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REPORT ON
NIAMODLAOC MOUNTAIN COAL PROSPECT
NORTHEAST SECTOR
1971 FIELD SEASON

BY

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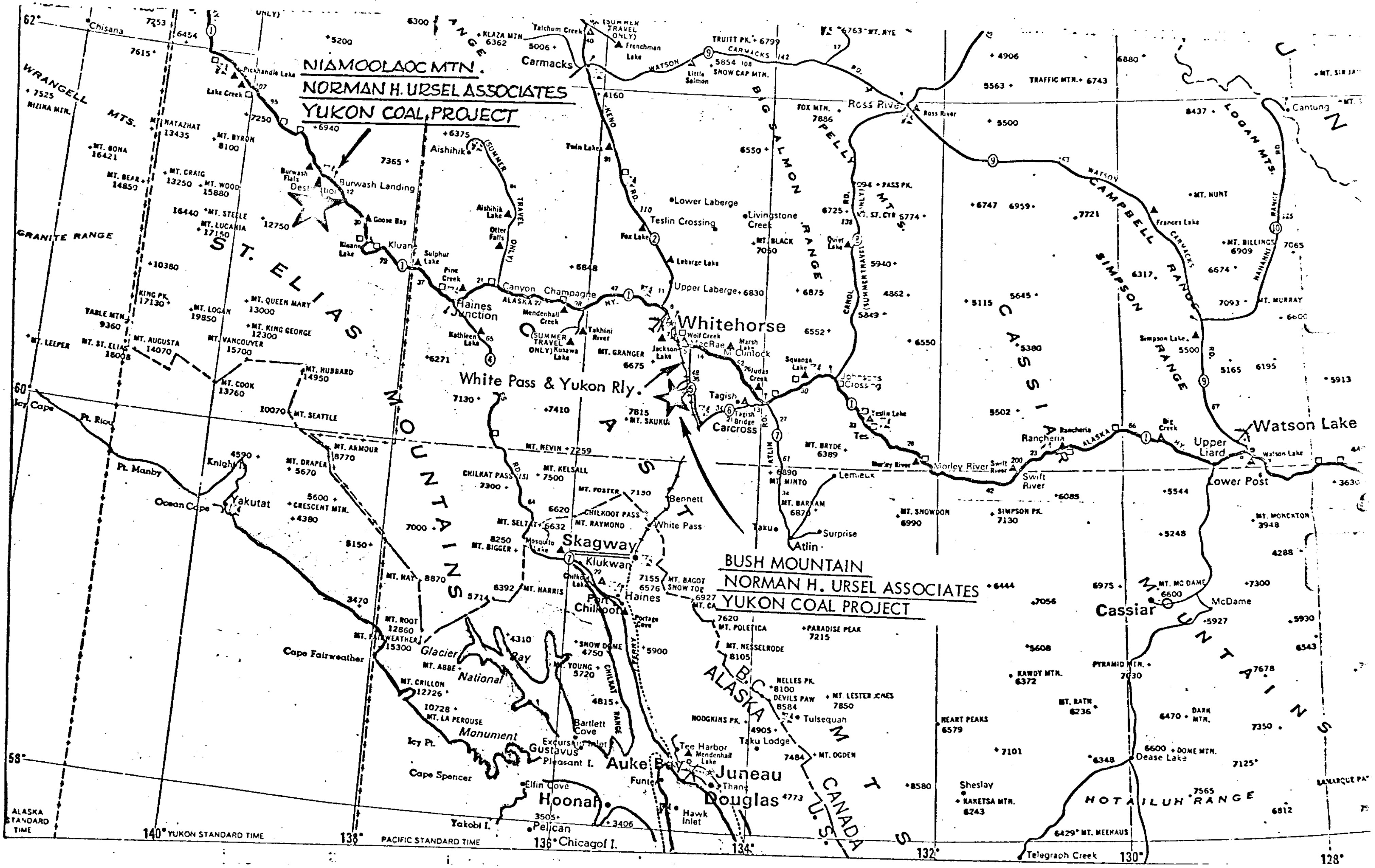

NIAMOOLAOC MTN.

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BUSH MOUNTAIN

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ABSTRACT

Minable coal, particularly lump-resiniferous coal, was sought during a portion of the 1971 summer field season by prospecting the Amphitheatre formation in the northeast sector of Niamodlaoc Mountain. Areal extent of sedimentary exposures, and thickness of stratigraphic section revealed in them, is much less than in the 1970 field area on the western mountainside. Scattered to clustered, erosion-resistant volcanic bodies, apparently intrusive volcanic plugs, form conical landforms (coniforms) in predominantly Amphitheatre formation terrain. The exposed Amphitheatre sediments are poorly lithified to unlithified sand, pebbly sand, silt, and clay. Thin lenses of banded black coal are widespread and common. Larger lenses up to 6.5 feet in thickness are present. For the purpose of extracting a resin separate for analysis and testing, a semi-bulk sample of coal was taken from three subjacent lenses.

Should continuous seams of coal be found in the northeast sector, some of the reserves may be amenable to strip mining. This possibility arises from the combination of flat-lying to gently dipping coal measures and fairly low slope angles on the northeast sector lower slopes. The poorly indurated to unindurated nature of the clastic sediments may make feasible the removal of cover by hydraulic methods. This incorporates a means for concurrent thawing of permafrost, whose extent is unknown. The clastic sediments are themselves possessed of a dispersed lens coal content which may be partly recoverable in the case of the larger lenses by selective removal during hydraulic stripping, and/or by washing all of the coal-bearing slurry produced by hydraulic stripping.

The possibility that the horizons bearing coal beds as found on the western mountainside in 1970 are not naturally exposed in the northeast sector is discussed. It is concluded that strip mining potential warrants trenching and/or drilling to determine if the coal seams are present in this sector. Reconnaissance geology and prospecting in other unexamined sectors of the mountain is recommended first, followed by measurement of stratigraphic sections and geological mapping in all sectors in preparation for trenching and/or drilling in the northeast, and other sectors.

INTRODUCTION

Airborne and ground prospecting during 1970 field work (Speelman, 1970) indicated that several coal seams of minable thickness were present in the Amphitheatre formation (Muller, 1967), on the west side of Niamodlaoc Mountain. Golden yellow to orange lump resin was commonly observed, especially in the upper seams. Preliminary tests of melting point range, solubility, and ash content (Montgomery, 1970; Speelman, 1971, Section E), and acid number, performed on small hand-picked resin samples, are sufficiently interesting to warrant evaluation of "the complete range of solubilities and compatibilities of the resins in various ink solvents and oils.........also.........solvent release properties, colour values, and possible odour levels." (Winandy, 1971). For this testing, resin samples each weighing about one pound are required, in turn requiring that resiniferous coal samples weighing several hundred pounds be obtained.

It was first intended to camp on the southeastern portion of the mountain, adjacent to the Halfbreed Creek road, and from there prospect the southwestern portion of the mountain for resiniferous coal in the upper horizons of the Amphitheatre formation. During the last aerial reconnaissance observations in 1970, dark grey or black horizons were noted in additional stream cut exposures present to the south of localities C and D (Speelman, 1970, Plate 1). It was planned to thus both extend the western mountainside ground prospecting southward, and hopefully to also obtain the desired sample of resiniferous coal in the southwestern sector. A contingency plan was to return to locality AA (ibid., Plate 3-I), near which the most highly resiniferous coal was noted in 1970. Due to access problems (infra), neither plan was workable.

Access to the northeastern portion of the mountain was found to be possible from a campsite located as far up the Halfbreed Creek road as it was possible to go by 4 x 4 truck. Coal float was discovered in the creek bed near the campsite, indicating that coal must outcrop on the east side of the mountain. A firm field decision was then made to prospect for coal in the northeast sector, in anticipation that resiniferous coal might also be found on the east side of the mountain.

The field party consisted of one geologist (the writer) and one assistant (Mr. Scott Lyle), with local transportation support from Mr. Jack Gwartney.

ACCESS

A locally-based helicopter was not available as was the case last year. Infrequent spot charters could be obtained, but not at the required times. Nor could a caterpillar-type tractor be locally obtained for setting out and picking up a camp, or for repairing bush roads. Mr. Maloney bases a construction business in Burwash Landing, but he was working elsewhere.

Although the area is eminently suited for horseback travel, and free-ranging horses are abundant, it was discovered that in fact there are no horses commercially available for packing or riding except for hunting parties during the big game season. The use of horses for commercial purposes other than hunting appears to be at variance with local tradition.

A bush road, passable by passenger car for about 3 miles to elevation 2975 feet leaves the Alaska Highway at Mile 1089 on the east side of Halfbreed Creek. From about the 4 mile point onward, the road crosses and recrosses the creek several times. It was found to be passable by 4 x 4 truck, with some removal of fallen boulders, some short detours around active earthflows, and travel at reduced speeds over washouts, to a point about 5.5 miles from the highway where the elevation is about 3700 feet. A camp was set up at this point (Figure 3) where a major

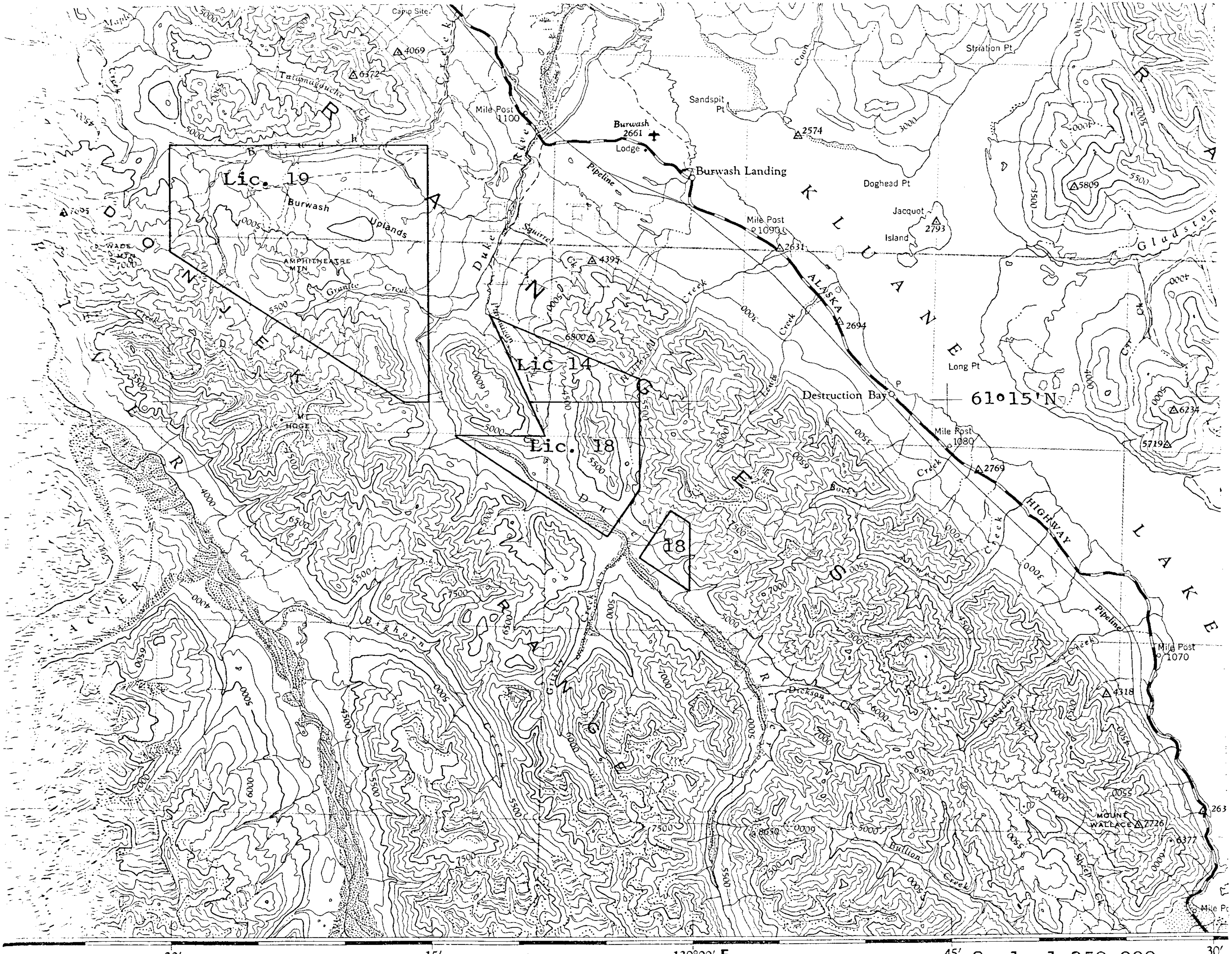

FIGURE 2

Scale 1:250,000

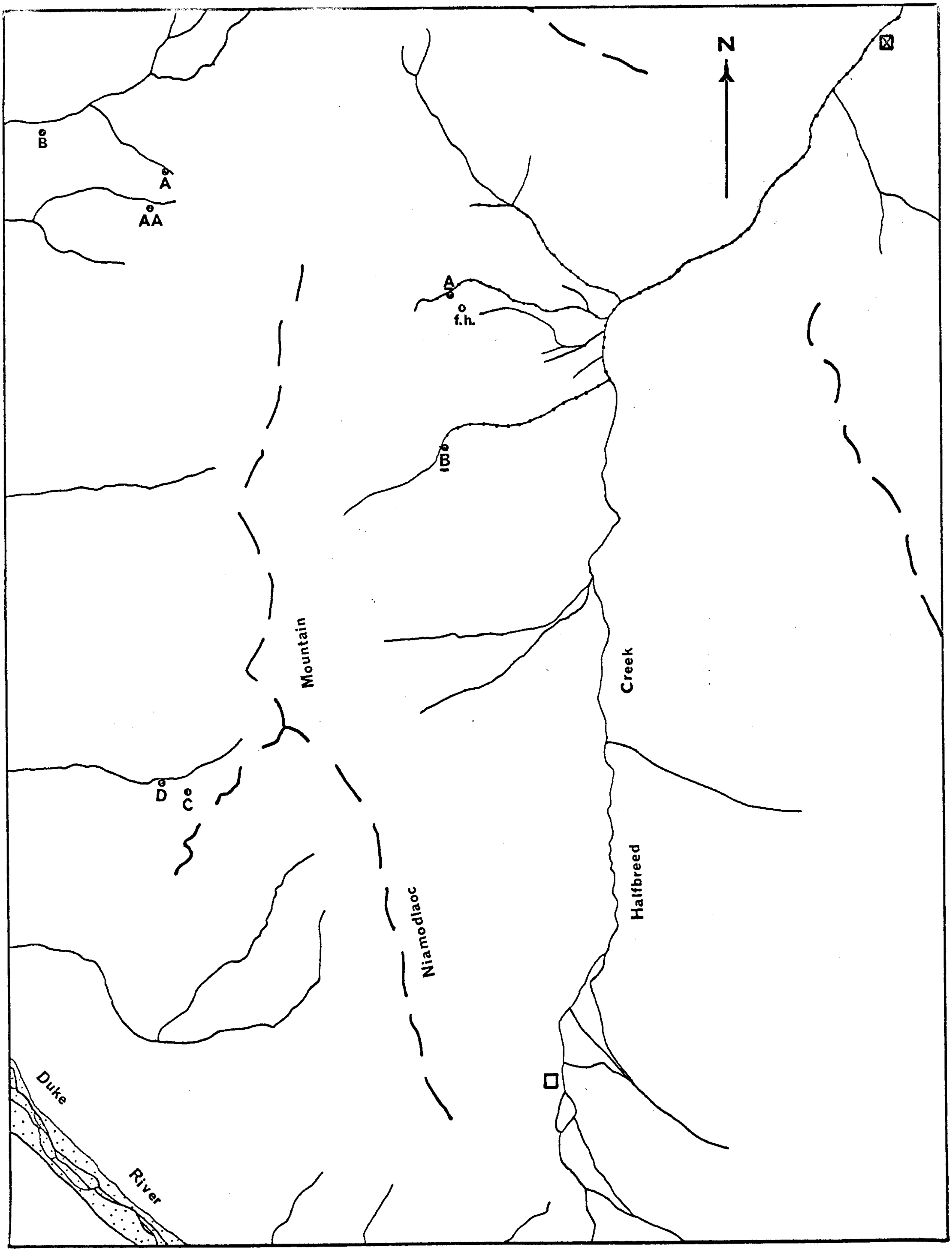
N
B
A
AA
A
f.h.
B
Mountain
Creek
D
C
Niamodlaoc
Halfbreed
Duke
River

FIGURE 3

west-flowing tributary of Halfbreed Creek had this spring completely washed out the road for a distance of about 100 yards. From this campsite to the prospect area located on the northeastern lower slopes of Niamodlaoc Mountain (Plate 1), the average daily traverse lengths were about 5 miles.

The average grade of the Halfbreed Creek road is approximately 2.2% for the first 3 miles. It is approximately 5.2% for the next 4 miles, at which point, about 7 miles from the Alaska Highway at an elevation of about 4000 feet, the road enters the coal prospect area underlain by the Amphitheatre formation. About 2 days of work with a D-8 caterpillar tractor would be required to repair the road for routine access by 4 x 4 vehicles.

Subsequent to the departure of the field crew, the semi-bulk sample of resiniferous coal was removed from near the sample site on Niamodlaoc Mountain to Burwash Landing by helicopter (Trans North Turbo Air Ltd.) over an air distance of approximately 10 miles. It was freighted to Whitehorse by truck (White Pass & Yukon Route).

PROSPECTING AND GEOLOGICAL RECONNAISSANCE CONDITIONS AND PROCEDURES

Direct prospecting for coal, and geological reconnaissance of east-side coal measures began with a brief airborne examination of the east side in 1970 after completion of ground/airborne work on the west side. Light-coloured sediments, apparently belonging to the Amphitheatre formation, were sighted in a few places in stream cuts on the lower slope of the mountain, below the general break in slope above which the reddish-brown, layered St. Clare Group volcanics capping the mountain hold steep slopes and form cliffs (Plate 3). Dark grey horizons, which invariably signify coal on the west side, were not sighted from the air on the east side. The east-side lower slope cut banks expose much less of the stratigraphic section than those on the west side.

For the present (1971) work, two sets of airphotos covering the northeast sector at one inch to the mile and at two inches to the mile (approximate), were interpreted for areas of sedimentary outcrop. Exposures appeared to be confined to stream cuts. Traverses were planned to reach these areas mainly by following streams in order to look also for outcrops too small to discern on the airphotos. Traversing procedure included side traverses up small sub-tributaries of the main east-flowing tributaries of Halfbreed Creek (Figure 3). During the mid-August period some were dry, and others contained running water and could usually be followed to source spring areas. Some of these small streams exhibit disappearance and reappearance along their channels, and the larger main tributaries, while not completely disappearing into their stream gravels, do exhibit considerable variations in volume of surface flow along their channels.

Some traversing in search of frost-heaved coal was undertaken away from stream cuts in vegetated areas. Stone ribbons (Plate 13) are direct evidence of active frost-heaving in the area. The following features are additional evidence that permafrost is extant in at least some portions of the area: (a) Small mudflows observed to be most actively moving when exposed to the sun; (b) Daily fluctuation in flow of streams not fed by glaciers or by snow in the late-summer period of observation; (c) Slump depressions probably representing thermal karst. Some slump depressions are well-drained (e.g. Plate 11); others contain water. Ground ice encountered in a bench cut exposure of coal (Plate 8) constitutes direct evidence of permafrost.

The general procedure in stream traversing was to walk on the stream beds, and observe the banks for exposure. Scanning the creek bed itself became regular procedure after discovery of coal float in stream gravel.

STREAM FLOAT AND FROST HEAVE RESULTS

Stream Float

Sporadically distributed coal float was found more or less continuously along the length of the stream portions indicated on Figure 3. It is usually found as small piles of coal fragments representing the weathered disintegration products of lumps ranging up to several inch size. This coal occurs on flood levees and flood terraces, as well as underwater in the summer channels. No attempt was made to determine the abundance patterns of the coal float. The overall impression was gained that although some fairly continuous sections show higher abundance than others, the average abundance in, say, a 1000 foot stretch of stream channel would be roughly equivalent to the average abundance in any other 1000 foot stretch. The probable rapid downstream dispersal of coal during spring flooding, and the tendency of lumps to rapidly disintegrate on surface, means that the common presence of coal float in a stream virtually proves that coal outcrops somewhere along that stream. Upstream from the coal lenses at cut bank Locality B (Figure 3, Plates 15 and 16) no other bedrock coal was seen, and no float could be found, though the stream bed was examined up to the St. Clare Group volcanic outcrops.

Frost Heave

Frost heave coal was found in one area centred about 400 feet southeast of Locality A (Figure 3, Plate 3). Here coal fragments occurring sporadically over an area of vegetated, marshy mountainslope must have been transported to surface by frost heaving.

BEDROCK RESULTS

Locality A

Locality A is a cut bank on the south side of a tributary of Halfbreed Creek (Figure 3, Plates 4 through 9). The tributary is not shown on NTS Sheet 115G/6 (First edition), but was flowing in mid-August, 1971. The exposure extends in a southwest-northeast direction for about 800 feet along the stream, and slope distances to the top of the bank are about 60 to 100 feet.

Vesicular to highly vesicular reddish-brown volcanic rocks, probably intrusive, comprise the northeast end of the exposure (Plate 4) and various volcanics also occur in the southwestern portion (Plate 5). Very poorly indurated clastic sediments, essentially flat lying, comprise about 80% of the exposed rocks. In the upper part of the bank, pale yellow and light brown, very soft, argillaceous sandstone is present. The sand is slightly lithified, holding steeper outcrop faces than would loose sand (Plate 5). Lenses of soft, brown claystone-siltstone and of brittle coal are present. In the lower part of the bank, low-relief badlands topography is exhibited by intermittent exposures of a white-weathering (Plates 6, 7, 8 and 9), pale greyish-green, gritty, pebble-bearing sandstone. This micaceous sandstone is massive and very poorly indurated. The pebbles include well-rounded white quartz, and clasts of (a) various volcanic lithologies, (b) coal, and (c) green siltstone. This is the only significantly rudaceous unit observed in the northeast sector.

The larger coal lenses occur in the lower part of the upper bank sandstones, near the contact with the lower bank sandstone. One of the largest lenses, 6.5 feet thick, was exposed by several bench cuts (Plate 8). A few feet in from the original slope surface this coal was solidly frozen. A local stratigraphic section which includes the thickest part of this coal lens is given in Table 1.

Another sizeable lens of coal, occurring west of

TABLE 1

Stratigraphic Section at Locality A

Elevation: 4730' (approx.)	Co-ordinates: 139°04'49"W 61°15'23"N

Thickness of Unit	Lithology
Not measured	Sandstone, argillaceous, pale yellow and light brown, very soft, with thin lenses of soft, brown, claystone-siltstone and brittle coal.
2' (top covered)	Sandstone, moderately coarse-grained, pale yellow, very soft, with thin lenses of coal.
1' to 2'	Clay, silty, light brown, upper two-thirds unindurated, lower one-third chunky, soft; with thin lenses of coal.
6.5'	Coal, banded, fairly hard, clean, and brittle, occurring in a lens at least 15' wide (sides covered), frozen a few feet beneath surface.
Not measured, mainly covered	Sand, argillaceous, medium grey, frozen a few feet beneath surface.
Not measured, lower portion covered	Sandstone, pebbly, gritty, micaceous, "salt-and-pepper" type, pale greyish-green, white, weathering, pebbles include well-rounded white quartz and clasts of various volcanic lithologies, of coal, and of green siltstone; very soft, massive, outcrops form subdued badlands topography.
	Base: Stream

the above, has been intruded by a dyke which is fine- to medium-grained, slightly porphyritic, light to medium grey, buff-weathering, apparently altered, and contains disseminated carbonaceous matter. Though less porphyritic, this body is on the whole similar in lithologic appearance to the sill found intruding coal at west-side Locality D (Speelman, 1970, p. 5, 13 and Table 3, p. 14) and later studied in some detail (Speelman, 1971, Section D). The dyke is about 10 feet high and 15 feet wide (Plate 9). Contact metamorphism of coal is evident. Briefly examined, the mesoscopic zones of altered coal are not as well defined as those at the west-side intruded coal locality.

Locality B

On the next tributary stream to the south of that hosting Locality A, and approximately 3500 feet south of that locality, there is another prominent northwest-facing cut bank, the eastern portion of which is designated Locality B (Plates 12, 13 and 14). Along the exposure, the maximum vertical rise from a point on the stream bed to top of adjacent cut bank is about 65 feet. The place of maximum vertical exposure happens to be the location of the three largest coal lenses now revealed in the cut bank.

A measured section (Table 2), which included the

TABLE 2

Measured Stratigraphic Section at Locality B

Elevation: 4750' (approx.) (top of coal)	Co-ordinates: 139°04'42"W 61°14'40"N

Thickness of Unit		Lithology
2'0" (top covered)	(a)	Sandstone, medium-grained to moderately coarse-grained, yellowish-grey, chunky, soft, (poorly indurated).
0'8"	(b)	Claystone, yellowish-grey, chunky, soft, becoming smaller chunks intermixed with wet clay in lower one-half.
1'0"	(c)	Siltstone, medium-grey, chunky, soft.
0'8"	(d)	Siltstone, medium-brown, chunky, soft.
0'5"	(e)	Clay, light grey, with thin lenses of coal.
2'8" (thickest part of lens)	(f)	Coal, medium and thick banded, fairly hard, clean, and brittle, occurring in a lens, about 16' wide, which is the westernmost of a group of the 3 largest coal lenses occurring at Locality B from which composite semi-bulk sample NHUA 8/18/71-4,5,6 was taken for resin extraction, disseminated mainly pale yellow to golden yellow lump resin present in low concentration.
0'5"	(g)	Sandstone, coaly, medium-grained to moderately coarse-grained, brittle (medium induration).

14'0"	(h) Sandstone, coarse-grained, micaceous, "salt-and-pepper" type, light yellowish-brown, dark buff to orange-brown staining common, very soft (very poorly indurated), with various lenses consisting of one or more, often all three, of the following lithologies: (1) medium-grey to greenish-grey, soft, chunky claystone, (2) coal, (3) medium-brown to dark-brown siltstone to fine-grained to coarse-grained sandstone.
4'0" (base covered)	(i) Sandstone, coarse-grained, "salt-and-pepper" type, light grey, very soft (very poorly indurated), some cross-bedding, with lenses of soft, fossiliferous (carbonaceous), brown weathering, medium-grey siltstone to sandstone. (Note: To the east of this measured section site, in this sandstone unit (i), occur the other two coal lenses sampled to make up part of composite semi-bulk sample NHUA 8/18/71-4,5,6.)
7'0"	Covered
	Base: Stream

westernmost and largest coal lens (Plates 15 and 16) in its thickest portion, was measured from the creek to a point halfway up the cut bank. This is a simple stratigraphic section since the bedrock sediments, which are largely poorly indurated yellowish-grey, light yellowish-brown, and light grey sandstone, together with lenses of finer-grained, usually darker clastics and of coal, are essentially flat-lying. The top of the measured section ends in these Amphitheatre formation sediments which, more or less exposed, also comprise the section in the upper part of the cut bank.

These Amphitheatre formation strata are overlain, apparently paraconformably, by well-stratified sand, gravel, and boulder beds of a predominantly reddish-brown colour (Plate 14). Provenance of these gravels is the St. Clare Group, outcrops of which are present in the stream cut on the far right hand side in Plate 13. Stratigraphic position of horizons bearing the larger coal lenses at Locality B is estimated to be roughly 100 feet stratigraphically below the lowest St. Clare Group volcanic flows. Age of the stratified gravels is Tertiary or younger.

The other two main coal lenses at Locality B are visible in Plates 15 and 16. As measured along the stream, the west end of the middle lens is approximately 12 feet from the east end of the west lens. The middle and east lenses occur in the light grey sandstone unit (i), the top of which, in the measured section (Table 2), is 14 feet 5 inches below the base of the west coal lens. Exposed length (or width) of the middle lens is 6 feet, and maximum thickness is 10 inches. For the east lens these dimensions are 3 feet, and 16 inches, respectively. Both lenses are overlain by dark brown, soft, chunky siltstone-claystone, and underlain by a brown, resiniferous, coaly sandstone which, over a few inches, grades into light grey sandstone unit (i). Similar lens "sandwiches" consisting of coal between overlying fine clastics and underlying coarser clastics, both (roof and floor) being darker than the enclosing sandstone, were also observed for smaller coal lenses occurrring in light yellowish brown sandstone unit (h) (Table 2).

The coal appears megascopically to be dominantly vitrain, medium and thick banded. The vitreous lustre of the vitrain indicates a higher rank than lignite (Schopf, 1960, p.48). Cleat is poorly developed; therefore the coal is probably of sub-bituminous rank. It is interesting to note that coal is the hardest rock present in the local section.

Lump resin, averaging about 1 to 3 millimetres in diameter, and generally finer-grained than that observed in 1970 in upper seams on the west side of the mountain, was observed in the 3 large lenses. It occurs sparsely more or less throughout the thickness of the lenses, but is usually more abundant in lower parts, and is also present in the coaly sandstone immediately underlying the lenses. Lump resin in the latter type of occurrence tends to be amber to dark amber in contrast with the largely pale yellow to golden yellow resin visible within coal lenses. Average abundance of resin across full thickness of lenses is roughly estimated at 0.5%, or less, and is thus also less than estimated for some west-side occurrences observed in 1970.

A semi-bulk sample (approximately 560 lbs.), comprised of coal from the east, middle, and west coal lenses, was taken in an attempt to extract enough resin for commercial test purposes (see Appendix 1 for description of sampling procedure).

Other Stream-Cut Exposures of Sediments

A number of other exposures of Amphitheatre formation sediments occur along stream-cut banks at elevations below Localities A and B in the northeast sector (e.g., see Plate 2). The exposed sediments, sand, silt and clay, are light-coloured and unlithified to poorly lithified. Thin lenses of coal are common in all cases. A distinctive white-weathering colour is noticeable at most exposures, and this, together with the presence of coal, helps to distinguish these Tertiary sediments from unconsolidated Recent clastic sediments which may also occur along the streams. However, along Halfbreed Creek, downstream from the northeast sector of the Niamodlaoc Mountain coal area (Figure 3), there are some deposits of white-weathering sand in which coal, occurring in streaks and lenses, is essentially unconsolidated, and may be clastic, reworked material. If so, these are probably Recent beds, consisting of reworked Tertiary age Amphitheatre formation sediments.

Coniform Exposures of Volcanic Intrusives

Solitary conical landforms, or coniforms, a few feet or tens of feet to a few hundred feet wide at base, occur as projections dotting the rolling lower slopes.* Clusters of coniforms occur near the top of the lower slope (see Plate 10), forming catchments behind which marshy alluvial-colluvial slopes gently rise toward the base of the upper slopes.

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*Coniform - Here proposed and defined as a cone-shaped landform of any size, but for the larger examples the term is superceded by terms such as "mountain peak", "peak", or "mount", already in common usage.

Outcrops occur on most coniforms, and on several, brief examinations were made. The rocks when fresh are grey or reddish-brown, mainly reddish-brown weathering, fine- to medium-grained volcanic rocks, with massive, amygdaloidal, and vesicular to highly vesicular structural-textural varieties. Flow layering was not detected, and in the few cases where structural-textural contacts were detected, these were moderately to steeply inclined.

Except for the dyke/coal (intrusive) contact at cut bank Locality A, no well-exposed volcanic/sediment contact was observed. However, it is reasonably clear that the lateral continuity of sedimentary units must be interrupted by volcanic bodies exposed on the east end of the cut bank, and near its west end. The projected contact relationships are either intrusive, or constitute nonconformities. In the latter case, the volcanic units would be volcanic cones or domes from which detritus was shed to accumulate in flanking sedimentary units. It seems more likely that the former alternative is the case, and that the coniform-forming volcanic bodies are erosion-resistant volcanic plugs.

DISCUSSION

Possible Correlations

No immediately apparent marker horizon has been found in the Amphitheatre formation as a result of the 1970 and 1971 reconnaissance field work. Coal seams exposed on the west side of Niamodlaoc Mountain are potential markers, and the lowermost volcanic flows in the overlying St. Clare Group should be examined for marker bed potential in future work. Even if good marker horizons cannot be found, sections comprising as much stratigraphic thickness as possible should be measured at several places of available exposure around the mountain. There may be detectable patterns of stratigraphic succession and of lateral facies variation from which to judge if a coal seam present at one locality is or is not present in the succession at another locality. The short sections measured at various coal localities are inadequate basis for judgement until some feeling for rapidity or scale of facies changes can be gained by measuring greater thicknesses of strata at different places.

Due to lack of sedimentary outcrops between Localities A and B (1971), which are about 3500 feet apart, the intervening structure is unknown. Observable structure is essentially flat-lying at both localities, and both lie at approximately the same elevations (conf. Tables 1 and 2), so they could have structural horizons in common. In comparing stratigraphy, we note that at both localities the larger coal lenses occur near a contact or transition between grey sandstones and overlying sandstones which are mainly yellow or brown. This generalization ignores stratigraphic details, and in detail, no lithologic correlation is apparent. This does not preclude correlation between the more prominently coal-bearing horizons at the two localities, and this remains a possibility.

Stratigraphic separations between prominent coal-bearing horizons and one potential stratigraphic marker, the lowest volcanic flow in the overlying St. Clare Group, has not been measured on the west side (1970), nor in the northeast sector (1971) of Niamodlaoc Mountain. This separation at Locality B (1971) is roughly estimated at 100 feet. Greater uncertainty attaches to any estimate of this separation at Locality A (1971), up-slope from which the lower St. Clare Group flows are less well exposed than at Locality B, and those which are exposed (Plate 3) are also laterally (to the west) farther removed from the coal locality than is the case at Locality B. However, a very rough estimate, made by projecting to a hypothetical simple stratigraphic section situation, gives us a separation at Locality A some 2 to 3 times that at Locality B.

A somewhat similar situation exists on the west side where at Locality C (1970) stratigraphic distance from base of St. Clare Group down to the uppermost seam ($3\frac{1}{2}$ foot thick) of the three main upper seams is roughly estimated at 100 feet. To the north at Locality A (1970) the estimate is again more uncertain than at C (1970), but separation is also thought to be greater than at Locality C. The middle seam (6 foot thick) and the lowest seam ($3\frac{1}{4}$ foot thick) at Locality C (upper seams, 1970) are respectively 31 feet and 43 feet stratigraphically below the uppermost seam (Speelman, 1970, Table 2, p. 12).

If the horizons bearing the larger coal lenses at northeast sector Localities A and/or B (1971) correlate with a horizon containing one of the upper seams at west-side Localities A, AA, or C (1970), then one of those seams has apparently become lensy to the east and northeast. On the other hand, some of the upper seams present on the west side, if continuous beneath the mountain, could be present on the east side some tens of feet lower down in the section than the lowest exposures (Plates 6 and 14) at the northeast sector Localities A and B (1971). On the western mountainside the upper seams are only slightly more resistant in outcrop than the sediments with which they are interlayered. The coal observed in lenses in the northeast sector, although more competent than host sediments in fresh exposure, appears to weather rapidly to small pieces, and is no more resistant in outcrop than the host sediments. Taking these two facts into consideration, we can predict that if an upper seam is present in the northeast sector, it will be little likely, or no more likely to outcrop than the soft sediments in that sector, and these seldom outcrop except at some places in stream cuts.

Trenching and Drilling Required

In summary, there is no evidence that the upper seams are present in the northeast sector of the mountain, but exposure is insufficient to determine if they are absent. In view of the important implications for seam continuity that their presence on the east side could have, it is worth 1 or 2 drill probes and/or long trenches, to determine whether or not they are present.

Regarding the lower seam occurring on the west side at Locality D (1970) and possibly at Locality B (1970), it is roughly estimated that if present in the northeast sector it will be at an elevation around 4000 feet. But the lowest surface elevation in this sector of the Niamodlaoc Mountain coal area, in the bottom of Halfbreed

Creek, is also about 4000 feet. Therefore, a vertical subsurface probe of several tens, perhaps up to a few hundred feet, from a low elevation set-up, is required to test for the presence of the lower seam in the northeast sector. It is desirable to first do the above discussed section measurement work, in order to refine the estimate of the expected elevation of the seam, and thus decide what length of drill hole would constitute an adequate search.

Strip Mining Potential

It is roughly estimated that 50% or more of the lower northeast mountain slope, mainly underlain by coal-bearing Amphitheatre formation sediments, lies at a 7 to 17% grade. The sedimentary units are flat-lying to gently dipping. In this northeast lower-slope sector of the mountain alone, there is thus an estimated area of about 1 square mile in which bedrock structural attitudes and slope attitudes on an average diverge by less than 10°. This condition of near-conjunction between bedrock and slope attitudes is favourable for strip mining. Moreover, if continuous coal seams can be found in this sector, it appears that the bedrock material to be stripped will be unindurated to poorly indurated after permafrost is thawed. Larger coal lenses might be selectively recovered during stripping. Also, the apparently ubiquitous coal occurring in smaller lenses might be sufficiently abundant to warrant treatment of the friable material to be stripped, in its entirety, as a pseudo-placer deposit from which coal in low concentration might be recovered by washing. A portable washing plant to produce a rougher concentrate would minimize transport of waste, an important operational characteristic of placer mining. A coal pre-concentrate might be obtainable simply by screening, since the coal in fresh exposure is the most competent sedimentary rock seen in the northeast sector. Stripping might be done by hydraulic giants, as has been done at the Healy Creek operation in Nenana coal field in Alaska (Barnes, 1964, p. 93). One conceivable technique for rapidly thawing permafrost would employ water passed to the hydraulic monitor from a coal-fired water heater.

Lump Resin

While lump resin concentration and average size as observed in northeast sector lenses is lower than observed in west-side upper seams, especially as observed near Locality AA (1970), the 1971 observations indicate that lump resin occurrence is widespread in Amphitheatre formation coals. There is obviously considerable variation in grade.

Resin extracted from a lens occurrence of coal should be a valid sample for establishing the range of resin quality to be expected in potentially minable seams. It is known that in a general way the abundance of coal lump resin increases with decreasing age of the host coal, and this is substantiated by comparison of Jurassic-Cretaceous coals and Tertiary coals observed by the writer in the Yukon. It is unknown if there is also an age effect on resin composition. If so, then depending on the magnitude of the age difference between a coal lens and a younger or older seam, a resin sample taken from the former is obviously not directly valid as a sample of the resin in the latter, but it is still valid in defining the limits (upper or lower) of composition of resin in a potentially minable seam in the same coal field.

CONCLUSIONS AND RECOMMENDATIONS

Ground-traverse surface prospecting for stream float coal and outcrop coal has proven to be an effective method in the Niamodlaoc Mountain area. Prospecting by airborne observation of surface has also been effective on the west side of the mountain, but not on the east side where sizeable coal lenses found on the ground in 1971 were not spotted from the air in 1970. It is recommended that ground-traverse surface prospecting be carried out in the as yet unexamined central-eastern, southeast, and southwest sectors of Niamodlaoc Mountain.

It is concluded that the surface exposure available in the northeast sector is insufficient to prove the absence of the upper seams, or of the lower seam, found on the west mountainside in the previous period of field work. It is possible that a horizon correlative with one of the western upper seam horizons is somewhere included in the available, albeit limited, northeast sector exposures as discussed above. Given this possibility, the fact that a seam was not observed in available exposures in this sector could be an unfavourable result.

On the other hand, the discovery in the northeast sector of topographic/bedrock structural conditions conducive to strip mining is a favourable result. In addition, the preponderantly poorly indurated sedimentary rocks in this sector could probably be stripped by hydraulic methods. On net, the 1971 results indicate to the writer that the overall geologic potential of the Niamodlaoc Mountain coal prospect is about the same as it was when considered in light of the 1970 results.

Because reconnaissance results so far obtained show that the coal measures are flat-lying to moderately dipping (less than 30°), mining costs should be lower here than in the tightly-folded Jurassic-Cretaceous coal measures in the Whitehorse Trough. Moreover, coal in seams of minable thickness in the Bush Mountain area, one of the Whitehorse Trough coal areas close to Whitehorse, and heretofore considered a possible source of coal for thermal power generation, has recently been found to be high-ash, meta-anthracite or graphitic anthracite (E.L. Speelman, in preparation; W. J. Montgomery, 1971; B. N. Nandi, pers. com., September, 1971), and is probably unsuited for combustion (D. S. Montgomery, pers. com., October, 1971), though an investigation is planned.

Besides further work to evaluate thermal coal potential, continued study of by-product or co-product potential of Niamodlaoc Mountain coal is recommended. Investigation of the economic potential of lump resin occurring in the coal, now underway with an attempt to separate resin from a semi-bulk sample from northeast sector lenses, should be continued in the field with a minimum objective of next obtaining a large sample from a west-side seam, as originally intended for 1971.

From information gained by surface work to date, it is clear that much more of significance remains to be learned from completion of reconnaissance geology work to include the central-eastern, southeast, and southwest sectors, plus measurement of stratigraphic sections, and detailed geologic mapping of all areas of the Amphitheatre formation, up to the basal units of the St. Clare Group. Measurement of sections and geologic mapping should have first priority after completion of prospecting and geological reconnaissance. Ideally, the geological work should be substantially completed before trenching and/or drilling is begun. The short field seasons make this impractical however, and enough is now known to plan to begin some trenching and drilling while the above work is underway.

Access problems in 1971 stemmed from several unanticipated washouts and blockages on the Halfbreed Creek road, which had been reported to still be in good condition when patrolled by snowmobile just prior to 1971 spring breakup. According to local reports, the 1970-71 winter snowfall in the mountains was heavier than normal. Some repair of this road by bulldozer will probably be required at the start of each field season. A 4 x 4 truck for supply, and a few small all-terrain vehicles for off-road travel, should give sufficient access to most of the area, with little helicopter support required.

An outline of field work tactics for one field season is given in Appendix No. 2.

November 22, 1971.

All of which is respectfully submitted,

Norman H. Ursel Associates Limited

Edwin L Speelman

Edwin L. Speelman, B.Sc.

REFERENCES

Barnes, F. F. (1964) Mineral and Water Resources of Alaska: Report Prepared by the U. S. Geol. Surv. in Cooperation with State of Alaska Dept. of Nat. Res. at the Request of Senator Ernest Gruening of Alaska of the Committee on Interior and Insular Affairs U.S. Senate, Coal, p.77-94.

Montgomery, D. S. (1970) Report of Analysis on Coal Resin Sample NHUA 30/7/70-4: Fuels Research Centre, Dept. of Energy, Mines and Resources, Ottawa, Sept. 4, 1970; reported in Speelman (1970, Appendix 1) and in Speelman (1971, Section E).

Montgomery, W. J. (1971) Analyses of Four Prospect Samples From Mount Bush, Yukon Territory: Fuels Research Centre, Divisional Report FRC 71/63-SF, Department of Energy, Mines and Resources.

Muller, J. E. (1967) Kluane Lake Map-Area, Yukon Territory (115G, 115F E$\frac{1}{2}$): Geol. Surv. Can., Mem. 240.

Schopf, J. M. (1960) Field Description and Sampling of Coal Beds: U. S. Geol. Surv., Bull. 111-B.

Speelman, E. L. (1970) Report on Niamodlaoc Mountain Coal Prospect, 1970 Field Season: Norman H. Ursel Associates Limited, Toronto, Ontario, Canada, Oct. 6, 1970.

Speelman, E. L. (1971) Addendum 1 (to Speelman, 1970): Analyses of Coal, Natural Coke, Igneous Rock Intruding Coal, and Lump Resin in the Niamodlaoc Mountain Coal Prospect: Norman H. Ursel Associates Limited, Toronto, Ontario, Canada, Mar. 19, 1971.

Winandy, G. J. (1971) Letter dated April 13, 1971 and pers. com. by telephone on April 16, 1971 re tests performed on Yukon coal resin samples by Lawter Chemicals (Canada) Ltd., Rexdale, Ontario, Canada.

PLATE 1. Northeast sector of Niamodlaoc Mountain as viewed from Halfbreed Creek Road, showing layered volcanic capping of the mountain, and lower slopes underlain by coal bearing clastic sediments (Amphitheatre formation) and volcanic plugs.

PLATE 2. A closer view of the northeast sector as seen from the Halfbreed Creek floodplain. Cut banks left and right of centre (distant foreground) expose predominantly light-coloured, unindurated to very poorly indurated clastic sediments of the Amphitheatre formation.

PLATE 3. Looking upslope over the lower slopes. Upper slopes (with volcanic cliffs) in distant background. Cut bank exposure Locality A is right of centre, on upper part of lower slope. Coniforms developed on volcanic plugs on extreme left, also near top of lower slope. Frost heave coal occurs in low area lying between Locality A and coniforms on extreme left.

PLATE 4. Reddish-brown and grey, highly vesicular volcanics exposed at northeast end of cut bank Locality A. Looking southeast.

PLATE 5. Light-coloured Amphitheatre formation sediments exposed at the southwest end of cut bank Locality A. Cluster of small volcanic coniforms visible from top of bank to upper right of photograph. Looking southeast, with Kluane Range mountains in distant background.

PLATE 8

PLATE 6

PLATE 9

PLATE 7

PLATE 6
(left)

PLATE 9
(right)

Plates 6 - 9

PLATES 6 through 9. Overlapping scan view, looking southeast (left) through southwest (right) at shaded to partly shaded, main central portion of cut bank Locality A. Scott Lyle stands on upper level of bench cut exposure of coal lens (Plate 8). Contact between upper bank and lower bank sandstone units occurs immediately above white-weathering outcrops (e.g., outcrop to the left of coal tailings, Plate 8). Coal lens on far right is intruded by buff-weathering dyke, below which dyke talus is visible (Plate 9).

PLATE 10. Looking downslope at coniform cluster (volcanic plugs), immediately upslope of which is a grassy marsh area probably overlying Amphitheatre formation sediments. Camera site is on top of a solitary coniform, and reddish-brown weathering volcanic talus is visible in foreground. Kluane Range mountains east of Halfbreed Creek in distant background.

PLATE 11. Dry sink-hole about 10 feet deep developed at the toe of a coniform slope on a grassy low area similar to that visible on Plate 10.

PLATES 12 through 14. Successively closer views of cut bank Locality B, looking south across the sloping alluvial/colluvial plain which forms a step-like boundary between the upper and lower slopes of Niamodlaoc Mountain in its northeast sector.

PLATE 12. Camera site same as Plate 10.

PLATE 13. Parallel stone ribbon pair extends from right foreground.

PLATE 14. Stratified sand, gravel, and boulders, predominantly reddish-brown and derived from upper slope bedrock, are visible in upper right hand portion of cut bank exposure mantling lower slope bedrock consisting of poorly indurated, predominantly light-coloured Amphitheatre formation sediments.

PLATE 12

PLATE 13

PLATE 14

PLATES 15 and 16. Close-ups of cut bank Locality B showing Amphitheatre formation sediments and coal. Stream in foreground bears coal float from this point downward to Halfbreed Creek.

PLATE 15. Faces of coal lenses partly prepared for sampling.

PLATE 16. After semi-bulk sample removed from three coal lenses. Largest lens (upper right) partly obscured by cave-in.

PLATE 15

PLATE 16

APPENDIX 1

Sampling Procedure to Obtain Semi-bulk Coal Sample NHUA 8/18/71-4,5,6 at Locality B

Sampling Procedure

In preparation for sampling, approximately 1 to 3 feet of coal was stripped from the surface exposed coal lenses. There is an ongoing natural stripping of coal in the stream-cut banks, resulting in the coal being fresher than is usual for an outcrop exposure. The resin was lustrous and fresh in appearance.

Coal was taken by hand implements along the full "length" (exposed long dimension) of the lenses, except at the thin extremities. Due to weak roof ground conditions, it was not practical to achieve uniform depth (distance in away from stripped surface) in sample removal. Therefore, to eliminate possible bias of resin composition due to variation in composition with stratigraphic position, coal was taken as a side-by-side series of channel samples, each removed across the full thickness in each of the lenses, generally cutting from roof to floor, with uniformity of depth in any one channel, but with variation of depth from channel to channel.

Due to the poor induration of the overlying sediments, it was not possible, without ground support in conjunction with excavation, to prevent some contamination of the sample by mineral matter moving downslope. Since specific gravity of mineral matter is about 100 to 200% higher than that of coal resin, this contamination is of no consequence to the immediate purpose of the sample, i.e., to obtain a resin separate by gravity methods.

The coal sample, weighing approximately 560 pounds, is described as follows:

Field Sample No.	No. of Sacks	Body Sampled	Sample Weight (pounds, approx.)
8/18/71 - 4	1	East lens	80
8/18/71 - 5	1	Middle lens	80
8/18/71 - 6	5	West lens	400

Approximate Total Sample Weight = 560 lbs.

The semi-bulk sample, NHUA 8/18/71-4,5,6, was sent in seven sacks from Burwash Landing (via Whitehorse) to Western Regional Laboratory, Department of Energy, Mines and Resources, Clover Bar, Alberta, where it was received on October 21, 1971.

APPENDIX 2

Working Outline of Field Work Tactics for Next Field Season

A. Working out of accommodations at Burwash Landing or Destruction Bay.

1. Repair of Halfbreed Creek Road by bulldozer. 2 days.

2. Pathfinding reconnaissance of southeast and southwest sectors by all-terrain vehicle to determine if any trailbreaking or pioneer roadwork is required of the bulldozer to provide routine access by all-terrain vehicles to western mountainside via southern end of the mountain. 2 days coeval with above.

3. One long exploratory trench, by ripper-equipped bulldozer, across strike (trench orientation probably perpendicular to topographic contours) on the southern mountainslope where airborne-observation surface reconnaissance (1970) indicated little natural exposure of bedrock. 6 days minimum.

4. (Optional) Trenching in one other area, possibly in the northeast sector. If great difficulty is encountered in ripping/trenching in permafrost at this time, a further optional plan would be to make first scraping passes to clear vegetation and promote thawing in some other prospective trench locations so that these can more easily be trenched later in the summer.

5. Set up camp to accommodate full contingent of personnel required in August (infra). (Optional) Contract camp construction to be carried out after A.1.

6. Release of bulldozer.

B. Working out of a camp set-up near small lake in southeast sector of Niamodlaoc Mountain coal area (see Figure 3).

1. Transit-and-stadia closed traverse encircling Niamodlaoc Mountain. Following achievement of adequate closure, easily recognizable topographic

points (tops of coniforms, stream intersections, etc.) will be tied in to be used for control in photogrammetric production of large scale topographic base map. Two survey field men. 20 to 30 days.

2. Geological reconnaissance and prospecting in central-eastern, southeast, and southwest sectors. Two men (party chief and assistant). 5 days, coeval with first 5 days of B.1. (above).

3. Measurement of stratigraphic sections. Two men (party chief and assistant). 15 to 25 days to be arbitrarily terminated to coincide with completion of B.1. survey.

(End of June)

4. Systematic plane table topographic/geologic mapping of lower slope sectors of Niamodlaoc Mountain. Selected key areas to be mapped first. Topographic aspect of mapping to be largely dispensed with after receipt in field of topographic base map prepared on contract specifying delivery date to be X days after receipt of B.1. field data. Two 2-man crews. 30 days each crew.

(End of July)

5. Begin second-phase bulldozer trenching; supervision and mapping of trenches by 2-man crew. Time required indefinite.

6. Begin diamond core drilling (1 drill); supervision and logging by other 2-man crew. 30 - 45 days terminating by mid-September.

7. Personnel leave, except party chief, assistant, and cook.

(Mid-September)

8. Close up camp, cache and store equipment.

(End of September)

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REPORT ON
NIAMODLAOC MOUNTAIN COAL PROSPECT
1970 FIELD SEASON

ADDENDUM 1

ANALYSES OF COAL, NATURAL COKE, IGNEOUS ROCK INTRUDING COAL, AND LUMP RESIN

BY

E. L. SPEELMAN

NORMAN H. URSEL ASSOCIATES LIMITED

ADDENDUM 1

ANALYSES OF COAL, NATURAL COKE, IGNEOUS ROCK INTRUDING COAL, AND LUMP RESIN IN THE NIAMODLAOC MOUNTAIN COAL PROSPECT.

INTRODUCTION

Analytical, petrographic, and alteration calculation studies begun as part of the 1970 Yukon Coal Exploration Program of Norman H. Ursel Associates Limited are continuing. Some of the data and discussion which follow here, together with data not yet available on coal and natural coke reflectance, and experimental carbonization studies being done at the Fuels Research Centre, Ottawa, Department of Energy, Mines and Resources, will be prepared for joint publication by B. N. Nandi, E. L. Speelman and D. S. Montgomery. Responsibility for presentation and treatment of data and opinions expressed in the present report (Addendum 1), written by E. L. Speelman, is assumed by him.

COAL

In the upper part of the upper Amphitheatre formation, the higher rank is found for the stratigraphically lower of two seams (Section A). A yet lower seam, sampled about 2.5 miles to the south, shows further increase in rank (Section B) with decreasing stratigraphic height. The rank sequence for these seams is sub-bituminous C - sub-bituminous B - sub-bituminous A.

Two of the three seams are low in ash, and all are low in sulphur. The rank of the lowest of the sampled seams is near the sub-bituminous-bituminous classification boundary. The latter dips into the base of Niamodlaoc Mountain, and lateral variation in rank, for example, increase in rank with structural depth, is a possibility to consider. Some insight into the effect of heat per se on coalification can be gained by studying igneothermal alteration of coal. Such an occurrence of thermal alteration was available for investigation, and is discussed in the following sections.

SECTION A

COAL CHANNEL SAMPLES NHUA 31/7/70-1 AND NHUA 31/7/70-2

NTS Area: SEQ 115G-6

Coal Exploration Licence: No. 14, Jeffrey J. Van Zant

Sample Co-ordinates: 61°15'54"N 139°7'18"W

Location Description: Outcrops in stream cut exposure on south side of a small west-flowing tributary of Ptarmigan Creek, on northwestern slope of Niamodlaoc Mountain.

Producing Unit: Amphitheatre formation (Muller, 1967). Paleocene or Eocene age. Thickness at least 1500 ft., possibly up to 2500 ft. Formation, which is overlain by St. Clare Group, occurs in discontinuous patches in Duke Depression. In this area forms plinth for Niamodlaoc Mountain and has an extent of about 12 square miles.

Stratigraphic Position of Coal: Upper part of upper Amphitheatre formation.

Coal: Two seams measured (see local stratigraphic section in Table 1, p.9, Report on Niamodlaoc Mountain Coal Prospect, 1970): 3.0 ft; 6.0 ft; dip 15-25° SE; Prominent cleat strikes 155°, dip 75° NE; Another cleat strikes roughly 70°, dip steeply N.

Proximate Analyses (follows): 31/7/70-1, 3.0ft; 31/7/70-2, 6.0 ft. Both are standard 3" x 4" channel samples freshly exposed at least 5 ft. from original outcrop surface by trenching.

Maceral Analyses: (Fuels Research Centre, qualitative): 31/7/70-1, coal consists principally of vitrinoid, with many resin inclusions. Rank appears too low for coking coal. 31/7/70-2, coal is low in mineral matter, vitrinoid predominates, in which cellular structure is evident showing low level of metamorphic development. Coal is rich in exinite and has a low concentration of coal inerts. Rank of coal still appears too low for coking but low mineral matter and high resin content make this coal worthy of further study.

SECTION B

COAL CHANNEL SAMPLES NHUA 27/8/70-5 AND NHUA 27/8/70-4

NTS Area: NEQ 115G-3

Coal Exploration Licence: No. 18, Ian Wilson

Sample Co-ordinates: 61°13'45"N 139°6'15"W

Location Description: Outcrops in stream cut of a small, west-flowing tributary of Ptarmigan Creek, on lower western slope of Niamodlaoc Mountain. Stream forms small cataract in flowing over cliff face of conglomerate which overlies coal. Sample site is south of stream.

Stratigraphic Position of Coal: Lower part of upper Amphitheatre formation.

Coal: One seam intruded by a sill (see local stratigraphic section in Table 3, P.14, Report on Niamodlaoc Mountain Coal Prospect, 1970): 11 ft. of coal and altered coal below sill, 2 to 4 ft. above sill; dip 27° NE.

Proximate Analyses (follow): 27/8/70-5, lower 8 ft. of unaltered lower coal; 27/8/70-4, 1 ft. of unaltered and slightly altered coal (3" coal - 3-5" claystone parting - 9" slightly altered coal) separated from underlying lower 8 ft. of coal by 1½-5" claystone parting. Both are 4" x 8" channel samples freshly exposed at least 5 ft. from original outcrop surface by trenching.

Maceral analyses and reflectance measurements (Fuels Research Centre): In progress.

- CHEMICAL RESEARCH AND ANALYSIS
- CONTRACT LABORATORIES

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CERTIFICATE OF ANALYSIS

SAMPLE(S) FROM
Norman H. Ursel Associates Limited,
Suite 520,
85 Richmond Street West,
Toronto, Ontario.

REPORT NO.
T-21302

SAMPLE(S) OF COAL

Sample No. NHUA 27/8/70-4	Air Dried	Dry Basis
Moisture %	4.34	---
Ash %	9.68	10.12
Volatile Matter %	40.67	42.51
Fixed Carbon %	45.31	47.37
Sulphur %	0.40	0.42
B.T.U./pound	11,510	12,032

Samples, Pulps and Rejects discarded after two months

DATE Feb. 9/71

SIGNED

CTA

SECTION C

NATURAL COKE SAMPLE NHUA 27/8/70-2y

Sample Location: Same as NHUA 27/8/70-5 and 27/8/70-4.

Natural Coke: Five to ten inch band of columnar structured natural coke developed below lower contact of sill.

Proximate Analysis (follows): 27/8/70-2y, composite grab sample of coke band taken from approximately 1 ft. beneath original outcrop surface.

Reflectance Measurements: In progress.

REPORT OF ANALYSIS

Sample of coal submitted by N. W. Coal Associates Ltd through V. Tibbetts

Date Received.			27/8/70 - 2Y	
Sample Mark.	13-450 70			
Moisture Condition	Eq ~~As Rec'd~~ Moisture	Air ~~Dry~~ Dried	Dry ~~As Rec'd~~	Dry
Proximate Analysis				
Moisture. . . . . %	8.55	4.21	0.00	
Ash. . . . . %	16.63	17.41	18.18	
Volatile Matter. . . . . %	14.69	15.38	16.06	
Fixed Carbon (By Difference) . . %	60.13	63.00	65.76	
Ultimate Analysis				
Carbon. . . . . %				
Hydrogen. . . . . %				
Sulphur . . . . %	0.38	0.40	0.42	
Nitrogen. . . . . %				
Ash. . . . . %				
Oxygen (By Difference). . . . . . %				
Calorific Value. . . . .Btu/lb Gross	10010	10480	10940	M.M.free 13650

Fusibility of Ash

Initial Deformation Temperature. °F	
Softening Temperature. . . . . . °F	
Hemispherical Temperature. . . . °F	
Fluid Temperature. . . . . °F	
Grindability Index, Hardgrove. . .	

Screen Analysis

Screen Size

Non Agglomerate

Moist m/m/f B.T.U. 12250

A.S.T.M. Rank - High Volatile "C" Bitumin

Remarks:

Reported by:

Head, [illegible]

Dr. D.S. Montgomery,
Head,
Fuels Research Centre.

Distribution:

NATURAL COKE

Contact metamorphism of coal often produces four zones of altered coal which are identifiable underground or in the field (Williamson, 1967, p.50-51). From outer to inner thermal aureole the zones encountered are as follows:

(a) Zone of increased coal lustre.

(b) Cinder (dull) coal zone.

(c) Columnar natural coke zone.

(d) Coke skin on the intrusive.

All four zones appear to be present at a locality in the Niamodlaoc Mountain area where the lowest of the sampled seams is intruded by a sill (Section D). Channel sample NHUA 27/8/70-4 (Section B) includes a partial channel of zone (a) for 9/12 of the total channel length of 12 inches. The proximate analysis of this channel differs little from the analysis of the lower 8 ft. of the seam. The latter appears to be unaltered coal.

Analysis of zone (c), columnar natural coke (Section C), indicates that extensive alteration has occurred in this zone. Volatile matter has decreased from 42.5% to 16.1% (dry basis), and is even lower in the natural coke proper, because volatile matter analysis includes CO_2 from the carbonate inclusions and fracture-fillings which are observable in hand specimen. Inclusions and fracture-fillings of carbonate and other material occurring in zone (d) were examined microscopically as discussed in the next section.

SECTION D

PARTLY ALTERED ANDESITE PORPHYRY PETROGRAPHIC SPECIMEN NHUA 27/8/70-2W and SILICATE ANALYSIS SAMPLE NHUA 27/8/70-1

Sample Location: Same as NHUA 27/8/70-5 and 27/8/70-4.

Partly Altered Andesite Porphyry: Sill, 3 to 6 ft. thick, intruding coal seam.

Petrographic Study (follows): 27/8/70-2W, Specimen from lower contact of sill.

Silicate Analysis (follows): 27/8/70-1, Sample from centre of sill.

SILL INTRUDING COAL

Petrographic Study

The petrography of the sill, and of the relationships across the coke-sill contact, were studied in thin section oriented normal to the contact, and included approximately a 1 centimetre width of the skin of natural coke occurring on the sill.

Dr. R. W. Deane, of Lakefield Research of Canada Limited, examined this thin section, and his report (1971) is closely paraphrased and in part directly quoted for the remainder of this section:-

-: The modal and grain size estimates for the sill material are listed in Table 1. The sill material consists of an iron-stained turbid albite-oligoclase feldspar and carbonate matrix carrying phenocrysts of An_{40} - An_{50} plagioclase feldspar. It was not possible to identify all constituents of the matrix, which is an extremely fine-grained mixture. Part of the turbidity of the matrix is ascribed to the presence of sub-microscopic particles of organic inclusions in the matrix, i.e., what appeared as submicron-sized particles of coke. The iron staining is in the form of hydrated iron-oxide coatings on and in the matrix. The sill material is not uniform in colour. A gradational zone extending at least 1 centimeter from the contact is noticeable in hand specimen. The reason for this is in the higher concentration of iron-oxide and in the generally

Table 1. Modal and Grain Size Estimates for a Partly Altered Andesite Porphyry.

Sample No: 27/8/70 - 2W

Minerals	Est. % by Vol.	Grain Size (mm)	
		Max.	Avg.
Carbonate	15%	.18	.02
Feldspar Phenocrysts	5	.6 x .3	.45
	20	.2 x .03	.15
Feldspar Matrix	40	<.01	<.005
Iron oxide	5-10	<.01	<.005
Coke	1-5	?	<.005

increased turbidity of the matrix with increasing distance from the coke-sill contact.

Carbonate includes both siderite and calcite, with siderite present throughout the matrix and in fracture fillings in coke. A thin layer of rust-coloured siderite forms an interface between the coke and the main contact zone. The latter consists of matrix material and phenocrysts and siderite (probably from reaction of iron oxide with CO_2).

The coke is opaque in thin section. Columnar or polygonal jointing per se were not observed in this skin of natural coke in immediate contact with the sill. Fracturing of this coke is general, and the longest fractures are parallel with the contact. Fracture widths range from 5 to 150 microns, and filling material consists of carbonate, groundmass material from the andesite, and a mineral which may be either chabazite or pectolite.

Vesicles are present in both sill and coke. The average diameter is approximately 30 microns. They are oval in shape, and the interior surfaces carry rhombohedral platelets of calcite and drusy crusts of what may have been zeolitic material. In general, most of the vesicles were barren of fillings, but this may have been the result of plucking of filling material during thin section preparation. The few vesicles present in the coke, ranging from 100 to smaller than 30 microns, are lined with the unidentified drusy material, and in one or two cases with platelets of calcite.:-

Silicate Analysis

An analysis of a sample from the centre of the sill is given in Table 2. The high FeO/Fe_2O_3 ratio of 2.27, together with the high CO_2, indicates that matrix iron carbonate is also abundant in the interior of the sill. Calcite in vesicles and amgdules contributes to the high CO_2, but any carbonaceous material present cannot, because CO_2 was analyzed by combustion in a nitrogen atmosphere.

Silica content is near the chemically defined ultrabasic/basic classification boundry. Assuming that the high CO_2 is the result of contamination, a recalculated SiO_2 increases to a value in the range for basic rocks. The rock is highly potassic, and in its overall chemical composition resembles certain volcanic rocks in the Bufumbira Field of Uganda, including a leucite basalt, a trachybasalt, and a melilite-leucite nephelinite (Holmes and Harwood, 1937, p. 91, anal. H, p. 159, anal. O; Sahama, 1953, p. 15, as reported in Turner and Verhoogen, 1960, p. 238). TiO_2 is high, which is usual for alkaline rocks. The high potash suggests that the sill could be a trachyandesite, however, the observed low silica would be unusual for this rock type, and a potash feldspar was not identified petrographically near the sill margin. The lithology of the sill appears to be essentially uniform, including the porphyritic texture which extends to the contacts. The presence of feldspar phenocrysts close to the contacts suggests that they crystallized prior to intrusion of the sill. The high potash indicates that the matrix feldspar (albite-oligoclase) is appreciably potassic, or that a potash feldspar is present in the centre of the sill.

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CERTIFICATE OF ANALYSIS

SAMPLE(S) FROM
Mr. E.L. Speelman,
c/o Norman Ursel Associates,
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Toronto, Ontario.

REPORT NO. T-21248

SAMPLE(S) OF IGNEOUS ROCK

Table 2

Sample No. 27/8/70-1

Silica (SiO_2)%	44.82
Alumina (Al_2O_3)%	16.49
Ferric Oxide (Fe_2O_3)%	2.84
Ferrous Oxide (FeO)%	6.45
Calcium Oxide (CaO)%	6.32
Magnesium Oxide (MgO)%	3.33
Titanium Oxide (TiO_2)%	1.50
Manganese Oxide (MnO)%	0.13
Sodium Oxide (Na_2O)%	3.51
Potassium Oxide (K_2O)%	5.77
Carbon Dioxide (CO_2)%	6.88
Water of Crystallization (H_2O+)%	0.90
Moisture (H_2O-)%	0.46

N.H.U.

E.L.S.

amples, Pulps and Rejects discarded after two months

DATE Jan. 25/71

SIGNED

CTA

Contamination Alteration of the Sill by Volatile Carbonization Products Introduced Prior to Crystallization

Both rock analysis and petrographic observations indicate that the sill has been altered by gain of CO_2. In the field, alteration is indicated by the light grey colour of both the sill and suspected feeder dikes, which are bleached compared to the predominantly reddish-brown surface flows of which they may be shallow intrusive equivalents. Alteration of igneous bodies which intrude coal is known in other coalfields, and the term "white trap" has been applied to bleached and softened rocks of a greyish colour (Williamson, 1967, p. 49). In northern Hobart quadrangle in the State of Washington, a very light grey to yellowish grey sill 5-8 feet thick intrudes the top of the Big Elk coal bed, of which only 1-3 inches are altered, while the sill is completely altered to kaolinite, quartz, limonite veinlets, calcite pods, and dawsonite aggregates (Vine, 1969, p. 34-35).

It is interesting to test by calculation the assumption that the high CO_2 content of the sill was gained by thermal devolatilization of coal in the Niamodlaoc Mountain area. Where a sill follows a coal bed, there is for each unit area of contact surface a corresponding volume of sill and of altered coal so that quantitative loss-gain estimates are possible. We would expect to find that more CO_2 was lost from the coal than is present in the sill because the communicating system probably included feeder dikes, and indeed, the several dikes observed downsection below the sill are not only bleached, but also possess thin coaly margins thought to be condensed coal distillation products.

Since the relative proportions of the various thermal distillation products, gases, light oils, and tar, vary from coal to coal, the ideal treatment would use experimental determination of the proportions produced for the coal in question. In the absence of this, we have used the results for another high volatile coal (Coal No. I, Zeigler, Illinois, Peter and Ovitz as reported in Sperr, 1922, Table XXIII, p. 190). Compositional data for the gas mixture produced at different temperatures are available. The data used are for a coke oven wall temperature of 700°C, under which condition the maximum temperature reached in the coal was 585°C. With decreasing temperature of carbonization, the gas mixture becomes richer in carbon and in CO_2, while total gas yield decreases, with the result that variation in net yield of carbon and CO_2 is not large. Thus, differences of plus or minus 100°C between temperature chosen for the calculation and those which actually occurred, will not affect the validity of this exercise.

With decreasing temperature of carbonization, yield of tar (plus light oils) increases, and gas yield decreases. Per-ton yields of 9,000 cubic feet of gas and 15 gallons of tar (S.G. 1.140) used here, are taken from the results of V.B. Lewes (as reported in Coffin, 1922, Table XLVI, p. 410) for carbonization of a coal at 700°C. The per-ton weight yield of different gases in the mixture are first calculated, neglecting minor ammonia. These yields are summed for comparison with the weight yield of tar (including light oils):

Weight of Gases in the Volatile Matter Gas Mixture

$$\frac{\text{Weight of gas}}{\text{Ton of coal carbonized}} = \frac{\text{Volume per cent}}{100} \times \frac{\text{Total volume}}{\text{Ton of coal carbonized}} \times \frac{\text{Moles}}{\text{Unit volume}} \times \text{Gram-molecular weight}$$

$$\frac{\text{Weight } CO_2}{\text{Ton of coal carbonized}} = \frac{6.4}{100} \times 9{,}000\ \text{ft.}^3/\text{ton} \times 2.79 \times 10^{-3}\ \frac{\text{lb. mole}}{\text{gm ft.}^3} \times \frac{44\ \text{gm}}{\text{mole}} = \frac{\text{lbs./ton}}{70}$$

$$CO = \frac{21.1}{100} \times 9{,}000 \times 2.79 \times 10^{-3} \times 28 = 148$$

$$\begin{array}{l} C_nH_{2n} \\ (n = 2,\ \text{est.}) \end{array} = \frac{4.1}{100} \times 9{,}000 \times 2.79 \times 10^{-3} \times 28 = 29$$

$$\begin{array}{l} C_nH_{2n} + 2 \\ (n = 1.21) \end{array} = \frac{41.4}{100} \times 9{,}000 \times 2.79 \times 10^{-3} \times 18.9 = 196$$

$$H = \frac{26.9}{100} \times 9{,}000 \times 2.79 \times 10^{-3} \times 2 = \underline{14}$$

Total gas = 457

$$\text{Weight of Tar} = \frac{15\ \text{gallons}}{\text{Ton of coal carbonized}} \times 1.140 \times 8.35\ \frac{\text{lbs.}}{\text{gallon}} = 143$$

Total Volatile Matter = 600 lbs./ton

$$\frac{\text{Weight total gas}}{\text{Weight total volatile matter}} = \frac{457}{600} = 0.762$$

Tar comprises about 24% by weight of total volatile matter yield. We have evidence of marginal segregation of condensates in the dikes. Possibly the coke skin on the sill also represents a thin zone which was enriched in tars. We assume then that tars mainly condensed at the cooler intrusive margins and contributed little to carbon content within the body of the sill. This leaves for consideration the gases CO_2, CO, CnH_2n, and CnH_2n+2, which together with hydrogen comprise about 76% by weight of total volatile matter lost.

In the equilibrium system $CO_{2(g)} - CO_{(g)} - C_{(s)}$, at 1 atmosphere total pressure, the ratio $\frac{pCO_2}{pCO}$ increases with decreasing temperature, from approximately 0.56 at 700°C to approximately 160 at 400°C (Muan and Osborn, 1965, Figure 35, p. 51). Below about 750°C, the pO_2 of this system is such that $FeO_{(s)}$ is stable relative to $Fe_{(s)}$ and $O_{2(g)}$. Cooling of the sill should favour the reaction $FeO_{(s)} + CO_{2(g)} \rightarrow FeCO_{3(s)}$, suggested by Deane (above).

All of the above considered equilibria and reaction data, including that for thermal devolatilization of coal, were for a total pressure of about one atmosphere. Because gases are involved, pressure will have the effect of raising reaction temperatures in most cases. No attempt has been made to estimate these effects. Fortunately, we are dealing with geologically low to moderate pressures. The shallow intrusive volcanic sill is thought to have been emplaced at some time during accumulation of an overlying load of volcanic flows. Lithostatic load pressure on the intruded sill is estimated at between 75 to 230 atmospheres, corresponding to 1,000 to 3,000 feet of cover.

If maintenance of CO_2 - CO - C equilibria was dependent on communication of CO_2 and CO with carbon in the coke at the sill contact, then temperature gradients near the contact may have precluded equilibrium exchange. However, carbonaceous matter is present in the sill itself, at least near the contact. This suggests that CnH_2n and CnH_2n+2 gases, which upon entering the sill were subjected to higher temperatures than those obtaining in the coal, may have undergone pyrolysis resulting in solid carbon as one of the products. For example, with increasing temperature, methane can decompose to a mixture of complex aromatic hydrocarbons, free carbon, and hydrogen.

There is no reason to suspect that the originally volatilized hydrocarbon gases, CnH_2n and CnH_2n+2, or their pyrolytic reaction products, contributed to the present CO_2 content of the sill. Preferential loss of hydrogen or gain of oxygen would be required. While this is possible, it is beyond the scope of this exercise, which assumes that the sill (plus feeder dike)/altered coal system was essentially closed to all components during crystallization of the sill. Only the contributions of originally volatilized CO_2 and CO are considered in the following calculations:

Weight of CO_2 + CO_2 equivalent of CO as a proportion of volatile matter

$$\begin{aligned} &CO_2 && = 70 \\ &CO = 148\ \frac{\text{lbs.}}{\text{ton}} \times \frac{44}{28} && = \underline{233} \\ & && \quad 303\ \frac{\text{lbs.}}{\text{ton}} \end{aligned}$$

$$\frac{CO_2 + CO_2 \text{ equivalent of } CO}{\text{Total volatile matter}} = \frac{303}{600} \simeq \frac{1}{2}$$

CO_2 + CO_2 equivalent of CO lost from altered coal

Calculation of weight of CO_2 + CO_2 equivalent lost from thermally altered coal is based on the assumptions that the pre-alteration V.M. content (1) varied little with stratigraphic position in the seam, and (2) as an approximation was equal to that now observed for the unaltered or little altered coal. The first assumption is justified by virtually identical V.M. values, 42.3 and 42.5%, for two unaltered or little altered sequential channel samples (27/8/70-5 and 27/8/70-4). Since these values represent the present result of any normal geothermal coalification which may have continued to occur since intrusion of the sill, the second assumption cannot lead us to overestimate volatile matter present prior to igneothermal alteration, nor for young, high volatile coal should it lead to a seriously underestimated value.

Natural igneothermal alteration under lithostatic load causes coal thickness to decrease and density to increase according to the data of Edwards and Tomlinson (1958, as reported in Williamson, 1967, p. 50, Table 10, p. 51). By relating our altered coal volatile matter content to their data on thickness, V.M., and specific gravity for different sections of a coal seam contact metamorphosedby a dike, the density, and the thickness decrease factors for our thermally altered zones are estimated as given in Table 3. A plot from their data shows that as volatile matter decreases, the specific gravity increase is initially gradual, becoming more marked for the most altered coal. This is probably explained by the fact that with increasing temperature of carbonization, the composition of the mixture of volatile gases becomes "leaner", i.e., poorer in carbon and richer in hydrogen (above). Thus, in contact metamorphic zones of progressively higher temperature, the density contrast between volatilized gas mixture and residual coal became correspondingly higher, resulting in an increasing rate of specific gravity increase per unit decrease of V.M. Thickness decrease factors were obtained by linear extrapolation of their data (thickness vs. % V.M.) to higher volatile matter values.

Average V.M. value for the natural coke zone is as observed, while that for the zone of cinder coal, which as exposed was unsuitable for sampling, is estimated to have an average value equal to the average of the natural coke and the unaltered or little altered coal. This allows for either essentially linear variation in V.M. content vs. position in the cinder coal zone, from 42.5% at the base to 16.1% at the top, or an essentially stepwise variation between the little altered coal below and natural columnar coke above.

The two main thermally altered zones are calculated separately (Table 3). The volumes considered are columns perpendicular to the contact, with cross-sectional areas of 1 square foot.

The weight of CO_2 + CO_2 equivalent lost from natural coke and cinder coal zones combined = 16.9 + 11.4 = 28.3 lbs.

Table 3

	V.M. %	S.G.	Density lbs./ft.^{3}	Altered coal thickness ft.	$\frac{\text{Original coal thickness}}{\text{Altered coal thickness}}$
Natural Coke	16.1	1.35	84.2	0.75	1.69
Cinder Coal	29.3	1.32	82.3	1.17	1.26
Unaltered Coal	42.5	1.31	81.7		

Natural Coke

$$\text{Weight } CO_2 = \left(\frac{\%\text{ V.M.}}{100} \times \frac{CO_2 + CO_2 \text{ equivalent of } CO}{\text{Total V.M.}} \times \text{Density} \times \text{Volume}\right)_{\text{Original coal - altered coal}}$$

$$CO_2 = \frac{42.5}{100} \times \frac{1}{2} \times 81.7 \times 1.69 \times 0.75 \times 1 - \frac{16.1}{100} \times \frac{1}{2} \times 84.2 \times 0.75 \times 1$$

$$CO_2 = \frac{0.75}{200} \; (5860 - 1354) = 16.9 \text{ lbs.}$$

Cinder Coal

$$\text{Weight } CO_2 = \frac{42.5}{100} \times \frac{1}{2} \times 81.7 \times 1.26 \times 1.17 \times 1 - \frac{29.3}{100} \times \frac{1}{2} \times 82.3 \times 1.17 \times 1$$

$$CO_2 = \frac{1.17}{200} \; (4370 - 2413) = 11.4 \text{ lbs.}$$

We have accounted for only one of the two contacts, and addition of an equal amount assumed to have been lost by alteration of coal overlying the sill doubles this value, giving us 2 x 28.3 = 57 lbs. lost to the sill through two 1 $ft.^2$ contact areas. This compares well with a figure of 51 lbs. of CO_2 calculated to be present in a corresponding columnar volume of the sill having a cross-sectional area of 1 $ft.^2$, and a height equal to an average sill thickness:

CO_2 content of the sill

$$\text{Weight } CO_2 = \frac{\text{Weight per cent}}{100} \times \text{Density (sill, est.)} \times \text{Volume}$$

$$CO_2 = \frac{6.88}{100} \times 160 \frac{\text{lb.}}{\text{ft.}^3} \times \frac{55.5}{12} \text{ ft.} \times 1 \text{ ft.}^2$$

$$CO_2 = 51 \text{ lbs.}$$

Considering the several subestimates and assumptions which led to the final figure of CO_2 lost, this particularly close agreement is probably fortuitous. One would not have been surprised to find calculated CO_2 loss to significantly exceed, perhaps by 50% or more, the amount present in the sill, the excess having been transferred to feeder dikes. Sampling and CO_2 analysis of the latter would be of interest.

The results suggest that devolatilization from one contact is insufficient to account for sill CO_2 content unless the sill is appreciably thinner elsewhere. This allows the prediction that it is unlikely that the sill elsewhere drifts or jumps section to the top or bottom of the coal seam, so presenting only one contact to the coal, or if it does, its areal extent in this stratigraphic position is not large as a porportion of the total extent of the sill. Predictions of this type have obvious utility in planning exploration of this coal seam.

SECTION E

RESIN SAMPLE NHUA 30/7/70-4

NTS Area: SEQ 115G-6

Coal Exploration Licence: No. 14, Jeffrey J. Van Zant

Sample Location: Small exposure of resiniferous coal approximately 1500 ft. southwest of NHUA 31/7/70-1 and 31/7/70-2 locality.

Location Description: West of Locality AA (p.9, Report On Niamodlaoc Mountain Coal Prospect, 1970), on south side of the next stream gully to the south of 31/7/70-1 and 31/7/70-2 locality. Extensive downslope movement in this area suggests many exposures, including this one, are detached or slumped blocks, not outcrop.

Stratigraphic Position of Sample: Apparently same horizons as for 31/7/70-1 and 31/7/70-2, in upper part of upper Amphitheatre formation.

Resin: Golden yellow to orange lump resin whose abundance in resiniferous coal may be as high as 10%.

Resin Analysis (follows): 30/7/70-4, Lump resin hand picked from surface grab sample of coal.

Coal Resin: Golden yellow to orange lump resins were observed in most of the coal occurrences in the Niamodlaoc Mountain area. Of the various Yukon coal occurrences examined, those in this area are the most noticeably resiniferous. Lump resin is much less common in the older Jurassic-Cretaceous coals examined at various localities in the Whitehorse Trough. Qualitatively, this fits a pattern established by observation of coals from different parts of the world, namely, that lump resin is most abundant in the younger coals.

The fact that lump resin can usually be easily separated from the coal by gravity methods was not appreciated during the field work. The following comments are therefore recalled impressions only, and are not based on observations recorded in the field:

1. Abundance of lump resin in some cases varies noticeably with stratigraphic position in a seam.

2. Average abundance varies between the various occurrences.
3. Abundance varies from insignificant amounts up to possibly 5%.
4. At one poorly exposed occurrence, abundance may have been as high as 10%.

Lump resins hand picked from a surface grab sample of the latter occurrence were tested by Western Regional Laboratories, Mines Branch, Dept. of Energy, Mines and Resources. There are innumerable tests which can be performed on resins, but melting point range, solubility in various common organic solvents, and ash content are important ones from the standpoint of possible commercial utilization.

Tests on resins from various parts of the world are reported in the paper "Resins in Coal" (Selvig, 1945). Only one resin described in this paper has a higher melting point (395°C) than the Niamodlaoc sample. The solubility of the latter also compares well with those reported, although a direct comparison is not possible since different solvents or solvent mixtures were employed.

The writer is not aware of any current utilization of lump resin physically separated from coal. The above paper points out (p.1) that coal resins are "probably......similar in many properties to the natural resins of commerce, which are not associated with coal and which are used extensively in manufacturing products such as varnish, lacquer, paint, printing ink, and linoleum." Up until 1945 the main use contemplated for coal resin was in the manufacture of varnish.

Currie Products Limited, Hamilton, Ontario, synthesize a resin using the distillation products of coke ovens. It is not clear to the writer what relationship this resin bears to the resin initially in the coal. Colour is important since the main use is as a filler and binder in rubber products. For many uses, the lighter the colour the better. Currie Products could possibly double their domestic market if a suitable light-coloured resin could be obtained.

The writer has conferred with various individuals involved with coal chemicals, thermoplastics, plastoids and other chemical products, concerning possible commercial applications for the Niamodlaoc coal resins. The consensus is that there is a very good possibility of developing, through industrial research, new products based on these resins. The high melting point indicates that their market value will be higher than that for the natural resins of commerce and also most existing synthetic resins.

The next step is to obtain a large sample of the resins on which to begin industrial research.

March 19, 1971.

Respectfully submitted,

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REFERENCES

Coffin, F. P. (1922) The distillation of coal at low temperatures: American Fuels, Volume I, first ed., New York, McGraw-Hill Book Company, Inc., Chap VII, p. 394-514.

Deane, R. W. (1971) Microscopic examination of a rock sample submitted by Norman H. Ursel Associates Limited: Project No. L. R. 1432, Lakefield Research of Canada Limited, Lakefield, Ontario, January 27, 1971.

Muan, A. and Osborn, E. F. (1965) Phase Equilibria Among Oxides In Steelmaking, Reading, Massachusetts, Addison-Wesley Publishing Company, Inc.

Muller, J. E. (1967) Kluane Lake map-area, Yukon Territory: Geol. Surv. Can., Mem. 340.

Selvig, W. A. (1945) Resins in coal: U.S. Bur. Mines, Tech. Paper 680.

Sperr, F. W. (1922) The technology of coke: American Fuels, Volume I, first ed., New York, McGraw-Hill Book Company, Inc., Chap. III, p. 82-223.

Turner, F. J. and Verhoogen, J. (1960) Igneous and Metamorphic Petrology, second ed., New York, McGraw-Hill Book Company, Inc.

Vine, J. D. (1969) Geology and coal resources of the Cumberland, Hobart and Maple Valley Quadrangles, King County, Washington: U. S. Geol. Surv., Prof. Paper 624.

Williamson, Iain A. (1967) Contact metamorphism of coals: Coal Mining Geology, London, Oxford University Press, p. 49-53.