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DEPARTMENT OF ENERGY, MINES AND RESOURCES

PAPER 68-66

REVIEW OF GEOCHEMICAL AND GEOBOTANICAL PROSPECTING METHODS IN PEATLAND

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ABSTRACT

The literature on prospecting in peatlands is reviewed. Suggestions are made for further work on a detailed and regional scale using peatlands in geochemical and geobotanical surveys to outline mineral belts and locate mineral deposits. A comprehensive bibliography is included.

REVIEW OF GEOCHEMICAL AND GEOBOTANICAL PROSPECTING METHODS IN PEATLAND

INTRODUCTION

In 1960 Hawkes and Salmon wrote that "the location of ore deposits beneath organic swamp soil is one of the principal prospecting problems in Canada". It is not surprising that this observation should be made in a country covered by at least 500, 000 square miles of water-saturated, organic terrain variously known as bog, muskeg, peatland, swamp, mire, beaver meadow, etc. Furthermore, such terrain conditions are particularly common over much of the Canadian Shield, an area potentially rich in mineral deposits, but where geological and geophysical exploration methods have had only limited success. It is, therefore, imperative to develop other methods suitable to these areas. These will include geology, geophysics, geochemistry, and geobotany. This report attempts to discuss only the geochemical and geobotanical methods.

An extensive bibliography has been compiled from a literature survey on all aspects of the subject including: the definition, classification, origin, development, ecology and environmental factors of peatland (and of other wet-site areas); organic and peatland chemistry and geochemistry; and prospecting in peatland using geochemical, biogeochemical, geobotanical, and airphoto interpretation methods.

Although there is some disagreement even among ecologists concerning the terminology and classification of wet-site areas (Sjörs, 1963; Ritchie, 1960), it is generally agreed that bog, fen, mire, muskeg, peatland, organic terrain, and tamarack swamp refer to wet sites that have an accumulation of organic matter called peat which is the fossilized and partially decomposed remains of plants that grow on it. The two other most common water-saturated terrain conditions, marsh and swamp, are not marked by peat accumulation. This report deals only with peat areas and refers to all their variations, i.e., bog, fen, muskeg, etc., as peatland or organic terrain. Areas of confined peat deposits, usually depressions of limited area, are commonly referred to as bog, whereas extensive peatland areas, as found in northern Ontario, particularly in the Hudson Bay Lowland, are known as muskeg. Full bibliographic references to the definition, terminology, and classification of peatlands (and other wet-site areas) in Canada may be found

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in Dansereau and Segadas-Vianna (1952), Moss (1953), Ritchie (1960, 1962), Sjörs (1961a, b, 1963), and Radforth (1961, 1962, 1966).

Peatland is familiar to most if not all geologists and prospectors and the various terms bog, fen, etc. are used synonymously by most to refer to almost any water-saturated terrain condition. It is important, however, to understand that there are clearly delimited types of peatland which are characterized by a complex of environmental factors. A knowledge and recognition of the physical, chemical, hydrological, geological topographical, ecological, and botanical factors is of the utmost importance to the successful application and interpretation of geochemical and geobotanical prospecting. Discussion of these factors as they apply to North American peatlands may be found in Chalmers (1904), Auer (1930), Dansereau and Segadas-Vianna (1952), Moss (1953), Heinselman (1963, 1965) La Roi (1967), and Janssen (1967). References to the Shield and Hudson Bay Lowland include Hustich (1955, 1957), Sjörs (1959, 1961a, b, 1963), and Ritchie (1960, 1962). In addition, references to European peatland literature may be found in the bibliography.

SUMMARY OF PREVIOUS RESEARCH ON MINERALIZED PEATLANDS AND ON GEOCHEMICAL PROSPECTING IN PEATLANDS

The formation of bog iron and bog manganese ores is well known to most. Less familiar, however, are the references to bogs highly enriched in copper, zinc, uranium, and other metals. As early as 1824 certain bogs in Ireland were reported to contain sufficient copper for economical extraction (Townsend, 1824) and peat bogs over lead-zinc veins at Strontian in Scotland have been found to be enriched in both lead and zinc. Numerous accounts of metal enriched bogs are reported from the U.S.S.R.; copper bogs are described by Manskaya *et al.* (1960) and Albov and Kostariev (1968) and uraniferous bogs by Moiseenko (1959) and Kochenov *et al.* (1965).

In America, native copper is present in peat in Montana (Lovering, 1927), and copper-bearing peats developed in bogs downstream from copper deposits have been described in Montana and Colorado (Forrester, 1942; Eckel, 1949). As much as 16 per cent zinc is present in peats overlying the zinc-bearing Lockport dolomite in New York according to Canon (1955). After the discovery of several uraniferous bogs in California the use of 'boggy areas' was recommended for reconnaissance prospecting for uranium by Bowes *et al.* (1957). Zinc carried into bog and muskeg by surface waters is concentrated in abnormal amounts in the Keno Hill area, Yukon Territory and at Chibougamau, Quebec (Boyle and Cragg, 1957; Ermengen, 1957a, b) and a copper-bearing swamp occurs near Sackville, New Brunswick (Fraser, 1961a, b). Iron is concentrated in the organic matter in a swamp overlying a copper-bearing iron sulphide deposit in the Bathurst area, New Brunswick (Hawkes, 1960).

Only a few detailed studies of the metal distribution in peat areas and the factors controlling the distribution of the various metals in the peat components are extant. Almost all work of this kind has been done in Scandinavia and the U.S.S.R., with only limited investigations in Canada. Peat deposits in the vicinity of sulphide orebodies generally contain more copper, zinc, and nickel than those remote from mineralized zones according to Salmi (1950, 1955) and the content of metals in bogs is an indicator of deposits. Thus, near the vanadium-bearing titaniferous iron ores of the Otanmaki district in Finland, peat samples from profiles of several bogs gave anomalous amounts of all the ore elements studied. Maximum concentrations occur over or near the suboutcrop of the orebodies which can be detected even where the peat is underlain by as much as 40 feet of sand and till. In the vicinity of copper-zinc deposits in the Vihanti ore field in western Finland Salmi (1956b) also found that the metal content of bogs is indicative of the presence of mineralization. In this region the largest concentrations of lead, zinc, and copper occur in the bogs in the vicinity of ore deposits. Also, zones of high pH in bogs outline lenses of limestone which are commonly associated with zinc deposits in Finland (Salmi, 1958).

A high content of uranium (and radon) in peat deposits in the Norrbotten district of Sweden is associated with radioactive springs (Armands and Landergren, 1960; Armands, 1961). Four different kinds of waters are responsible for the supply of radioactive material to the peat-surface water, groundwater, spring water, and groundwater emanating from fractured rocks. Uranium is probably transported by bicarbonate waters from dolomite deposits or pegmatitic granitic dykes in the vicinity of the peat occurrences.

Geochemical prospecting in extensively covered peat areas in the Sukharikha River basin of Siberia by hydrochemical methods revealed a number of anomalous metal-bearing sites trending northeast and roughly coinciding with the known principal fault systems of the region (Shvartsev, 1966). These were related to springs that welled up along the fault zones and precipitated their metal in the peat areas. The difficulty of prospecting in peat covered terrain is emphasized by Shvartsev, and metal ratios and metal assemblages of mobile elements in the waters are suggested to be more indicative of the presence of orebodies than individual determinations of any specific element.

Several factors affect the concentration of trace elements in the 'peat marshes' in the Baltic Shield of the U.S.S.R. These are: (1) the type rock surrounding the peat area: high amounts of Cu, Ni, Co, and V are detected in deposits surrounded by ultrabasic rock, whereas high amounts of Be, Ga, and rare earths occur in those peat areas surrounded by arenaceous-argillaceous rock; (2) the geomorphology of the area: the largest amounts of trace elements are detected in peatlands of intermontane depressions and the smallest in present depressions and river valleys; (3) the kind of waters received by the peat deposit: 'Low peats' (i.e. those receiving waters draining from surrounding rocks and soils) are richer in elements than the 'upper' (i.e. those receiving rain water solely) and 'intermediary' peats; and (4) the acidity of the medium: different concentrations of the elements are associated with different pH.

The presence of uranium in peats is not a regional but a local phenomenon and is related to a source in the underlying bedrock according to Lisitsin et al. (1967). Also, the distribution of copper in peat depends on proximity to the underlying bedrock, on the copper content of the underlying bedrock, and on the type of formed peat, i.e. low moor, high moor, etc. Furthermore, the capacity of humic acids for retaining the metal is reported to play a decisive role in the copper distribution at different depths in the peat profile (Manskaya et al., 1960).

According to Gleeson (1960) and Gleeson and Coope (1967) peat profiles in bogs in the Shield in Ontario and Quebec and in the Daniels' Harbour area in Newfoundland overlie compact clays and are essentially similar and consistent with depth. The zinc, copper, and nickel contents in the organic horizons increase with depth, and maximum values are present in the upper layer of the clay adjacent to the peat. Below the uppermost clay layer the metal content decreases with depth. The pattern of zinc distribution in anomalous bogs sampled close to areas of bedrock in the Daniels' Harbour area is similar to the background bogs. The zinc content of the upper clay layer beneath the peat increases in the vicinity of known mineralization, and the contrast between the metal content of surface organic samples, the upper clay layer, and the lower clay layers is more marked for the areas near mineralization than in the background profiles.

Gleeson and Coope (op. cit.) concluded from their investigations that there is a tendency for certain trace metals to distribute themselves regularly in the peat profiles in poorly-drained, heavily-glaciated areas. The increase in zinc content in the vicinity of known mineralization suggests that careful sampling of specific horizons in the bog peat profiles can be used as a useful geochemical tool when prospecting for unknown ore deposits in the Canadian Shield.

As much as 10 per cent by weight of copper is reported in a copper swamp in southeastern New Brunswick (Fraser, 1961a and b). This swamp is unique because of its subneutral to slightly alkaline peat conditions as compared to all other reported copper swamps in American literature which are acidic. The factors responsible for the movement of the metal in the mobile state are diffusion, capillarity, evaporation, and the growth of frost crystals. Vegetation concentration, sorption, and coprecipitation slightly modify the dispersion pattern, and the dominant factor immobilizing the metal appears to be the sequestration of the copper by the organic matter by the formation of a chelate compound.

GEOCHEMICAL AND GEOBOTANICAL METHODS OF INVESTIGATION

The development of geochemical and geobotanical methods in the search for mineral deposits in areas of organic deposits should be approached on two levels: (1) regional; (2) local. Local investigations are probably necessary before undertaking regional problems. Thus, good sampling technique must be established for peat (and other organic material, e.g. gyttja, muck) in order to obtain consistent results with a minimum number of samples.

Detailed Local Studies

Investigation on a detailed local basis in bog and muskeg should take the form of:

(1) Studies of physical conditions such as groundwater flow, upwelling of groundwaters, porosity conditions, diffusion of elements, etc.

(2) Studies of the vertical layers in profile in peat areas including their underlying clays, tills, etc.

(3) Studies of the vertical and areal distribution of pH, Eh, and metal and gangue elements.

(4) Studies of the nature of binding of elements in organic matter i.e. adsorption, chelation, etc.

(5) Botanical-ecological studies.

Physical conditions

The most important physical parameter is the hydrological condition. For example, peatlands can be classified into two main categories depending upon the type of water they receive. Minerotrophic peatland mainly receives waters that drain or percolate through soil, till, rock, etc. Ombrotrophic peatland receives water solely from the precipitation on the area. The ombrotrophic condition being extreme may not vary much in a given district and is, therefore, poor in mineral-influenced drainage waters. The minerotrophic condition, on the other hand, is highly variable because its waters are influenced by precipitation, by the amount of water entering, and by the type of rock, soil, or overburden through which the waters pass. It is reasonable to expect the minerotrophic condition to be more favourable for reflecting mineralization related to a metal deposit beneath it or in its vicinity, than the ombrotrophic environment, and hence more favourable for exploration prospecting. Studies of the water factor will include, therefore, type of water received, drainage patterns, surface and groundwater movement, and the effect of these on the chemistry, mode of metallization and vertical and lateral dispersion patterns of the elements in the peat area.

Drainage courses and surface water patterns in a peatland can be studied from air photographs and in the field. Radioactive tracers and fluorescein may be helpful in tracing the flow where the surface waters are sluggish or practically stagnant (Ochiai, 1964). Knowledge of the flow direction is imperative to determine peatland metallization on an areal basis where peatlands receive effluent from metal-rich springs that leach mineralized areas.

Determination of the flow direction and characteristics of groundwaters, or more accurately, below-surface-waters is a more difficult problem. Movement can be detected by experimental methods. Rings of holes surrounding a central reservoir hole into which a radioactive tracer or fluorescein is introduced may be most effective. The rate of flow and the gradient can thus be determined approximately, but there are many problems involving adsorption of the radioactive tracer or dye by the organic material. Underground water movements can also be delineated, probably more readily, by vegetation interpretation. This is discussed more fully in the section on botanical studies.

The effect that upwelling groundwaters, for example from springs along faults or other open structures, have on mineralization of peat deposits can only be examined in the field. Such springs are often marked by more alkaline pH or by specific ratios of elements such as the alkalis or alkaline earths. Sulphate and carbonate measurements may also reveal the presence of the springs as may botanical indicators. Where such springs are arranged in linear manner as along faults, the mineralization may exhibit a linear pattern. Other patterns are, however, to be expected and can only be delineated by detailed chemical and botanical investigations of an area.

The diffusion of elements upward and laterally in a peat area can be examined both in the field and laboratory. In the field, patterns can be defined by chemical analyses of the layers over a grid extending throughout the study area. In the laboratory, columns and prisms of organic profiles can be used to determine the rate of diffusion of the elements by the use of radioactive tracers.

Metal distribution in peat profiles

Elemental distribution in peat profiles has been studied by Hvatum (1964), Mitchell (1954) and Gleeson (1960). Lead, zinc, and molybdenum concentrate in the upper layers of peat, and copper, cobalt, and manganese are generally present in maximum concentration at the top and bottom of bogs in Norway (Hvatum, op.cit.). The copper, zinc, lead, and nickel contents increase with depth in Scottish peats overlying rocks containing background quantities of metals according to Mitchell (op.cit.).

Studies of this kind can only be done in the field. A grid of closely spaced sampling sites for peat profiles is required. The vertical and areal elemental distribution should be determined for each bog type characterized by its physico-chemical, hydrological and botanical features. Areas that have a background elemental content should be compared with those that are enriched in metals from known nearby mineral deposits (Salmi, 1955; Gleeson and Coope, 1967).

Special attention should be given to clay, till, or other mineral matter immediately underlying the organic material. For example, at Timmins, Ontario, the migration of the elements into the peat above is reported to be impeded by an underlying impervious varved clay layer (Fortescue and Hornbrook, 1967).

Patterns of metal distribution along the margins of the peat areas where they overlap onto mineralized terrains should be investigated. Mineral matter carried by waters draining from mineralized terrains is precipitated, absorbed, or otherwise removed from solution comparatively close to the marginal parts of the bog according to Salmi (1949). The factors influencing the removal of material include the particle size and degree of humification of the peat. The central portions of the bog are not influenced by the mineral matter of these waters.

Eh and pH patterns, both vertically and laterally, should be carefully studied in relation to metal distribution as well as to underlying bedrock, clay, till, etc. Different concentrations of the elements and different bedrock types are associated with different pH (Saprykin and Sventikhovskaya, 1965; Salmi, 1958; Tikhonov, 1966).

Geochemistry of organic matter

Studies of the nature of the binding of metals by organic matter are necessarily long-term and will require the co-operation and assistance of organic chemists. The mechanisms by which metals and other elements are fixed appear to involve sorption processes, exchange reactions, and chelation. Other complex organic reactions that may be revealed by further research may also be involved. Many organic deposits concentrate the hydroxides of iron, manganese, alumina, and silica, all of which may have strong adsorptive and fixative properties for many metals. Also, hydrogen sulphide, liberated by bacterial action of decaying proteinaceous substances, may precipitate the chalcophile elements and influence the precipitation of metals such as vanadium and uranium.

The adsorptive and exchange capacities of organic matter can be readily determined for most elements by well established techniques. Radioactive tracers are particularly useful in this respect. It would be interesting to examine the various layers of a peat profile for their adsorption and exchange capacities in relation to depth and peat quality, i.e. degree of humification, botanical origin (sphagnum peat, woody peat, gyttja, etc.). These would be invaluable data in the interpretation of metal distribution in peatlands.

The importance and necessity of this type of research for prospecting purposes in organic terrain has only recently been recognized. Several papers on the subject have appeared in the past few years in the U.S.S.R. and Europe. Copper is fixed by various natural organic compounds and in part forms chelate compounds with humic acids (Manskaya et al. 1958, 1960) Nickel and copper chelation by organic matter has also been reported by Pratt et al. (1967). Molybdenum is adsorbed onto humic acids, and vanadium is also associated with humic acids (Szalay and Szilagyi, 1967). Iron interacts with peat soil humic and fulvic acids and uranium is strongly bonded by peat (Manskaya et al., 1956; Titaeva, 1967; Kranz, 1968).

The copper chelation reported by Fraser (1961b) in New Brunswick bogs has already been mentioned. Two other studies on copper behaviour with organic matter were made by Lees (1950) and Dawson and Nair (1950).

Pertinent detailed studies on organo-metallic complexes have been reported (Broadbent, 1955, 1957; Schnitzer et al., 1964, 1965, 1967; Aleksandrova, 1954, 1960; Aleksandrova and Nagy, 1958). A recent treatise on the geochemistry of organic substances deals with the organic substances of peat, paths of formation, structure of humic and fulvic acids and the importance of organic substances in the migration and accumulation of the elements (Manskaya and Drozdova, 1964).

Detailed botanical studies

Botanical features or 'indication geobotany' (Chikishev and Viktorov, 1963) are becoming increasingly important in geological (Sigafoos, 1958; Shacklette, 1966), geomorphological (Shvyrayayeva, 1961; Sjörs, 1961b; Radforth, 1962; Usik, 1966), and hydrogeological (Viktorov, 1955, 1961; Chikishev and Viktorov, 1963; Sloan, 1967) interpretation. The work of geobotanists and geologists in analyzing the geological adaptability of plant growth and in applying this to practical geologic interpretation has perhaps achieved its greatest development in the U.S.S.R. (Viktorov, 1955; Viktorov et al., 1964; Boch, 1965). This is especially true in the case of geobotanical prospecting for mineral deposits (Malyuga, 1954; Nesvetaylova, 1955; and others). The use of vegetation as a tool in mineral exploration and prospecting in peatlands opens wide and practical prospects.

Briefly, the botanical indicator method is based on the principle that environmental conditions - hydrology, chemistry, mineral (nutrient) content, etc. - of the plant growth substrate may be reflected in the vegetation.

The geobotanical prospecting method can be developed and applied in peatland areas for direct and indirect indicators of mineral deposits. Direct plant indicators are those affected by the presence, or by an abnormal (for the plant) concentration, of an element in the soil or soil waters. Such indicators can be recognized by investigation of: (1) the plant species or assemblage composition and distribution - where presence (because of an affinity to an element) or absence (because of the toxicity of an element) may be indicative of mineralization, and (2) plant appearance - where aberrations or variations in the morphological (size, colour, shape) or physiological (vitality, reproduction, flowering) features of the plant are indicative of mineralization. Recognition of direct plant indicators requires a careful detailed systematic survey both over areas of known and unknown mineralization. It also requires knowledge of plant physiology and ecology in order to distinguish features (variations) that are directly or indirectly induced by the presence of mineralization.

In a study of the flora at Great Bear and Great Slave lakes in the Northwest Territories, Shacklette found variations in the fruit of the bog plant, dwarf blueberry (Vaccinium uliginosum), which grew over a pitchblende deposit. This species and many of the other blueberries are ubiquitous and grow most commonly or exclusively in peatlands.

Another group of plants common to wet organic soil sites that merit serious investigation as potential plant indicators in peatlands are the mosses. In Canada 'copper mosses' were reported for peat bogs in New Brunswick (Beschel, 1959; Fraser, 1961a). Pohlia nutans grew in a peat deposit highly enriched in copper. The presence of this species invariably indicates excessive surface copper content (Fraser op. cit.). Furthermore, the high concentration of copper killed the trees on this site.

Other reports on copper mosses, on bryophytes (mosses, liverworts, lichens) associated with mineral deposits, and on the element content of bryophytes may be referred to for investigating these plants as direct indicators in peatlands (Shacklette, 1965a, 1965b, 1967).

Some plants accumulate abnormally high concentrations of the elements from the substrate without any visible effects. Such accumulator plants can only be investigated by careful chemical analysis. This method is known as the biogeochemical method and has received much attention in the U.S.S.R. (Malyuga, 1964), in the U.S.A. (Cannon, 1961) and in Canada (Warren and Delavault, 1955, etc.).

Relatively few of the studies, however, have been carried out on peatlands. In the U.S.S.R. birch and pine are effective for delineating copper mineralization in bogs (Poskotin and Lyubimova, 1963). In Finland, twigs of Labrador tea (Ledum palustre) contaim more Zn, Cu, and Pb than the peats in which they grow (Salmi, 1956 a, b). It was concluded that plant-chemical sampling is better than peat-chemical prospecting where the peat is not greater than several metres deep and where water conditions are very high.

Nettle, willow, and aspen species concentrate abnormal amounts of zinc and have been used to discover two areas of mineralization in the U.S.A. In the Bathurst area, New Brunswick, mosses growing in a peat bog situated over a copper-bearing sulphide deposit concentrate iron.

The ubiquitous bog species Labrador tea (Ledum groenlandicum) is conspicuous in accumulating manganese and two other well known species indigenous to peat areas - black spruce (Picea mariana) and tamarack (Larix laricina) are found to respond to even small amounts of Cu and Zn in the substrate (Warren and Delavault, 1955a, 1955b). The familiar alder (Alnus) of bog, muskeg, and swamp is also reported to be an accumulator of copper. Labrador tea, black spruce, and tamarack offer the best hope of exploring biogeochemistry in 'muskeg country' according to these authors. However, the application of biogeochemistry in peatland areas is limited to the depth of the organic deposit; useful results can only be expected when the peat is less than 30 feet - or at the most 50 feet thick.

The development of the biogeochemical method for peatland prospecting should be directed towards the examination of the concentration of elements in indigenous peatland plant species in order to establish accumulator plants. This will require investigation of element behaviour in species from peat areas with similar and with different environmental conditions that are either mineralized or nonmineralized. There is a need to recognize and interpret the effects of the numerous environmental factors - chemical (e.g. pH), hydrological (e.g. water regime), physical (e.g. soil temperature) - on the chemical relationships of the plant. Such recognition will facilitate the interpretation of elemental accumulation, and levels of toxicity and tolerance in plants for prospecting. A basic knowledge of plant physiology, ecology, and taxonomy are, therefore, essential to successful research of this type.

Not only do the phytocenoses (plant community, plant species) in water-saturated organic soil sites differ from those of dry mineral soil sites, but variations within the peatland vegetation are indicative of variations in the environment. Hence, the physical, chemical, hydrological, and pedological characteristics of a peat area can be interpreted by botanical indicators and thus facilitate prospecting. Classification of different kinds of peat areas related to their physico-chemical conditions may be made from their vegetation. The minerotrophic condition of a peat area discussed earlier, is characterized by a 'fen vegetation', i.e. a rich herb flora of basiphilous or calcareous plant species such as buckbean (Menyanthes), bladderwort (Utricularia), birch (Betula), sweet gale (Myrica), and the brown (Hypnum) mosses. Plant species will even reflect the degree of minerotrophy in this condition. For the poorly mineralized (i.e. in plant nutrient content), acidic ombrotrophic condition there is a 'bog vegetation' in which black spruce, leather leaf (Chamaedaphne), Labrador tea, bog laurel (Kalmia), and sphagnum mosses predominate. The classification of peatlands in relationship to their vegetal cover and environmental conditions, and the relationship between mineral influenced bog waters and vegetation cover and patterns in peatlands have been studied by various investigators (Gorham, 1956; Heinselman, 1963, 1965; Sparling, 1966; Sjörs, 1950, 1961a, 1963; Ritchie, 1960, 1962; Pierce, 1963; Bay, 1966).

The pH of bogs is related to the underlying bedrock and it has been suggested that pH can be used in prospecting (Salmi, 1958). Ionic composition and pH are also related to the vegetation cover type and may be predicted by observation of the plant cover alone (Sjörs, 1950a, b; Pierce, 1953; Bay, 1967b). Another possible use of vegetation in prospecting peatland is thus well illustrated.

Vegetation may also be used to interpret the type of mineral substratum beneath the peat as well as peat depth, peat type, degree of peat humification and botanical origin (Sjors, 1961a, b, 1963; Ritchie, 1962; Boch, 1965). Such information will undoubtedly facilitate the application of and the interpretation of results from the geochemical, geobotanical, and biogeochemical methods.

Finally, vegetation can be used to investigate and interpret the hydrologic environment of a peat area. The type of water an area receives is reflected in its plant cover. Drainage courses, seepages, and springs can be delineated by plant indicators as can underground water movement (Yurkevitch, 1966; Heinselman, 1963; Sjörs, 1961a, b, 1963; Radforth and Usik, 1964). Hydrological conditions may be reflected by: (1) the presence of a particular plant species or community of species, e.g. cedar (Thuja) is almost always indicative of fresh or spring water; or (2) the vitality and quality of growth, e.g. taller and larger (in diameter) black spruce are found in areas of active (underground) water movement (Ritchie, 1960; Heinselman, 1963; Sjörs, 1961b).

The geobotanical method is greatly facilitated by the use of aerial photographs because of the inaccessibility of and difficult trafficability over peatlands. Airphoto interpretation using vegetation has already been recognized in mineral reconnaissance and development and botanical investigations of environmental plant indicators in peatlands as described above have been easily and readily made from airphoto interpretation (Dyukarev, 1936; Galinka, 1937, 1964a, b; Radforth, 1955, 1956, 1958; Radforth and Usik, 1964; Sjörs, 1959, 1961b; Finley, 1960; Heinselman, 1963; Usik, 1966).

The use of colour and infrared photography also offers great possibilities for application of botanical interpretation to peatland prospecting. Recent work has shown a greater range and better quality of interpretation in botanical, geological, and hydrological studies by use of these media (Colewell, 1968). Geologic interpretation of coloured air photographs can lead to the discovery of orebodies. The hydrologic environment of an area can be inferred from vegetation interpretation of infrared photographs (Schneider, 1968). Ecological conditions, plant communities and even plant species can be investigated on colour photographs (Plummer, 1968). Plant vigour and health such as dying and disease-infected forest trees are detected by infrared photography (Colewell, 1967; Marshall, 1968; Meyer, 1967). The use of these tools for the investigation of botanical indicators of mineral deposits and of environmental conditions in peatlands is recommended.

Each of the detailed studies discussed above is required to characterize accurately the different types of peat (and other wet-site) areas in order to frame the most suitable method of approach and sampling technique for investigations on a regional basis.

Regional Studies

The principal difficulty in the regional approach is to obtain an adequate sampling of the peat areas for geochemical analyses. This will depend essentially on the results obtained and techniques developed from detailed local studies of peat areas, both in the vicinity of mineral deposits and well removed from them.

It is probable that mineral belts or zones are reflected by haloes or strings of peatlands enriched in metals or gangue elements compared with similar peatlands that occur in unmineralized areas. In relatively flat-lying areas a mineralized belt is likely to be surrounded by a metal-enriched halo which grades into the background bog. In an area in which there is definite water movement the metal-enriched halo is likely to form a linear band 'downstream' from belt roughly parallel to a mineralized belt. Great variation is to be expected in individual cases because of drainage, underground water circulation, upwelling of groundwaters, topography, geology, climate, and botanical conditions.

Once satisfactory sampling procedures are established, a broad survey may be carried out using air photographs to delineate the peat areas and their hydrological, botanical, geological, and physical features, and helicopters to collect samples for chemical and botanical analyses. Two general areas should be chosen - one a background area where no mineral deposits are known, and the other, a test area where mineral deposits are known and relatively undisturbed. Geochemical and geobotanical data obtained from the survey should be plotted and the patterns studied carefully.

CONCLUSION

Areas of water-saturated organic-covered terrain can be effectively investigated by geochemical and botanical methods in order to explore and discover mineral deposits in heavily glaciated areas of Canada. Much work on a detailed local and regional basis is necessary in order to establish local and regional background information as against metal anomalies in peatlands. Background data on metal migration and behaviour and concentration in water, peat, and plants is essential. The establishment of geochemical and geobotanical background data will require the knowledge of geologic, geomorphologic, geogenic, hydrologic, chemical and ecological characteristics of the peatlands. Botanical investigations can greatly facilitate the investigation of the above factors. A classification of peatlands using established geochemical and botanical indicators of mineral deposits or of conditions most favourable for their presence, may enable qualitative prediction of mineralization or possible mineralization in any region.

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