

## Geological Association of Canada, Newfoundland Section - 1997 Annual Technical Meeting

Volume 33, numéro 2, summer 1997

URI : [https://id.erudit.org/iderudit/ageo33\\_2abs01](https://id.erudit.org/iderudit/ageo33_2abs01)

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### Éditeur(s)

Atlantic Geoscience Society

### ISSN

0843-5561 (imprimé)

1718-7885 (numérique)

[Découvrir la revue](#)

### Citer ce document

(1997). Geological Association of Canada, Newfoundland Section - 1997 Annual Technical Meeting. *Atlantic Geology*, 33(2), 169–179.

# Abstracts

1997 Annual Technical Meeting  
Geological Association of Canada  
Newfoundland Section

**Newfoundland and Labrador Resource Exploration :  
Alive and Looking to the Future**

**February 24-25, 1997  
Department of Earth Sciences  
Memorial University of Newfoundland  
St. John's, Newfoundland**

## So...you want to be a gem prospector?

Randal Andrews

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The announcement of the recovery of gem sapphire (corundum) in southeastern Labrador by Rockhopper Corporation represents the first potentially significant discovery of gem material in the Province of Newfoundland and Labrador. Gem prospecting is a little understood niche of the mineral exploration industry that is becoming ever more important to the world's perception of mineral wealth. As the supply of gem material from established, historically significant, producers is quickly dwindling, the demand for precious

coloured stones is rising exponentially. Worldwide, an increasing number of companies and prospectors are intensifying their efforts to explore for gem material.

This presentation outlines a variety of marketable commodities and favourable exploration environments for the discovery of significant gem materials, as related to the geology of Newfoundland and Labrador. As well, the talk will provide a brief overview of the Rockhopper sapphire development, and exploration plans for the coming season.

## Structural, tectonic and seismo-stratigraphic study of the Terra Nova oil field, Jeanne d'Arc Basin, offshore Newfoundland

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Discovered by Petro-Canada *et al.* in 1984, the Terra Nova field contains 400 million barrels of recoverable oil (estimated by C-NOPB). Terra Nova is the second largest discovery in the Jeanne d'Arc Basin, after Hibernia. The Jeanne d'Arc Basin is the lone oil province on the Grand Banks of Newfoundland and up until now, the only North American East Coast shelf area that contains giant oil fields. Thirty years after the initiation of hydrocarbon exploration in the Canadian Frontiers, Grand Banks of Newfoundland is rapidly becoming an important oil producing region. The Terra Nova field is slated to be developed by the end of this decade and will produce up to 125 to 150,000 bopd by the dawn of the new millennium. A floating production facility (FPF) rather than a gravity based structure (GBS) will be used for Terra Nova development.

Two 3-D marine seismic surveys (shot in the eighties) with 48 and 60 fold data, cover an area of 292 km<sup>2</sup> centered on the field. Within this merged survey, 11 wells (1 discovery, 5 delineations, 3 shows and 2 non commercial discoveries) allow for reliable correlation of the seismic markers to the Mesozoic stratigraphy. Stacked sandstones of the Mid to Late Kimmeridgian aged Jeanne d'Arc Formation constitute the field reservoir. Unfortunately, the individual sand bodies are not uniformly distributed and the top of the pay zone is not a dependable seismic marker. Consequently, the mapping of the field was done at the base of the reservoir, on the intra-Kimmeridgian Unconformity or Top of the Rankin Formation. The pay zone depth ranges between 3,000 to 3,500 m. The field is a complex structural-stratigraphic trap and is located on a large northerly plunging salt-cored arch, that was formed in an elbow of the Voyager Fault. The trap is a multi-side fault bounded depositional wedge, limited toward the east by the Voyager Fault and its lower imbricates, toward the north by the Trinity Fault and toward the west by the King's Cove Fault. An apparent anticline is visible in the downthrown block of the Voyager Fault on a west-east (dip) seismic section. On a south-north line (strike), the oil-prone

Jeanne d'Arc Formation constitutes a northerly deepening and thickening structural wedge. The sinuous depositional edge of the pay zone represents the southern limit of the field.

Terra Nova faults are components of two main linked and intersecting systems of extensional listric faults that fragment the basin. The Voyager Fault is the main antithetic of the Murre Fault and marks the eastern limit of the Cretaceous Basin. The deep-penetrating faults trending approximately north-south are antithetic and synthetic to this major fault. They compartmentalize the area into the West Flank Block, the Graben, the East Flank Block and the Far East (undelineated). These faults were active during the main rifting phases in the basin and correspondingly, structural growth is episodically recorded in their hanging walls. The east-west faults are minor and have smaller throws. Knowledge of smaller and sub-seismic fault distribution is important for field development. The quality of the present seismic data sets generally preclude a detailed fault pattern study at the reservoir level. Thorough fault mapping was performed on the clearly imaged B Marker. The fault population observed on the B marker time structural map may be used to evaluate the density and distribution of fracturing in the reservoir interval. Fault distribution and linkage can also be analyzed by means of "Continuity Cube" displays.

The stratigraphic seal is represented by the massive overlying Fortune Bay Shale Formation. Immediately under the base of the reservoir lies the Egret Member. Egret Member of the Rankin Formation contains organic rich limestones and calcareous shales and is the major source rock in the basin. In the southern sides of the field, the Top of the Rankin Formation closely corresponds to Top of the Egret Member and is a regional unconformity, which is strongly channelized. A seismic amplitude study performed on this marker had previously illustrated a paleodrainage system and a possible shoreline associated with the oil-host seismic sequence. Several other workstation implemented displays such as the dip, azimuth

and penneplanum slices were used to identify, map and visualize the paleogeography of the Kimmeridgian Unconformity and Jeanne d'Arc Formation.

Two models of paleo-deposition have been suggested in the past for the Terra Nova reservoir. One implies a continental, mainly alluvial origin for the reservoir sands and shales while the other infers a stronger marine influence on the depositional system. The present seismo-stratigraphic study and reevaluation of electric logs and cores, indicate that the Jeanne d'Arc reservoir sandstones were deposited in a continental to estuarine to marginal marine environment, with the intervening shales clearly of marine origin. The inferred shoreline extracted from the seismic attribute displays extends eastward toward the Voyager Fault. The shoreline represents a stabilized

Kimmeridgian paleoshore which was structurally or lithologically controlled and was most likely the southern limit reached by the sea during transgressive highstand episodes. A lowstand shoreline, contemporaneous with valley incision within the field area is probably located north of the Trinity Fault. Marine reworking of alluvial and shallow marine sands took place during sea level oscillations on the broad, gentle sloping shelf occupied now by the Terra Nova field reservoir. Several other erosional surfaces such as the Avalon Unconformity, Petrel Limestone, Sub-Tertiary Unconformity, etc., were mapped using 3-D special attributes and visualization. They all illustrate the persistence through time of the southern drainage system and its structural congruence to the Voyager Fault.

### Exploration activity in the Dunnage Zone, central Newfoundland

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Dunnage Zone exploration activity focused on the search for base-metals and gold. Although activity was not at record levels, it was at a healthy pace in comparisons to recent years. Several of the more advanced projects began production in 1996 or have set production dates for 1997. Cambro-Ordovician and Ordovician volcanic sequences such as the Victoria Lake Group, the Buchans Group and the Catchers Pond Group were the main focus of base metal exploration, with significant activity on prospects at Hungry Hill and Rendell-Jackman (Lochinvar).

Gold activity was concentrated mainly on the Baie Verte Peninsula with the continued development of the Nugget Pond deposit, the Rambler property and the Rambler tailings project. A number of new gold zones were also discovered at the Rendell-Jackman property on the Springdale Peninsula. Exploration activity in the eastern Dunnage Zone was limited and was concentrated along the northern GRUB line and in the vicinity of the Beaver Brook antimony deposit.

### Identifying mineral exploration targets in the eastern Grenville Province

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In the rush that followed the discovery of the Voisey's Bay Ni-Cu-Co deposit, large areas of the eastern Grenville Province were staked. As was inevitable, a considerable number of these claims have now been dropped, but, rather than this being regarded as an indication of lack of potential, the release of these regions should now be taken as an opportunity for more systematic mineral exploration at a less frenzied pace. In many cases, dropped claim blocks were not visited and assessment work never carried out. This is not entirely surprising, given that the geological database remains sparse for many areas and, except along the coast, dense forest, vast swamps and poor access render this region hostile to mineral exploration. The thesis of this presentation is that known or inferred mineralization targets, when placed in the context of the geological evolution of the eastern Grenville Province, encourage continued exploration.

The geological history of the eastern Grenville Province can be classified into eight stages: (i) pre-Labradorian basin formation, (ii) Labradorian (1.71-1.60 Ga) accretionary orogenesis, (iii) Pinwarian (1.51-1.45 Ga) orogenic(?) activity, (iv) Elsonian (1.45-1.23 Ga) anorogenic events, (v) Elzevirian (1.23-1.18 Ga) orogenesis, (vi) Adirondian (1.18-1.09 Ga)

events, (vii) Grenvillian (1.08-0.97 Ga) collisional orogenesis, (viii) post-Grenvillian events. Each stage created an environment conducive to some form of mineralization. The pre-Labradorian basin (back-arc or small ocean) collected detritus from pre-Labradorian Laurentia and probably also from pre-Labradorian crust recently recognized in the southern part of the eastern Grenville Province. The detritus is now preserved as extensive regions of dominantly pelitic gneiss, with minor calcareous and quartzitic gneiss and mafic volcanic rocks. If not starved, the basin was certainly underfed, either implying low-lying flanks incapable of providing material or that only distal parts of the basin remain. High sulphide content, as indicated from numerous gossans in well-exposed coastal areas, suggest an anoxygenic environment. The pelitic gneisses show anomalously high Cu contents and are associated with Cu-U-Mo-As-(Co) lake-sediment anomalies. U, Mo and Cu (up to 2.8%) mineralization have been discovered in places. Present data suggest a spatial association for the Cu mineralization with pillowed mafic flows, pointing to a deep, volcanically active setting. Also, the non-metallic potential of the pelitic gneisses (e.g., muscovite and sapphire) should not be forgotten.

Labradorian orogenesis can be divided into pre-, syn- and post-accretion sub-stages. The pre-accretionary stage generated calc-alkaline rocks between 1.68 and 1.66 Ga. Mylonitization and migmatization dated between 1.66 and 1.65 Ga are evidence of the syn-accretion stage. The post-accretion stage produced the 1.65 Ga Trans-Labrador alkali-calcic batholith, coeval felsic volcanic rocks, and post-collisional (1.65-1.62 Ga) layered mafic-felsic plutonic suites. Present data offer little inducement to explore the pre-accretionary calc-alkaline plutonic rocks; perhaps dearth of mineralization can be linked to their juvenile crustal status. In contrast, the syn- and post-collisional rocks offer a wealth of targets. The syn-accretionary felsic volcanic rocks along the northern fringe of the Trans-Labrador batholith host numerous epithermal Cu-Zn-Pb-U showings (one containing over 2.5% Cu), have anomalous Au values, and contain indications of Mo mineralization. Coeval quartzofeldspathic gneisses in southeasternmost Labrador, believed to have a similar felsic volcanic protolith, show traces of Cu and Mo mineralization and have associated Cu-Zn-U-Mo-Ag-As lake-sediment anomalies. From the layered mafic-felsic intrusions, minor Ni-Cu sulphide and Ti(Fe) oxide mineralization and anomalous platinum-group-element values have been reported. These intrusions, in particular, remain underexplored despite recent staking. They provide well-defined targets for grassroots exploration, especially in the twin contexts of being related to a major tectonic interface and having been emplaced into sulphide-rich supracrustal rocks (both factors deemed to be important controls in locating the Voisey's Bay deposit).

The Pinwarian period involved widespread plutonism and thermal effects. In the southern part of the eastern Grenville Province, plutonism included emplacement of the Upper Paradise River AMCG (anorthosite-monzonite-charnockite-granite) intrusion and smaller quartz monzonite to granite bodies, in contrast to more northerly regions where the only Pinwarian activity was either dioritic or comprised minor granitoid dykes. The undated Kyfanan Lake layered mafic intrusion in southeastern Labrador may be part of the Pinwarian event. From a continent-scale tectonic viewpoint, an inboard continental arc setting is suggested by extrapolation from the west, whereas an anorogenic setting seems more likely by extrapolation from the east. The granitoid rocks have yet to be explored, but massive Ti(Fe) oxide mineralization has been discovered in the layered mafic intrusion, which also features Ni-Co-V-(Ag) lake-sediment anomalies.

Elsonian events opened with extensive Michael-Shabogamo mafic magmatism (1.46-1.42 Ga) in the northern part of the eastern Grenville Province that was coeval with AMCG massif emplacement (Harp-Michikamau-Mistastin) north of the Grenville Province. By 1.42 Ga, AMCG plutonism was also active within the Grenville Province and continued until at least 1.30 Ga, thus overlapping with the time of emplacement of the Nain Plutonic Suite, host to the Voisey's Bay deposit, farther north. Between 1.33 and 1.31 Ga, alkalic and peralkalic magmatism (Red Wine Intrusive suite and Letitia Lake Formation) also occurred at the northern margin of the eastern Grenville Province. The end of Elsonian activity was characterized by mafic volcanism (Seal Lake Group) and dyke emplacement both at the northern margin of the eastern

Grenville Province and well within it (Wakeham Supergroup). Evidence of mineralizing activity during the early Elsonian is meagre, but the 1.33 to 1.31 Ga alkalic and peralkaline rocks contain Nb-Be and minor Cu mineralization and show anomalous Y and Zr values. The Seal Lake Group is well known for its numerous Cu occurrences, and the Wakeham Supergroup contains Cu-Au showings. By analogy with other regions, Sn-W mineralization might be expected in late granitoid fractionates of AMCG suites. The apparent termination of anorogenic events in eastern Laurentia at 1.23 Ga coincides with the onset of Elzevirian orogenesis in the southwest Grenville Province, provoking the speculation that some form of compressional orogenesis was also initiated farther east. Geochronological data lend some support to this notion, but are inadequate to develop a comprehensive model for the event's nature. In any case, no mineralization has been linked to this period, so far.

As the name 'Adirondian' (newly coined) suggests, events from 1.18 to 1.08 Ga have been extensively documented in the southwest Grenville Province, but similar activity extended the full length of the Grenville Province and reached southern Greenland. Huge AMCG suites are the most obvious Adirondian contribution and were mostly emplaced between 1.17 and 1.12 Ga. Mylonitization, dated to the same period, indicates tectonism was compressional during at least part of this time. In the eastern Grenville Province, the commercial Lac Tio Ti deposits and Cu-Ni-Co mineralization in the Havre-Saint-Pierre (Allard Lake) AMCG suite, together with the subeconomic Ti-Cr-V deposit at Magpie, and Cu mineralization in the Atikonak (Lac Fournier) AMCG suite leave little doubt that these rocks are highly prospective.

The 1.08 to 0.97 Ga stage of evolution of the Grenville Province has been widely attributed to collisional orogenesis. Magmatism associated with this event is ascribed to concomitant crustal thickening, which, in the east, produced rocks ranging from monzogabbro to granite, including some nepheline- and aegerine-bearing syenites and alkali-rich mafic dykes. In the central Grenville Province, some anorthositic rocks were also emplaced and similar intrusions will, most likely, be eventually recognized farther east. U mineralization has been correlated with granitoid rocks of this age in both eastern Quebec and southern Labrador, but prospecting for other commodities (e.g., Sn-Ta-W) should be considered. Post-Grenvillian events in the eastern Grenville Province are mostly linked to the rift-drift stage of Iapetus Ocean development, and involve formation of the Lake Melville rift system and emplacement of the Long Range dykes. Elsewhere, some of the most economically important mineralization in the Grenville Province (e.g., Nb in the St. Honoré carbonatite) is connected with this period, or later reactivation. Similar rocks should be present in the east and, in particular, unexplained small circular aeromagnetic anomalies coinciding with major tectonic lineaments deserve examination.

It is commonly maintained that the best place to look for a new deposit is next to an existing mine. In reality, for world-class deposits, the best place is where sound mineral exploration reasoning dictates and nobody has looked before. The eastern Grenville Province falls in the latter category.

## Marine operations on Hibernia and the mating and towout of the production platform

Ovyind Hagen

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A brief review of all marine operation activities related to construction and installation of the Hibernia Platform will be presented. The sequence of past activities and how they

are tied in with the construction program will be covered, as well as some details of upcoming major operations, such as mating and towout to the Grand Banks.

## Western Newfoundland petroleum exploration: where are we headed?

John D. Harper

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The activities of the last two years in western Newfoundland have stirred the imagination of those interested in pursuing the oil shows and small discoveries which have occurred over the last 100+ years in that area. The Hunt oil discovery (Port au Port #1) has heated up leasing and seismic acquisition. Subsequent wells drilled (4) have dampened the enthusiasm of some companies. Yet drilling activity is still being planned, seismic data are adding exciting new information supportive of ideas previously held but unprovable. It appears now that the Ordovician carbonate platform does extend beneath the Long Range granites. Earlier concerns about maturation of organics increasing to the north and toward the granites can now be explained by heating associated with the thrusting of the granites over the younger Paleozoic sequences. Consistent with trends seen elsewhere in the Appalachians we can now expect the thermal maturation of organics to decrease beneath the granites. Thus the associated sedimentary section is more likely to be thermally mature than overmature. Structure seen on seismic in the north have the potential to be trapping situations. Structure to the south is exceedingly more complex and requires improved processing of seismic, improved understanding of facies, and improved understanding of the structural models in effect. The Vulcan discovery of Carboniferous oils on the east side of Bay St. George coupled with the Hunt discovery to the west puts live oil on both sides of the Bay. The abundant distribution of gas in the sediment of the Bay adds to growing awareness that hydrocarbons are ubiquitous in the region, the trick will be to find the traps that undoubtedly exist there.

Looking at the types of reservoirs to be addressed, lessons can be learned from other regions. Ordovician production in Michigan and Ohio often began at rates as high as 4000 to 10,000 bopd from depths as shallow as 1200 feet. The problem was that the production was/is from fractured dolomites sealed laterally by tight and fine fractured limestone. Gas tends to halo the oil fields. The high initial production rates were not sustainable for more than a few months after which

the rates dropped to 1000 bopd or significantly less. As well these reservoirs were water-driven and water readily coned the wells. Attempts to fracture the reservoir led to 50% of the wells increasing oil and 50% increasing water. The Albion-Scipio field produced about 130 MMBO and an indeterminate amount of gas from 30 miles of field, and up to 600 feet of gross pay interval. In reality the pay was confined to fractures so volumetric estimates were subject to tremendous variability. On a strictly gross volumetric basis the field produced only 42 bo/acre, but this value is meaningless relative to the actual fracture setting, these carbonate reservoirs have to be "babied" to produce effectively. Attempts to push production generally leads to destruction and loss of a well to water. The occurrence of karsted surfaces enhances the reservoir potential of the carbonates. Ordovician fields typically display the karst character but this type of reservoir is very erratic in the distribution of porosity and permeability, thus reservoir characterization must start early in the history of the field if production is to be efficient.

Carboniferous reservoirs are not abundant in North America in the context of rifted sequences. However in basins where such reservoirs occur there is often an initial problem with seismic interpretation. There is a great deal more information to be gained before discoveries become more regular but this is the typical learning path for any rank basin. Perseverance, innovative interpretation, good reservoir practices, and an entrepreneurial spirit will result in growth of the western Newfoundland industry. Western Newfoundland suffers from the "away" thought process that it is only a small area, that the oil occurrences are of little meaning, and that there could not be significant deposits so close to home. If this basin was in a foreign setting, with worse political conditions it would still attract considerable foreign and Northern American attention. Proper marketing on a broad front will find the funds necessary to bring this basin greater respect than it has received to date.

## **Progress at St. Lawrence and exploration plans of Burin Minerals Limited**

Alex Harris and Fouse Cooper

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Burin Minerals Limited has been working on plans for reopening fluorspar mines at St. Lawrence, Newfoundland. The mill is in good condition, and known reserves are adequate for production over a 15 year period. Fluorspar from St. Lawrence is low in both arsenic and phosphorus, and we are confident that we can sell all the acid-grade fluorspar we can produce at St. Lawrence. Some 40 fluorspar veins are associated with the St. Lawrence Granite, a late Devonian intrusion. The three largest veins contain reserves of about 8 million tonnes. All but one of the known veins were found by surface prospecting. Approximately 70% of the known mineralized structures at St. Lawrence can be detected by VLF-EM surveys. Several of the deposits are open to depth, and have potential for increased reserves.

Metallurgical-grade fluorspar is used in the iron and steel industry. There is also some use in aluminum and ceramics industries. The biggest use is in the fluorochemicals industry. The fastest growing segment of the fluorochemicals industry

is fluoropolymers. Fluorite crystals are up to 30 inches in size, and have a market as specimens to mineral collectors, and additional potential uses in craft and dimension-stone markets.

St. Lawrence is well-located to supply markets in North America and Europe. The harbour is ice-free all winter. Miners from St. Lawrence are currently working in mines all across Canada and are anxious to move home. Completing feasibility analysis and obtaining various government approvals has had its moments of frustration. Financing a fluorspar project isn't an easy matter, either. We completed a private placement financing in October, and anticipate starting a public share offering late in the first quarter of 1997. We anticipate an 11 month pre-production development period. The likely mining method is open blast hole stoping. We also have eight other exploration projects in Newfoundland; six gold projects, one Co-Ni-Cu prospect, and a silica prospect.

## **A review of the geology and mineral potential of Archean greenstone belts in Labrador**

Donald T. James

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Archean greenstone belts of the Canadian Shield and Archean cratons elsewhere are well-known for their significant volcanogenic polymetallic and mesothermal precious metal deposits. The greenstone belts in Labrador, particularly the low- to medium-grade Florence Lake and Hunt River belts in the Hopedale Block (southern Nain Province) have the potential to host similar deposits. Medium to high-grade greenstone belts in the southeastern Churchill Province, and the sediment-dominated supracrustal belts in the Archean Ashuanipi Complex (Superior Province) of central and western Labrador, respectively, have not been extensively explored, but do have some mineral potential.

In the Archean greenstone belts of Labrador, current exploration activity is concentrated in the Florence Lake greenstone belt. It has been infrequently explored for the past 40 years; much of this activity focused on the komatiite-associated Ni-sulphide occurrences at, and around, the Baikie showing. However, the belt also has good potential to host volcanogenic massive sulphide and gold deposits. This paper will review aspects of the geology and mineral potential of the Archean greenstone belts in Labrador, with an emphasis on data arising from recent studies in the Florence Lake and Hunt River belts.

## **Modelling and migration of Hibernia seismic data**

Irene Kelly, Phil Bording, Andrew Burton and Larry Lines

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Seismic migration is a valuable processing tool in the accurate imaging of complex subsurface features. Reverse-time depth migration offers particular advantages due to its generality and lack of dip limitations. A successful migration is especially necessary in complex geological areas such as the Hibernia oil field, where the accurate location of complex faults and sedimentary boundaries is of particular importance. This paper compares the results from various 2-D and 3-D

migrations for both model data and seismic data from the Hibernia field. In this comparison, we use the Stolt and Gazdag algorithms in 2-D and the reverse-time algorithm in both 2-D and 3-D. We optimize reverse-time migrations by least-squares inversion of layer depths to formation tops. This use of migration and inversion also allows for velocity sensitivity analysis.

## **Exploration for Ni-Cu-Co sulphide deposits in northern Labrador : hype or bonanza?**

Andrew Kerr

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In the two years since drillhole #7 at Voisey's Bay hit 104 m of massive sulphides, northern Labrador has seen exploration activity unprecedented in its history. This effort has yet to result in a second Voisey's Bay deposit, but it has unearthed widespread and diverse sulphide mineralization of probable magmatic origin. The appeal of northern Labrador for junior exploration companies may appear to be waning, but it must be remembered that magmatic Ni-Cu sulphide deposits (despite their immense potential value) represent small and difficult exploration targets, even in areas where the geology is well-understood. This is certainly not the case in Labrador, where new discoveries are in essentially unmapped areas. It is against this background that the results of two years of mineral exploration should be judged.

This presentation outlines several of the more active exploration properties outside the immediate Voisey's Bay area. These illustrate a diversity of mineralization styles, ranging from discordant (epigenetic ?) vein-like massive sulphide zones, to syngenetic sulphides in pyroxenitic and gabbroic dykes, to stratigraphic sulphide accumulations hosted by layered gabbroic intrusions. Although the initial drill results may not have been spectacular, some of these areas have clear potential for longer-term exploration programs, and many other projects were only in the early stages of exploration during 1996. Labrador is a rugged, remote area similar in size to northern Ontario, and exploration of its mineral potential is in its early stages.

## **A review of the Carboniferous petroleum test hole at Flat Bay, western Newfoundland, by London Resources Incorporated**

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London Resources, Inc., an affiliated company of Vulcan Minerals Inc. (ASE: VUL), drilled a 500 foot test hole on its petroleum permit in western Newfoundland during November, 1996. The purpose of this test was to confirm a previously reported oil occurrence in a Carboniferous conglomerate unit at the Flat Bay gypsum quarry just north of the Flat Bay anticline. London employed a Longyear 34 mining rig, modified to deal with formational fluids, to drill the test hole. A petroliferous conglomerate was penetrated

from 452 feet to 500 feet--the total depth of the hole. A light brown unbiodegraded oil bled from the entire length of the conglomeratic core in varying amounts. Subsequent analysis indicates that the oil is of Carboniferous age and of lacustrine origin, not unlike Horton-aged oil in the Maritime Basins.

The hole has been suspended for probable re-entry and deepening to penetrate the full thickness of the conglomerate, and underlying strata.

## **Depth imaging of seismic data from structurally complex areas in Canada**

Larry Lines and Jinming Zhu

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Recent geophysical research has made widespread use of depth migration and velocity analysis in our efforts to improve seismic images. Exploration problems include the imaging of salt intrusions and faulted structures from offshore Newfoundland and the imaging of thrust faulted structures from the Alberta foothills, which are similar to structural features in Western Newfoundland. We show that migration methods such as reverse-time migration and Kirchhoff depth

migration can lead to significant improvements in our knowledge of geological formations. Two characteristics of migration which make a substantial difference in our results include "prestack migration from topography" and the use of "iterative interactive image interpretation". The definition of an accurate seismic velocity model for complex geological formations is the key to obtaining useful seismic depth images.



## Industrial minerals in Newfoundland and Labrador : past, present and future

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The production and trade of industrial minerals in the province of Newfoundland and Labrador dates back thousands of years. In northern Labrador, the flint-like Ramah chert, used in spearpoints and knives, was quarried and traded as far south as the United States thus establishing north-south trade routes still used today. In addition, soapstone deposits on the island and in Labrador were quarried for use as cooking utensils and ornaments. In the last century and early in this century, small industrial mineral operations were established mainly in response to local needs. Limestone from Cobb's Arm was used to flux copper ores from the booming Notre Dame Bay mines. Granite from The Gaff Topsails, Benton, and Petites, was used for bridge abutments on the Newfoundland railway, and (along with sandstone) to construct some of St. John's most prominent buildings. The pioneer brick and slate operations in Trinity Bay supplied local markets and some slate was exported. Early efforts to mine gypsum, asbestos, and chromite on the west coast encountered many insurmountable problems, including "protection squadrons" of the French navy. The 20th century saw the beginning of a new era in the province's industrial minerals industry. Much larger operations were established which made, and in some cases continue to make, significant contributions to the economy. These operations include the Aguathuna limestone quarry, fluorspar mining operations at St. Lawrence, gypsum quarries at Flat Bay, pyrophyllite quarry at Manuels, asbestos mines at Baie Verte, and limestone and shale quarries at Corner Brook. Most were relatively high volume, low value operations with production exported as raw materials for further processing elsewhere.

Current operations in the province produce a wide variety of industrial minerals. An overall trend toward the production of value-added commodities is reflected in such products as roofing slate from Burgoyne's Cove and specialty peat products from Bishop's Falls. The change of focus by Atlantic Minerals from the export of aggregate to high-calcium limestone and high-magnesium dolostone from Lower Cove is giving this operation a very bright future. Spin-off demands from Hibernia

have resulted in the development of a magnetite quarry near St. George's to supply heavy ballast to the Hibernia G.B.S. A granite monument plant at Buchans now processes stone from central Newfoundland quarries, adding value, for example, to the production of gabbro from Borney Lake, while in Labrador the anorthosite quarry near Nain continues to sell an extremely high-value stone to exclusive world markets.

The future holds many opportunities in the field of industrial minerals in the province of Newfoundland and Labrador. In central Newfoundland, a stibnite mine and antimony-trioxide plant is being developed and there are renewed efforts to reopen the fluorspar mines at St. Lawrence. The Argentia smelter announcement has created a staking rush for silica, while in western Labrador the establishment of a silicon metal smelter is being carefully evaluated. Marketing efforts are continuing with respect to the iron oxide pigment deposits at Schefferville. Promising new showings of nepheline, amazonite, and corundum (sapphire), have been identified in southeastern Labrador thus representing new targets for further research and potential development. Significant deposits yet to be developed include the Strange Lake Zr-Nb-Y-REE deposit (now attracting renewed interest because of the developing nickel mines directly to the east at Voisey's Bay), high purity white marble deposits (Roddickton), barite (Buchans), and talc (Deer Cove). There are huge unexploited reserves of limestone and dolomite on the west coast and Northern Peninsula. The St. George Carboniferous Basin also hosts important salt deposits (and associated potash). The dimension stone industry continues to expand with growth in existing operations, and discovery of new deposits.

Newfoundland and Labrador's strategic location on major North Atlantic shipping routes will continue to be a vital factor in the planning, development and production of our industrial mineral resources. Secondary processing of these market-driven commodities will add value to their production and the contribution which they will make to our provincial economy.

### The economics of west coast petroleum

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Imperial Venture Corporation (IVC) of St. John's, Newfoundland, holds exploration rights to two parcels in western Newfoundland, one onshore and one offshore. Prospect leads have been identified on both parcels by IVC's exploration

consultants, which have been used as input to a study of the economics of potential discoveries. The results of this study are presented, detailing risk and reward parameters for the identified prospect leads.

## Gold mineralization in the Neoproterozoic Avalonian rocks of the Newfoundland Appalachians

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Much of the southeastern (Avalonian) margin of the Newfoundland Appalachians is cored by Neoproterozoic (760-540 Ma) volcano-plutonic arcs of peri-Gondwanan paleogeographic affinity. Similar successions extend southeastward along the eastern seaboard through maritime Canada and coastal New England, into the Carolinas and Georgia. Avalonian rocks host a variety of mineral occurrences, most notably gold. Extensive areas of argillic and advanced argillic alteration and associated epithermal-style gold mineralization accompanied the formation of volcano-plutonic arcs in at least two distinct episodes within the Newfoundland Avalon Zone (635-620 Ma and 590-560 Ma). Examples of

high sulphidation (acid sulphate) and low sulphidation (adularia-sericite) systems are preserved. In several examples, the host rocks are calc-alkaline subaerial felsic volcanics and/or coeval intrusions. There is a spatial relationship of altered rocks with adjacent, overlying, marine siliciclastic rocks. The geological setting and the type and size of hydrothermal systems present in the Newfoundland Avalon Zone, coupled with the existence of similar styles of mineralization in gold deposits in Avalonian rocks of similar age in maritime Canada and the Carolina Slate Belt emphasizes the potential of Newfoundland's Avalonian rocks for epithermal and porphyry-style gold and copper-gold mineralization.

### The Lac Volant Cu-Ni-Co showing and the mineral potential of the eastern Grenville Province, Québec north shore

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The discovery of the Lac Volant Cu-Ni-Co showing generated a staking rush on the Quebec North Shore that had never been seen before. Companies ground staked over 12,000 claims in less than 3 months. At one time, more than 300 stakers were in the field and over 25 companies were involved in the staking rush. Over \$4.5 million of staking expenditures and \$1.5 million of exploration work were recorded from late August to December 1996.

The Lac Volant Cu-Ni-Co showing is located 60 km northeast of Sept-Îles in the Polycyclic Allochthons of the eastern Grenville Province. The mineralization is found in a late to post-Grenvillian mafic dike injected along a major northeast trending lineament. The country rocks, belonging to the Matamec igneous complex, are composed of granulite facies metagabbro and highly deformed "augen" K-feldspar and pyroxene-bearing monzonite and leucogranite. The dike is characterized by multiple injections of gabbroic phases. The mineralization, composed of pyrrhotite, chalcopyrite, pentlandite, pyrite and magnetite, is associated with the later gabbroic phases. A mean average content of 2.3% Cu, 2% Ni and 0.12% Co is found on a series of channels with a total length of 6 m. The mineralization occurs as disseminated and massive sulphide, and the highest Ni content is 2.5%. The massive mineralization occurs in 3 zones, with

the dike zone, traced over 100 m with widths of 1 to 10 m, being the most important. Airborne EM and magnetic surveys indicate that the massive mineralization of the dike zone extends at shallow depths and appears to plunge to the northeast.

Except for localized Cu-Ni exploration in the 40's and from the early 60's to the late 80's, and U-REE exploration in the 60's and 70's, the eastern Grenville Province was known as unfavorable ground for exploration, except for the Wakeham Terrane. Most of the exploration work in the Wakeham Terrane was on Cu, Cu-Au-Ag, Au-Ag and U mineralization. The discovery of a major Cu-Ni-Co deposit at Voisey's Bay attracted companies to look for similar settings in the eastern Grenville Province. In 1995, prospectors and junior companies discovered over 15 new Cu-Ni-Co showings in the Quebec part of the eastern Grenville Province. Most of these showings are associated with mineralized mafic to ultramafic layers in marginal zones of anorthositic complexes. Today, the eastern Grenville Province provides a new "play" for exploration companies. Despite the complicated structural geology and high grade metamorphism, which might scare some geologists, the Lac Volant Cu-Ni-Co discovery demonstrates that unremobilized primary mineralization does exist in the eastern Grenville Province, and that more exploration and investment are needed in the near future.

**The Mesoproterozoic Nain Plutonic Suite in eastern Canada,  
and the setting of the Voisey's Bay Ni-Cu-Co sulphide deposit\***

**\*Geological Association of Canada, H.S. Robinson Lecture for 1997**

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A world-class magmatic nickel-copper-cobalt massive sulphide deposit, containing probably in excess of 150 million tonnes, was discovered near Voisey's Bay, Labrador, in 1993. The mineralization is hosted by igneous rocks of the Nain Plutonic Suite (NPS), a 1350 Ma to 1290 Ma assemblage of coalesced basic and silicic plutons emplaced across an 1860 Ma collisional suture between the Archean Nain Province and the Paleoproterozoic Churchill Province. The NPS covers 20,000 km<sup>2</sup> and encompasses a diverse group of rocks of which the main "families" are anorthosite, troctolite, diorite and granite. These rocks represent a significant magmatic contribution to a tectonically quiescent crust, probably generated in an intracontinental extensional zone above a mantle plume. The Voisey's Bay deposit sits within a massive troctolite, the Reid Brook intrusion, interpreted to be the oldest pluton

of this type within the NPS. The Voisey's Bay mineralization is disposed as intercumulus concentrations and as massive sulphide (pyrrhotite, pentlandite, and chalcopyrite) zones in several settings, including a steeply dipping dyke, a bowl-shaped "ovoid", and a bifurcating lens ("Eastern Deeps") at the base of the intrusion. The Ni-Cu-Co mineralization represents gravitational accumulation and concentration of a sulphide liquid in the plutonic environment, coeval with formation of the Reid Brook intrusion. The sulphide liquid is interpreted to have been an integral part of the silicate magma at the time the Reid Brook intrusion was emplaced. The formation of the sulphide liquid is best interpreted to be a result of contamination of the metal-laden Reid Brook magma by crustal derived sulphur from underlying metasedimentary rocks.

**Structure and tectonics of the external Humber Zone, western Newfoundland:  
implications for hydrocarbon exploration**

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Much of the Appalachian structural front in western Newfoundland lies in the immediate offshore, where it is marked by a thin-skinned, north-northeast-striking, structural triangle zone, or tectonic wedge. The west-northwest-directed basal detachment of the triangle zone lies above the Cambro-Ordovician platform, whereas the east-southeast-directed upper detachment (the Tea Cove Thrust) is structurally overlain by, and folds, Upper Ordovician through Lower Devonian sediments of the Anticosti foreland basin. Therefore, the triangle zone, which is occupied by the Humber Arm Allochthon and slices of foreland basin and platform rocks, is probably a Middle Devonian (Acadian) feature.

This thin-skinned package is known to be overridden obliquely by thick-skinned structures in two locations: (1) on Port au Port Peninsula, by the east-northeast to northeast-striking Round Head Thrust, and (2) southwest of Portland Creek Pond, by the north-northwest to north-northeast-striking Parsons Pond Thrust. The Round Head and Parsons Pond thrusts carry Grenville basement, the platform succession, and overlying Taconian foreland basin deposits in their hanging walls. These Taconian foreland successions include the

spectacular conglomerates of the Cape Cormorant Formation (Round Head Thrust hanging wall) as well as the conglomeratic Daniel's Harbour Member (Parsons Pond Thrust hanging wall). Published provenance data and the known, limited, spatial distribution of the Cape Cormorant Formation suggests the Round Head Thrust is a reactivated fault with normal offset in Taconian time; it may even be a reactivated rift-stage fault. We infer a similar history for the Parsons Pond Thrust, where the hanging wall carries an anomalous thickness of Goose Tickle Group sediments and the spatially restricted Daniel's Harbour Member.

The thick-skinned Round Head and Parsons Pond thrusts were reactivated following thin-skinned deformation, with reverse motion occurring prior to Viséan (middle Early Carboniferous) time, and probably in Middle Devonian (late Acadian) time. Subsequently, the region was exposed to regional pre-Viséan erosion, and significant Viséan and later sedimentary burial. Both the thin-skinned and thick-skinned structures are targets in the latest round of petroleum exploration onshore and in the near offshore of western Newfoundland.

## **Thermal history of the external Humber Zone, western Newfoundland, as constrained by apatite fission track modelling: implications for hydrocarbon exploration and evolution of the Maritimes basin**

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Western Newfoundland has become a recent focus of renewed petroleum exploration in the wake of reinterpretations of its structural and tectonic setting. To better constrain the timing of structural trap development relative to hydrocarbon generation and migration, we have examined apatite fission data from two key areas: (1) Port au Port Peninsula, and (2) the Bonne Bay-Table Point area. Among maturation indicators, the apatite fission track technique is unique because it provides constraints on the time-temperature history, as opposed to constraining maximum temperatures only.

Fission tracks are zones of linear crystal damage produced almost exclusively through spontaneous fission decay of <sup>238</sup>U. Track density is a measure of fission track "age", whereas the length distribution of tracks provides thermal history information because fission track length reduction (annealing) is a temperature-dependent process. The annealing zone for apatite is 60 to 120°C; therefore, the technique is very useful for petroleum exploration. Using an inverse model to fully assess the range of possible time-temperature solutions permitted by the data, we construct a set of acceptable time-temperature paths which statistically fit the observed fission track age and track length distribution of a given sample.

Our solutions for western Newfoundland are additionally constrained by independent geological information: (1) available Conodont Alteration Index (CAI) values; (2) known regional erosional denudation of the Carboniferous Maritimes basin following North Atlantic rifting; and (3) for the Port au Port Peninsula area: pre-Visean erosional exhumation followed by Visean and later burial in the Maritimes basin. Our results indicate that all our apatite fission track samples were heated into the partial annealing window in post-Visean time; in nine of eleven samples, this heating event represented the thermal peak. Significantly, this timing also post-dates Ordovician through Devonian thin- and thick-skinned deformation. The results for seven of eleven samples are fully consistent with the CAI values; the remaining samples can be modelled with temperatures only 10°C warmer than indicated by the CAI values. Extrapolation of these temperatures to depth suggests temperatures of 100 to 160°C in the autochthonous platform, which lies comfortably within the oil window, consistent with the results of traditional maturation studies in the area.