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GEOCHEMICAL PROSPECTING FOR PETROLEUM AND NATURAL GAS IN CANADA

A. H. Debnam

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By

A. H. Debnam

DEPARTMENT OF
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PREFACE

Geochemical prospecting methods for oil and gas have not achieved the popularity of established geophysical methods although they have been applied widely in both the U.S.A. and the U.S.S.R. Many new discoveries in each of these countries have been directly attributed to the use of geochemical methods. In Canada only a very limited application has been made of geochemistry as a prospecting tool for oil and gas.

In this paper the author has attempted to establish whether geochemical prospecting methods for oil and gas can be successfully applied in Canada where thick glacial deposits are present and where large amounts of hydrocarbons all through the sedimentary column tend to obscure the hydrocarbon haloes associated with concentrations of oil and gas. He finds that the geochemical method based on microanalysis of gas from soil and till has some merit and should be applicable in Canada when used in conjunction with established geological and geophysical methods.

Y. O. Fortier,
Director, Geological Survey of Canada

Ottawa, June 25, 1965

BULLETIN 177 — Die geochemische Suche nach Erdöl und Erdgas in Kanada

Von A. H. Debnam

Der Verfasser weist nach, dass die geochemische Methode der Suche nach Erdöl und Erdgas ihren Wert hat und sich in Kanada in Verbindung mit den bewährten geologischen und geophysikalischen Methoden anwenden lässt.

БЮЛЛЕТЕНЬ 177 — Геохимическая разведка нефти и природного газа в Канаде

А. Г. Дебнам

В предлагаемой работе автор доказывает, что методы геохимической разведки нефти и природного газа практически ценны и должны применяться в Канаде наряду с уже испытанными геологическими и геофизическими методами.

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Abstract

In this bulletin an attempt is made to evaluate the application of a geochemical method for locating oil and gas fields in Canada. The Innisfail and Pincher Creek fields in Alberta and the Gobles and Colchester fields in southwestern Ontario were chosen for study.

Of the numerous geochemical techniques available the author chose soil sampling from a depth of 8 feet with subsequent extraction and determination of the gaseous hydrocarbons ethane, propane, butanes, and pentanes as being the most direct and reliable prospecting procedure. Reproduction of the sampling technique and repetition of the analytical techniques appear to be within acceptable limits.

Factors that may cause erroneous results include variations in soil type and uneven topography, and the writer recommends that surveys be restricted to areas in which adverse factors contribute minimum errors rather than to attempt to apply corrections to results obtained in unsuitable areas. The presence of deep glacial deposits at the surface and of large amounts of hydrocarbons distributed through the sediments above the oil and gas pools does not seem to have an unduly adverse effect on the results.

Geochemical anomalies appear to be associated with all the fields studied with anomaly intensity roughly proportional to productivity. Each of the "halo" and "solid" types of anomalies can be recognized.

The writer concludes that the geochemical method can be a valuable addition to the usual geological and geophysical exploration methods if used under favourable circumstances.

Résumé

L'auteur de ce bulletin tente d'évaluer l'application d'une méthode géochimique à la localisation des champs gazifères et pétrolifères au Canada. Pour les besoins de cette étude, on a choisi les champs d'Innisfail et de Pincher Creek en Alberta et ceux de Gobles et de Colchester dans le sud-ouest de l'Ontario.

De toutes les techniques géochimiques applicables, l'auteur a choisi l'échantillonnage du sol à une profondeur de 8 pieds et l'extraction subséquente ainsi que la détermination des hydrocarbures gazeux (éthane, propane, butane et pentane); cette méthode de prospection serait la plus directe et la plus sûre. La reproduction de la technique de l'échantillonnage et la répétition des techniques analytiques semblent donner des résultats satisfaisants.

Les variations dans les genres de sol ainsi qu'un terrain accidenté sont des facteurs susceptibles de fausser les résultats; l'auteur recommande que les relevés soient limités aux régions où les facteurs nuisibles ne causent que des erreurs négligeables, plutôt que de tenter de rectifier les résultats obtenus dans des régions impropres. La présence en surface de dépôts glaciaires épais et de quantités considérables d'hydrocarbures répartis dans les sédiments au-dessus des gisements pétrolifères et gazifères ne semblent pas avoir d'effet trop néfaste sur ces résultats.

Les anomalies géochimiques semblent s'associer à tous les champs déjà étudiés et leur intensité est à peu près proportionnée à la productivité. Les anomalies des types à «halo» et «solides» sont reconnaissables.

L'auteur conclut que la méthode géochimique, utilisée dans des circonstances favorables, améliorera les méthodes habituelles d'exploration géologique et géophysique.

INTRODUCTION

Geochemical prospecting methods for oil and gas were first developed in 1929 by Laubmeyer (1932). Although they have since been used in many forms by a great number of individual workers with varying degrees of success, the techniques have apparently received little recognition, presumably because many geologists believe that hydrocarbons cannot possibly migrate from a pool at depth to the surface where they can be detected by sensitive modern analytical procedures. Unsuccessful geochemical surveys are often cited to discredit geochemistry even when the failure was probably due to inexperienced operators whose methods were not based on sufficient research, or to too shallow drilling of test holes. On the other hand a great deal of positive evidence has appeared in the literature, and if these results are accepted it is obvious that the geochemical methods have at least some value in locating oil and gas pools.

One of the main problems for the geochemist is that at present there is no satisfactory theory to link the surface geochemical anomalies with the hydrocarbon accumulation at depth. Several gas-migration theories have been proposed, but none appears to be entirely satisfactory. Hence the geochemist must refer to the wide accumulation of empirical evidence which indicates beyond a doubt that hydrocarbon migration to the surface of oil and gas pools does take place.

The basis of the geochemical prospecting methods—the fact that gas migration occurs—may best be considered as a logical development from our knowledge of macroseeps of gas. It is well known that in petroliferous areas visible gas and oil seeps, together with their derivative paraffin dirt, have been widely used in oil prospecting; in fact this method of direct observation has resulted in the discovery of more oil and gas fields than any other single method. Because of this it should be relatively easy to accept the possibility of the presence of microseeps in addition to the obvious macroseeps. The much smaller quantities of gas and liquid and solid petroliferous materials involved in such microseeps were undetectable until the extremely sensitive analytical procedures of modern chemistry were developed. These new analytical tools have revived the field of geochemical prospecting in which materials

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actually derived from the deposits (or closely related materials) are determined, making it the most direct of the prospecting techniques. In comparison, geophysical methods and geology are indirect because they only outline structures which may or may not contain oil or gas. Another advantage of geochemistry over geophysics and geology is that it is not limited by the type of trap in which the hydrocarbons have accumulated. Anomalies are normally present over all types of traps whether they be structural, fault, or stratigraphic (reef, porosity, or pinchout), provided hydrocarbon accumulations are present.

Acknowledgments

The author wishes to thank the National Research Council of Canada for the granting of a Post-doctorate Fellowship for the project and the Geological Survey of Canada for the use of laboratory and office facilities together with field personnel and equipment. In particular the assistance of Dr. R. W. Boyle was much appreciated.

MIGRATION OF GASES

Gas migration is possible because no rock is wholly impervious to the passage of mobile gases. With a time factor involving millions of years, the great pressure and concentration gradients, and the high temperatures usually present in subsurface formations, we have the conditions that make possible the effusion and diffusion of gases through a sedimentary pile. The amount and rate of effusion and diffusion of the hydrocarbons are of secondary importance, for over the tremendous span of geological time the effects of minute but continuous leakage will give totals of appreciable magnitudes.

Gas migration is a physical process and occurs in a number of ways: as a free migration or effusion along fissures and zones of disturbance to produce macroseeps, by diffusion through sedimentary rocks to produce microseeps, and in certain cases dissolved in groundwaters. Diffusion is considered to be the most important process involving the movement of gas molecules through water-filled pores (molecules dissolved in water), through the crystal lattices of minerals, and along surfaces of mineral particles (adsorbed molecules). The phenomenon of adsorption is probably the most important of the diffusion processes.

Although definite proof of gas migration by diffusion has not yet been established it is possible to relate migration to the empirical results both at the surface and at depth. Surface indications appear as hydrocarbon anomalies which usually bear some definite relationship to the size and position of the oil and gas accumulation. The common types encountered are the "halo" and the "solid" anomalies. Indications at depth are found as higher-than-normal hydrocarbon concentrations in the sedimentary strata for several hundreds of feet above the accumulations.

In the halo-type anomaly the maximum hydrocarbon content develops in a ring pattern above the edge of the pool rather than over the centre. The halo is the most common geochemical surface expression of oil and gas accumulations, and in general the inner edge of the halo lies directly above the production limits of the pools. Several explanations for this halo pattern have been proposed. Rosaire (1940) considered that as a pool forms the high concentrations of carbon dioxide in the oil and gas cause reactions with relatively soluble bicarbonates in the cap rock resulting in precipitation of carbonates that block the pores in the rocks above the accumulation. This causes a lower permeability in the formations directly above the oil or gas and less upward migration of hydrocarbon gases that are forced to escape in greater quantities from the edge of the pool. Nisle (1941) explained the phenomenon on a thermodynamic basis. As the hydrocarbon gases migrate upward they induce evaporation of groundwaters in the upper 1,000 feet of the sedimentary column. The evaporated groundwater is replaced by waters moving inward toward the migrating hydrocarbons and this inward drift localizes laterally the escape paths of the hydrocarbons producing quite narrow geochemical anomalies even from deep-seated accumulations. In addition this inward drift of waters accounts for the presence of anomalies of secondary silicates, carbonates, and radioactive materials in the near-surface deposits. Other workers postulate the presence of microscopic fissures in the cap rock at the edges of oil and gas pools as the cause of halo type anomalies.

The solid anomaly is probably the result of migration of gases from pools contained below steeply folded anticlines in which microfissuring may be present throughout the entire cap rock. An elongate or semicircular form of the solid anomaly is often found above stratigraphic and fault traps, but in many cases the shapes of the anomalies depend on many unpredictable factors that are not always clearly defined.

The effects of gas migration from oil and gas accumulations are often utilized in the application of geochemical well logging during drilling. In this procedure the drill cuttings (rock chips) are analyzed for hydrocarbons. Ransone (1941) and Horvitz (1954) both showed how the presence of a pool can be predicted perhaps 500 to 1,000 feet ahead of the bit due to a rapid increase in hydrocarbon content of the cuttings as the pool is approached. No such increase in hydrocarbon values in cuttings occurs in the case of dry wells.

GENERAL DISCUSSION OF GEOCHEMICAL PROSPECTING METHODS FOR OIL AND GAS

When Laubmeyer (1933) took the first steps towards microgeochemical prospecting he collected samples of the free gases in the near-surface soils and analyzed them for saturated hydrocarbons. These free-gas methods were further developed in the U.S.S.R. (Sokolov, 1935) where they are still used. The gas survey utilizes capping devices over bore-holes from which the gas is either pumped or collected by sorbents. Field procedures and apparatus are complicated, samples are difficult to collect and store, and it is often impossible to collect samples from below the water-table. In general the free-gas techniques have been replaced by soil sampling methods.

Soon after the geochemical methods were introduced in the U.S.A. in 1935 Horvitz (1939) realized the limitations of the free-gas technique and began to collect soil samples from which the gases were extracted for analysis. Horvitz claimed a simplification in sample collection, a more uniform sample of improved quality, lower cost, and the extention of sampling to the regions below the water-table.

As the use of the geochemical methods developed, various phenomena were recognized such as secondary inorganic anomalies, variations in the hydrocarbon content of groundwaters, anomalous numbers of hydrocarbon-consuming bacteria, and the presence of waxes in the surface soils. All these manifestations appeared to be related to the leakage of hydrocarbons from accumulations at depth.

The various geochemical methods based on these phenomena have been classified in the U.S.A. by Rosaire (1939) and in the U.S.S.R. by Kartsev, *et al.* (1959). Briefly they can be summarized as follows:

1. Gas (free hydrocarbon gases in soil)
2. Soil (adsorbed hydrocarbon gases in soil)
3. Bitumen (soil wax, e.g., paraffin dirt)
4. Hydrochemical (hydrocarbon gases dissolved in water)
5. Oxidation–reduction potential
6. Soil salt (chloride, carbonate, sulphate, etc.)
7. Inorganic hydrochemical (salts dissolved in water)
8. Microbiological (bacteria, particularly specific methane- or ethane-consuming genera)
9. Geobotanical (plants develop characteristic forms and features when soil contains bitumen)

Methods 1 to 4 are considered to be direct methods as they determine materials which are either found in the oil and gas accumulations or are directly derived from them. Methane is usually eliminated from gas determinations because its origin may be other than from oil or gas deposits, e.g., it has a biochemical origin in marshes. Methods 5 to 9 are indirect because they use phenomena or materials not originally associated with or present in the accumulation.

A survey of the literature reveals that the direct prospecting procedures have the greater success ratios. With this in mind the project described in this report was based on the determination of the light saturated hydrocarbons other than methane (i.e., ethane, propane, butanes, and pentanes) extracted from soil samples. Although the following discussion will be limited to this particular procedure it should be pointed out that the other methods listed above could also have been applied.

Many arguments have been presented against the use of soil as a sampling medium. At first sight the difficulties appear to be insurmountable, a feature that may have discouraged many workers from using soil surveys for locating oil and gas accumulations. The main objections to soil sampling have been considered by Sanderson (1940) and Pirson (1946). Sanderson's arguments concern the difficulty in determining correction factors for: (1) the accuracy of the analytical results because gas extraction from different soils even under similar conditions may be different, (2) the variations in soil types both in chemical composition and degree of subdivision, (3) the conditions of sorption when many other more readily sorbed gases are present. In practice the writer has found that any one extraction procedure is apparently uniform and that the results given by soils of entirely different types appear to be similar. This may indicate that the soil type plays an insignificant role in the interpretation of the data. In fact in the writer's experience it appears that sorption plays only a minor role as a mechanism for retention of hydrocarbons in soils.

The disturbing factors discussed by Pirson concern topography and underground water circulation. In practice these factors may cause considerable variations in results, but if the operator is aware of their presence suitable corrections can be made.

In a recent paper Smith and Ellis (1963) question the applicability of direct detection of hydrocarbons from near-surface soil samples in prospecting for gas or petroleum. They claim that the paraffinic and olefinic hydrocarbons in soils originate at least in part from living and dead plant matter. In the present study such effects have not been evaluated. However it should be noted that the samples analyzed came from depths varying from 5 to 10 feet, well out of the range, it would seem, of any contaminating influence from the surface vegetation.

Probably the best approach when applying geochemical methods is to seek conditions that will keep uncontrolled variables to an absolute minimum, such as making comparisons between similar soil types and selecting areas with flat topography. It is interesting to note that Rosaire, *et al.* (1940) applied no correction factors because the geochemical anomalies appeared to be readily distinguishable without correction of the data.

CASE HISTORIES

Davidson (1963) deplored the lack of published information in the scientific journals on geochemical case histories; there are, however, many references in the literature either to specific case histories or to the success ratios established by a particular group or company.

Stormont (1939) cited the discovery of an oil field in the Texas Gulf Coast on soil-survey information. In 1942 a geochemical survey predicted the discovery of the West Edmond oil pool in Central Oklahoma (Bronson, 1947). The discovery of the Hardy oil field in Texas followed drilling on a geochemical anomaly where no evidence of the stratigraphic trap was given by the reflection seismograph (Ransone, 1947). Tabasaranskiy (1946) credits geochemistry with an important oil discovery in Alamyshik and also stated that in Central Asia positive geochemical indications proved largely correct and negative indications invariably correct. Pomeyrol, *et al.* (1961) reported that geochemical surveys in the Sahara successfully predicted a gas accumulation. In reply to a question on case histories at a symposium on geochemical exploration, Rosaire (Rosaire, *et al.*, 1940, p. 1449) cited a gas discovery at Stroud in Oklahoma and other successes which included examples of field extensions, well logging, and new pay zones. Davidson (1963) cited a recent case in which the discovery of the Kohav oil field in Israel (the second oil field in that country) is credited entirely to hydrocarbon geochemistry. Stepout wells at both this field and at the original Heletz field were dry, confirming the geochemical predictions.

Several reports of group results have appeared in the literature and the overall success ratios of the geochemical predictions are usually given. Simmons (1940) cited the results of 300 geochemical surveys made in 1939. Failures nearly equalled discoveries producing a success ratio of greater than 50 per cent. Petroleum Week (1960) quoted a success ratio of 65 per cent for twenty geochemical anomalies drilled in the Texas Gulf Coast; there were thirteen productive wells and seven wildcats. In North Texas the success ratio is given as 75 per cent. Geochemical Surveys of Dallas claimed twenty-six discoveries from the one hundred and two anomalies drilled (Petroleum Week, 1959). Their success ratio of 25.5 per cent is lower than those reported by other groups because this company used an indirect inorganic analytical method rather than a direct hydrocarbon method. Of the one hundred and nine geochemical anomalies discovered by Horvitz of Houston during the period 1942–53, thirty-nine were drilled to yield twenty-three discoveries, a success ratio of 59 per cent (Pirson, 1960). In a recent report to the 5th World Petroleum Congress, Sokolov, *et al.* (1959) gave a success ratio of 70 per cent for wells drilled on geochemical anomalies in the Soviet Union. Using a soil–air technique the Rayflex Exploration Company of Dallas successfully forecast fourteen out of seventeen producers, four of which were exploratory wells (Davidson, 1963).

Pirson (1942) applied the laws of probability to the various prospecting methods. His figures converted to success ratios were: random drilling 5.75 per cent, geology 8.18 per cent, geophysics 14.9 per cent, and geochemistry 57.8 per cent. When considered against the overall success ratios for wildcats drilled in the U.S.A., which were 11.8 per cent for 1957, 10.7 per cent for 1958, and 10.9 per cent for 1959 (World Oil, 1960), the performance of the geochemical methods is outstanding.

THE PROJECT

The project described in this report was designed to evaluate the possibility of using geochemical prospecting methods for locating oil and gas accumulations in Canada. In Canada the two factors that may complicate the application of geochemistry are the deep surface glacial deposits and the enormous amounts of organic material (hydrocarbons) found all through the sedimentary columns of most oil-bearing regions. These problems may not be as great as they first appear. In the case of the glacial deposits it must be remembered that gases are the most mobile of materials, and there is, therefore, a reasonable chance that gas migration through several hundred feet of relatively unconsolidated deposits will occur given sufficient time, say 20,000 years. Saukov (1960) reported that direct observations in the Timan-Pechora oil-bearing province indicate a recent vertical migration of hydrocarbon gas in overlying deposits for more than 1,000 metres from the oil pools. With regard to the organic material, some geologists estimate that the amount in the sediments above a deep pool probably exceeds the amount of oil or gas within the accumulation. The distribution of this organic material throughout the sediments would likely be fairly uniform, and the surface expression, if any, would be an increased hydrocarbon background upon which any anomalies due to oil or gas pools would be superimposed. The empirical results obtained in the present project appear to bear out this assumption.

Selection of Areas

The writer has no desire to convey the impression that geochemical methods will replace the accepted tools of geology and geophysics for oil finding. They should, however, receive much greater attention than is now given them in areas suited for their use. Assuming that it is within a petroliferous province a suitable area must satisfy certain conditions, each of which should be considered independently.

The main requirement for geochemical prospecting is a deep soil cover preferably with a thickness greater than 10 feet to permit a uniform sampling depth of 8 feet over the entire area. Shallower soils need not be excluded, but more attention must be given to interpretation of the results. Although not an essential requirement it is preferable if possible to avoid wide variations in soil type. Clay is the most suitable soil material for sampling; coarse gravels are difficult to sample and should be omitted during a sampling program. An accurate soil log should be maintained for all samples to keep the geochemist aware of variations in soil type throughout the area being surveyed. The only other significant requirement is that the area should be reasonably flat. Marked differences from one or more of these conditions may preclude the use of geochemical prospecting within an area. In the writer's opinion broken topography is the major cause of erroneous results encountered in geochemical prospecting.

The main limitation of the method is its inability to predict the depth of the hydrocarbon accumulation. This factor is not serious, however, if drilling can proceed to the Precambrian basement, and it is in such areas that the methods have their greatest potential, e.g., in southwestern Ontario. Davidson (1963) illustrated this by pointing out that geochemical anomalies previously condemned after shallow drilling are now producing fields as a result of deeper drilling.

If a survey is to cover a producing field for orientation purposes the field should have been recently discovered because it has been established that a surface geochemical anomaly diminishes in intensity as production proceeds and eventually disappears. In the present project this factor was a prime consideration. Only producing fields were surveyed where production had recently begun.

Procedures

Sampling Procedures

One fortunate aspect with regard to soil sampling in Canada is that most oil- and gas-bearing areas are covered by a good network of roads. Thus automobiles can be used for sample collection, eliminating tedious cross-country traversing which can be expensive. Reconnaissance sampling can usually be achieved by driving along parallel roads 1 mile to 1½ miles apart and selecting sample stations ⅕ or ¼ mile apart with the aid of the mileage metre. In more remote areas helicopter traverses are probably the best method of collecting samples.

The sampling program is normally divided into two distinct stages: (1) reconnaissance sampling to locate anomalies and (2) detailed sampling to investigate and delineate the anomalies. A typical reconnaissance program requires a sample density of five to ten samples per square mile achieved by collecting samples ⅕ to $\frac{1}{10}$ of a mile apart along parallel roads a mile apart or on a ½-mile grid pattern. A detailed program would require fifteen to forty samples per square mile depending on the size of the anomaly under investigation. Sample station locations can be plotted directly on maps of suitable scale. One inch to the mile topographic or soil survey maps are convenient for this purpose.

As a general rule samples on which gaseous hydrocarbon determinations are to be made should be collected as deep as is economically possible. A depth of 5 feet should be the minimum; 8 to 10 feet is the normal depth used for geochemical surveying. It is essential to keep sampling depth uniform throughout any one survey to avoid erroneous results.

Most Canadian soils can be sampled with hand-operated spiral augers as small as 1 inch in diameter although sands may require a bucket-type auger. Mechanically operated augers can be used, and in fact they are essential for penetration of hard, indurated soils. Small ¼-pint paint cans are convenient for sample storage but any wide-mouth screw-top glass jars (such as fruit jars) may be used.

The sampling crew normally consists of a chief and one or two labourers. The responsibility for correct sampling rests with the chief who must realize that the final results can only be as good as the original samples. High quality analytical results cannot correct careless sampling. An accurate description of each sample (soil log) should be maintained by the chief on special field data sheets. Information relating to sample location depth, soil characteristics, surface features, topography, vegetation, and local features must be recorded.

Laboratory Procedures

The treatment of soil samples and the determination of their hydrocarbon content has been described in a previous publication (Debnam, 1964).

Areas Studied in Canada

The oil and gas fields studied in the project were selected primarily on the basis of recent discovery. Extremely rough topography was avoided but even so some of the areas selected may have been too rough for the successful application of the method. No control was possible over variations in soil type. The type of trap and depth of the oil and gas accumulations were not considered as limiting factors.

Details of the fields investigated are given in Table I. For further information on individual fields the various references can be consulted.

The six fields listed were sampled during a brief period in the summer of 1961. In each survey samples were collected at locations $\frac{1}{3}$ mile to $1\frac{1}{2}$ miles apart along a traverse across the field. The aim was to obtain soil samples for use in the development of an analytical procedure and to determine the distribution of hydrocarbons in the soils, both laterally and in profile, in the vicinity of and remote from established oil and gas fields.

The main points that emerged from this preliminary program were:

1. Extraction and determination of hydrocarbons from soils was a relatively simple procedure.
2. Lateral variations in hydrocarbon content of the soils were evident, and these variations appeared to have some relationship to the location of the fields, although sample spacing was too great to permit a reliable interpretation of the results.
3. The hydrocarbon content of the soils varied considerably with differences in sample depth, and lateral comparisons were meaningless unless constant depths were maintained. In general the deeper samples gave the most reliable values.
4. Any component or group of components (except methane) of the gases in the soil, e.g., ethane, propane, ethane+propane+butanes, could be used for establishing anomalies.
5. Soil samples could be dried and pulverized without affecting their hydrocarbon content. Drying, pulverizing, and sieving was adopted as a standard procedure to eliminate variations due to moisture and coarse rock fragments.
6. Sieving sand samples and using the −200 mesh fraction for analysis produced values more comparable with those given by clay samples from the same location.
7. Samples could be heated to 400 degrees Centigrade without significant change in their hydrocarbon contents. This led to the theory that the hydrocarbons may be incorporated in the soluble portion of the soil rather than being adsorbed to the clay minerals. For several groups of results a correction factor was introduced whereby it was possible to compare the hydrocarbon content of the soluble portion of the soil samples rather than the content of the total bulk of the samples.
8. In general the soils from southwestern Ontario contained approximately five times the quantity of hydrocarbons as those from Alberta, possibly due to the shallower pools in Ontario.

The encouraging results obtained in 1961 were followed up in the summer of 1962 when four of the fields, Gobles, Colchester, Innisfail, and Pincher Creek, were re-sampled at much closer intervals along the same or similar traverses. The Morpeth and Joffre Viking fields were omitted due to lack of time and not because the preliminary results were less interesting than those of the other fields.

TABLE I *Details of Oil and Gas Fields Investigated*

Field	Location	Type	Discovery date	Approximate depth, feet	Producing zone	Trap	Topography	Soil data	References
Gobles	Southwestern Ontario	Oil and gas	1960	2,900	Theresa, Upper Cambrian	Stratigraphic pinchout of sandstone	Flat to rolling	Wide range of soil types from coarse sands to heavy clays	Burgess, 1962
Colchester	Southwestern Ontario	Oil and gas	1959	2,200	Trenton, Middle Ordovician	Secondary-dolomitized stratigraphic	Flat	Mostly heavy clay but coarse sand in places	Burgess and Hadley, 1960; Burgess, 1960
Morpeth	Southwestern Ontario	Gas	1954	1,630	Salina, Upper Silurian	Dome	Flat to slightly rolling	Heavy clay	Geol. Surv. Can., 1958
Innisfail	Alberta	Oil and gas	1957	8,500	Leduc, Upper Devonian	Stratigraphic reef bioherm	Flat to rolling	Mostly silty clay with heavy clay or coarse sand in places	Alta. Soc. Petrol. Geol., 1960; White and Charles, 1958
Pincher Creek	Alberta	Gas-condensate	1947	12,000	Turner Valley, Mississippian	Fault	Rolling	Only heavy clay from local depressions sampled; soil in high areas too rocky	Rhodes, 1957; Fox, 1959
Joffre Viking	Alberta	Oil	1953	4,900	Viking, Upper Cretaceous	Stratigraphic	Slightly rolling	Light to heavy clay	Alta. Soc. Petrol. Geol., 1960

Results

General Remarks

In the accompanying Figures 1 to 12 the primary aim is to present the results exactly as they were recorded in the laboratory. In practice it is often more advantageous to apply one or more of the accepted averaging or weighting systems to groups of consecutive values to arrive at a more representative value for any one point, e.g., the normal second-degree binomial weighting averages three values by doubling the centre value and dividing the total by four. The use of such techniques produces much smoother graphs than those shown and also assists interpretation by reducing the effects of "wild" values.

A considerable improvement in the quality of the results could have been achieved by a closer sample spacing. At Gobles the samples were ½ mile apart, and at Innisfail and Pincher Creek the spacing averaged ⅓ mile. Recent experience has shown that the minimum desirable spacing is five samples per mile with a preference for eight to ten per mile. The wide spacing was due to the desire to cover as great an area as possible in the time available, a practice not always advisable.

The great variety of soil types encountered over short distances owing to variations in the texture of the glacial till presented a problem that was minimized in the present project by the application of two entirely separate procedures. First, the samples were dried and sieved to obtain relatively uniform samples for analysis; the −200 mesh fraction was used in all cases. This procedure improved the quality of the results and eliminated a moisture determination and correction. Secondly, the amount of soluble material in the samples was determined, and the hydrocarbon value related to the soluble material content rather than to the total sample weight. The latter procedure was adopted after it was found that the hydrocarbons appeared to be occluded in the soil salts (soluble in hydrochloric acid) rather than being adsorbed on the clay particles.

Determinations on fractions of sand samples of various sizes from the Gobles area, southwestern Ontario, indicated the presence of hydrocarbon maxima in the −10 +35 mesh and the −200 mesh fractions (Tyler sieves) separated by hydrocarbon minima in the intervening fractions. This is illustrated by the results for the sand sample from position No. 11, Figure 1:

Mesh fraction	*Wt. % of sample*	*HC Value*
+10	0.2	not determined
−10+35	7.5	8,380
−35+80	78.0	5,140
−80+150	8.8	4,310
−150+200	1.4	5,380
−200	4.1	13,200

Note: The hydrocarbon (HC) values reported in this publication refer to the areas of peaks on the chromatograms. As relative values only were required, the results were not converted to quantitative gas contents of the soil samples. The sum of the chromatogram areas for ethane, propane, butanes, and pentanes has been used in all cases.

It is interesting to note that Dreimanis (1961) found a similar variation of percentage carbonate with grain size in coarse till samples from southwestern Ontario.

The adjustment to refer the HC content of the sample to the amount of soluble material only can be made in either of two ways. A dilute acid extraction (0.05 N HCl) can be employed as this will remove a fairly constant proportion of the solubles in the sample; or the total hydrocarbons can be extracted with a strong acid (2 N HCl) and a separate estimate made of the acid-soluble content. The first procedure is the more convenient.

It did not appear to be a problem to obtain representative samples, at least not for similar soils within a limited area. At sample location No. 13 of the main traverse on Figure 5, samples were collected at each of the four corners of a cross-roads with the following results:

		2 N HCl extraction		0.05 N HCl extraction
Corner	HC value (5-gm sample)	% solubles	HC value per gm solubles	HC value
SE	835	20	835	54
NE	795	15	1,060	80
NW	950	22	865	52
SW	750	20	750	48

These results all fall within the background range of values for the area and could not be confused with anomalous values (2,000–3,000 for the 2 N acid extraction and 200–400 for the 0.05 N acid extraction). Many duplicate samples at other locations gave less variation than that shown above.

It is interesting to note that in general the soils of southwestern Ontario contain four to eight times as much hydrocarbon as those in Alberta. Part of this difference is accounted for by the contents of soluble materials—southwestern Ontario soils contain twice the amount found in Alberta soils. Also, the deeper pools in Alberta may result in a greater dissipation of hydrocarbons as they migrate to the surface.

Gobles Field, Southwestern Ontario

Weak acid extraction of samples produced a distinct hydrocarbon anomaly directly above the oil and gas pool (Fig. 1). The soluble material percentage and adjusted hydrocarbon values have been plotted to illustrate the assumption that dilute acid will extract a fairly consistent amount of soluble material from the samples.

With the 2 N acid extraction a narrow anomaly occurs above the centre of the pool (Fig. 2). This anomaly coincides with an increase in the soluble portion of the samples, however, so that when the values are adjusted to take this into account the anomaly is eliminated. The increase in soluble material in the soil above the pool may in itself be an important factor for consideration at this field.

Perhaps the presence of a high-contrast anomaly cannot be expected above the Gobles pool. The pool pressure is much lower than would be expected for an accumulation at its depth (2,900 feet), an abnormality resulting from processes affecting the formations subsequent to accumulation of the oil and gas. This below-normal pressure would probably restrict the escape of gaseous hydrocarbons from the pool with a resulting decrease in intensity of any hydrocarbon anomaly at the surface.

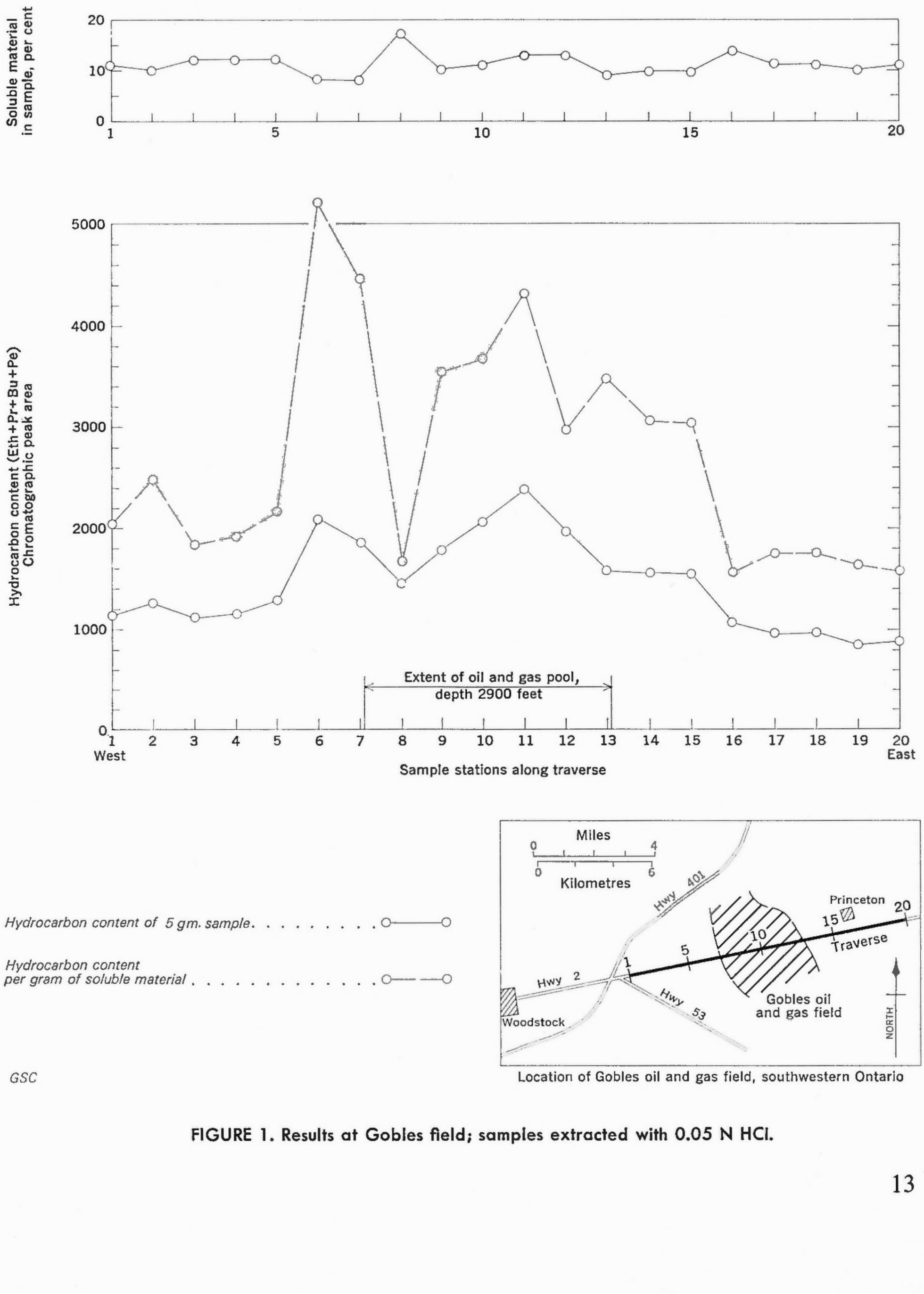
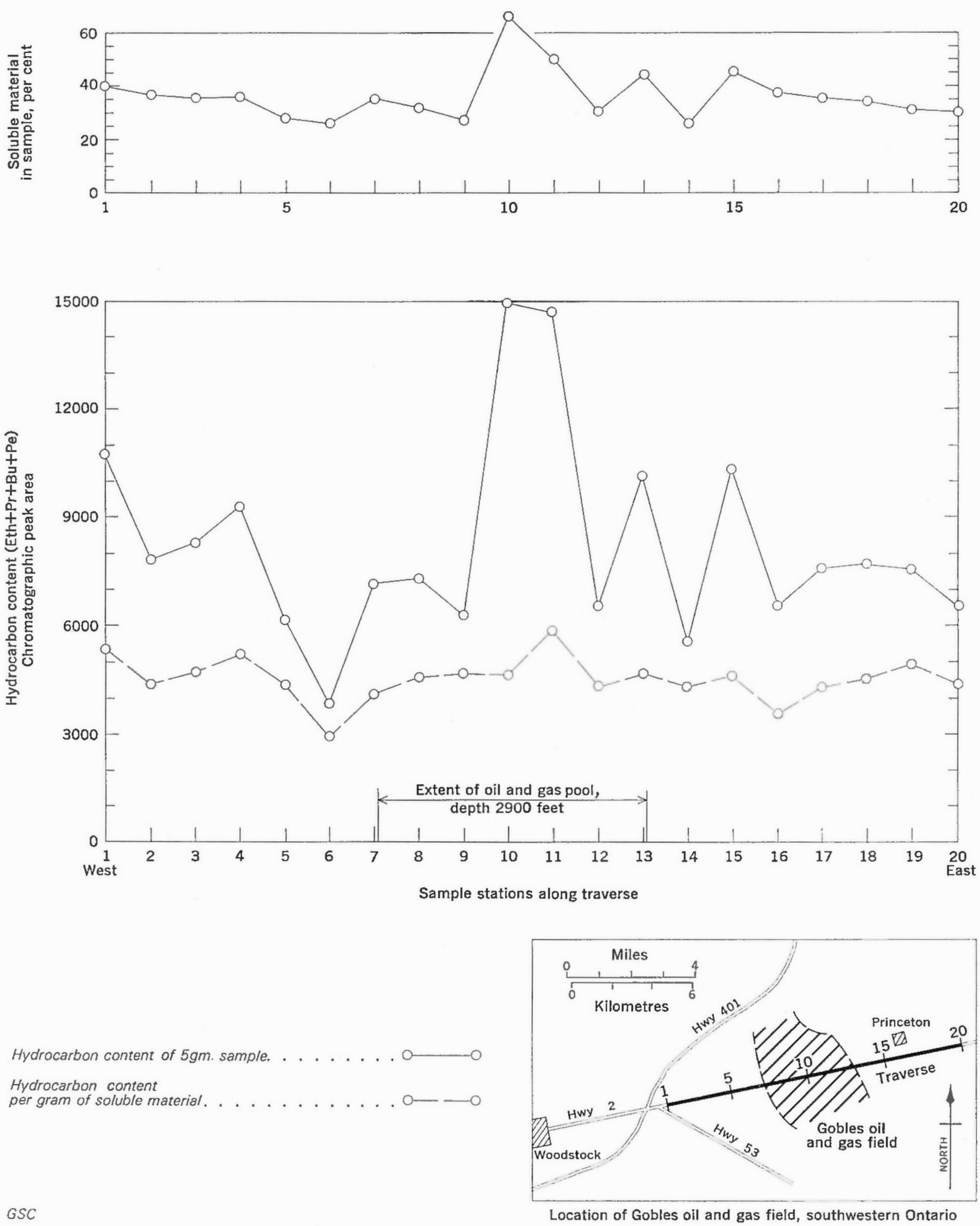


FIGURE 1. Results at Gobles field; samples extracted with 0.05 N HCl.



Location of Gobles oil and gas field, southwestern Ontario

FIGURE 2. Results at Gobles field; samples extracted with 2 N HCl.

Colchester Field, Southwestern Ontario

As at Gobles the Colchester results show a possible anomaly directly above the pool by extracting the soil gases with 0.05 N HCl (Fig. 3). With the 2 N acid extraction there is no apparent anomaly, and the values again parallel those for the soluble material content so that on adjustment there is little variation in hydrocarbon values across the field (Fig. 4).

The Colchester field has proved to be a poor producer, and the presence of a pronounced hydrocarbon anomaly would have been surprising. The pool is confined in an unusual type of trap, a syncline in which the normally tight limestones have been dolomitized along fracture zones resulting in zones of porosity.

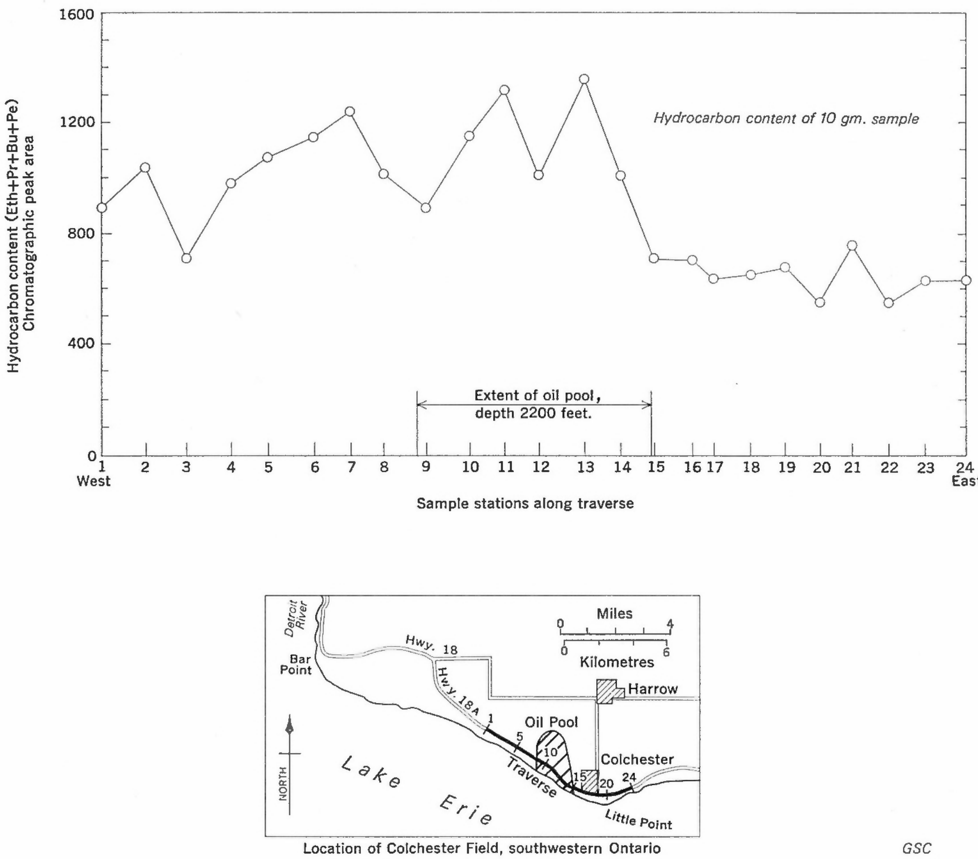


FIGURE 3. Results at Colchester field; samples extracted with 0.05 N HCl.

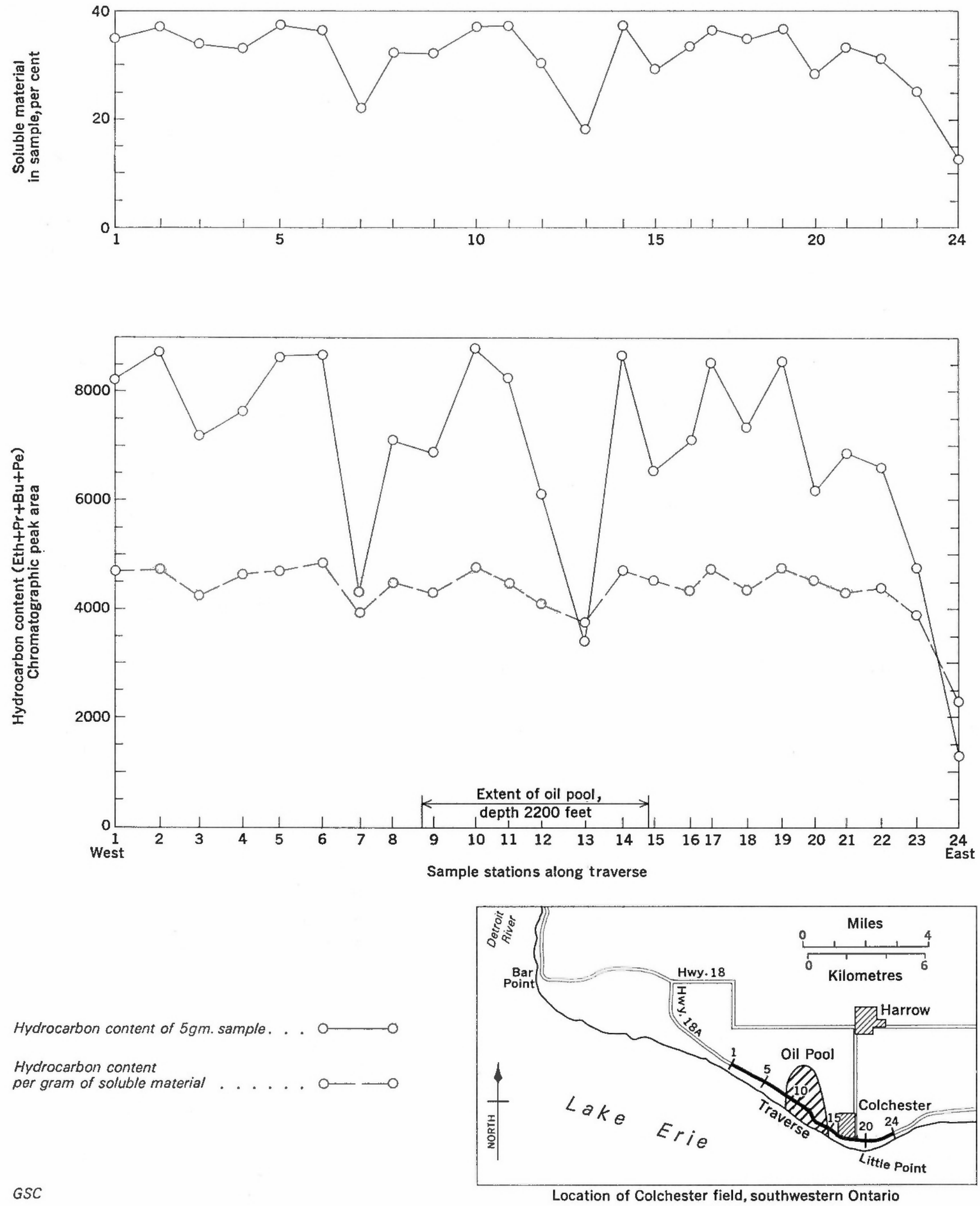


FIGURE 4. Results at Colchester field; samples extracted with 2 N HCl.

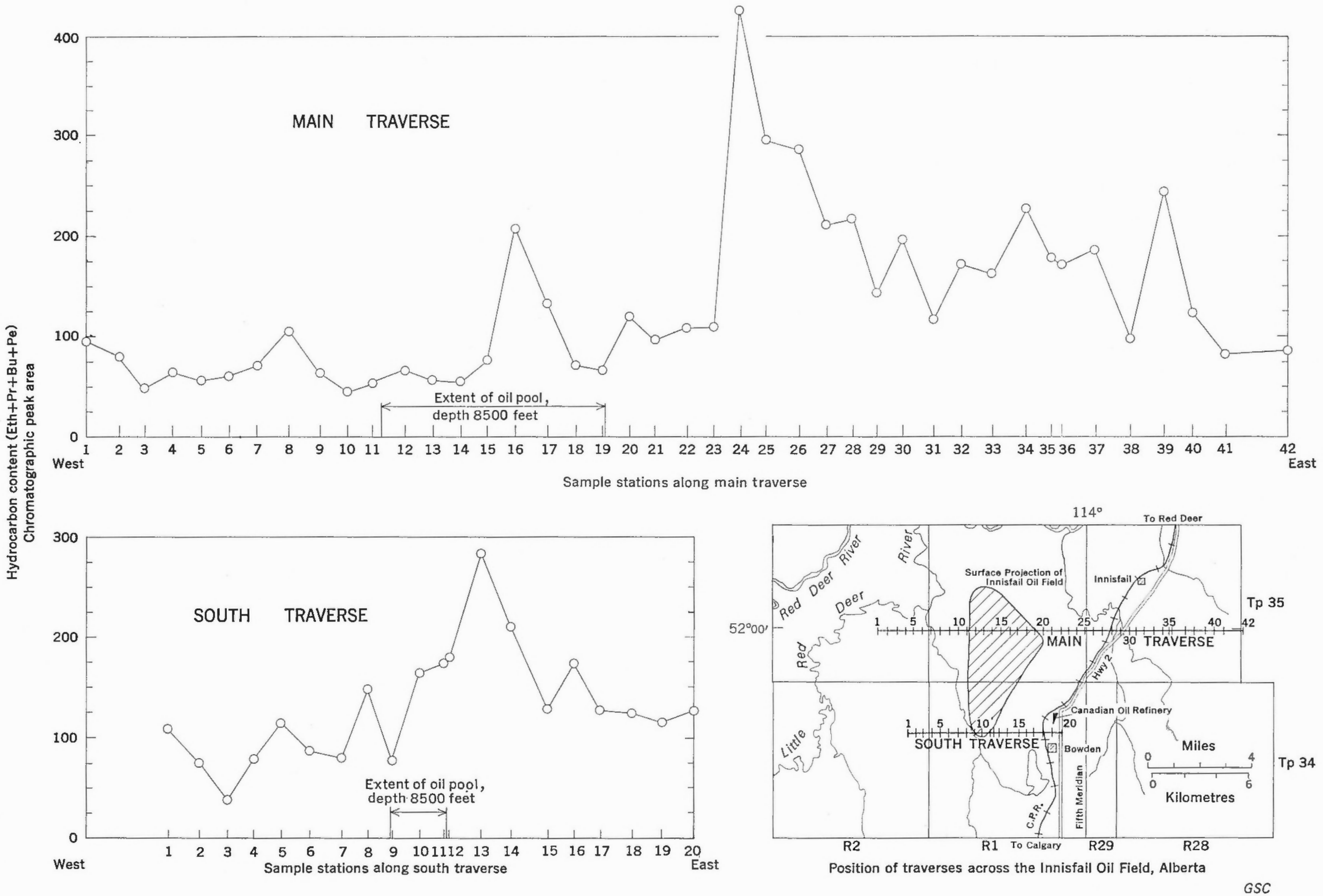


FIGURE 5. Results at Innisfail field; samples extracted with 0.05 N HCl.

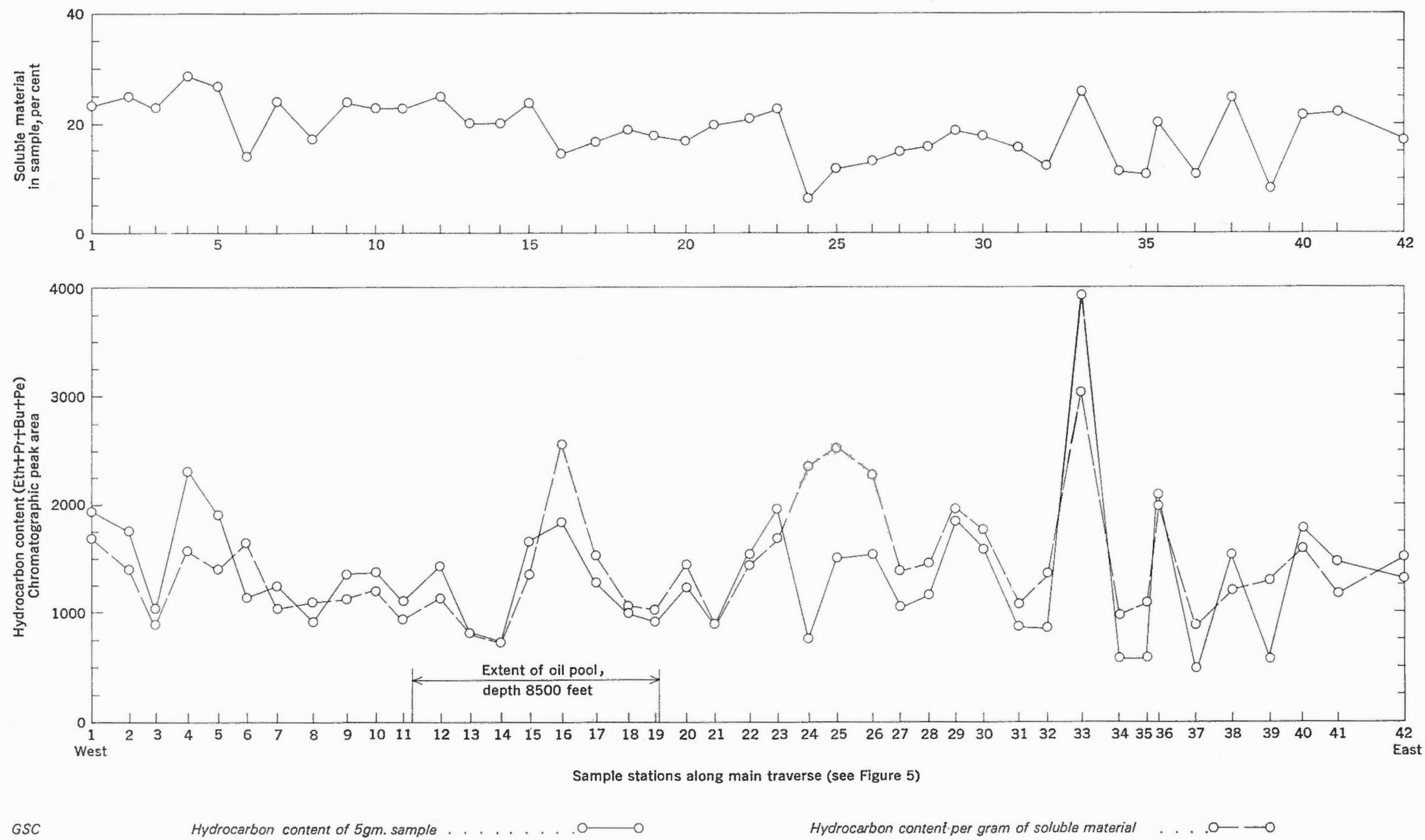


FIGURE 6. Results for main traverse at Innisfail field; samples extracted with 2 N HCl.

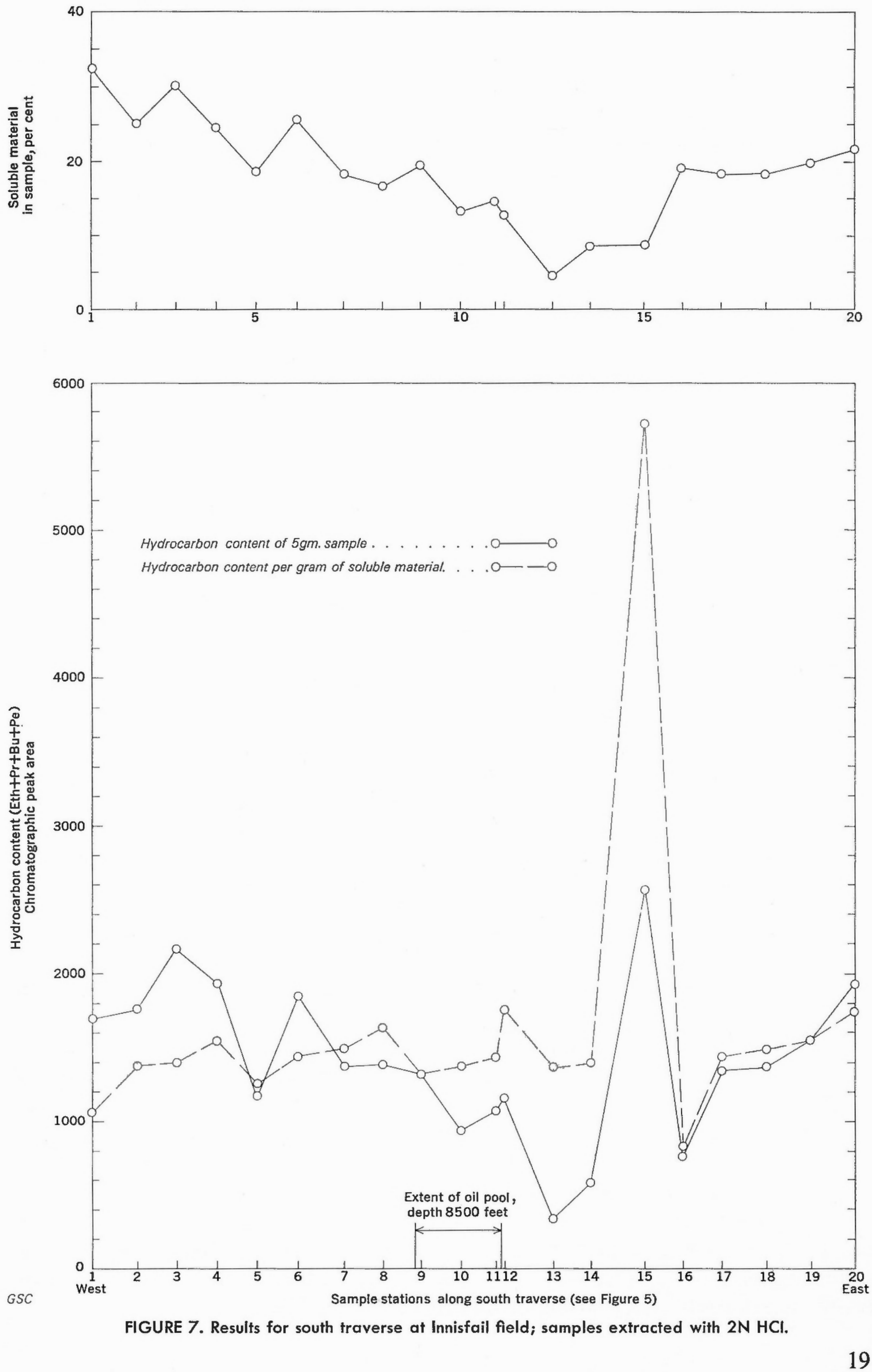


FIGURE 7. Results for south traverse at Innisfail field; samples extracted with 2N HCl.

Innisfail Field, Alberta

The results for the 0.05 N HCl extraction of samples from Innisfail indicate the presence at the surface of a pronounced hydrocarbon anomaly, probably of the "halo" type (Figs. 5 and 8). The anomaly is evident on each of the two traverses. The plot of the 2 N acid extraction results (Figs. 6 and 7) roughly follows that for the soluble material contained in the samples without showing any significant anomaly. The adjusted values, however, which represent the amounts of hydrocarbons in the soluble material, give an anomaly with characteristics similar to those shown by the weak acid extraction anomaly.

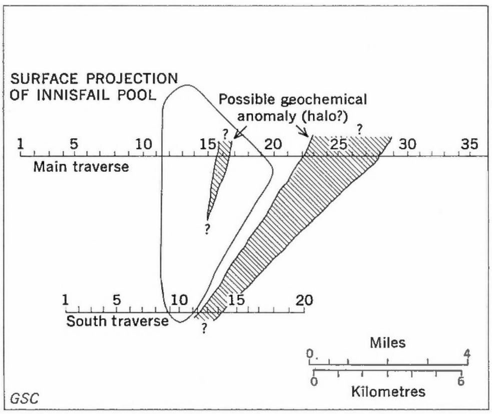


FIGURE 8
Plan of possible geochemical anomaly, Innisfail oil field (for location see Fig. 5).

The fact that the major portion of the "halo" is east of the pool may be due to the shape of the oil reservoir. The oil is contained in a porous dolomite reef that has a maximum buildup near its eastern end and gradually thins to its pinchout at the western limit. Gas migration would take place predominantly from the section of maximum accumulation at the eastern side of the reservoir.

Pincher Creek Field, Alberta

The 0.05 N acid extraction results at Pincher Creek (Fig. 10) do not indicate the presence of a hydrocarbon anomaly; the two high values at points 22 and 37 are not considered to be significant. With the 2 N acid extraction (Fig. 11), however, a halo anomaly appears to be present with the low values situated directly above the pool and much higher values on either side. The eastern limit of the halo may not have been reached in the sampling program. The Pincher Creek results present a case in which the total hydrocarbon values for the samples do not follow the trend of the soluble material content of the samples, at least in the halo sections of the traverse.

As at the Gobles Field in southwestern Ontario the inorganic materials (soluble salts) in the soils may play a significant role in the results for Pincher Creek. The acid-soluble content of the samples exhibits wide variations directly above the pool in contrast to its relatively even distribution on either side (Fig. 11).

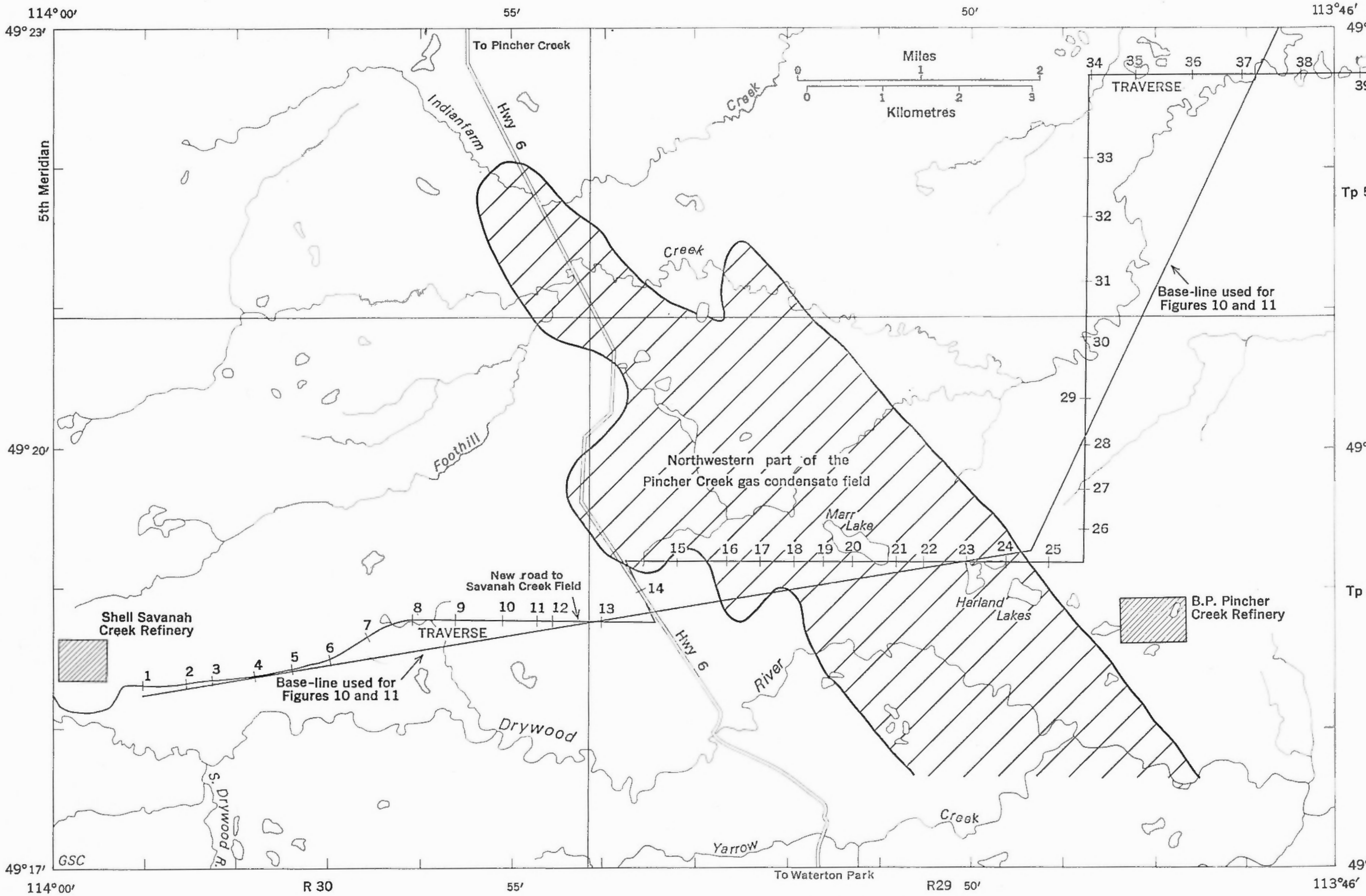


FIGURE 9. Location of traverse across Pincher Creek field, Alberta.

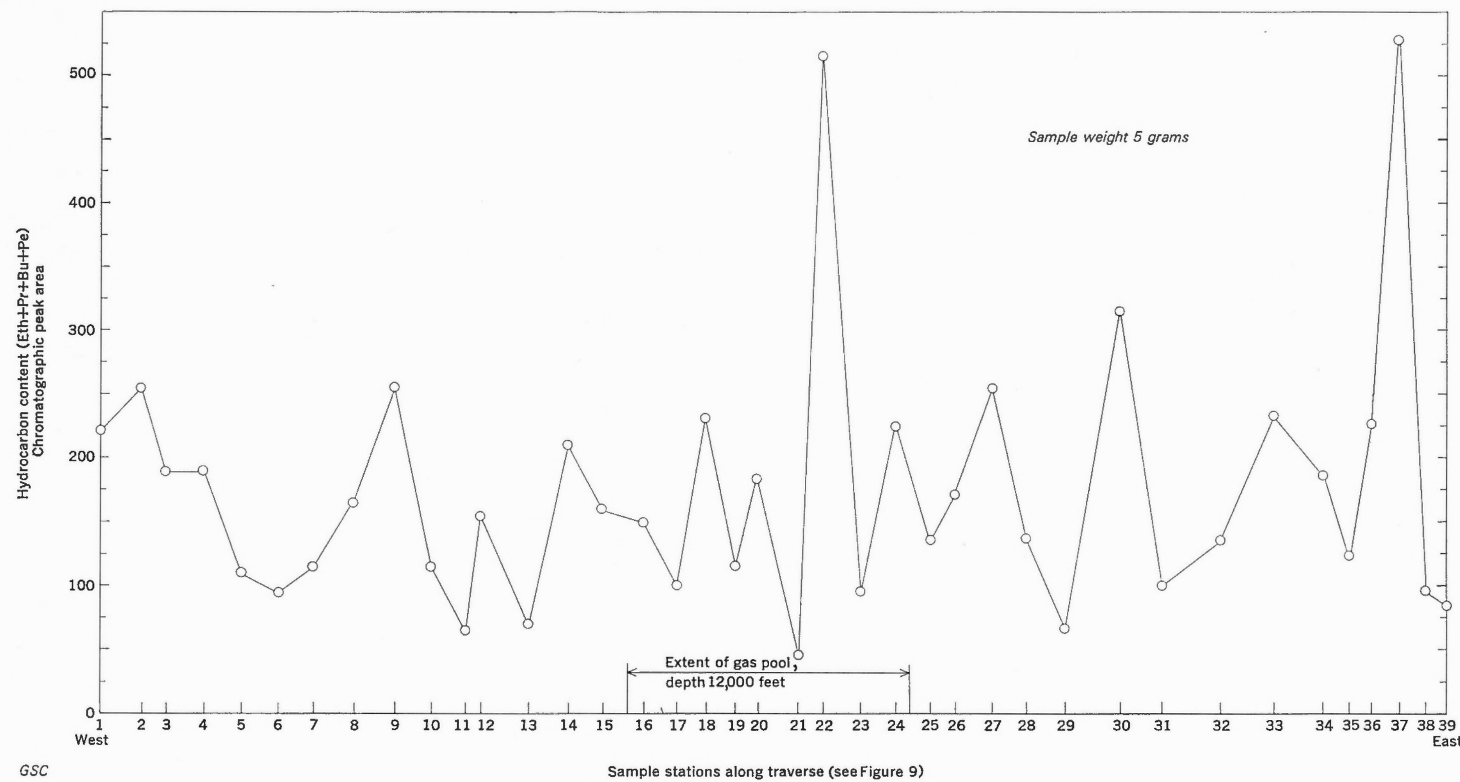


FIGURE 10. Results at Pincher Creek field, samples extracted with 0.05 N HCl.

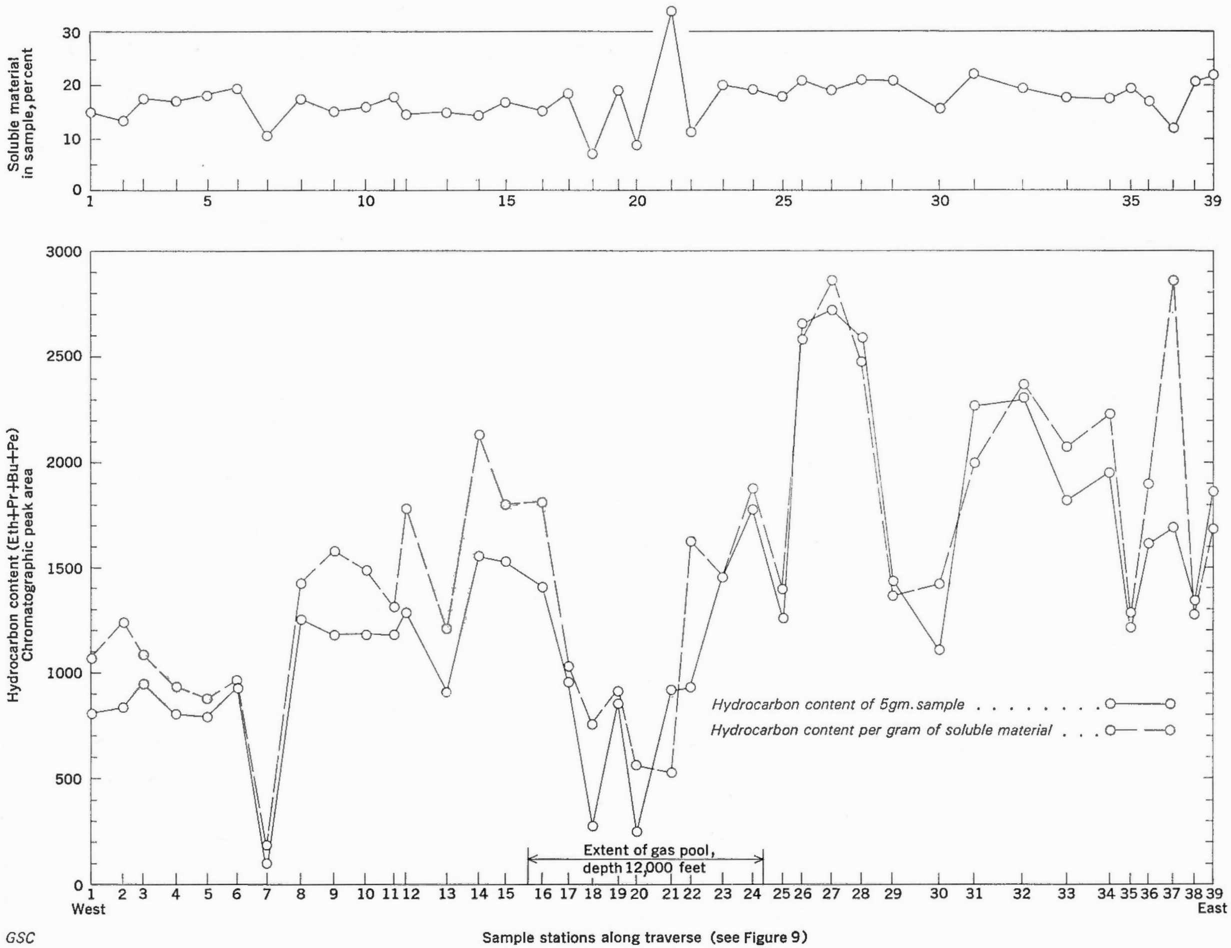


FIGURE 11. Results at Pincher Creek field, samples extracted with 2 N HCl.

If a true hydrocarbon halo is actually present around the Pincher Creek gas-condensate pool it is rather a surprising circumstance. First, the depth of the pool is 12,000 feet; secondly, there are numerous thrust faults between the accumulation and the surface, any of which could divert the vertically migrating hydrocarbons. Indeed, these faults may in fact be responsible for the very wide halo shown to the east of the pool. Finally, the foothills topography in the vicinity of the Pincher Creek field is of a rolling nature and is not entirely suitable for the application of geochemical prospecting. Such a set of circumstances would normally rule out the use of the method. It may be, however, that with such a prolific pool as that known to exist at Pincher Creek all the above objections are overruled by the sheer quantity of hydrocarbons present and presumably migrating to the surface.

CONCLUSIONS

If geochemical prospecting is to become a useful method of exploring for oil and gas in Canada it is essential to choose suitable areas for its application. The features to aim for are a deep soil cover with the least possible variation in soil type and a relatively flat topography. Pool depth does not appear to be a limiting factor. It is possible that the more prolific the field being sought the more prominent will be the geochemical anomaly associated with it. Sample spacing should not be too great, and experience shows that five to eight samples per mile along lines a mile apart with samples from a uniform depth of 8 to 10 feet probably give the optimum results when seeking pools of average size.

It may be that no one particular geochemical method can be applied universally to all areas, one procedure (such as weak acid extraction) may be suitable in one area but inapplicable in another. In some areas the variation in the amount of acid-soluble material in the soil may be an important indicator of oil or gas accumulations, whereas in other areas it may not be a useful factor. The inability to devise a universal procedure may merely be due to the lack of a full understanding of the processes of gas migration and the formation of anomalies.

The pools selected in southwestern Ontario may have been poor choices for such a study. They were selected with regard to the date of discovery rather than productivity. The recently discovered and very productive Clearville pool in southwestern Ontario would be a logical choice for future studies.

Geochemical prospecting often finds its greatest use where the other exploration methods fail. For instance in southwestern Ontario air photos and magnetic surveys are of little use and seismic and gravity surveys have only a limited application, leaving subsurface geology as the only useful tool. If geochemistry can contribute to increase the success ratio of wildcat drilling in such an environment it should receive much more attention than it has in the past.

The present project has demonstrated that the geochemical method has at least some merit and that it should be possible to apply it successfully in Canada. It should, however, be used in conjunction with the established geological and geophysical methods where these are applicable. It may be that the project has uncovered more problems than have been solved. The various factors that can cause spurious results, such as topography, sampling depth, soil type, and the amount of soluble material in the soil, each call for additional research if geochemical methods are to be applied with greater confidence.

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