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Combustion metamorphism in the Hat Creek area, British Columbia

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Conclusions

Preliminary evidence indicates that a large area of coal exposed at Hat Creek has been burnt prior to glaciation. This combustion produced clinker-like yellow and reddish "bocanne–buchites" and pseudovolcanic rocks with peculiar chemical composition and high temperature mineralogy. The effect of combustion on the residual subjacent coal is perhaps less obvious but appears to have caused a reversal in the normal coalification–depth relationship.

Additional studies are suggested to improve the documentation of combustion metamorphism at Hat Creek and to investigate the possibility of similar phenomena at other Tertiary coal deposits in British Columbia.

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BENTOR, Y. K., and KASTNER, M. 1976. Combustion metamorphism in southern California. Science, **193**, pp. 486–488.

BRITISH COLUMBIA HYDRO and POWER AUTHORITY. 1978*a*. Hat Creek Project; final report on bulk sample program, August 1978.

——— 1978*b*. Hat Creek Exploration Project; assessment report, November 1978.

BUSTIN, R. M., HILLS, L. V., and GUNTHER, P. R. 1977. Implications of coalification levels, Eureka South Formation, northeastern Arctic, Canada. Canadian Journal of Earth Sciences, **14**, pp. 1588–1597.

CHURCH, B. N. 1975. Geology of the Hat Creek coal basin. Geology in British Columbia. British Columbia Ministry of Mines and Petroleum Resources, pp. G99–G118.

DUFFELL, S., and MCTAGGART, K. C. 1952. Ashcroft map-area, British Columbia. Geological Survey of Canada, Department of Mines and Technical Surveys, Memoir 262. 122 p.

HÖY, T. 1975. Geology of a Tertiary sedimentary basin northeast of Hat Creek (92I/NW). Geological Fieldwork, British Columbia Ministry of Mines and Petroleum Resources, pp. 109–115.

JESSOP, A. M., and JUDGE, A. S. 1971. Five measurements of heat flow in southern Canada. Canadian Journal of Earth Sciences, **8**, pp. 711–716.

MACKAY, B. R. 1925. Upper Hat Creek coal-deposit, British Columbia. Annual Report of the Minister of Mines, British Columbia, pp. A318–A333.

ROSS, J. V. 1974. A Tertiary thermal event in south-central British Columbia. Canadian Journal of Earth Sciences, **11**, pp. 1116–1122.

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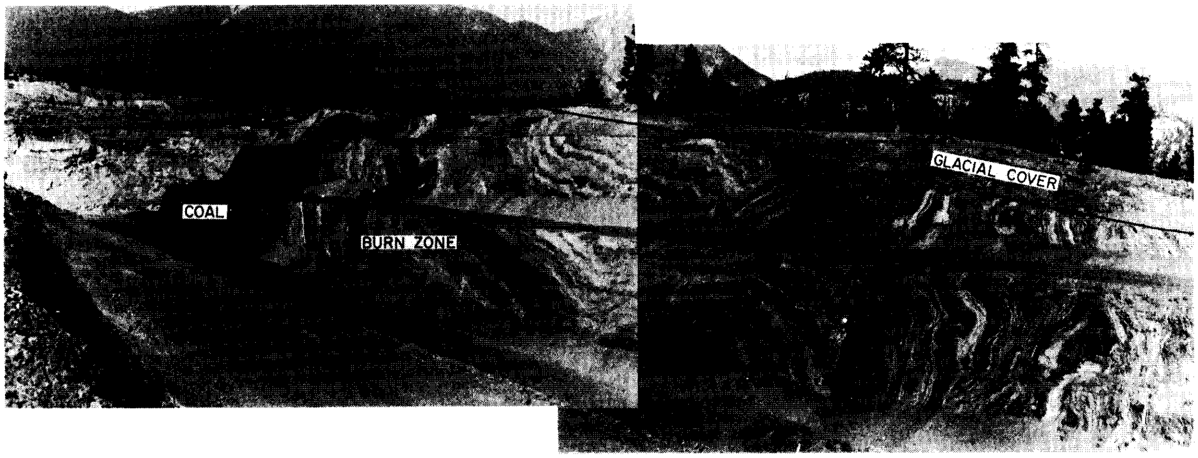

FIG. 3. View of the north wall of trench A showing collapsed "buchites" of the burnt zone (bench height approximately 6 m).

TABLE 1. Chemical analyses

	Oxides recalculated to 100%				Oxides as determined (%)		Molecular norm (%)
	(1)	(2)	(3)		(1)		(1)
SiO_2	46.98	58.78	55.94	H_2O^+	0.50	Quartz	15.1
TiO_2	0.86	1.23	nd	H_2O^-	0.29	Plagioclase (An_{85})	53.5
Al_2O_3	25.86	23.93	30.04	CO_2	0.30	Cordierite	20.6
Fe_2O_3	14.06	10.61	7.93	P_2O_5	0.39	Hematite	10.3
FeO	0.36			S	0.02	Corundum	0.5
MnO	0.19	0.14	0.11	SrO	0.021		
MgO	1.97	1.65	1.47	BaO	0.048		
CaO	8.70	2.22	2.74				
Na_2O	0.50	0.49	1.23				
K_2O	0.52	0.95	0.54				
Total	100.00	100.00	100.00				

NOTES: (1) Cinders from burnt coal (pseudovolcanic rocks); Church (1975, No. 12, p. G106). (2) Bottom ash analysis, burn test on Hat Creek coal; British Columbia Hydro and Power Authority (1978, unpublished report on bulk sample program, pp. 5–9). (3) The average ash analysis from No. 1 Coal Reserve (fusion temperature 1330–1400°C); British Columbia Hydro and Power Authority (1978, unpublished report on Hat Creek coal exploration program, p. 24).

volcanic agglomerate consisting of welded scoriaceous clasts composed of numerous microlites of calcic feldspar, mostly 0.2–0.6 mm in length, and interstitial opaque oxides and glass. However, chemical analysis shows that this material is unlike normal volcanic rock, being unusually enriched in alumina and iron oxide, having a composition more similar to the ash residues obtained from a burn test on Hat Creek (Table 1). X-ray diffraction analysis reveals an abundance of anorthite, cordierite, hematite, tridymite, and cristobalite, agreeing in general with norm calculations.

The effect of metamorphism is also manifest in the physical characteristics of the coal. For example, fresh samples taken from trench A near the burnt zone have a peculiar appearance displaying a hard clean surface with a waxy luster and conchoidal fracture not typical of low rank coal. Determination of the coalification level of this material by reflectance measurements gives a R_0 maximum value of 0.42%, according to the procedures of Bustin *et al.* (1977, p. 1590). A second sample taken from a cut between Dry Lake and trench B, more remote from the burnt zone and at a lower stratigraphic position (approximately 1000 m), yields a R_0 maximum value of 0.36% which is appreciably less than the reflectance value for coal from trench A. This apparent reversal in the normal trend of increasing coalification with stratigraphic thickness (depth of burial) agrees with the visual evidence suggesting metamorphism of the coal by combustion. However, it seems certain that the effect of combustion on the subjacent coal is masked to some degree by regional metamorphism.

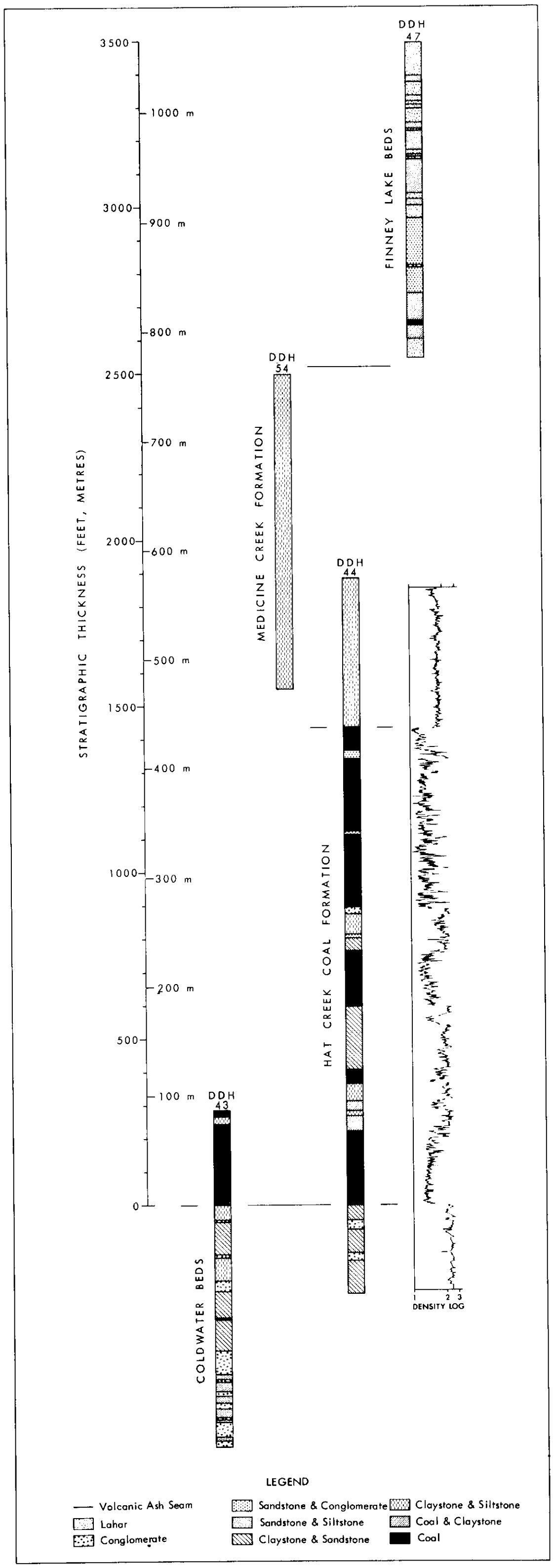

FIG. 2. Drill section of the Hat Creek coal measures and accompanying strata.

central zone of the main valley, underlain mainly by the coal measures and associated sedimentary formations, has been downfaulted forming a graben. This has been achieved principally by movement on a series of north–south tension faults trending in the direction of maximum regional stress. Locally the walls of the graben, particularly at the northern and southern extremities of the basin, are offset somewhat by a series of northwest and northeast-striking conjugate shear faults. Easterly-trending gravity faults in this area appear to be more recent in origin, being superimposed on the graben.

Other subparallel graben-like structures occur to the northeast, exposed along the lower course of Hat Creek and in the Trachyte Hills (Höy 1975, p. 110). In this area Coldwater sandstones and conglomerates are tilted to the east and west in fault-bounded panels and are unconformably overlain by near horizontal dacite and rhyolite outliers of the Kamloops Group.

Metamorphism

It was noted by Church (1975, p. G110) that some of the coal in the Hat Creek area appears to be burnt. Evidence of this is the occurrence of yellow and reddish partly fused shales (bocanne–buchites) above the Hat Creek Coal Formation in the area of the No. 1 Coal Reserve. This observation was confirmed in July 1977 during work by British Columbia Hydro and Power Authority on a 300 m long east–west trench for bulk sampling of the coal.

At the beginning of excavations hard clinker-like material was encountered (trench A, see inset of Fig. 1). The layered structure of this material, although somewhat rumpled and deformed, proved to be continuous with bedding planes in the adjacent coal. A sharp line visible on the walls of the trench cuts sinuously across the strata marking the boundary of the burnt zone (Fig. 3).

The extent of the burnt zone has been established by drilling. The thickest section, about 75 m deep, underlies the Dry Lake gulch near the base of the coal measures. Other profiles of the burnt zone give an average thickness of about 25 m, although thinning and some discontinuity is apparent. The present area of the burnt zone, amounting to about 3.5 km^2 buried under a mantle of glacial alluvium, is evidently only an erosional remnant of a much broader area of altered rocks. Similar reddish rocks and soils can also be seen 8.5 km to the south near the No. 2 Coal Reserve.

Reexamination of MacKay's so-called volcanic dyke on the south wall of Dry Lake gulch (MacKay 1925, plate opposite p. A320) indicates that this rock has been reconstitued by fusion and recrystallization. In thin section a typical sample resembles

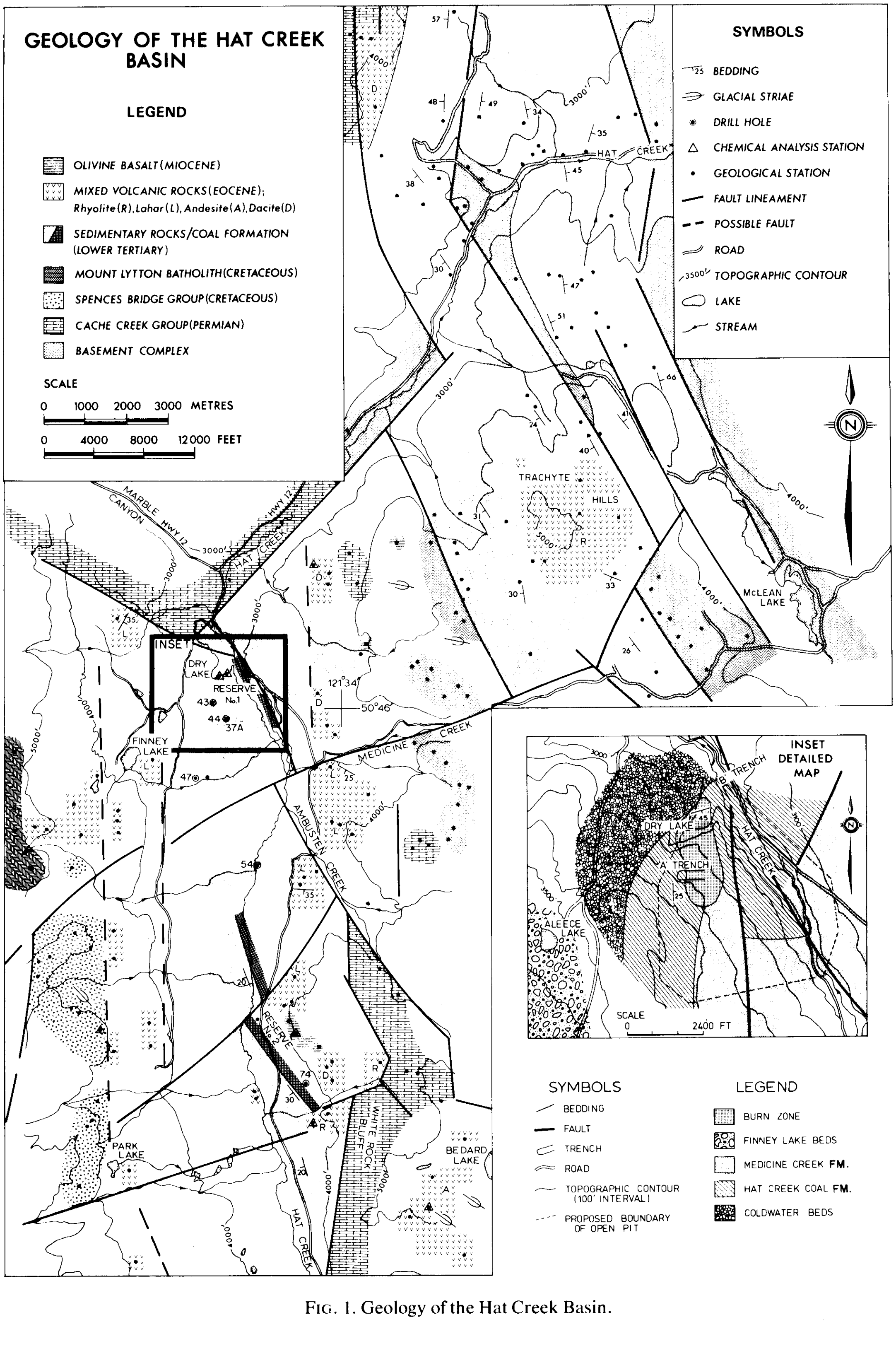

FIG. 1. Geology of the Hat Creek Basin.

Un gisement de charbon subbitumineux couvrant une région de plusieurs kilomètres carrés près de Hat Creek a brûlé au cours des temps préhistoriques, probablement à la suite de la combustion spontanée. Le produit de cette combustion est une roche jaune à rougeâtre, partiellement fondue, avec des minéraux de haute température et une composition chimique différente des roches volcaniques. L'effet du métamorphisme thermique à moins de quelques centaines de pieds de la zone brûlée s'est manifesté par une légère augmentation du degré de houillification au-dessus des degrés de métamorphisme régionaux.

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Introduction

A rock shown to be a volcanic dyke by MacKay (1925) found near the No. 1 Coal Reserve of the Hat Creek coal deposit, 20 km west of Cache Creek, B.C., now appears not to be volcanic in origin but rather the fused residue of burnt coal. This paper gives some preliminary evidence supporting the "burnt coal" theory and suggests that large areas underlain by coal at Hat Creek may have been affected by natural combustion in prehistoric times.

It is generally known that low rank coals are susceptible to spontaneous combustion. All that is required in many cases is the loose stacking of broken coal and average to warm temperatures. It has been demonstrated that within several days temperatures can rise steadily due to oxidation from 30–80°C at which time fire might suddenly break out (unpublished report on the bulk sample program at Hat Creek by British Columbia Hydro and Power Authority). Such combustion can generate temperatures to more than 1400°C causing partial fusion of ash residues and clay impurities and thermal metamorphism of the surrounding rocks.

The phenomena of natural combustion of coal and carbonaceous beds is becoming widely recognized and studied. Bentor and Kastner (1976) report examples from Israel, Iran, India, Australia, California, and elsewhere, which involve a great diversity of host rocks including shales, sandstones, carbonates, and phosphates, etc. Owing to the wide variation in composition of the host rocks, a large number of high temperature minerals have been identified in such deposits. According to Bentor and Kastner the fusion of the host rocks in some cases also produces pseudomagmas having many of the features of small-scale igneous intrusions, including sill and dyke-like forms.

Geological Setting

The geological setting of the Hat Creek coal deposit and the location of a major burnt zone is outlined in Fig. 1. The principal lithological units in the area consist of Tertiary coal, clastic sedimentary, and volcanic formations which rest unconformably on Cretaceous volcanic rocks and metamorphosed Paleozoic carbonates and greenstones.

Much of the detailed stratigraphic information now available on the Tertiary rocks is the result of a recent intensive drilling program sponsored by British Columbia Hydro and Power Authority in the valley on the upper course of Hat Creek. This work shows that the coal-bearing unit, referred to as the Hat Creek Coal Formation, is almost everywhere succeeded by a thick claystone unit, the Medicine Creek Formation, which in turn is unconformably overlain by a volcaniclastic sequence known as the Finney Lake Beds. The Finney Lake volcaniclastic rocks appear to be contemporaneous with outlying rhyolite, dacite, and andesite lavas assigned to the Kamloops Group by Duffell and McTaggart (1952).

Owing to the great stratigraphic thickness of the Tertiary rocks, more than 1300 m in the centre of the basin, few drill holes have penetrated to the base of the section (Fig. 2). An equally thick succession of sandstones, conglomerates, and siltstones comprising the Coldwater Beds is exposed mainly to the northeast of the drilling area along the lower course of Hat Creek. These rocks are largely fluvial in origin and are thought to partly underlie, and to be partly equivalent to, the Hat Creek Coal Formation and the Medicine Creek Formation.

The age of the coal measures is believed to be Early Tertiary, bracketed by a date of 51.2 ± 1.4 Ma on overlying rhyolite of the Kamloops and a 91.6 ± 3 Ma determination on much older feldspathic basalt tentatively assigned to the Spences Bridge Group which lies unconformably below the Tertiary beds. (These ages have been supplied by J. Harakal at the University of British Columbia and are corrections of previous data published by Church (1975, pp. G107 and G110), the corrections being based on newly accepted decay constants proposed by Steiger and Jäger (1977) for the potassium–argon method.)

The structure of the Hat Creek basin is straightforward and simple in broad aspects. The

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An area of several square kilometres of subbituminous coal at Hat Creek has been burnt in prehistoric times, probably as a result of spontaneous combustion. The product of this combustion is a yellow and reddish partly fused rock with high temperature minerals and chemical composition unlike volcanic rocks. The effect of thermal metamorphism within a few hundred feet of the burnt zone is an apparent slight increase in coalification levels above regional metamorphic grades.

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