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GEOLOGICAL ASSOCIATION OF CANADA

NEWFOUNDLAND SECTION

ABSTRACTS

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Structure of the Buchans mine area: new approaches to exploration

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Structural analysis of the Buchans mine area confirms that the volcanic and sedimentary rocks of the early Ordovician Buchans Group comprise an extensive south-verging, linked thrust system. This interpretation contrasts strongly with views held during the period of production of the Buchans orebodies, that the Buchans Group occurred in a structurally little disturbed north-dipping homocline. Structural approaches are outlined to unravel the complicated macroscopic geometry of the Buchans thrust stack, using the revised stratigraphy of the Buchans Group proposed by Thurlow and Swanson (1987). Emphasis is placed on delineating the distribution of the prospective Buchans River Formation in blind settings within the thrust stack. The structural controls on the setting of the Oriental #1 and blind Sandfill and Middle Branch prospects are illustrated using various types of structural geological maps and cross sections.

Sequences of the Buchans Group occur in a number of imbricate thrust systems, in the form of duplexes, which are exposed in eyelid windows and half-windows through a broad, east-west trending culmination. The geometry and stacking order of the duplexes can be explained in terms of a kinematic model, involving south-directed inbrication of the Buchans Group by progressive footwall collapse (piggy-back stacking) along complicated frontal and lateral ramp systems beneath the advancing Hungry Mountain crystalline thrust sheet.

The Oriental #1 orebodies form two fine scale imbricated antiformal stacks of ore lenses in a sheared matrix of volcanic and volcaniclastic rocks. This structural belt extends to the northeast, where it comprises the Sandfill and Middle Branch prospects which occur in a blind setting beneath the Middle Branch duplex. The trend of the belt is controlled by a structurally underlying culmination consisting of arkose of the Sandy Lake Formation (which lithostratigraphically overlies the Buchans River Formation). The culmination forms a highly prospective target for exploration at 1500-2000 feet depth from surface, because it may be cored by an antiformal stack of rocks of the Buchans River Formation. Drill holes in the area only penetrated to top arkose of the culmination, because this unit was considered to form the "Footwall Arkose" to the ore zone in the old stratigraphic scheme for the mine area.

Timing and character of mid-Paleozoic deformation in western Newfoundland

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Western Newfoundland underwent widespread deformation and metamorphism following emplacement of the Taconian allochthons but prior to deposition of onlapping Carboniferous sediments. Stratigraphic and radiometric data in the southern White Bay allochthon indicate that this orogenic event took place during the latest Silurian or early Devonian and forms part of the Acadian Orogenic cycle.

Acadian deformation is characterized by an overall pattern of west-directed thrusting. The basal detachment extends into Grenville basement resulting in the thrusting of basement and the overlying Cambro-Ordovician cover sequence of platformal carabonates over the transported rocks of the Taconian allochthons. Locally, in the Humber Arm allochthon, cover and basement are delaminated with a series of east verging folds and thrusts developed above an inferred west-directed passive roof duplex in Grenville basement. Metamorphism accompanying deformation reaches upper greenschist to lower amphibolite grade.

West Newfoundland lies at the Acadian mountain front. The intensities of deformation and metamorphism decrease and die out westward. Structural and topographic relief across the front resulted in its gravitationally induced collapse and the generation of a series of extensional structures. The basal detachment of west Newfoundland ophiolites truncates Acadian compressive structures and probably reflects late-Acadian extensional tectonics rather than initial Taconian emplacement.

Canada's Ice Island: a platform for the characterization of the Arctic Ocean through stable isotope studies

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Canada's Ice Island, presently located off Ellef Rignes Island in the Arctic Ocean, offers earth scientists a unique opportunity for research in several fields. The research group that I am associated with is attempting to characterize the Arctic Ocean through organic geochemical and isotopic studies from the Ice Island.

Studies of the organic content of sedimentary cores from the Arctic Ocean show increases in both the C and N concentrations with depth from 0.07% N and 0.6% C near the surface, to a maximum of 0.13% N and 2.5% C at the bottom of the cores (80 cm). An isotopic depletion downcore is seen, with 15N decreasing from +6 ‰ to +4 ‰, and 13C decreasing from -23 ‰ to -24.5 ‰. These data indicate that a terrestrially sourced material has been overlain by a marine-looking deposit. These sequences are related to the most recent glacial retreat in the area.

Physical water mass studies have delineated two primary water masses, an upper photosynthetic-related layer (high dissolved oxygen content of 10-12 mg/l and a depleted isotopic oxygen value ranging from -1.5 ‰ to -3.5 ‰, and a lower respiration-related layer (high DIC concentration of 1.8-2 mM/kg and a depleted isotopic carbon value decreasing from 1 ‰ to 0 ‰ with depth).

These studies help to establish the relationship of the water masses to the cycling of organic material within the water column, and also help interpret the paleohistory of the area.

Deep seismic: a new exploration tool

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Seismic reflection studies of the deep continental crust provide new and startling views of the nature and physical behaviour of this region which controls sedimentary basin development. Unexpected layering in the deep crust provides a horizon for detachment of dipping shear zones which approach the lower crust from either the upper crust or the mantle. Some shear zones appear to cut through the whole crust and some clearly offset the Moho. Clear evidence of repeated movement on earlier compressional structures reactivated in extension (e.g., Viking Graben, Jeanne d'Arc Basin) is recognized. Some zones lacking obvious extensional faulting have associated dipping shears. The depth to detachment of faults in extension, whether shallow in the deep crust, or lower in the mantle, has significant bearing on basin formation, and on thermal maturation.

In compressional regimes, foreland propagating thrusts are often "blind" and deeply penetrating, and may be responsible for structures well away from the supposed deformation front. Models of Appalachian foreland thrusts permit comparisons with Rocky Mountain features flanking the Alberta Basin.

Deep seismic has much to offer for understanding the history and internal structure of basins. Recording to 15 or more seconds should become routine in basin exploration, especially in reconnaissance. Reconsideration of in-house data can be significant for appreciation of deep structure.

Such results, in conjunction with fluid and sedimentary facies basin analysis, provide exciting insight for definition of new exploration targets. This research, underway at the Centre for Earth Resources Research (CERR), utilizes a newly acquired CONVEX minisupercomputer funded by Petro-Canada and NSERC.

Geochemistry of, and mineralization at the Adeline Island Prospect, Seal Lake, Labrador

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The 1320 Ma Seal Lake Group consists of five formations viz. the Bessie Lake/Majoqua, the Wuchusk Lake, Whiskey Lake/Salmon Lake, Adeline Island, and Upper Red Quartzite Formations and is the youngest of the six Proterozoic supracrustal sequences that comprise the Central Mineral Belt of Labrador. This group is reputed to contain over 250 copper occurrences. Structurally the Seal Lake Group consists of a 200 km x 50 km folded syncline with structural detachment zones. Copper mobilization occurred along these thrust planes, presumably in response to the Grenville Orogeny. The mineralization was concentrated along these sheared zones in quartz veins that are syn- to post- D_1 folding. The Adeline Island Prospect consists of bornite, chalcocite, and ± pyrite hosted by pink-grey quartzite and green-black phyllite. The mineralization occurs in disseminated form analogous to the White Pine Deposits. All of these epigenetic occurrences appear to be the products of a single stage of mineralization, but the ultimate source of the fluids (magmatic and/or meteoric) is still a matter of some speculation. Preliminary geochemical and structural evidence, however, suggest that the copper was deposited as a product of hydrothermal fluid flow along fracture planes and was not leached from the surrounding sediments.

Previous assays from this showing have documented surface values ranging from 5.1% Cu over 0.84 m to 2.45% over 6.3 m. Grab sample collected during this study have values ranging from a low of 0.5% Cu up to 3.5% Cu. Analysis of other base metals has yielded negligible values.

The St. George Unconformity, Ordovician, northern Appalachians: effects of lithosphere dynamics on the Sauk-Tippecanoe sequence boundary

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The Middle Ordovician St. George Unconformity in western Newfoundland is the Sauk/Tippecanoe sequence boundary and reflects the change from a passive to convergent, low latitude, continental margin during initial stages of the Taconic Orogeny. It is a karst unconformity to disconformity to paraconformity resulting from faulting and subsequent subaerial erosion.

Regional mapping and drillholes indicate that erosion was proceeded by gentle uplift accompanied by block faulting and folding of the shallow water platform carbonates. Erosion locally removed up to at least 50 m of stratigraphy. The time of exposure was short by North American standards lasting roughly 1 to 3 m, during the early part of the Whiterock Stage (*Orthidiella* Zone). Surface karst is reflected by surface solution sculpture, rubble breccias rich in chert clasts, solution-enlarged joints and faults, near-surface porosity and sets of reticulate, sediment-filled fissures.

Stratabound dolomitization followed by development of subsurface karst occurred while pre-unconformity peritidal sediments were still accumulating and gentle flexuring of the platform was occurring. Mixing zone diagenesis and solution caused by fluids migrating into the area and tectonic sagging resulting in the formation of broad, subsidence dolines that were infilled by contemporaneous sediments. Subsurface karst resulted in shallow tabular caves and stratiform to discordant rock matrix breccias. Stoping upwards of the breccias eventually created collapse dolines at the unconformity. Post-unconformity sediments are lags of chert-pebble conglomerate, non-marine to marine doline fills and widespread peritidal dolostones which onlapped and finally buried the karst paleotopography.

Detailed biostratigraphy and lithostratigraphy yields a remarkably detailed geohistory for the development of the unconformity. Conclusions from this analysis indicate that many aspects of the St. George Unconformity in particular and the Sauk/Tippecanoe sequence boundary in general can be explained just as easily by plate dynamics as by global eustasy. The alternative model also offers an explanation for pre-unconformity sedimentation.

The Laurentide ice sheet in west-central Alberta - implications for the ice free corridor

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The Grande Prairie area of west-central Alberta shows evidence of glaciation from both the Laurentide ice sheet, and ice derived from the Rocky Mountains. Over much of the area a single till of Laurentide provenance is found, and in some localities overlies Middle Wisconsinan fluvial sediments containing no Laurentide provenance clasts. Thus the surface till is Late Wisconsinan, and represents the only Laurentide glaciation in this part of Alberta. The distribution of Laurentide erratics suggests that Late Wisconsinan ice advanced into the foothills of the Rocky Mountains, and its limit was constrained by topography rather than obstruction by mountain derived ice. A prominent fluting field formed by the unrestricted advance of mountain ice onto the prairies predates Laurentide advance into the area, as the surface material is of Laurentide provenance, and the flutes are draped by lacustrine sediment deposited in pro-glacial lakes dammed by retreating Laurentide ice. Thus it is likely that Laurentide ice never coalesced with ice from the Rocky Mountains, and an ice-free corridor remained open throughout the Quaternary in west-central Alberta.

A review of applications of Cathodoluminescence microscopy to mineralogy and petrology

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Cathodoluminescence microscopy (CL) is used in several fields of petrology, particularly carbonate petrology, where it can yield information on the spatial distributions and qualitative concentrations of selected trace elements in many minerals with simple, relatively inexpensive equipment. Examples include: Mn^{2+} and rare earth elements (REE's) in carbonates; REE's in apatite; defects and (possibly) nitrogen in diamonds; Ag, Cu and Tl in sphalerite, REE's in fluorite, defects and (possibly) Fe^{3+} in quartz; Mn^{2+}, Fe^{3+}, Fe^{2+} and Ti^{4+} in feldspars. Applications include provenance studies and rapid thin section identification and mode estimation. Distributions maps in zoned minerals can be used to subdivide individual mineral grains for subsequent studies using microbeam or microsampling techniques.

Quantitative interpretations of CL spectra are possible with the addition of a monochromator and photometer system. These can be used to measure the wavelength and intensity of emission, parameters which are a consequence of the concentration and bonding environment of trace element or crystal defect emitters. Future studies will make more use of monochromators in order to extract the maximum information from CL emission patterns.

Geophysical characteristics of terranes in eastern Canada

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The geological terranes of eastern Canada are relatively well determined. There have been numerous attempts at correlating the geological terranes with diagnostic geophysical signatures. The geophysical data base for attempting such correlations has expanded dramatically in the past few years enabling a completely integrated approach to be undertaken.

The geophysical data enable the Humber Zone to be recognized throughout the Canadian Appalachians. The Dunnage Terrane is seen to be continuous only in Newfoundland; the Gander appears to be traceable from north of Newfoundland to Cape Breton; and the diagnostic patterns of the Avalon-Gander and Avalon-Meguma boundaries enable these features to be unequivocally identified. Recent geophysical mapping suggests that there are a number of lineations perpendicular to the general Appalachian trends. Paleomagnetic and other evidence suggests that movements along these features may be Carboniferous or younger. The new data also are indicative of modified boundaries for several terranes.

Groundwater flux and piezometric response of a small catchment in granitic terrain to precipitation

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Physical measurements of groundwater discharges and hydraulic gradients in pondbed sediments and piezometric levels in granite bedrock (Holyrood Pluton) at Seal Cove River valley, Newfoundland, are used to document the magnitude, duration and areal variability of changes in the shallow groundwater flow system due to precipitation during 1987. The 82 ha. study area is assumed to form a catchment on the eastern side of the valley, and is instrumented with six multilevel piezometers in fractured granite to depths of 63 m, and seepage meter/mini-piezometer nests around a 300 x 50 m pond along a branch of the Seal Cove River. Discharging seepage fluxes were consistently low (3-20 ml/m²/hr) during very dry summer months, then increased in magnitude and variability during wet autumn months (20-158 ml/m²/hr). Flux responses to individual storms were prompt, short-lived and strongly localized suggesting that fracture flow was the principal mechanism in supplying subsurface water to storm runoff. Prompt, short-duration (1-5 days) rises in bedrock piezometric levels are consistent with seepage increases and further show that shallow groundwater flow paths temporarily changed direction following storms. Piezometric response was simultaneous from surface to 63 m depth in high permeability areas of the granite, but showed lag time with depth low-permeability areas, indicating that permeability controls the timing of changes in groundwater flow paths. Areally, piezometric data show strengthening of recharge gradients and weakening of discharge gradients following storms, which is not consistent with the simple variable source area concept of ephemeral expansion of discharge areas during stormflow.

The marine mining program at C-CORE

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The Centre for Cold Ocean Resources Engineering is an engineering research institute located at Memorial University of Newfoundland. C-CORE receives its funding from industry and government sources. The research work is focused on problems related to northern offshore resource development. Since its establishment in 1974 the research has focused on three areas: ice research, remote sensing, and seabed geotechnics.

Recently, C-CORE has placed considerable emphasis on development of a research program in marine mining. At the present time the program has been aimed mainly at shallow offshore resources, particularly precious metal placers and aggregate sources: three aspects are being pursued. The first is the development of a genetic classification scheme for marine placers particularly those in which glaciation and variation of sea level have had an influence; the second is the development of geophysical techniques directed specifically towards outlining and assessing the economic potential of placer deposits; and the third is the study of the environmental impacts of marine mining and the mitigation of those impacts by appropriate measures.

This presentation outlines the program planned for the next three years, and gives examples of the present status of the marine placer genesis study and of geophysical techniques under development.

An overview of the Cape Smith Belt, northern Quebec: early Proterozoic oceanic spreading, continental rifting, and development of a collisional thrust belt

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The Cape Smith Belt contains evidence for early Proterozoic plate tectonics in the form of a 2.00 Ga ophiolite and a ca. 1.92-1.84 thrust belt which developed during A-type (continental) subduction. Five distinct tectonostratigraphic suites have been recognized: (1) fluvio-deltaic sediments; (2) proximal to distal fan clastics passing upwards and outboard into ca. 1.96 Ga continental rift basalts; (3) transitional crust basalts; (4) deep water sediments; and (5) sheeted dykes, basalts and mafic-ultramafic cumulates of a 2.00 Ga ophiolite. Suites (1) and (2) were intruded by layered mafic-ultramafic sills at 1.92 Ga, prior to any compressional deformation. Suites (1) to (3) reflect the development of a north-facing rift margin at the edge of the Superior province. The older age of the ophiolite suggests that it developed independent of the rift margin in a separate basin.

The tectonically dismembered and metamorphosed Purtuniq ophiolite is characterized by a structurally reversed stratigraphy. The igneous stratigraphic components, in bottom to top order are: (1) sheeted dykes passing upwards in a continuous sequence into pillowed flows and thin sills; and (2) ultramafic and mafic cumulates. The sheeted dykes are tholeiitic, and have rare earth element (REE) patterns that are either nMORB-like flat at 10x chondrite, or LREE enriched. The stratigraphically overlying tholeiitic volcanics have nMORB-like REE patterns. REE analyses of layered gabbros confirm their texturally interpreted cumulate origin; plagioclase-rich samples show striking positive Eu anomalies, while more mafic compositions have higher overall abundances of REE's, and slightly negative or no Eu anomalies. While REE patterns for similar bulk compositions within any one tectonostratigraphic body are remarkably consistent, significant differences in REE patterns occur between similar lithologies in different tectonostratigraphic bodies. These fundamental differences suggest that more than one magma chamber may be represented by the structurally juxtaposed cumulate bodies. Two distinct olivine populations are recognized in the ultramafic cumulates. Texturally relict igneous grains ranging from Fo_{81} to Fo_{92} record variations in magma composition, while neoblastic metamorphic olivines (Fo_{96-99}) in the regionally highest grade areas, suggest that some serpentinization occurred prior to prograde metamorphism.

The shortening episode involved southward thrusting of suites (2) to (5) above autochthonous basement gneisses and suite (1) sediments. The tectonothermal development of the thrust belt is marked by four temporal stages: (1) piggyback (regular) sequence accretion of cover rocks above a basal decollement; (2) thermal relaxation and prograde metamorphism of the thrust belt, leading to the development of a ductile basal shear zone and a suite of hot-side-down mineral isograds; (3) out-of-sequence thrusting at thermal peak conditions involving the incorporation of basement slices into the thrust belt; and (4) post-thermal peak out-of-sequence thrusting. Modelling of garnet zoning profiles in metapelites from the deepest structural levels reveal decompression P-T paths recording unroofing of the thrust belt from 10 to 5 kb during out of sequence thrusting. Syn- to post-shortening emplacement of tonalitic plutons in the internal part of the thrust belt constrains the initiation of stage (3) to be no later than 1.89 Ga, and brackets stage (4) between 1.86 and 1.84 Ga. The shortening episode is interpreted to result from a collision of the Superior province with a northern Archean terrane (Sugluk terrane). The nature of the ocean basin and rift margin developed, and style of their subsequent deformation are fully consistent with modern plate tectonic mechanisms.

Interrelationships between thrusting, migmatization and generation of a monzonite - anorthosite suite in the Mealy Mountains Terrane, Grenville Orogen, Canada

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The monzonite - anorthosite association is generally considered characteristic of stable-crust, anorogenic settings and is typically linked to generation by crustal rifting. An apparent exception is the Mealy Mountains Terrane (MMT), a large (1300 km^2) plutonic suite formed in association with the ca. 1650 Ma Labradorian orogeny, a major crust-forming event in the Grenville Province of Labrador. MMT comprises weakly deformed monzonite, gabbro, anorthosite and lesser granite. During Grenvillian deformation, ca. 1045 Ma, the terrane was translated northwards as a thick thrust slab over Labradorian plutonic and gneissic rocks. Burial of the footwall rocks under the slab resulted in melting, migmatization and generation of granitic melt. Tilting of the northwestern boundary of MMT has revealed a crustal cross-section from gneissic granulite to upper amphibolite facies rocks at the base, to plutonic rocks which have experienced only greenschist to lower amphibolite conditions, at the top.

Geochemically the rocks of MMT bear more similarity to anorogenic suites than to typical synorogenic (e.g., arc-related) suites. However, monzonite of MMT has been dated at 1640 Ma (Emslie *et al.*, 1983) indicating a close temporal association with the Labradorian event of 1700-1645 Ma. Structural evidence further indicates an overlap between intrusion and deformation. In a preliminary model it is proposed that the monzonite - anorthosite suite was generated as a post-collisional suite following accretion of Labradorian crustal elements to North America.

CAGS in the Ordovician of central Newfoundland

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An ongoing project involving graptolites from the Ordovician of central Newfoundland is producing some useful, and in some cases unexpected, results. The major thrust of the research is aimed at the ubiquitous middle Ordovician black shale (the "Caradoc black shale"), but collections ranging in age from early Arenig to late Ashgill have also been recovered.

Black argillites on Long Island, western Notre Dame Bay, assigned previously to the "Caradoc" shale belong to two stratigraphically distinct units of late Arenig and early Llanvirn age. Graptolite faunas agree well with ages established using shelly macrofossils and conodonts, and are of open ocean affinity. They demonstrate that volcanism on Long Island was entirely pre-Caradoc, and spanned a period of perhaps five million years from late Arenig to early Llanvirn.

Graptolites from Snooks Arm on the Baie Verte Peninsula and Corner Pond at the southern end of Grand Lake suggest two different early Arenig ages (probably lower *D. bifidus* Zone and *P. fruticosus* Zone respectively). Thus there is no one widespread lower Ordovician black shale in the Dunnage Zone. Such localized occurrences of graptolitic black shale are unusual; they clearly represent deposition in partially restricted, periodically anoxic basins, lending support to a marginal plate setting hypothesis, with complex series of back-arc and/or fore-arc basins.

Variation in onset of coarse clastic deposition in the Point Leamington and equivalent greywackes encompasses a maximum of one graptolite zone (perhaps two million years) and probably less. No systematic change across the region may be demonstrated as claimed previously. Graptolites from one interval at Point Leamington indicate a *D. anceps* Zone (mid-late Ashgill) age. These are by far the latest Ordovician graptolites discoveries to date in Newfoundland, and confirm the possible presence of the Ordovician-Silurian boundary within the Point Leamington Greywacke and Goldson Conglomerate.

Most graptolites in the Dunnage Zone have been distorted by tectonic stretching, making detailed taxonomy difficult. This problem is being overcome through digitizing of accurate drawings on a Mac II computer where distortion may be removed and publication-quality images printed on a laser printer. New

Macintosh software now permits high-quality maps and sections to be easily produced which in many cases are indistinguishable from professionally hand-drafted figures (as will hopefully be demonstrated during the talk). Thus the development of Computer Assisted Graptolite Studies is reaching new heights in St. John's, including the possible future development of computer-based identification!

Stable and radiogenic isotope tracing of fluids in epithermal gold mineralization in the Little Rocky Mountains, Montana

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The Little Rocky Mountains, Montana, are a result of doming of Archean basement gneisses and Phanerozoic sedimentary rocks produced by the emplacement of a quartz monzonite to syenite intrusive complex of Early Tertiary age. The intrusive rocks have whole-rock $\delta^{18}O$ values near 8 and initial $^{87}Sr/^{86}Sr$ ratios from 0.7050 to 0.7061. The Zortman and Landusky mining areas in the Little Rockies produce Au from fracture systems filled with clay minerals and low concentrations of Au-bearing pyrite. K-Ar ages of illites associated with the Au mineralization are near 60 Ma and are similar to K-Ar and fission-track ages of the intrusive rocks. δD and $\delta^{18}O$ values of these illites indicate that they, and the Au-bearing pyrite, formed at temperatures near 250°C from meteoric fluids having $\delta^{18}O$ values near 1 and δD values near -80. This Au event is characterized by illites having much higher initial $^{87}Sr/^{86}Sr$ ratios (as high as 0.7784) than the intrusive rocks that host the fracture system, suggesting that Sr, and by inference the Au, most likely were derived from Precambrian basement gneisses.

After the gold was emplaced, later fluids released the gold by oxidizing the pyrite and formed kaolinite and hydrothermal fluorite and dolomite, the latter of which are characterized by $^{87}Sr/^{86}Sr$ ratios near 0.708, similar to those of the intrusive rocks and Phanerozoic carbonates. Low salinity fluid inclusions in fluorite homogenize at 100 to 200°C and have $\delta^{18}O$ values near -10 and δD values near -110, consistent with those of Tertiary ground waters. $\delta^{34}S$ values of pyrite do not correlate with gold contents, and their wide variation from -11.4 to 6.3 cannot be used to distinguish among igneous, sedimentary and metamorphic sources.