Owen Lake
093L/02

821228

Implications of Bitumen and Hydrocarbon Fluid Inclusions to Fluid Source and Thermal History of Polymetallic, Epithermal Vein Deposits, Owen Lake, central British Columbia.

Thomson, M.L., Mastalerz, M., Sinclair, A.J.
and Bustin, R.M.
Department of Geological Sciences,
The University of British Columbia,
Vancouver. V6T 1Z4.

Abstract

Fluid source and thermal history are determined for the barite and bitumen-bearing, early Eocene (*ca*. 50 Ma) polymetallic, epithermal veins of the Owen Lake deposit, central British Columbia, Canada. Aqueous and hydrocarbon fluid inclusions occur within barite; T_h for both types of inclusions indicate three population ~~ranging~~ in the ranges, 101 - 118°C, 127-142°C and 154-182°C. T_m of aqueous inclusions range from -5.5 to +04.°C indicating a range of 0.4 to 8.5 equivalent weight percent NaCl. Bitumen (albertite variety) has a reflectance of 0.30 - 0.35% indicating low maturation level. Isotopic values for the bitumen are highly negative ($\delta^{13}C$ *ca* -29) indicating a probable terrigenous source.

Organic-bearing sediment, topographically above the deposit, on the slopes of a biotite-granite stock is a possible source of the hydrocarbons. Meteoric water is likely the transport fluid for the hydrocarbons.

Introduction

The determination of the fluid source and thermal history of metal-bearing fluids, an important objective in studying hydrothermal ore deposits, can be investigated fruitfully through the characterization of contained hydrocarbons. For example, Goodarzi and MacQueen (1990) studied bitumen in the carbonate hosted Mississippi-Valley type, Pine Point, North West Territories Pb-Zn deposits and Bakken and Einaudi (1986) studied calcite and hydrocarbon veins in Carlin-type deposits; both suggesting that local, heated organic-bearing sediment is the hydrocarbon source. Bitumen and liquid hydrocarbons also have been studied at spreading ridge hydrothermal sites such as the Guaymas Basin (Peter et al. 1990) and Middle Valley sulfide mounds, northern Juan de Fuca Ridge (Leitch 1991), indicating a fluid origin by dewatering of organic-rich sediments within the rift basins under relatively high temperature conditions. Hydrocarbons in active continental hydrothermal systems in Yellowstone National Park, U.S.A. (Clifton et al. 1990) and Waiotapu, New Zealand (Czochanska et al. 1986) appear to have local near-surface, organic rich sediment as the hydrocarbon source.

Literature descriptions of hydrocarbons within fossilized epithermal mineral deposits are rare (eg. Hoffman et al. 1988). This study was carried out on bitumen and barite-bearing veins, interpreted to be late in the development of the epithermal, polymetallic Owen Lake deposit, central British Columbia (Fig.

1). Our purpose is two fold: first, to document the nature of bitumen and fluid inclusions within barite to establish the thermal history during development of the associated veins; and second, to determine the source of the hydrocarbon and the flow path of the hydrocarbon-bearing fluids.

Methodology of Hydrocarbon Investigations

Organic petrologists commonly use biomarkers and carbon isotopes to determine the source of hydrocarbons. Biomarkers, such as waxes, porphyrins and steranes are compounds of undoubted organic origin, and are determined using gas chromatographic and mass spectrometric techniques.

Interpretation of carbon isotope data is based on the premise that in all organic matter ^{13}C is depleted preferentially relative to ^{12}C, so that $^{13}C/^{12}C$ in organic matter contrasts with values for limestones, magmatic rocks, meteorites and, atmospheric CO_2. The $\delta^{13}C$ values (($^{13}C/^{12}C$ sample $-^{13}C/^{12}C$ standard)/$^{13}C/^{12}C$ standard) of marine plants and invertebrates are the range -12 to -30, averaging -23; and terrestrial plants, coals, and soil humus range from -23 to -28 (North 1985).

Organic petrologists also investigate the thermal maturation of organic matter, an irreversible process, recording the peak thermal history of the system (Teichmüller 1973, Ammosov and Sharkova 1975, Mckenzie and Mckenzie 1983). The thermal maturity records the maximum thermal exposure to which organic matter has been subjected. The irreversibility of the maturation process is useful in interpreting fluid inclusion data from co-existing minerals. Commonly, the determination of homogenization temperatures (T_h) in a single mineral reveals more than one temperature population, raising the question of whether they represent formation during an increasing or decreasing thermal gradient. Normally one looks for growth zoning patterns in crystals with older primary inclusions trapped in the core, and paragenetically younger inclusions trapped toward the rim of the grain. However, in a system ~~where the~~ of temperature increasing, fluid inclusions formed at relatively low temperatures can become re-equilibrated at higher temperatures (Gratier and Jenatton 1984, Prezbindowski and Larese 1987). Thermometric data on co-existing organic matter may be utilized to interpret such complications in the thermal history.

Geologic Framework

Samples for our study are from veins in the Owen Lake area, central British Columbia (Figure 1). This deposit is an adularia-sericite (sericite only) epithermal system, enclosed in Late Cretaceous, Tip Top Hill volcanic rocks. Mineralization and alteration are dated at about 50 Ma based on ages of pre- and post-vein dykes (Leitch et al. 1990). The dykes appear to have no extrusive equivalents in the area; Mt. Nadina, a nearby biotite granite stock, dated at 53 Ma (Carter 1981) may be related.

The bitumen at Owen Lake commonly occur interstitial to euhedral 1-4 mm long, blades of barite and patchy manganosiderite which line and fill open spaces within brecciated and altered host rock (Fig. 2a). Less commonly, bitumen occurs as less than 1 mm wide black seams within altered porphyritic andesite. Megascopically all bitumen samples are dark brown or glossy black, and, except for one sample (OW32) are insoluble in chloroform. The barite-bitumen assemblage is interpreted to represent late stage of the paragenetic sequence, described by Hood et al. (1991).

Methods

Fluid inclusions

Doubly polished rock plates were prepared on standard size thin section glass. A Fluid Inc. R adapted U.S.G.S. gas flow heating/freezing system was used. Temperature calibration using SYN-FLINC R as described by Reynolds (1988; unpublished manual) results in an accuracy of +/- 0.4°C from 56.6° to +660°C and a precision of +/- 1% up to 200°C and +/-2 % above 200°C. Primary inclusions were distinguished from secondary using the criteria suggested by Roedder (1984).

The problem of the susceptibility of aqueous inclusions within barite to stretching when overheated past the T_h (Ulrich and Bodnar 1988), and when frozen (Keenan et al. 1978), was taken into consideration. After heating the ratio of vapor:inclusion area remained the same upon renucleating the vapor bubble, which is interpreted to indicate no significant stretching.

Organic matter: Optical and chemical studies

Solid bitumen samples were mounted in transoptic and polished using standard coal sample preparation technique (Bustin et al. 1985). Reflectance was determined under oil immersion at a standard wavelength of 546 nm. The chemical composition was determined using a Camecha SX50 electron microprobe.

Carbon Isotope Data

Bitumen was hand picked from the vugs with the sample size approximately 5 g. In sample 265 the bitumen was scraped from a fracture wall, and probably mixed with co-existing quartz and carbonate. Due to the fine grain size, separation of the bitumen was not possible.

Carbon isotope data were obtained from the Department of Oceanography, University of British Columbia. The samples were combusted in a CHN analyser and H_2O and CO_2 were separated and frozen separately, with N carried through in He gas. Carbon isotope vales were analysed in a VG ISOTECH PRISM R triple collector mass spectrometer.

Results

Fluid inclusions

Two types of fluid inclusions occur within barite: 1) aqueous and, 2) liquid hydrocarbon. The aqueous fluid inclusions are colorless, range in size from less than 1 μm to 10 μm, commonly less than 3 μm, and are distributed throughout the mineral (Fig. 2b). Vapor bubbles, 5 to 10 volume percent of the inclusion, are common. A small proportion appear to move vigorously at room temperature.

Three ranges of homogenization temperature (T_h) populations of aqueous fluid inclusions have been determined (Fig. 3a). The lowest temperature group ranges from 102 to 118°C, the middle temperature group ranges from 127 to 142°C, and highest temperature group ranges from 154 to 182°C. Undercooling of 40°C to re-nucleate the vapor bubbles indicates an aqueous inclusion. Complete melting occurred in a range of -5.5 to +0.4°C, indicating a salinity range of 0.35 to 8.54 equivalent weight percent NaCl, with an average of 2.81 equivalent weight percent NaCl (Fig. 3b).

The hydrocarbon fluid inclusions are amber-colored and range in size from 1 µm to 30 µm with the mode at 10 µm. Vapor bubbles, making up to 10 to 20 volume percent of the inclusion are common, and are dark brown (Fig. 2c). Similar T_h populations were recognized as for associated aqueous fluid inclusions (Fig. 3a) Upon heating, the vapor bubble moved in a sluggish manner compared to the vapour bubble in the aqueous inclusions and renucleated 30-40°C below the T_h. At temperatures as low as -90°C, no obvious ice crystals formed, the vapor bubble remained a constant shape and immobile.

Hydrocarbon filled inclusions fluoresce yellow under ultraviolet and blue excitation, confirming the presence of petroleum (Burruss 1981, Peter et al. 1990).

Organic Matter

In reflected light the textures of the solid bitumen is smooth, non-granular and, homogenous (Fig. 2d), with local shrinkage cracks. It is isotropic, reflectance (R_{oil}) from 0.30 to 0.35 % (Fig. 4), and displays weak brown to no fluorescence.

Optical properties, chemical composition and insolubility in CS_2 indicate the bitumen is the albertite variety (Jacob 1989). The maturity level of the bitumen corresponds to 0.6% R_o of vitrinite reflectance (Jacob 1981). Chemical compositions of the bitumens studied are rather uniform (Table 1), with 85.61 percent carbon, less than 1 percent oxygen and sulphur and 11-12 percent hydrogen. Only sample 265 shows a slight decrease in C content associated with the increase in hydrogen content.

Isotope Data

Carbon isotope analyses ($\delta^{13}C$) for three of four bitumen specimens are similar, ranging from -28.337 to -29.069 (Table 1). Only sample 265 has a higher $\delta^{13}C$ value, possibly indicating carbonate contamination during sampling as suggested previously. The isotope ratios are sufficiently negative in value to be characteristic of terrestrial organic material (Degens 1966; North 1985).

Discussion

Organic Source

Strongly negative carbon isotope data values for the bitumen suggest a terrestrial organic source for the mobilized hydrocarbon. Four sources are implicated (Fig. 5): 1) hydrocarbon-bearing sediments possibly present below the Tip Top Hill volcanic rocks; 2) intra-volcanic organic matter-bearing sediments within the Tip Top Hill volcanic host rocks; 3) intra-volcanic organic matter-bearing within the interpreted Eocene volcanic rocks overlying the Tip Top Hill volcanic rocks; or 4)

Late Cretaceous plant-bearing argillite interpreted to overly the Tip Top Hill volcanic rocks (Lang 1929)[1]. An unequivocal identification of vein hydrocarbon provenance is not possible at Owen Lake as no comparative organic geochemical data on potential sources are available; however, the presence of known Late Cretaceous plant fossils within the argillite overlying the Tip Top Hill volcanic rocks makes this unit favored over unknown, organic-rich sediments within, above, or below the Tip Top Hill volcanics rocks.

Timing and Fluid Flow Path

The vuggy morphology of the barite and bitumen-bearing veins and the decreasing core to rim homogenization temperatures of aqueous and hydrocarbon fluid inclusions within barite indicate that the temperature was decreasing during the formation of barite and precipitation of bitumen. This is confirmed by the low thermal maturation of the bitumen (0.30 - 0.35 R_o), which corresponds to 0.60 vitrinite reflectance . The temperature of the system continued to decrease after the precipitation of the bitumen, which is consistent with the late stage evolution of a hydrothermal system.

The fluid inclusion data indicate that the hydrocarbon-bearing aqueous fluids were low salinity (0.35 - 8.54 equivalent weight percent NaCl), strongly suggesting a meteoric source. A

---

[1]. The Late Cretaceous argillite could be an Eocene intra-volcanic sediment. Without an updated identification of the reported plant fossils it is assumed that the Late Cretaceous fossil identification of Lang (1929) is correct.

possible model for the fluid flow path, illustrated in Figure 5, is based on the assumption that the overlying Late Cretaceous argillites are the source of bitumen in the epithermal veins at Owen Lake. Late in the thermal history of the region, meteoric water flowed downward down topography, through the hydrocarbon-bearing argillite, collecting organic liquid and gas phases. The fluid became heated to at least 200°C, upwelling as a focused flow along fault zones. Heat necessary for catagenisis of the organic matter and heating the meteoric fluid may have been derived from the intrusion of the *ca*. 53 Ma biotite granite of Mt. Nadina and dykes.

This model is similar to that presented by Forster and Smith (1990, 1989) for the hydrologic evolution of a hydrothermal system driven by an intrusion and the influence of a steeply dipping fault. During the intermediate stage, near surface (2-3 km) fluid flow is controlled dominantly by a heat driven convective cell due to the intrusive body. The higher temperature isotherms shift toward the surface. Later in the thermal evolution, topographically driven meteoric fluid flow dominates the near surface and the higher temperature isotherms have relaxed.

Implication for Exploration

The recognition that hydrocarbons are a significant constituent of the vein paragenesis within the Owen Lake deposit was previously unrecognized. The presence of bitumen raises the possibility that a relatively new lithogeochemical technique of volatile hydrocarbon analysis (e.g. Disnar 1990) could be used in the evaluation of the extensive alteration zones associated with epithermal deposits. Late stage hydrocarbon-bearing veins within a targeted large alteration zone may be related in time and space to potentially economic Ag-Zn-Pb-Cu-Au concentrations.

Conclusions

1) Carbon isotope data indicate terrestrial plants as the likely source for the bitumen, in veins at Owen Lake.

2) Organic-bearing Late Cretaceous argillite, now limited to the apron of nearby Mt. Nadina is a possible source for the hydrocarbons.

3) Comparable trapping temperature ranges of (approximately 182° to 101°C) for aqueous and hydrocarbon-bearing inclusions within barite, indicate a common thermal history to both fluid types.

4. The low salinity aqueous fluid inclusions suggest that fluid originated as meteoric water.

5) Bitumen precipitated at temperatures of less than 90°C, and was not subjected to higher temperatures, confirming that the veins were deposited in a decreasing geothermal gradient.

6) Catagenisis of the organic-bearing sediments was probably the result of heat derived from the intrusion of local 51 Ma dykes and biotite granite.

Acknowledgements

This project is part of a study of the genesis of the Owen Lake deposit supported by grants to AJS, from Pacific Houston Resources Inc. and to AJS and RMB from the Natural Sciences and Engineering Research Council of Canada. Fluid inclusion studies were conducted at the Vancouver offices of the Geological Survey of Canada, with the assistance and advice of Dr. C.H.B. Leitch. Bente Neilson of the Oceanography Department, University of British Columbia provided the carbon isotope data and Yvonne Douma provided highly crafted fluid inclusion plates and polished bitumen samples.

References

Ammosov, J.J. and Sharkowa, L.S.: Paleotemperatures, lithification and oil and gas occurrence in Jurassic deposits in western Kasakhrstan and central Asia. In: Paleotemperatury zon nefteobrazovanija, J.V. Yeremin, Ed., p. 60-69. Moskwa: Nauka Press (1975).

Bakken, B.M. and Einaudi, M.T.: Spatial and temporal relations between wall rock alteration and gold mineralization, Main Pit, Carlin gold mine, Nevada, U.S.A. In: Proceedings of Gold '86, an International Symposium on the Geology of Gold, A.J. Macdonald Ed., pp. 388-403. Toronto (1986).

Burruss, R.C.: Hydrocarbon inclusions in studies of sedimentary diagenesis. In: Short course in fluid inclusions - Applications to petrology., L.S. Hollister and M.L. Crawford, Eds.: Mineralogical Association of Canada Short Course Handbook, Vol. 6, pp. 138-156 (1981).

Bustin, R.M., Cameron, A., Grieve, D. and Kalkveuth, W.: Coal petrology, its principles, methods and applications. Geological Association of Canada, Short Course Notes, (2nd edition), 230 p. (1985).

Clifton, C.G., Walters, C.C. and Simoneit B.R.T.: Hydrothermal petroleums from Yellowstone National Park, Wyoming, U.S.A. In: Organic Matter Alteration in Hydrothermal Systems - Petroleum Generation, Migration and Biogeochemistry, B.R.T. Simoneit, Ed., Applied Geochemistry 5: 169-191 (1990).

Czochanska, Z., Sheppard, C.M., Weston, R.J., Woolhouse, A.D. and Cood, R.A.: Organic geochemistry of sediments in New Zealand. Part I. A biomarker study of the petroleum seepage at the geothermal region of Waiotapu. Geochim. Cosmochim. Acta. 50: 507-515 (1986).

Disnar, J.R.: Volatile hydrocarbons in Ba-An-Pb ore genesis: analysis and use in mineral exploration. J. Geochem. Explor., 38: 205-224 (1990).

Degens, E.T.: Biogeochemistry of the stable carbon isotopes. NASA Rep., Cr 84046, 40 p. (1966).

Forster, C. and Smith, L.: The influence of groundwater flow on thermal regimes in mountainous terrain: A model study. J. Geophy. Res. 94, No. B7: 9439-9451 (1989).

Forster, C. and Smith, L., 1990. Fluid flow in tectonic regimes. In: Short Course on Fluids in Tectonically Active Regimes of the Continental Crust, B.E. Nesbitt, Ed., Mineralogical Association of Canada, Vol. 18, pp. 1-48 (1990).

Goodarzi, F. and MacQueen, R.W.: Optical/compositional character of six bitumen species from Middle Devonian rocks of the Pine Point Pb-Zn property, Northwest Territories, Canada. Int. J. Coal Geol. 14: 197-216 (1990).

Gratier, J.P. and Jenatton, L.: Deformation by solution-deposition, and re-equilibration of fluid inclusions in crystals depending on temperature, internal pressure and stress. J. Struct. Geol. 6: 189-200 (1984).

Hoffmann, C.F., Henley R.W., Higgins, H.C., Solomon, M. and Summons, R.E.: Biogenic hydrocarbons in fluid inclusions from the Aberfoyle tin-tungsten deposit, Tasmania, Australia. Chem. Geol. 70: 287-299 (1988).

Hood, C.T.S., Leitch, C.H.B. and Sinclair, A.J.: Mineralogical variation observed at the Silver Queen mine, Owen Lake, central British Columbia (931/2). B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1991-1: 185-190 (1991)

Jacob, H. Stoppel, D. and Wehner, M.: Untersuchung disperser Bitumina des Westharzes und deren geologische Deutung. Erdol-Erdgas-Z 97: 182-190 (1981).

Jacob, M.: Classification, structure, genesis and practical importance of natural solid oil bitumen ("migrabitumen"). Int. J. Coal Geol. 11: 65-79 (1989).

Keenan, J.H., Keyes, F.G., Hill, P.G. and Moore, J.G.: Steam tables, thermodynamic properties of water including vapor, liquid, and solid phase (SI units). New York: Wiley Interscience, 156 p. (1978).

Khavari-Khorosani, G.: The properties and structural ordering of some fossil bitumens. Ph.D. thesis, Newcastle-Upon-Tyne, England, 350 p. (1975).

Lang, A.H.: Owen Lake mining camp, British Columbia. Summary Report, 1929, Part A, Geological Survey of Canada, 93 p. (1929).

Leitch, C.H.B.: Preliminary studies of fluid inclusion in barite from the Middle Valley sulfide mounds, northern Juan de Fuca Ridge. In: Current Research, Part A. Geological Survey of Canada, Paper 91-A, pp. 27-30 (1991).

Leitch, C.H.B., Hood, C.T., Cheng, X-L, and Sinclair, A.J.: Geology of the Silver Queen Mine area, Owen Lake, central British Columbia. B.C. Ministry of Energy, Mines and Petroleum Resources, Paper 1990-1: 287-295 (1990).

Mckenzie, A.S. and Mckenzie, D.: Isomerization and aromatization of hydrocarbons in sedimentary basins formed by extension. Geol. Mag. 120/5: 417-528 (1983).

North,F.K.: Petroleum Geology, 607 p. Boston: Allen and Urwin (1985).

Peter, J.M., Simoneit, B.R.T., Kawka, O.E, and Scott, S.D: Liquid hydrocarbon-bearing inclusions in modern hydrothermal chimneys and mounds from the Southern of the Guaymas Basin. In: Organic Matter Alteration in Hydrothermal Systems - Petroleum Generation, Migration and Biogeochemistry. B.R.T. Simoneit, Ed., App. Geochem. 5: 51-63 (1990).

Prezbendowki, D.R., and Larese, R.E.: Experimental stretching of fluid inclusions in calcite - Implications for diagenetic studies. Geol. 15: 333-336 (1987).

Reynolds,T.J. (unpublished manual). Fluid Inc. adapted U.S.G.S Gas Flow Heating/Freezing System Instruction Manual, 34p. Denver, Colorado (1988).

Roedder, E.: Fluid Inclusions. Reviews in Mineralogy, Vol. 12, 644 p. (1984).

Teichmüller, R.: Die paläogeographisch - fazielle unol tektonische Entwicklung eines kohlenbeckens am Beispiel des Ruhrkarbons. Z. dt. geol. Ges. 124: 149-165 (1973).

Ulrich, M.R. and Bodnar, R.J.: Systematics of stretching of fluid inclusions II: barite at 1 atm confining pressure. Econ. Geol. 81: 1037-1046 (1988).

Table 1. Isotopic and chemical data on bitumen.

Sample	$\delta^{13}C_{PDB}$(%)	C^a	O	H	S
88-5-5	-28.337	86.61	0.92	11.48	0.84
265	-25.762	85.11	0.78	12.40	0.91
2-90-9	-29.022	86.42	0.91	11.62	0.72
OW-32	-29.069	n/a	n/a	n/a	n/a

---

a - weight percent

n/a - no analysis

Figure Captions

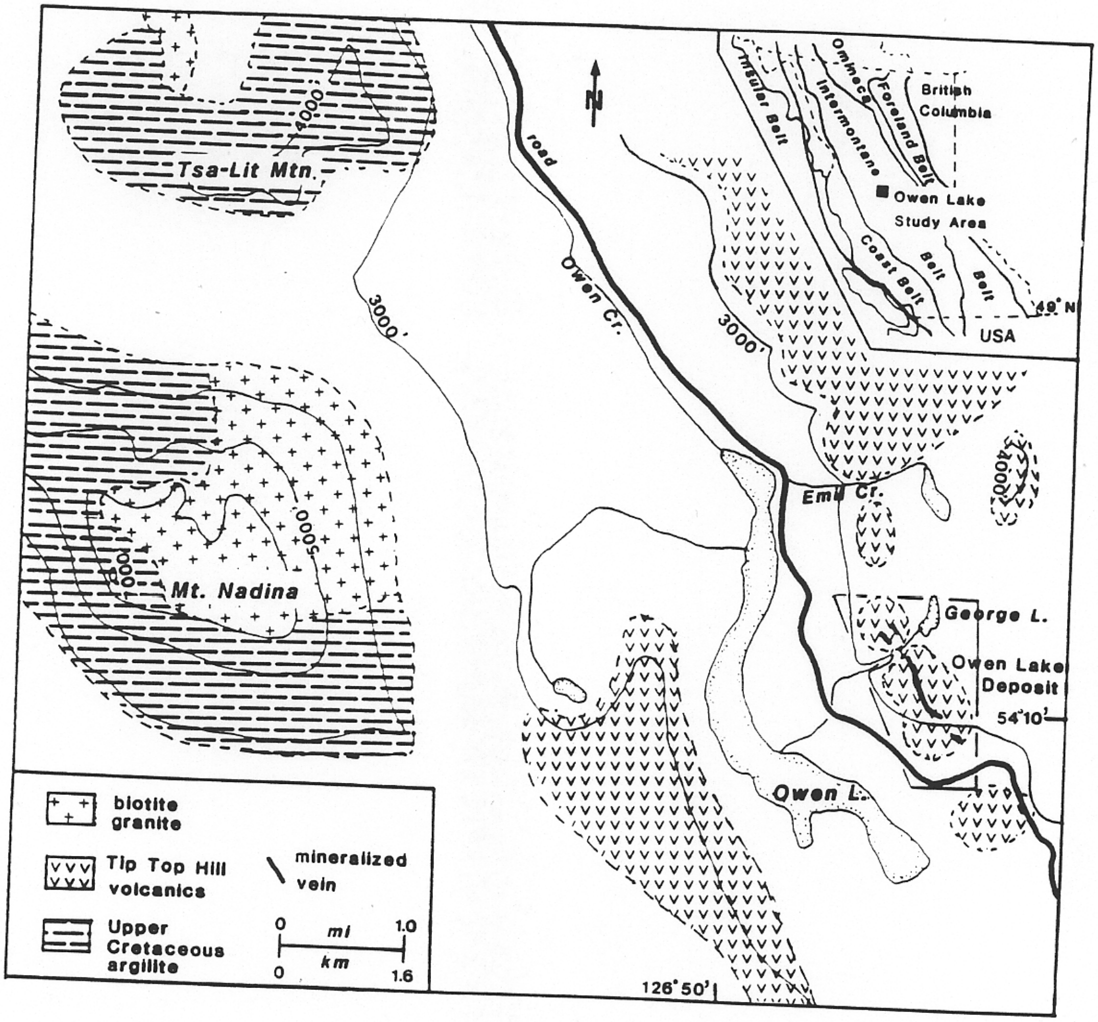
Fig. 1. Location and simplified geological map of the Owen Lake area, central British Columbia (after Lang, 1929, Leitch et al, 1990).

Fig. 2 a) Photograph of sample OW 32, illustrating typical bladed barite and interstitial bitumen. b) Photomicrograph typical aqueous primary fluid inclusions. Arrow points to inclusion with obvious vapor bubble. (transmitted, plane polarized light). c) Photomicrograph of probable psuedosecondary hydrocarbon inclusions (lower half of photo). Bitumen is black patch in lower right corner). (transmitted, plane polarized light). d) Photomicrograph of bitumen in reflected light. Note homogeneity and shrinkage cracks.

Fig. 3. Thermometric data for aqueous and hydrocarbon fluid inclusions.

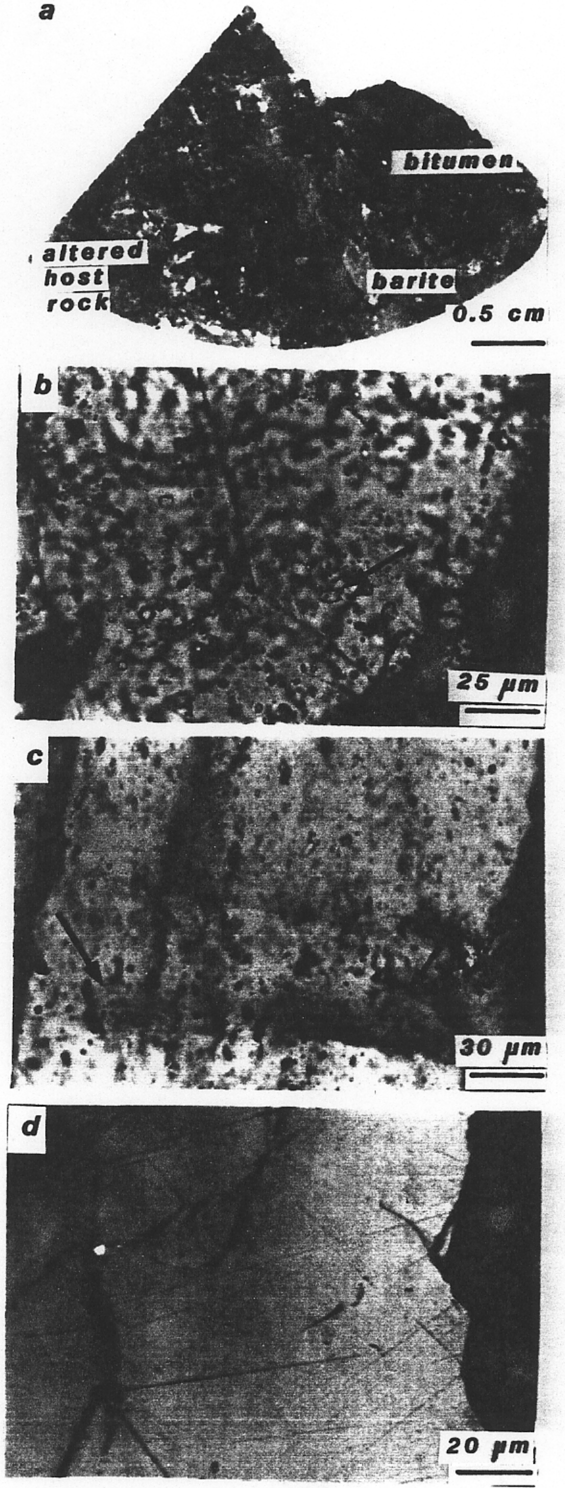
Fig. 4. Reflectogram of bitumen.

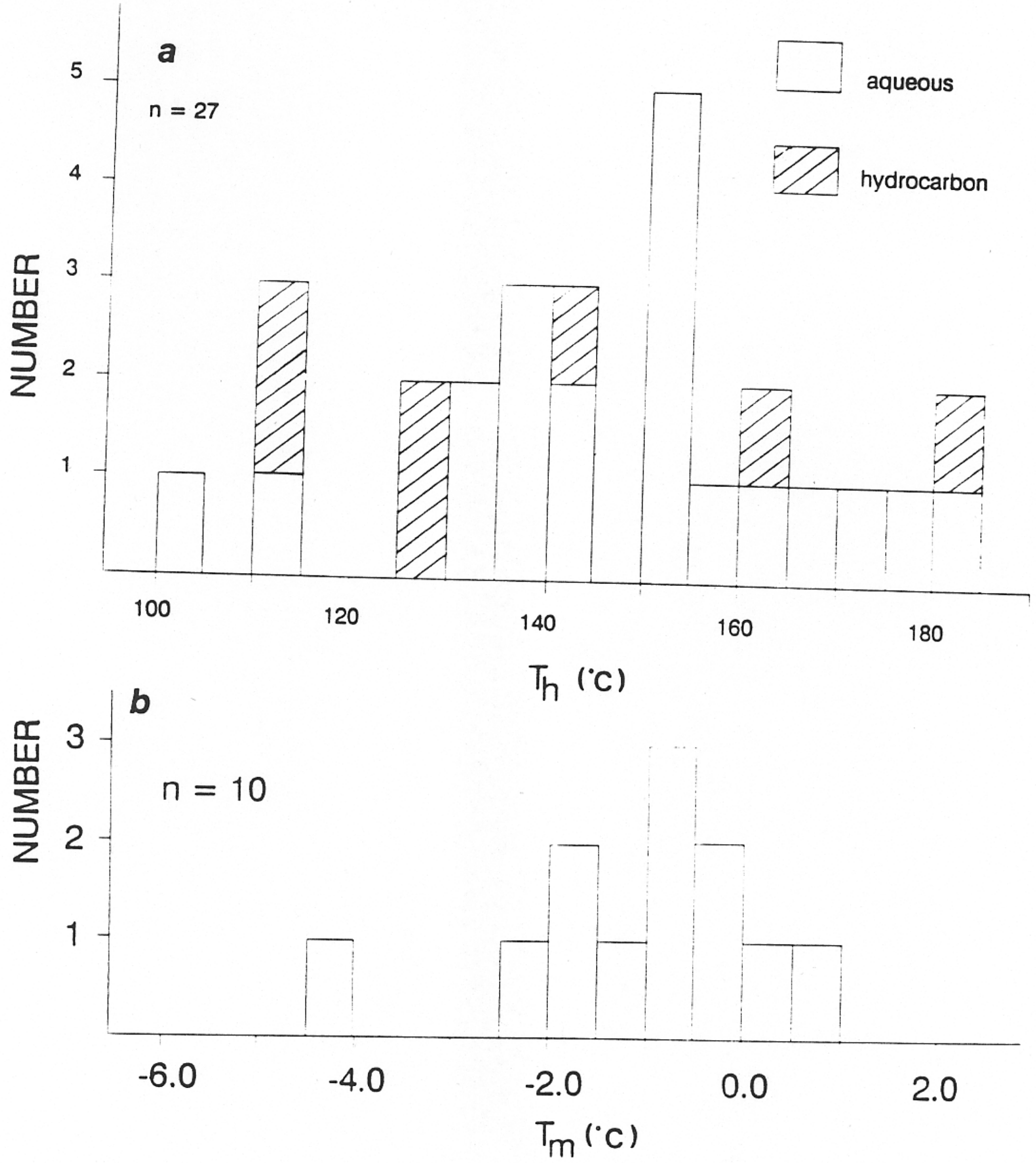
Fig. 5. Cartoon illustrating suggested geologic model of meteoric water flow within the Owen Lake area, resulting in bitumen-barite veins. Possible organic-bearing sediment sources are designated as: 1) unknown stratigraphically lower, 2) unknown intravolcanic within the Tip-Top Hill volcanic rocks, 3) unknown intravolcanic within now eroded Eocene volcanic rocks, and 4) known Upper Cretaceous organic-bearing argillite.



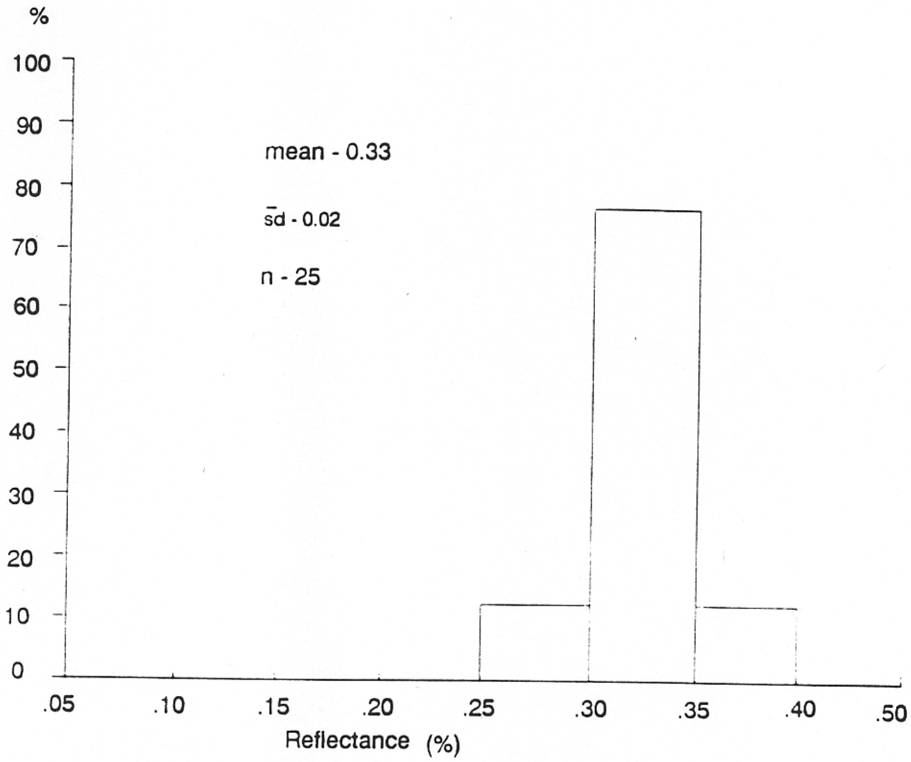
Thomson *et al.*

Figure 1


a
bitumen
altered host rock
barite
0.5 cm
b
25 µm
c
30 µm
d
20 µm

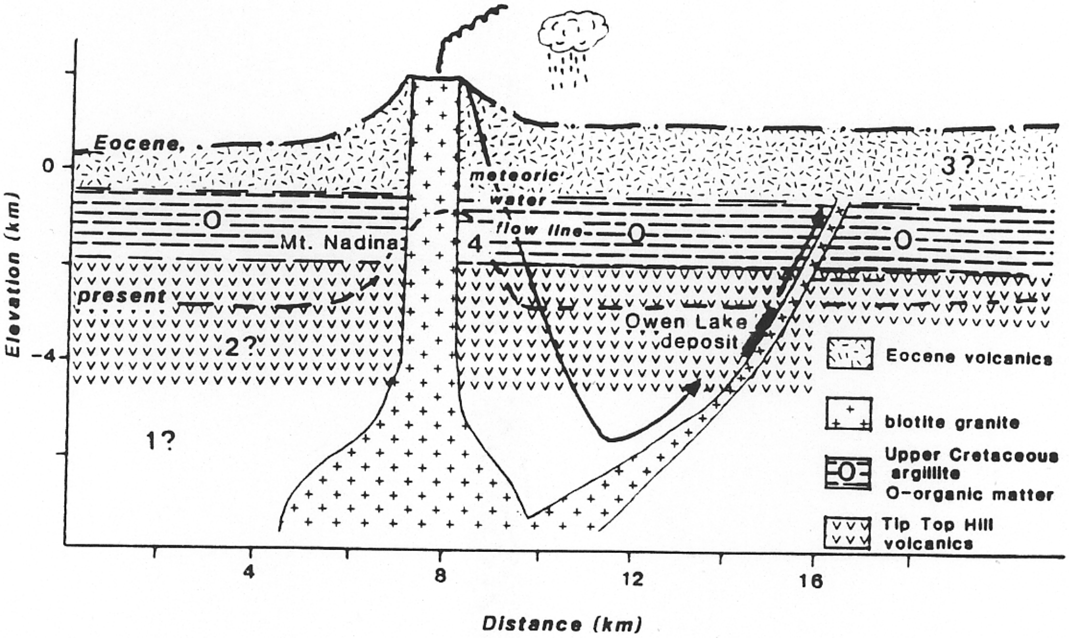


Thomson *et al*
Figure 3



Thomson et al

Fig. 4



Thomson et al.

Fig. 5