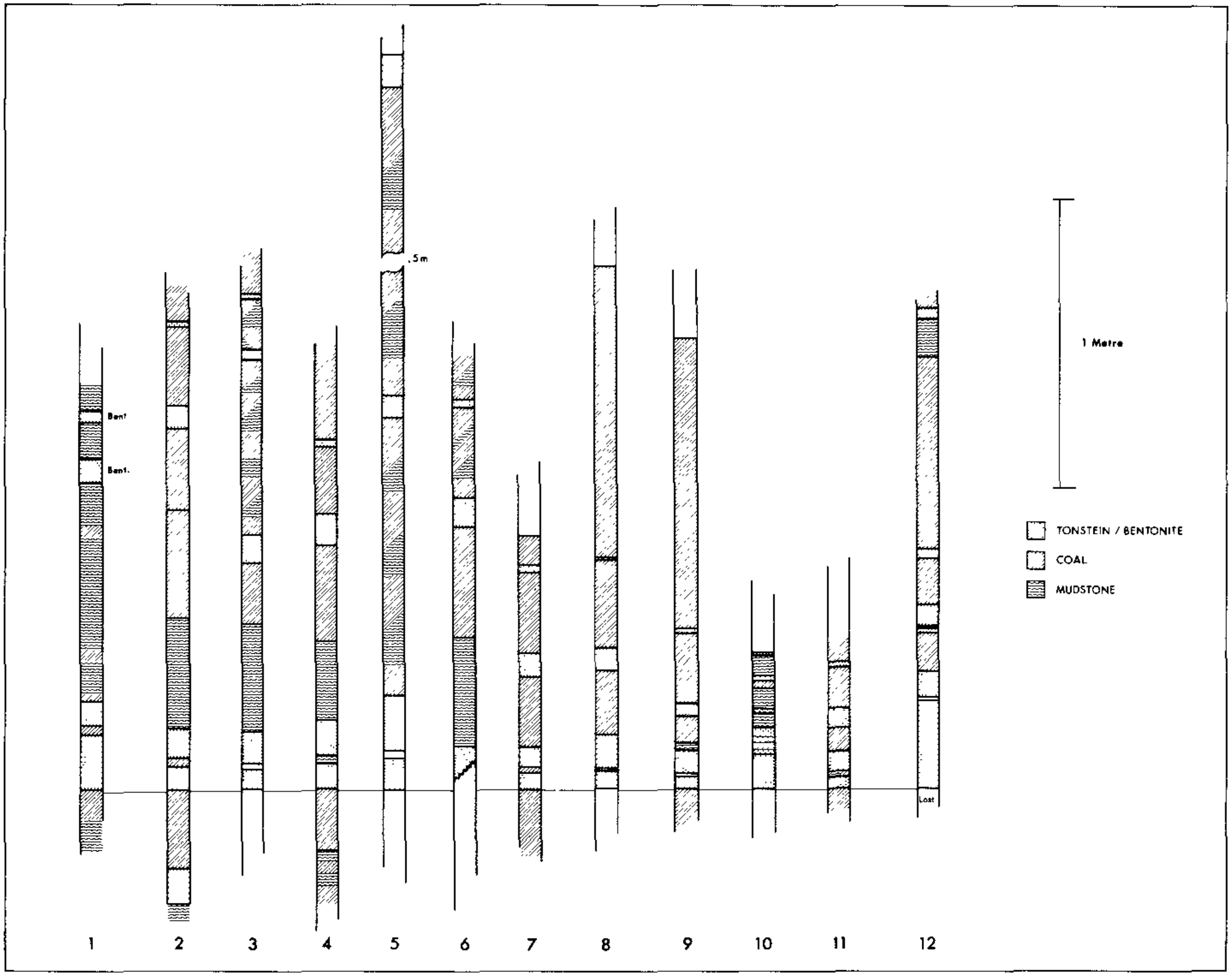


Figure 36. Fisher Creek Tonstein zone with the thick-parted tonstein at the base and thinner overlying tonsteins above. The exaggerated thickness in section 5 is due to structural thickening along numerous closely spaced shears.

Tonsteins are also present in the Gates Formation, but very little effort has been directed to these strata yet. Crows Nest Resources drilled through a clean (5-centimetre) tonstein near Mount Secus; in equivalent strata in the Grande Cache area a tonstein was found in and around the top of the Number 4 Seam. Carmichael (1983) noted bentonites in the Gates and Moosebar Formations south of the area of this study. The next phase of this study will include an investigation of the Gates strata for these time lines.

The availability of precise and recognizable time lines in the stratigraphic column enable a wide range of studies to be undertaken and problems solved. During the 1983 field season tonsteins-bentonties were used to solve several structural and stratigraphic problems and provided several hints about the paleogeography of Cretaceous coal-bearing and adjacent strata.

Mesoscopic structures within and around coal seams are often complex and difficult to map because distinct marker horizons are lacking and lateral lithologic variations are rapid. A large trench on Crows Nest Resources' property exposed a disturbed sequence of coal measures on the east limb of the Fisher Creek Syncline. Within this trench the Fisher Creek Tonstein sequence was repeated five times, each time with different orientations. This fortunate exposure (Fig. 39) enabled the detailed structural style in that locality to be understood and sedimentary variations over short distances to be examined (Fig. 36, columns 2 to 6).

During investigation of the Fisher Creek Tonstein one location was encountered where two of the upper bands were found to be bentonite or bentonitic (Fig. 36, column 1). Tonsteins are believed to form under acidic or possibly laterizing conditions in or adjacent to coal swamps. Bentonites apparently result when ash falls into a more normal or alkaline environment. Figure 37 illustrates the positions of some Fisher Creek Tonstein sections, Figure 36 shows the detailed lithology surrounding these bands, and the accompanying table contains a mineralogical description of some of these samples. The significance of this tonstein to bentonite transition is that some major facies boundary has been crossed. The bentonites formed outside the coal swamp facies, possibly in some abandoned channel, maybe even in a marine environment. At the very least the change marks the position of the edge of the swamp at the time of these ash falls.

In Duff and Gilchrist (1983, Fig. 7), drill hole Mount Spieker MS–1 contains an anomalous unit, the Lower Silty Member, at the bottom of the Moosebar Formation. This log was used while examining several outcrop sections of the Gething and lower Moosebar in the area of the hole. It was obvious that something was amiss because the two distinctive bentonite gamma kicks at 1,341 feet and 1,349 feet in conjunction with the common Gething-Moosebar pick at 1,386 feet matched outcrop sections exactly. Examination of the core stored at Charlie Lake revealed that this interval contains a thrust fault which duplicates the formation contact and several of the bentonites (Fig. 40). During relocation of the core to Charlie Lake several years ago, the core was reboxed; the interval above 1,350 feet is now completely shattered in typical mudstone fashion and no trace of the upper bentonite at 1,341 feet could be seen. This disturbed core and missing bentonite may have resulted in misinterpretation of this interval. In this case a combination of bentonites and distinctive stratigraphic markers were used to solve a 'sedimentological' problem and brought this section back in line with its surroundings.

The Moosebar transgression and associated Bluesky equivalent unit in the foothills belt may be effectively bracketted by tonsteins and bentonite horizons. At present regional correlations have not been made but on a local scale some observations will be made about this interval in an accompanying paper (this volume) which discusses some of the features of the Bluesky unit and surrounding strata.

This project is in its infancy but local and regional correlations now appear attainable. On a local (property) scale tonsteins-bentonites are now being used for borehole and outcrop correlations. Regionally, these ash bands provide an unparalleled opportunity to understand the coal swamps, their lateral extent, vegetation distribution, and the relative accumulation rates of vegetation and sediments within their bounds.

The objective of this study is to document the ash bands (tonstein-bentonite) in the coal-bearing and adjacent strata of the Northeastern British Columbia Coalfield. Analyses will be undertaken to find out if various tonstein-bentonite zones have unique chemical attributes which can be used to chemically fingerprint particular zones and fix their positions within the section. Chemical correlations have been promising in other studies (Amajor and Lerbekmo, 1980; Glass, 1981); chemical analysis of the collected samples is presently underway.

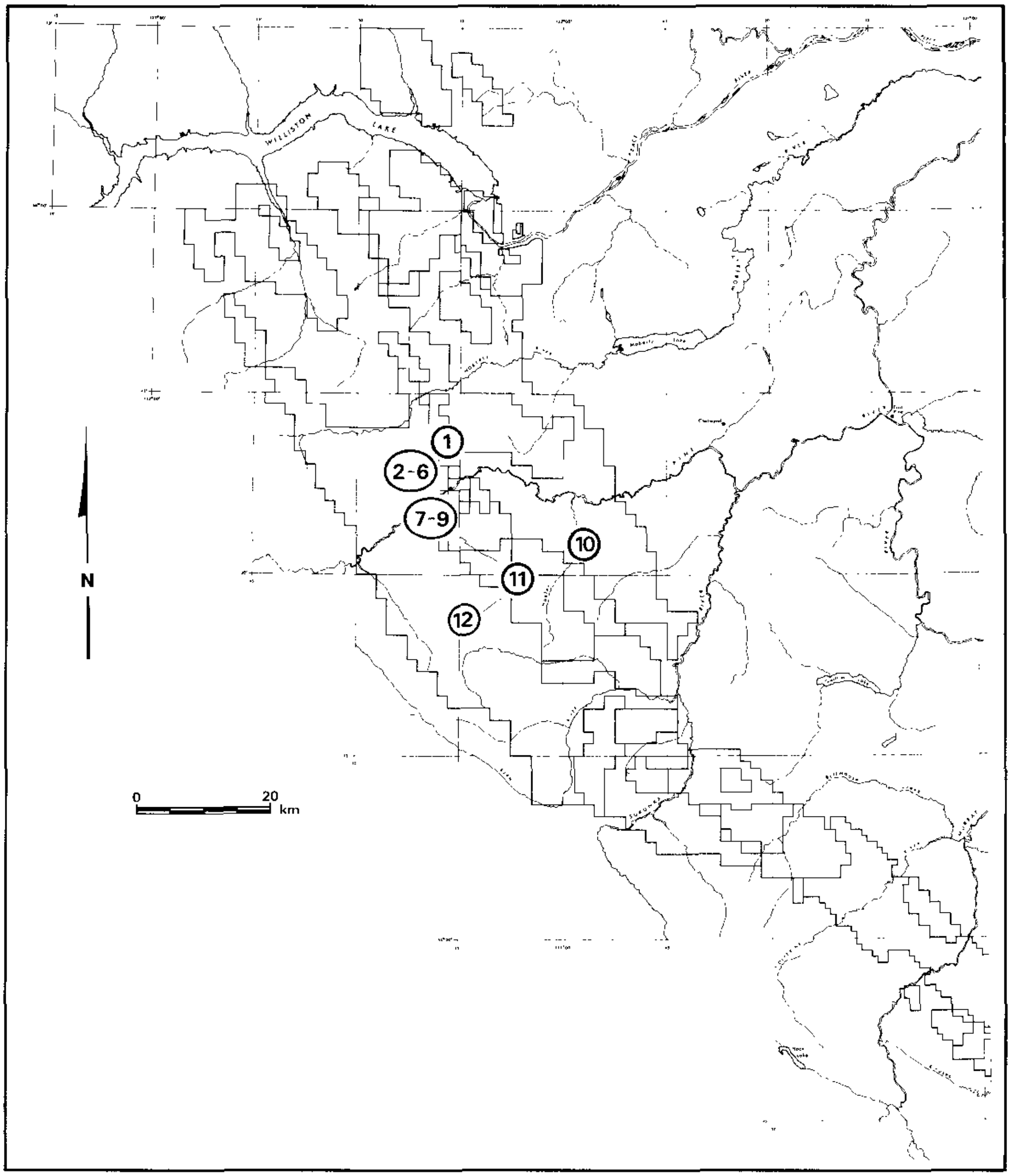


Figure 37. Approximate locations of Fisher Creek tonstein sections (due to the confidentiality of much of the data only one hole is accurately located — Pine Pass 75—10).

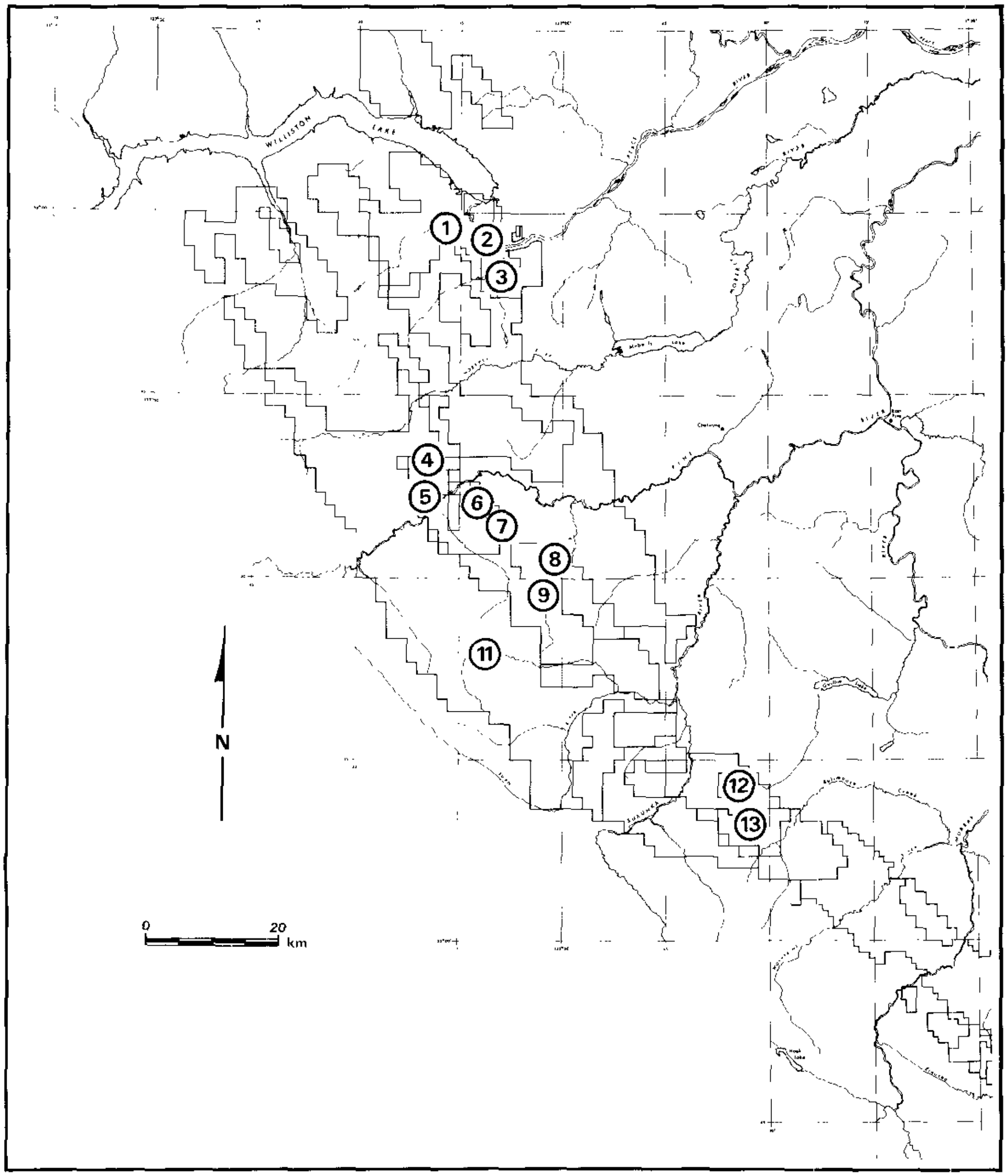
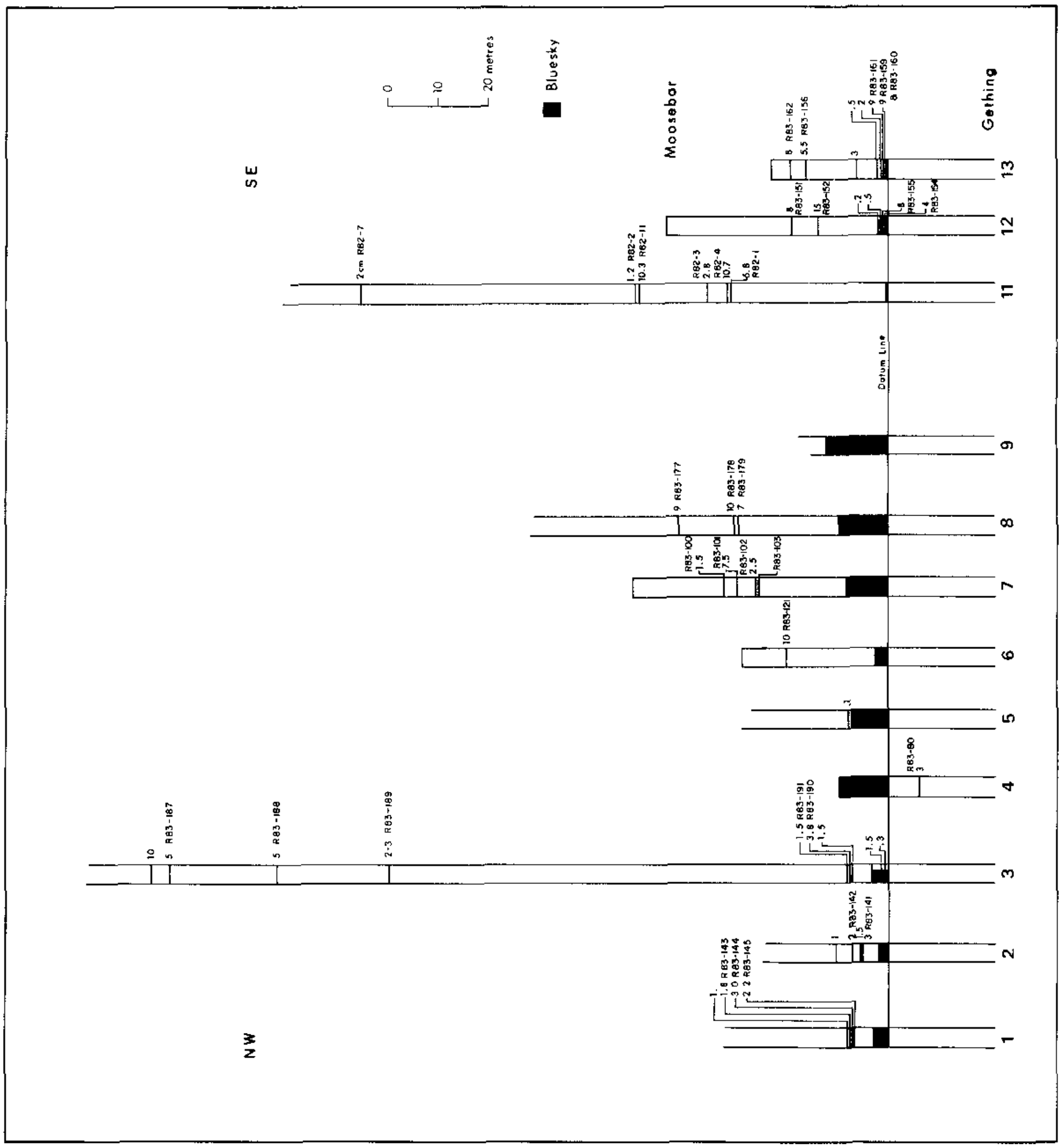


Figure 38a. Exact or approximate locations of drill holes used on Figure 37 (depending on their confidentiality).


NW
SE
Moosebar
Gething
Bluesky
0
10
20 metres
Datum Line
1
2
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5
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9
11
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13

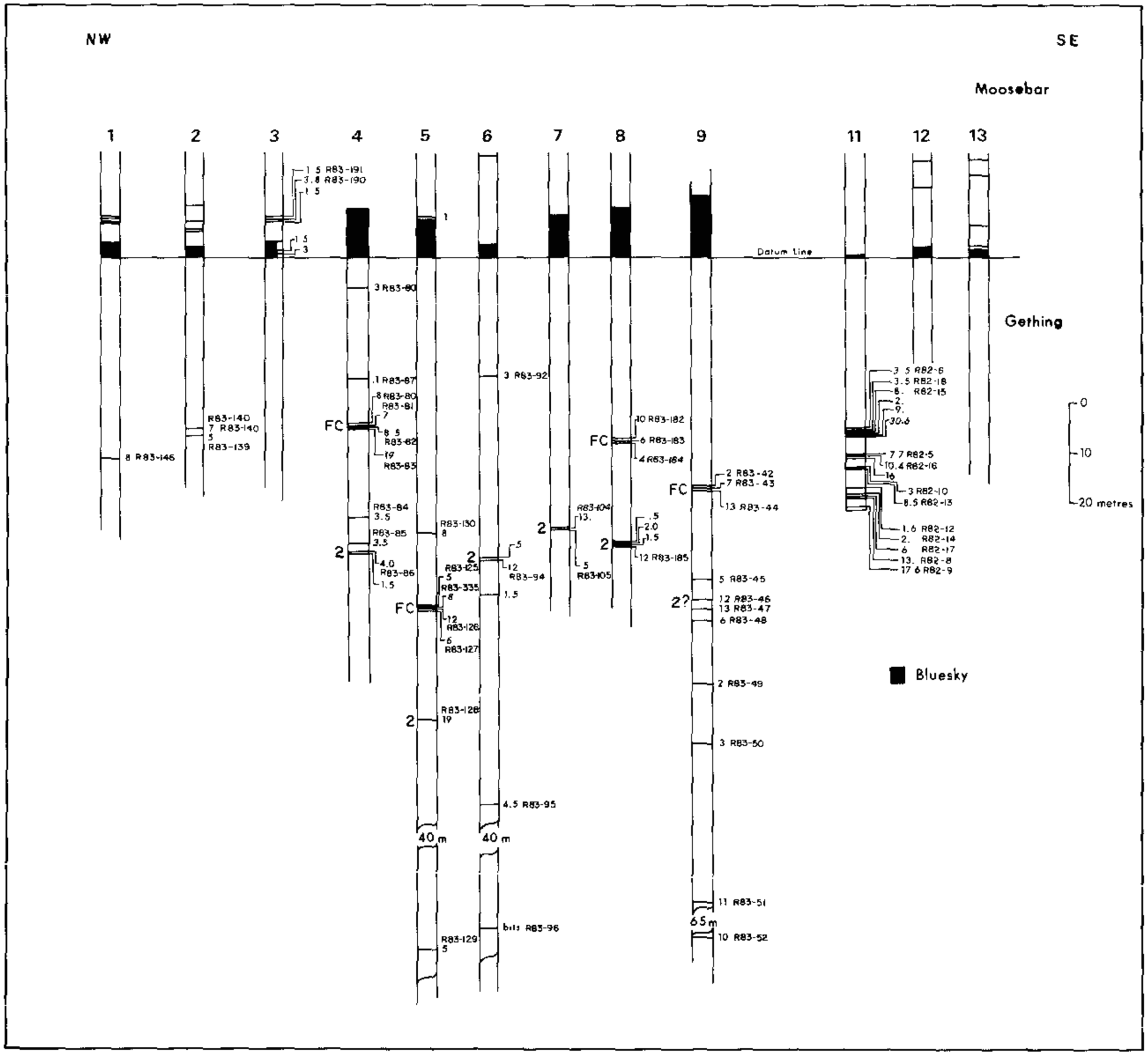

Figure 38b. Tonstein/bentonite locations in some borehole sections between Peace River and Bullmoose Creek. Datum is the base of the Bluesky unit. Ash bands are shown as solid lines with their thicknesses given *in cnetimetres.* Sample numbers are also given for all sampled bands.

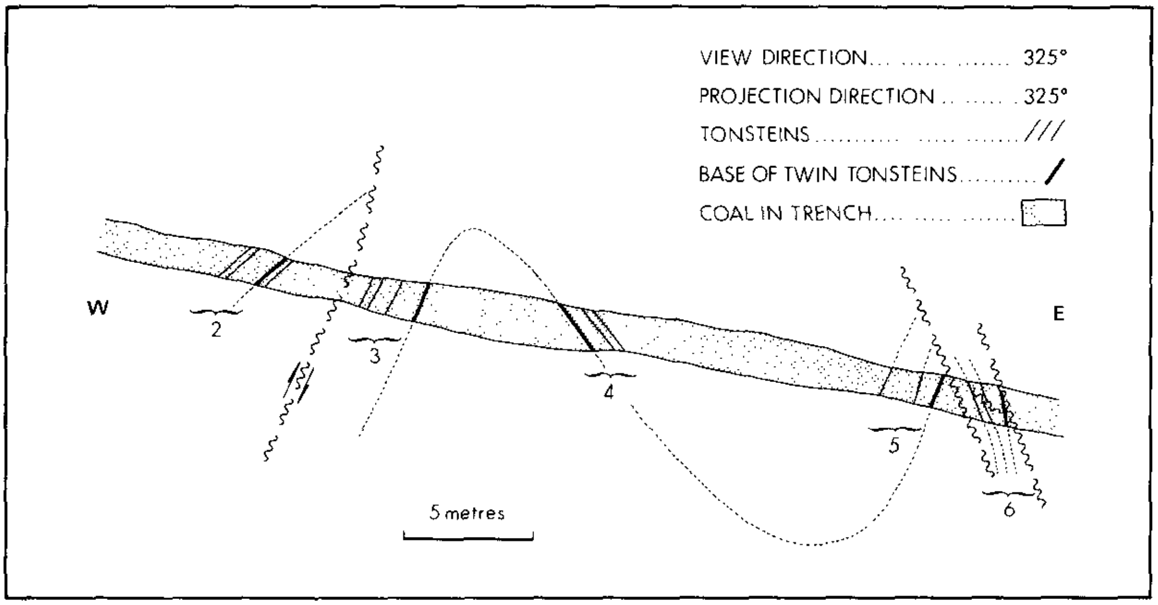

Figure 39. Section view of trench exposure with the deformed sequence containing the Twin Tonsteins. The numbers of the bracketted zones correspond with the detailed sections on Figure 36.

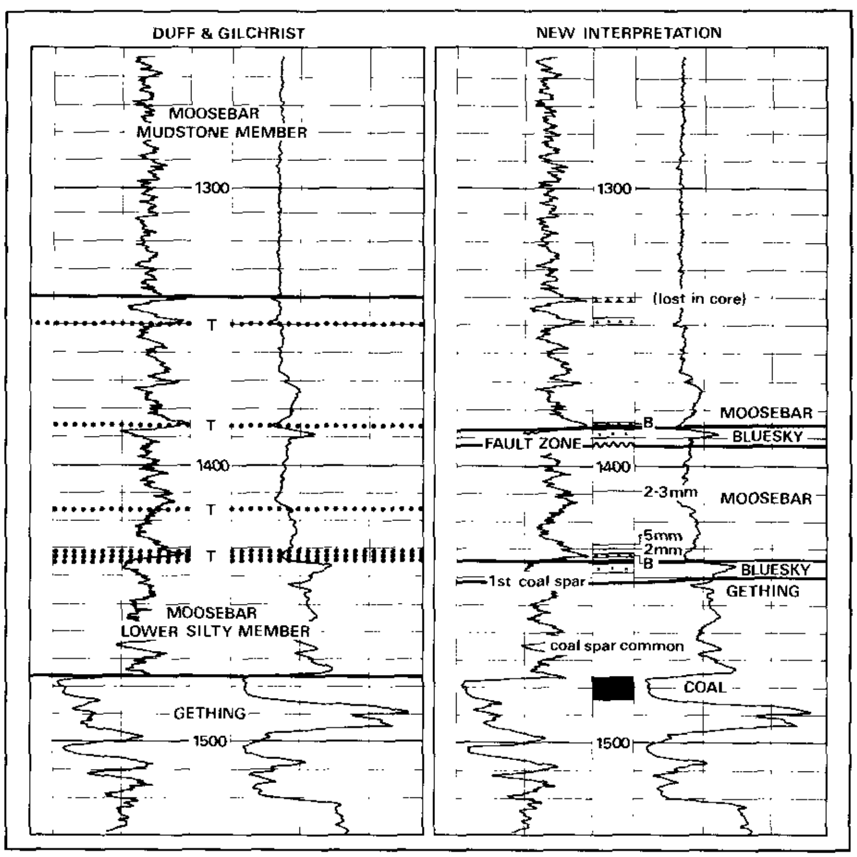

Figure 40. A structural explanation of a stratigraphic anomaly — fault movement resulted in 47 feet (14 metres) of repeated section. The Gething upper contact is also moved to the base of the Bluesky, above the first occurrence of coal spar and stringers.

REFERENCES

Amajor, L. C. and Lerbekmo, J. F. (1980): Subsurface Correlation of Bentonite Beds in the Lower Cretaceous Viking Formation of South-Central Alberta, *Cdn. Pet. Geol.*, Bull., Vol. 28, No. 2, pp. 149-172.

Carmichael, S.M.M. (1983): Sedimentology of the Lower Cretaceous Gates and Moosebar Formations, Northeast Coalfields, British Columbia, *University of British Columbia*, unpb. Ph.D. Thesis, 285 pp.

Duff, P.McL.D. and Gilchrist, R. D. (1983): Correlation of Lower Cretaceous Coal Measures, Peace River Coalfield, British Columbia, *B.C. Ministry of Energy, Mines & Pet. Res.*, Paper 1981–3, 31 pp.

Glass, D. E. (1981): Subsurface Correlation of Bentonite Beds in the Lower Cretaceous Viking Formation of South-Central Alberta, by L. C. Amajor and J. F. Lerbekmo: Discussion, *Cdn. Pet. Geol.*, Bull., Vol. 29, No. 3, pp. 426-428.

Price, N. B. and Duff, P.McL.D. (1969): Mineralogy and Chemistry of Tonsteins from Carboniferous Sequences in Great Britain, *Sedimentology*, Vol. 13, pp. 45-69.

Spears, D. A. and Duff, P.McL.D. (in press): Kaolinite and Mixed-Layer Illite-Smectite in Lower Cretaceous Bentonites from the Peace River Coalfield, British Columbia, *Cdn. Jour. Earth Sci.*, Bull.

Stack, E., Mackowsky, M.–Th., Teichmuller, M., Taylor, G. H., Chandra, D., and Teichmuller, R. (1982): Stack's Textbook of Coal Petrology, Third Ed., *Gebruder Borntraeger*, Berlin, 535 pp.

Stott, D. F. (1968): Lower Cretaceous Bullhead and Fort St. John Groups, between Smoky and Peace Rivers, Rocky Mountain Foothills, Alberta and British Columbia, *Geol. Surv. Canada*, Bull. 152, 279 pp.

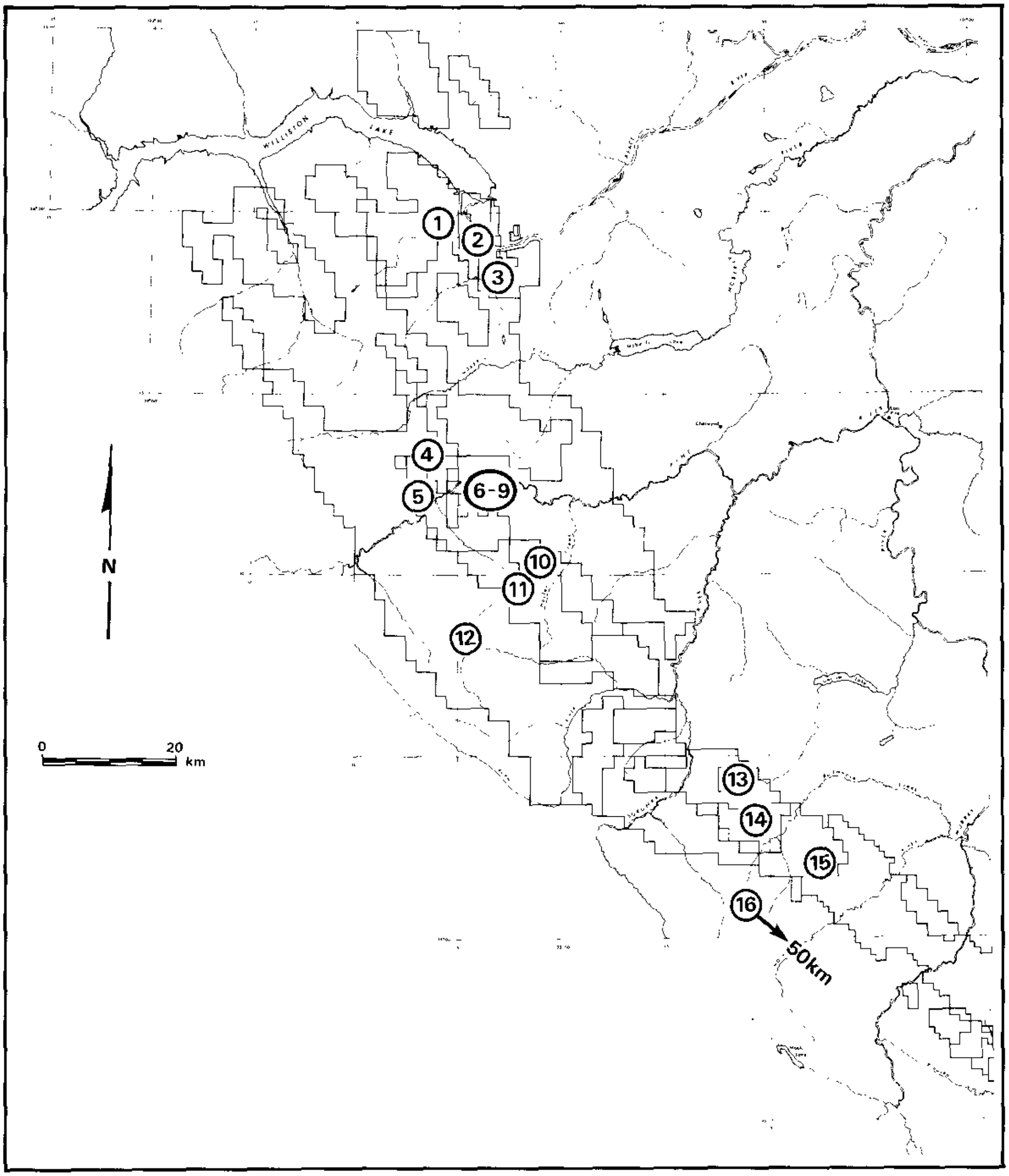

Figure 41. Location map of sections shown on Figure 42 (locations are exact or approximate, depending on confidentiality).