CHAPTER 8 PROSPECTING FOR INDUSTRIAL MINERALS IN CENOZOIC ROCKS

INTRODUCTION

This investigation has covered the occurrences of bentonite, kaolinite, zeolites, volcanic glass, perlite, and diatomaceous earth in south-central British Columbia. The occurrence of any of these industrial minerals requires a combination of suitable hostrocks and the appropriate physical and chemical conditions during and following the formation of the industrial mineral. The presence of rocks, that may act as suitable hosts for an industrial mineral deposit, may be gleaned from the geological literature. The presence of suitable environments for the development of industrial minerals may be interpreted from the age and geological setting of the enclosing stratigraphy and in part from any data which reflect the temperatures that have affected the hostrocks. Ultimately, the discovery of any occurrrence of an industrial mineral rests upon the prospector's ability to recognize it.

SUITABLE HOST ROCKS AND DETERMINATIVE TESTS FOR INDUSTRIAL MINERALS

Sedimentary or volcaniclastic sedimentary rocks are suitable hosts for the development of bentonite, kaolinite, and zeolites. Although these rocks usually have an abundant clay or silt-sized fraction, hostrocks suitable for zeolite occurrences may contain lapilli up to a few centimetres in size. To be suitable, the depositional environment should be subaqueous, as indicated by the presence of plant debris in the sediments, not subaerial. At least initially, a subaqueous environment insures the presence of a fluid that will modify the original sedimentary material, be it volcanic glass for bentonite or zeolite occurrences, or extensively weathered bedrock in kaolinite occurrences. Unfortunately the Cenozoic shale and siltstone hosts for bentonite and kaolinite deposits are poorly exposed and their presence may have to be interpreted from any unstable topography mentioned in the literature or seen in aerial photographs. In addition, bentonite-rich rocks yield a characteristic "popcorn" soil (McMechan 1983, Plate V, p.18) resulting from successive expansion and contraction cycles caused by wetting and drying of the soil. Bentonite deposits develop from waterlain volcanic ash or later-altered ash and lapilli tuff of intermediate composition. Kaolinite occurrences usually lie near unconformities and are the product of a period of intense weathering of the underlying granitic or quartzofeldspathic rocks. X-ray diffractograms of samples from occurrences not only determine the presence of kaolinite and other clay minerals, but also yield a qualitative estimate of the mineral content. However, pyrometric cone equivalent tests are required to determine the refractory nature of the samples.

Rhyolite and dacite ash and lapilli tuff act as hosts for zeolite occurrences. In British Columbia all the known bedded zeolite occurrences probably developed in open, nonmarine hydrologic systems (Hay and Sheppard, 1977) in contrast to the closed systems (Surdam, 1977) present in alkaline lakes. The discovery of dawsonite may indicate that closed systems existed locally. The percolation of groundwater in an open system can develop thick, areally extensive zeolite deposits of economic importance. Although extensive zeolitization decreases the density of the hostrock, and increases its porosity and whiteness, these changes are easily missed in the field. The presence of zeolites as coatings on joints and fillings of amygdules in nearby volcanic rocks suggests that extensive zeolitization may have occurred, but only the application of x-ray diffraction powder methods to samples will identify the zeolite species present and yield a qualitative estimate of its amount.

Thin-section examinations usually misidentify the finely crystalline, low birefringent zeolites as devitrified glass instead of heulandite-clinoptilolite, or as potash feldspar instead of laumontite.

Glassy dacite or rhyolite flows and hypabyssal intrusions are not only suitable candidates for the occurrence of volcanic glass, but also perlite. Rhyolite, and particularly dacite, are fairly common in Eocene volcanic rocks, but glasses are rare and not reported from the Miocene and younger Chilcotin Group. Although the characteristic crumbly outcrop and microbotryoidal weathering surface of perlite are helpful distinguishing characteristics, to determine qualitatively the perlitic nature of the glass requires a blowtorch expansion test. The expansion of perlite upon heating depends on retention of the water in the glass. Because devitrification of the glass spoils its perlitic nature, the volcanic glass should be unaltered. The presence of vesicles and lack of mineral coatings on joints or fillings of amygdules in nearby volcanic rocks are encouraging signs that the glass has not been altered. Near the Frenier deposit (P2, Map 7), Mathews and Rouse (1984, p.1135) noted

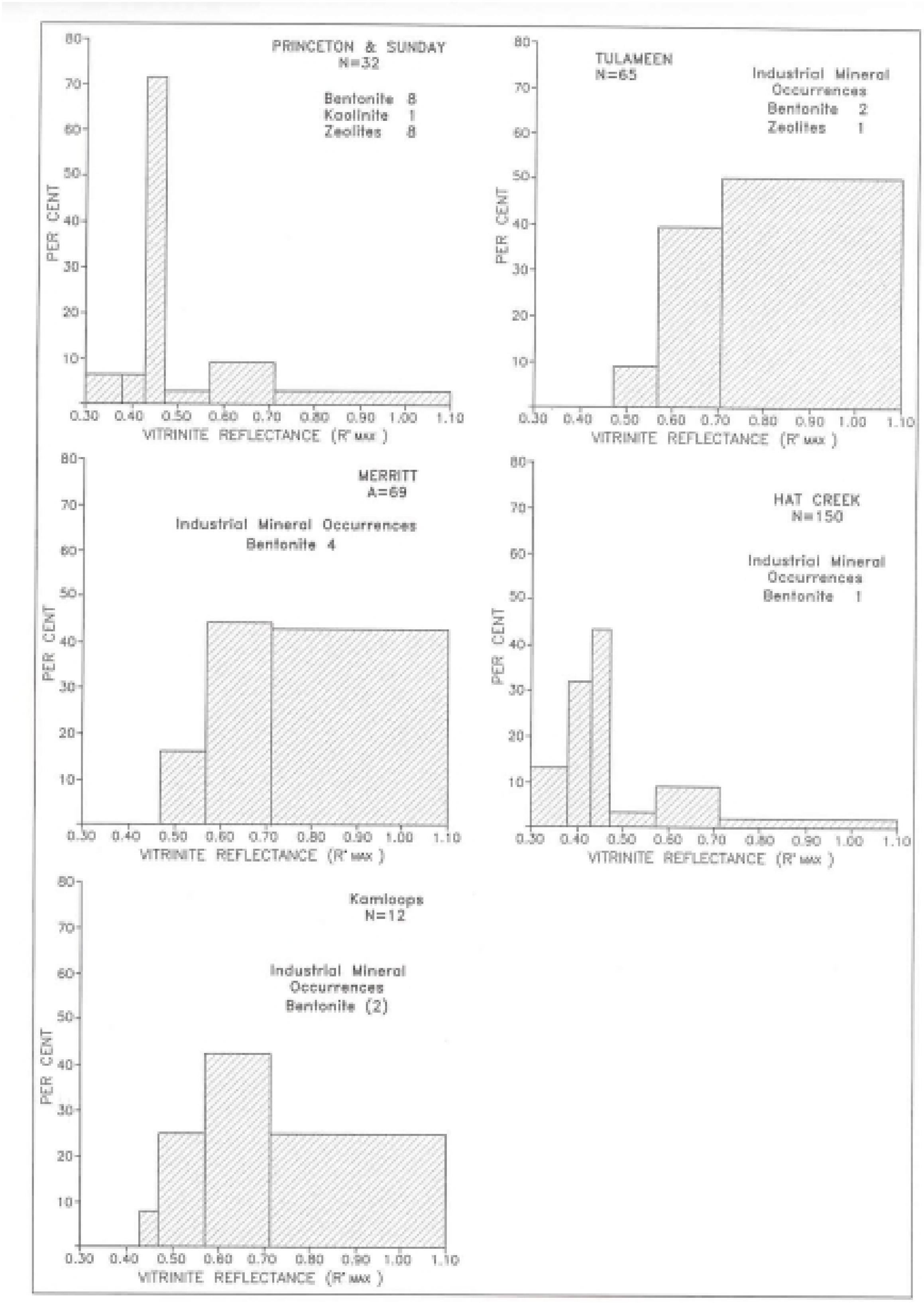

Figure 8.1. Vertical bar graphs showing thedistribution of vitrinite reflectance (Ro) and coal rank of Eocene coals for some of the industrial mineral bearing successions of Eocene age in southern British Columbia.

the lack of mineral coatings and vesicle fillings in the Eocene volcanic rocks.

Diatomite and diatomaceous earth occurrences are widespread in the Miocene and younger sedimentary Deadman River and Fraser Bend formations that fill Miocene channels up to 450 metres deep beneath the basalt flows of the Chilcotin Group. Some diatomite occurrences are compact, brittle and require crushing and screening for industrial use, such as the material from the Red Lake deposit. Others are soft, chalky and need sintering for use, such as the material from the Buck Ridge deposit south of Quesnel. Because natural exposures are slumped and weathered, the two types and amounts of impurities present cannot be distinguished without drilling. Southeastward from Clinton and northward from Gaspard Creek, fluviatile sediments, rhyolite tephra and accompanying diatomaceous sediments fill the northwestward to northward-draining Miocene channels. In the channel fill, unbedded rhyolite tephra up to 125 metres thick (Figure 4.1) indicates a massive filling and disruption of the pre-existing drainage system with the development of silica-rich lacustrine environments favourable to the growth of diatoms. Because the Miocene and younger sediments weather easily and are preferentially covered by slide debris from the overlying olivine basalt flows, outcrops of diatomaceous sediments are very rare. All the known occurrences are within the sediments of major channel fillings, such as Miocene Bonaparte, Miocene Deadman and Miocene Snohoosh channels (OF 1989-21), and Miocene Fraser channel north of Gaspard Creek (Map 7), or in sedimentary intercalations in the basalt flows immediately overlying these channels. As a result of this distribution prospecting should be restricted to the margins of extensive areas of basalt flows of the Chilcotin Group where present erosion is deep enough to expose the underlying Miocene channel sediments. In the field, the low density and stickiness to the damp tongue of diatomite-bearing samples are characteristic. The stickiness results from the absorption of moisture by the highly porous and permeable diatoms. If the sample has a high clay content, within a few dampenings, it will feel slick to the tongue. By scraping a minute quantity from a suspected diatomite-bearing sample onto a glass slide, capping it with a cover slip and using a refractive index liquid of 1.54 or less (mineral oil purchased from a drug store will suffice) to produce an oil-immersion grain mount, you can check a diatomite field identification. Because of the small diameter of the diatom genera present in most diatomaceous sediments in British Columbia, you will need to look at the oil immersion grain mount under transmitted light at a magnification of at least 60 power.

SIGNIFICANCE OF COAL RANK AND VITRINITE REFLECTANCE

All of the industrial minerals studied in this investigation are temperature sensitive. Their sensitivity ranges from the most sensitive, diatomite, through zeolites, bentonite and perlite, to the least sensitive mineral, kaolinite. Vitrinite reflectance and data on coal rank have been gathered from most of the mapped areas (Figure 8.1) and are tabulated together with industrial mineral occurrences from these and other areas which have an industrial mineral potential (Table 8.1). Because organic maturity data, specifically vitrinite reflectance, can be interpreted in terms of temperatures affecting the rocks since their deposition, the

TABLE 8.1
RELATIONSHIPS AMONG VITRINITE REFLECTANCE, COAL RANK AND THE OCCURRENCE OF INDUSTRIAL MINERALS IN CENOZOIC AND MESOZOIC ROCKS

Area	Vitrinite Reflectance and/or Coal Rank*	Number of Analyses	Occurrences
Lang Bay (92F)	0.75-0.95	6	1 kaolinite
Clayburn (92G)	0.67	1	1 kaolinite
Princeton (92H)	sb:B and sb:C	32	8 bentonites; 8 zeolites; 1 kaolinite
Tulameen (92H)	hb:A and hb:B	65	2 bentonites; 1 zeolite
Merritt (92I)	hb:A and hb:B	69	4 bentonites
Kamloops (92I)	hb:B and hb:C	12	2 bentonites
Hat Creek (92I)	sb:B and sb:C	150	1 bentonite; 1 kaolinite
Gang Ranch (92O)	hb:B and hb:C	5	5 bentonites; 5 zeolites
Chu Chua (92P)	hb:A and hb:B	4	none reported
Quesnel (93B)	sb:B and sb:C	9	bentonite present
Cheslatta Falls (93F)	0.36	1	waterlain ash present
Nazko (93G)	0.22 and 0.26	2	waterlain ash present
Bowron (93H)	hb:B and hb:C	16	none reported
Telkwa (93L)	hb:A and mb	15	none reported
Sustut (94D)	hb:A and mb	6	zeolites widespread

* sb:C, sb:B — sub-bituminous:C, sub-bituminous:B;
hb:C, hb:B, hb:A — high-volatile bituminous:C, high-volatile bituminous:B, high-volatile bituminous:A;
mb — medium-volatile bituminous.

TABLE 8.2
STABILITY LIMITS OF INDUSTRIAL MINERALS IN TERMS OF
COAL RANK AND VITRINITE REFLECTANCE

Industrial Mineral	Stability Limits in Terms of	
	Vitrinite Reflectance	Coal Rank
Diatomite	lower: 0.0 upper: about 0.30	no rank ligniteA(boundary)
Zeolites	Lower about 0.35 upper: 1.00 to 1.10 range	within lignitefield near the upper limit of high volatile A bituminous field
Bentonite	lower: within lignite B upper: 1.10 to 1.50 range	less than 0.25 within the medium-volatile bituminous field
Kaolinite	lower: 0.0 upper: more than 4.6	no rank graphite

* Zeolite data are for heulandite-clinoptilolite. The upper stability limit should be reduced in the range of 0.1 to 0.30 for the other industrially important zeolites mordenite, erionite and chabazite.

data can be used to target prospecting, as summarized in Table 8.2.

The opaline silica forming diatoms recrystallizes with the infilling of the skeletal voids at very low temperatures and depths of only a few kilometres. This renders the diatoms unuseable as an industrial mineral. Because they recrystallize easily, the search for them should be restricted to young rocks that have never been deeply buried. In southern British Columbia, the Miocene and younger Chilcotin Group are unmetamorphosed (Read *et al*., 1991a), but older rocks, such as the Eocene sedimentary and volcanic rocks are mostly in the zeolite metamorphic facies and the few occurrences of Eocene diatoms are recrystallized, such as in the Princeton basin at Vermilion Bluffs (Hills 1962, p.49), which lies within a kilometre of a vitrinite reflectance measurement of Romax = 0.60 (OF 1987-19), or near Cache Creek at showing Z4 (OF 1988-30). In general, if the vitrinite reflectance of organic material from the enclosing sediments exceeds about 0.30, or the coal rank is greater than lignite B, diatoms will be recrystallized.

Zeolites are present in rocks of the zeolite metamorphic facies (Table 8.3), but the industrially useful zeolites are only stable in the low temperature and pressure area of the zeolite facies field (Figure 8.2). Because these zeolites, such as erionite, mordenite, chabazite and heulandite-clinoptilolite, are highly hydrated and/or have large channelways in their crystal structures, they decompose at low temperatures and pressures within the zeolite facies to other minerals which do not have industrial applications. Organic maturity data (Read *et al*., 1991a) are available for stratigraphic successions containing heulandite-clinoptilolite which is the most widespread industrial zeolite in the Canadian Cordillera. These data show that heulandite-clinoptilolite is widespread in appropriate hostrocks that are part of successions containing sub-bituminous and high-volatile bituminous coals. Widespread heulandite-clinoptilolite-bearing tuffs from the upper part of the Sustut Group, the Brothers Peak Formation (Read and Eisbacher, 1974), combined with a few vitrinite reflectance measurements (McKenzie, 1985) yield sparse data to suggest that heulandite-clinoptilolite disappears near the coal rank boundary between the high-volatile bituminous A and medium-volatile bituminous. At present, industrially useful zeolites are not known to occur in successions containing medium-volatile bituminous or higher rank coals. A vitrinite reflectance (Romax) in the range 1.00 to 1.10 probably indicates that conditions exceeded the stability field for heulandite-clinoptilolite during the thermal history of the succession. In the Canadian Cordillera, organic maturity data are lacking for the other industrial zeolites, but as a first approximation, similar or slightly lower values for organic maturity parameters should be expected to represent the upper limit of stability for erionite, mordenite and chabazite.

Bentonite is widespread in industrial zeolite bearing successions in the Canadian Cordillera from coal ranks as low as the lignite-bearing succession at Hat Creek (showing B2, OF 1990-23) to the high-volatile bituminous A bearing succession in the Merritt basin. The apparent absence of montmorillonite along the western edge of the Okanagan Metamorphic Complex (Figure 1.1) may result from a lack of suitable hostrocks or it may reflect the fact that Eocene rocks were subjected to temperatures which exceeded the stability limit of montmorillonite, the principal mineral in bentonite. Along the western edge of the metamorphic complex, a few vitrinite reflectance and coal analyses indicate a low-volatile bituminous rank (Read *et al*., 1991a). In the absence of further organic maturity data, the upper thermal stability limit for montmorillonite probably lies within the medium-volatile bituminous rank between vitrinite reflectance values (Romax) of 1.10 to 1.50.

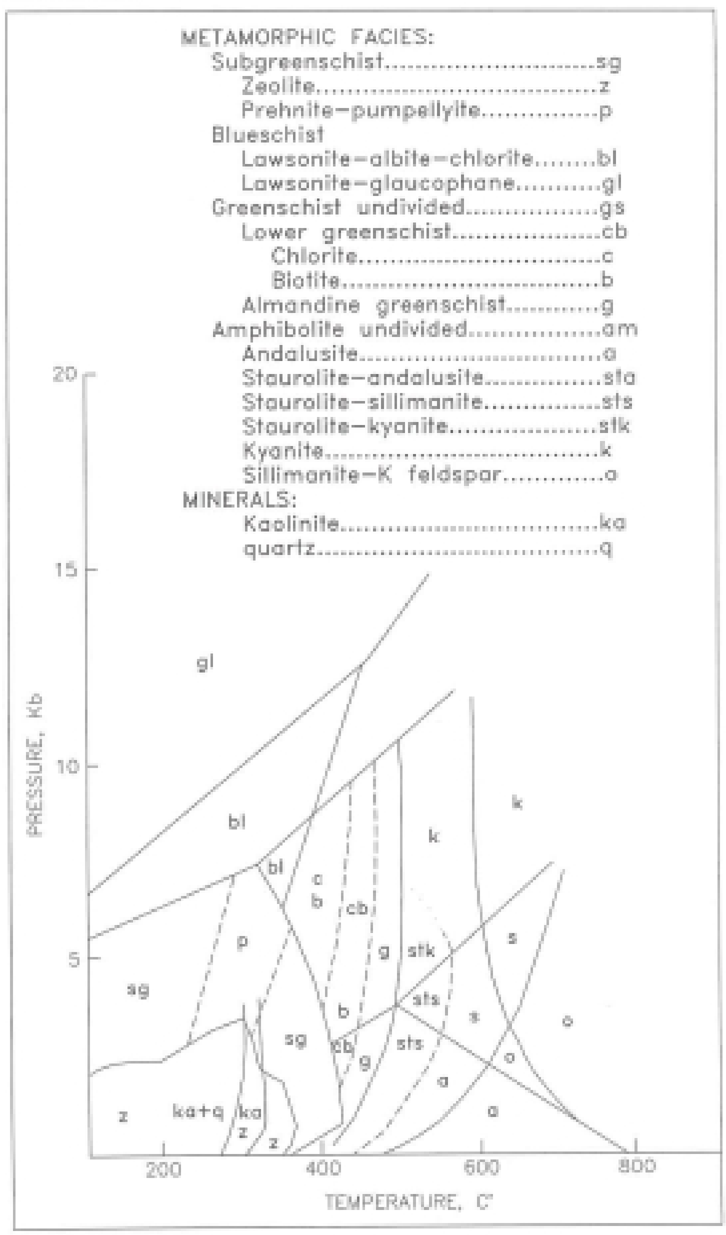

Figure 8.2. A pressure-temperature grid showing the distribution of metamorphic facies [slightly modified from Greenwood's diagram in Read *et al.* (1988) by the addition of the stability fields for kaolinite and kaolinite+quartz].

The extensive stability field of kaolinite (Figure 8.2) shows that the mineral is stable over a wide range of pressure-temperature conditions and may occur in rocks subjected to metamorphic conditions typical of the subgreenschist facies (zeolite and prehnite-pumpellyite) (Table 8.3). A wide range in vitrinite reflectance values from successions containing kaolinite occurrences or deposits reflects its large stability field. In the kaolinite-bearing sediments of Hat Creek, most of the vitrinite reflectance values lie in the range 0.38-0.47 (Figure 8.1). At the Fairley kaolinite showing (K1, Map 1) in the Princeton basin nearby Romax values lie in the range 0.43-0.47, a value of 0.67 comes from the kaolinite deposit at Clayburn (Soares, 1982), the nearest values to the Lang Bay deposit (Hora, 1989) lie in the range 0.75- 0.95 (Kenyon and Bickford, 1989), and the Groundhog coal basin, which has widespread kaolinite in the Cretaceous sediments, has vitrinite reflectance values in the range 2.6-4.6 (Moffat, 1985). As a result, the geological setting common to kaolinite deposits is much more useful than organic maturity in restricting the search area.

INDUSTRIAL MINERAL POTENTIAL IN CENOZOIC AND MESOZOIC ROCKS

Because the prospecting rationale outlined above is important in assessing the potential for industrial mineral occurrences in the Cenozoic and Mesozoic rocks of British

TABLE 8.3
CORRELATIONS AMONG COAL RANK, FIXED CARBON (F.C.), Btu/lb,
VITRINITE REFLECTANCE (Ro), TAI, CAI AND METAMORPHIC FACIES OR ZONES
(from Read *et al.*, 1988)

Rank	F.C.	R^{0}_{max}	TAI	CAI	Metamorphic Facies or Zones
				7.0	
					Biotite & Garnet Zones
				6.0	
					Chlorite Zone
				5.0	
				5.0	
Meta-anthracite					
	98	4.00	4.0	4.0	
Anthracite					**Prehnite Pumpellyite**
	92	3.00			
Semi-anthracite					
	86	2.05	3.75		
Low-volatile bituminous				3.5	
	78	1.50	3.5	3.0	
Medium-volatile bituminous					
	69	1.10	3.0	2.0	
High-volatile bituminous A					
	14,000*	0.71	2.75		
High-volatile bituminous B					
	13,000*	0.57		1.5	**Zeolite**
High-volatile bituminous C					
	11,500*	0.47	2.5		
Sub-bituminous A					
	10,500*				
Sub-bituminous B					
	9,500	0.43			
Sub-bituminous C					
	8,300	0.38	2.25	1.0	
Lignite A					
	6,300				**Unmetamorphosed**
Lignite B					

* Moist, mineral matter-free B.t.u./lb

Columbia, particularly southern British Columbia, it is presented in point form before proceeding to specific areas.

The geological factors important in the development of industrial minerals in Cenozoic and Mesozoic rocks are:

Kaolinite, bentonite, zeolites and diatomite develop in Cenozoic and Mesozoic sedimentary rocks; only volcanic glass and perlite are restricted to volcanic rocks of the same age.

Occurrences of diatomaceous earth are restricted to Miocene and younger sediments spatially associated with rhyolite tephra.

Waterlain dacite and rhyolite tuffs of Eocene or older age are suitable hosts for industrial zeolites, except on the Queen Charlotte Islands,

Waterlain intermediate ash and lapilli tuff of Miocene or older age are suitable hosts for bentonite.

Volcanic glass, and particularly perlite, require a water-free, low-temperature environment for their preservation.

Kaolinite is stable over a wide range of temperature and pressure conditions, but its occurrences lie close to deeply weathered unconformities developed on granitic or compositionally equivalent volcanic rocks.

Because each of these industrial minerals is stable within a different range of pressure and particularly temperature conditions, the stability field of each industrial mineral can be expressed in terms of coal rank and vitrinite reflectance (Table 8.2).

The overriding economic factors in transforming an industrial mineral occurrence into an industrial mineral deposit are development of a product that meets a market need, and proximity of the deposit to that market.

DIATOMACEOUS EARTH

In southern British Clumbia, all occurrences of diatomaceous earth are in the sediments filling the Miocene drainage system buried beneath basalt flows of the Chilcotin Group, or in thin sedimentary intercalations in the immediately overlying basalt flows. The potential for finding additional deposits lies in tracing the very poorly exposed sedimentary fill of the drainage system which extends northwestward from Deadman River to Bonaparte River north of Clinton, and probably projects farther to the Fraser River near Gang Ranch.

Near Clinton, two unexplored occurrences lie within 4 kilometres of the railway (showings D1 and D2, OF 1989-21). From Gang Ranch, the Miocene drainage system continues northward, probably close to the present course of the Fraser River, for another 230 kilometres to at least Prince George. Many of the known diatomaceous earth occurrences along this length are close to rail transportation. Because of the poor exposure of Miocene sediments and the extensive overburden along the river, many occurrences await discovery.

To the west, in the Chilcotin-Nechako area, an occurrence of diatomite on the south side of Tsacha Lake (Tipper, 1963) is associated with pumice and underlies basalt flows of the Chilcotin Group. The stratigraphic setting matches that of diatomite occurrences in the Bonaparte-Deadman river area (Maps 4 and 5) and implies that other occurrences, lying in buried Miocene channels, await discovery in this area of deep overburden.

A small Miocene drainage system underlies remnants of basalt flows east of Vernon and Kelowna (Mathews, 1988), Examination of drill core collected by Z.D. Hora from the Grouse Creek, Fuki, Hydraulic Lake, Lassie Lake, McCulloch and Cup Lake uranium properties southeast of Kelowna shows that diatomaceous earth is present only at Cup Lake where a compact and brittle variety is widespread, It is in excess of 8 metres thick and occupies a southeast-draining channel.

On the Queen Charlotte Islands, beds of marine diatomaceous clay in the Skonun Formation, up to 4 metres thick, form cutbanks along the lower Yakoun River between Black Bear and Canoe creeks (Sutherland Brown, 1968).

At most occurrences the combination of poor exposures and lack of drilling precludes any assessment of the dimensions, purity and compactness of the diatomaceous earth.

ZEOLITES

At present, all occurrences of industrial zeolites in British Columbia are heulandite-clinoptilolite developed in waterlain rhyolite and dacite tephra under open hydrologic conditions. These zeolitized tephra horizons form intercalations in sediment-rich Eocene and Upper Cretaceous terrestrial successions. With the exception of the Queen Charlotte Islands, Eocene and Upper Cretaceous sediments containing waterlain vitric or crystal-vitric tuffs of felsic to intermediate composition offer the best potential for industrial zeolite occurrences.

Organic maturity data curtail the vitrinite reflectance of potential zeolite hostrocks to the Romax range of 0.30 to 1.00-1.10 (Table 8.2). The combination of rocks of suitable age, bulk composition and organic maturity probably occurs in the Eocene exposed near Kamloops and northward up the North Thompson River. X-ray diffractograms of some tuffs from the Kamloops area indicate the presence of heulandite-clinoptilolite and analcime (Read, 1978).Farther to the southeast, Eocene rocks of suitable bulk composition occur in the Springbrook and Kettle River formations, but a few vitrinite reflectance values in the range 1.69 to 1.79 (Mathews and Bustin, 1986; Read *et al.*, 1991a) from the Springbrook suggest that the stability limit of industrial zeolites may have been exceeded because of the Eocene deformation and metamorphism affecting the high grade metamorphic rocks composing the south end of the Omineca Belt. Only the sedimentary and volcaniclastic rocks of the White Lake Formation with a few Romax values in the range 0.69 to 0.95 (Mathews and Bustin, 1986; Read et al., 1991a), may lie within the stability field of industrial zeolites.

Northwest of Kamloops, up the Fraser River, Lower Oligocene, Eocene and probably Upper Cretaceous sediments lie within the stability field of industrial zeolites. Although Tertiary sedimentary rocks are not common in the Chilcotin-Nechako area, earlier age assignments of rocks in this area to a Miocene and(?) later unit, and a Paleocene(?), Eocene and Oligocene unit (Tipper 1959, 1961, 1963, 1969) may be locally incorrect. Work by Rouse and Mathews (1988) showed that rocks outcropping along the Nechako River near Cheslatta Falls are not Miocene and (?) later as suggested by Tipper (1963), but instead Late Eocene in age, whereas at Nazko they corroborated Tipper's Paleocene(?) to Oligocene assignment (1961) with a Middle Eocene age.

The significance of the age of the stratified units is that Miocene and younger sedimentary rocks probably contain only diatomite occurrences, whereas Eocene and possibly Upper Cretaceous units will have an organic maturity suitable for bentonite and zeolite occurrences. In the absence of more reliable ages for the Tertiary units in the Chilcotin-Nechako area, all potential hostrocks, such as waterlain tephra, should be sampled and subjected to x-ray diffraction. Of the very few samples tested to date, x-ray diffractograms of samples of Eocene waterlain tephra from east of Horsefly on Black Creek road (Lay, 1930) and 3 kilometres north of Francois Lake on the road to Burns Lake (Armstrong, 1949) indicate that zeolites are present in some of the waterlain tuffs.

Farther to the north, in the upper part of the Sustut Group, waterlain rhyolite crystal-vitric tuff of the Brothers Peak Formation is extensively altered to heulandite-clinoptilolite (Read and Eisbacher, 1974).

The sediments of the Nanaimo Group are weakly altered by zeolites with laumontite acting as a cement and replacement of plagioclase (Stewart and Page, 1974). Heulandite is restricted to the uppermost Gabriola Formation. The sparse but widespread occurrence of laumontite probably reflects the lack of waterlain felsic to intermediate vitric ash in the sediments.

In the Queen Charlotte Islands, zeolitized tuffs have not been reported from the Tertiary in spite of the suitable bulk composition of the rocks and range of organic maturity. Although Read (1979) made a petrographic and x-ray diffraction examination of volcanic rocks collected by Sutherland Brown (1968) during his studies of the islands, zeolitized rocks were absent. Because the samples were as fresh as possible, the collection preferentially excluded the altered rocks so typical of zeolitized tephra and should not be considered a good test of the zeolite potential of the area. Zeolitized tephra containing erionite, chabazite or mordenite as the dominate zeolite species are presently unknown in British Columbia.

BENTONITE

Montmorillonite, the major mineral constituent of bentonite, is widespread in altered, waterlain ashes of intermediate composition that are Miocene and earlier Tertiary in age. Eocene sediments are a particularly favourable host for bentonite occurrences, but the organic maturity of the sediments may restrict the development of bentonite to hostrocks that have Romax values in the range of less than 0.25 to 1.10-1.50 (Table 8.2).

The combination of rocks of suitable age, bulk composition and organic maturity occurs in the Eocene exposed near Kamloops and possibly northward up the North Thompson River. X-ray diffractograms of tuffs from the Kamloops area indicate the presence of dominant montmorillonite in some tuffs of the Tranquille Formation (Read, 1977).

To the southeast, the development of bentonite may be curtailed in sediments of the Springbrook and Kettle River formations because, in some areas, they may have been heated beyond the stability field of montmorillonite, and in others waterlain intermediate ash may be absent. Northward along the Fraser River, Eocene and Lower Oligocene sediments outcrop, and at Quesnel the Lower Oligocene Australian Creek Formation contains swelling clays (Rouse and Mathews, 1979) in a succession with sub-bituminous B and C coals (Graham, 1978).

West of the Fraser River, a widespread cover of Tertiary volcanics and local thin sediments underlies the Chilcotin-Nechako region, and provides suitable hostrocks for bentonite occurrences, but the only occurrence known is on the banks of the Nechako River at Mile-post 19 on the Canadian National Railway west of Prince George (Cummings and McCammon, 1952). As explained, the uncertainty of the ages of Tertiary stratified rocks in the Chilcotin-Nechako area means that all waterlain ashes should be examined for bentonite.

On the Queen Charlotte Islands the Upper Oligocene to Upper Miocene Massett Formation contains some pyroclastic rocks and, along the west coast of Graham Island, intercalated sedimentary units (Hickson, 1989). Some of the tephra should form a suitable host for bentonite, and Sutherland Brown (1968, p. 176) reported bentonite from the formation in a road quarry on Blackwater Creek near Juskatla.

KAOLINITE

Kaolinite occurs in primary deposits formed by intense chemical weathering, and is generally more abundant in subtropical and tropical regions than in more temperate zones (Carroll, 1970).

In southern British Columbia, most of the occurrences or deposits of kaolinite lie close to either a Cretaceous or Eocene unconformity. In the Upper Cretaceous rocks of the Nanaimo Group, Bell (1957) noted that the flora include a number of genera that are now confined to warm temperate, subtropical or tropical floras and concluded that the climate during the deposition of the late Coniacian to late Campanian (Upper Cretaceous) plant-bearing formations of the group was probably warm temperate, and G.E. Rouse (personal communication, 1991) prefers a frost-free subtropical climate. For the Middle and Late Eocene, paleoclimatic interpretations based on palynomorph assemblages in the Canadian Cordillera indicate that subtropical conditions prevailed and were followed by a sharp temperature drop in the Early Oligocene (Rouse, 1977; Rouse and Mathews, 1988). As a result, Cretaceous and intra-Eocene and sub-Eocene unconformities of low relief in tectonically inactive areas might receive deep weathering. Where the underlying rocks are granitic or quartzofeldspathic, kaolinite may have accumulated. At Blue Mountain, Lower Cretaceous (Albian) sediments overlie diorite (Mustard and Rouse, 1991). Among the sediments, a blue shale, which did not fuse until cone 30 (Ries and Keele, 1915), probably contains significant kaolinite.

At Lang Bay, Upper Cretaceous (Santonian to Campanian) kaolinite-bearing sediments lie on a deeply weathered granodiorite (Hora, 1989; Mustard and Rouse, 1991). These kaolinite occurrences indicate that areas are worth prospecting for kaolinite where the sedimentary rocks of the Nanaimo and Gambier groups disconformably lie on plutonic rocks or stratified rocks of similar composition. The Middle and Upper Eocene sedimentary rocks of the Huntingdon Formation contain kaolinite-rich fireclay seams where they unconformably overlie a kaolinized metavolcanic and plutonic basement on Sumas Mountain (Church *et al.*, 1983). The remainder of this unconformity is unexposed in the lower Fraser Valley area.

In the interior of British Columbia, prospecting on the sub-Eocene unconformity is complicated by the lack of basal Eocene sediments west of the metamorphic core complexes. The typical Eocene succession in southwestern British Columbia is Eocene sediments overlying Eocene volcanic rocks (Read, 1990b).

Only in the sedimentary basins, where the underlying Eocene volcanics have been eroded, do the sediments lie directly on older rocks. The only plutonic basement so exposed is in Guichon Creek where the Coldwater Formation probably lies disconformably on the Guichon Creek batholith.

At Giscome Rapids, north of Prince George, china clay with pyrometric cone equivalents in the range 28 to 32?

(Cummings and McCammon, 1952) implies that kaolinite is an important constituent of the clay. Although the exact age of the Tertiary stratigraphy is uncertain and its geological setting unknown, the occurrence indicates that Tertiary unconformities in the Chilcotin-Nechako area should be prospected where they are overlain by sediments. Lay (1941, p.42) described such an unconformity 4 kilometres upstream from the mouth of Baker Creek west of Quesnel where extensively kaolinized Eocene(?) flows are overlain by Early Oligocene sediments.

Much of the Tertiary at the south end of the Omineca Complex is faulted onto the underlying rocks, but where unfaulted, the basal Eocene comprises coarse clastic sediments apparently without kaolinite. The combination of faulted basal Eocene contacts and coarse basal Eocene sediments, where the contact is unfaulted, apparently precludes the development of kaolinite.

VOLCANIC ASH

Rhyolite ash of Miocene age is a widespread component of the Deadman River Formation (Campbell and Tipper, 1971) and is in the southern exposures of the Fraser Bend Formation in the Fraser River south of its confluence with the Chilcotin River (Hickson *et al.*, 1991a). Its northern limit is in Sword Creek, west of the Fraser River at latitude 52 N.

In southern British Columbia, aside from the Bridge River ash, the areas of best potential for relatively unaltered rhyolite or dacite ash are underlain by the Deadman River and Fraser Bend formations south of Williams Lake between the Fraser River and Kamloops. As noted by McCammon (1960), the ash is suitable for use as a pozzolan. Eocene ash may be too altered to act as a suitable pozzolan.

PERLITE AND VOLCANIC GLASS

In southern British Columbia, perlite and volcanic glass mainly occur in Middle Eocene volcanic successions where rhyolite and dacite are volumetrically important. Volcanic rocks of the Princeton and Penticton groups and the Kamloops Group east of the Fraser River are usually too basic. However, the detailed stratigraphy of Eocene volcanic rocks is largely unknown and a restriction of the area of best potential for perlite and volcanic glass to along and west of the Fraser River may not be warranted.

MIOCENE DRAINAGE AND PLACER GOLD POTENTIAL

Miocene drainage channels are the sites of placer gold concentrations near Prince George on the Fraser River and southeast of Kelowna. North of Quesnel, the placer gold production of 62 500 grams from the Tertiary mine comes from the bottom 1.8 metres of the basal Fraser Bend conglomerate of Miocene age and cracks and crevices in the immediately underlying bedrock in a southeast-flowing channel of the ancestral Fraser River (Lay, 1940). Sediments of the Fraser Bend Formation are hosts of the nearby Canyon mine and placer workings of Frank Delong.

Northeast of Kelowna, placer gold occurs in a Miocene conglomerate filling a channel 160-metres deep near King Edward Creek (Church and Suesser, 1983), and in Miocene sandstone and conglomerate on the Winfield property (Hedley, 1937) where 2300 grams of gold were extracted from a series of small adits (Jones, 1959). Because Miocene drainage channels were unknown in the area covered by this investigation until their discovery in 1988 (Read, 1989a), a placer gold potential may exist in Miocene channels in this intervening area.