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EPIGENETIC GOLD OCCURRENCES IN THE EASTERN DUNNAGE ZONE, NEWFOUNDLAND: PRELIMINARY STABLE-ISOTOPE RESULTS

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ABSTRACT

Epigenetic gold within the eastern part of the Dunnage Zone comprises a widespread class of mineralization, the significance of which has only recently been recognized. These gold occurrences are structurally controlled and are divided into mesothermal and epithermal classes. The two classes share common characteristics including style of mineralization, alteration and geological setting, which may indicate a genetic link between them.

Preliminary stable-isotopic results indicate that there is a substantial variability in the oxygen, carbon and sulphur isotopic compositions of quartz, carbonate and sulphur minerals from the gold occurrences in the eastern Dunnage Zone. Such variability is not typical of Archean, Proterozoic or Mesozoic gold camps.

INTRODUCTION

The exploration boom for gold in the 1980's resulted in the discovery of more than 400 gold occurrences in Newfoundland, approximately 60 of which occur within the eastern part of the Dunnage Zone (Figure 1). In response to this, the Geological Survey Branch of the Newfoundland Department of Mines and Energy initiated a metallogenic study aimed at documenting the nature and setting of gold mineralization within the eastern part of the zone (i.e., east of the Red Indian Line). The field component of this study (1989 to 1993) involved regional geological mapping and deposit-level studies, which included detailed mapping, diamond-drill core logging, and sampling for geochemical and isotopic analyses. Office-based studies centred on analyzing field and laboratory data.

HISTORICAL PERSPECTIVE

Structurally controlled, epigenetic gold occurrences form a significant style of mineralization, the extent of which has only recently been recognized in Newfoundland. Historically, gold production in the province was limited to an important by-product of the mining of volcanogenic massive sulphide deposits such as the Buchans, Rambler and Notre Dame Bay copper mines (Tuach *et al.*, 1988).

Excluding volcanogenic massive sulphide deposits, there were approximately 15 mineral occurrences recognized within the eastern part of the Dunnage Zone prior to 1978 that contained significant concentrations of gold. In 1978, auriferous quartz veins were discovered in gabbroic rocks (Blackwood, 1979) of the Gander River Complex (O'Neill and Blackwood, 1989) and this sparked the first real interest in the gold potential of the area. The discovery of the Hope Brook deposit in 1983 (McKenzie, 1986) set off a flurry of exploration activity, which established Newfoundland's position as a prime exploration area for gold. Exploration in the eastern Dunnage Zone during the past ten years has resulted in the discovery of approximately 60 significant gold occurrences (Figure 1).

GOLD OCCURRENCES IN THE EASTERN DUNNAGE ZONE

REGIONAL SETTING

The study area is located within the Paleozoic Central Mobile Belt of the Newfoundland portion of the Appalachian Orogen (Williams, 1964). The mobile belt is divided into Gander and Dunnage tectonostratigraphic zones (Williams, 1979). The Gander Zone represents continentally derived sedimentary rocks deposited at the eastern margin of the Iapetus Ocean. Williams *et al.* (1988) redefined and expanded

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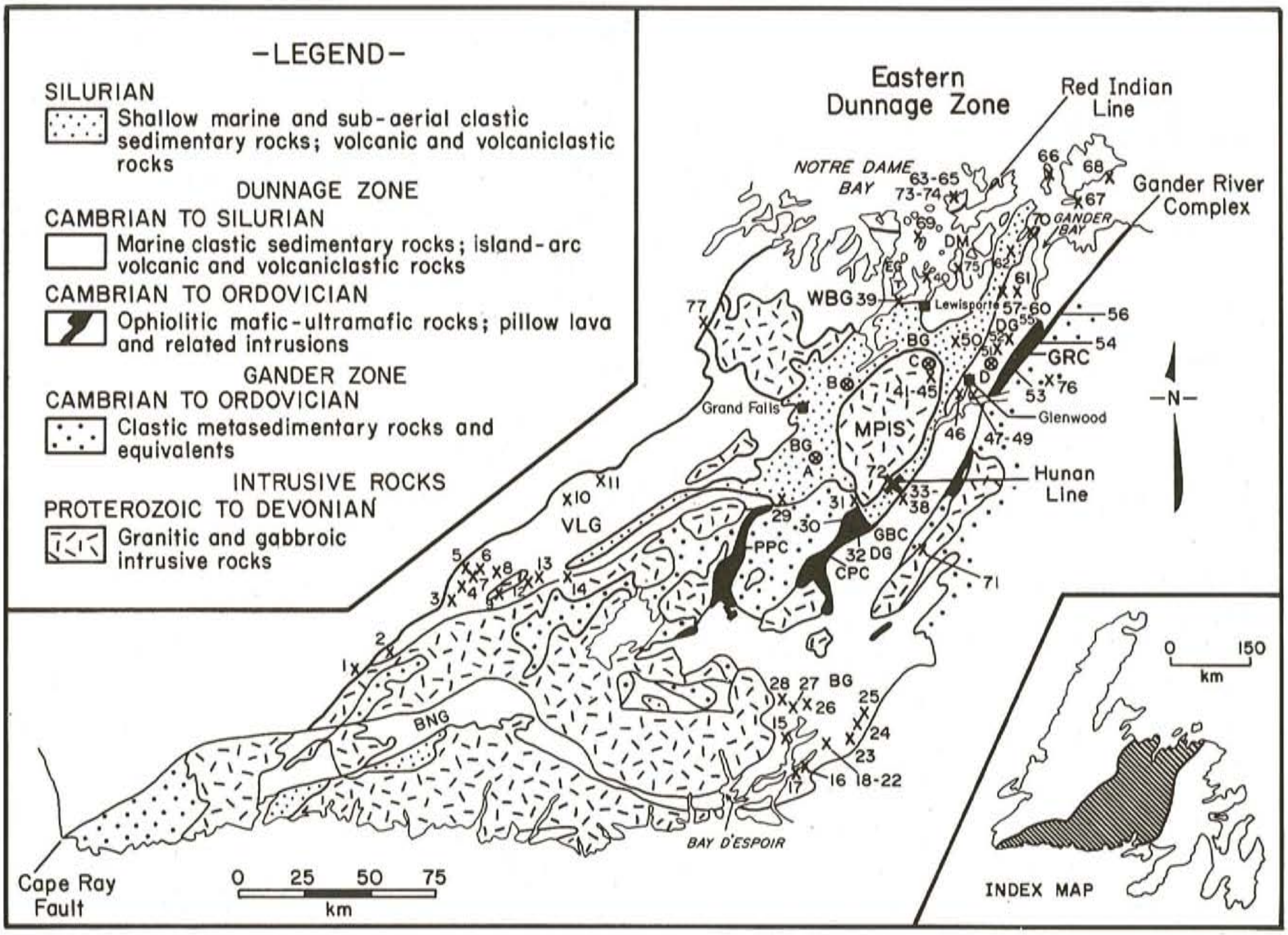

KEY (to Figure 1)

	OCCURRENCE	STYLE	GRADES	MINERALOGY	HOST ROCK	ALTERATION
1	SECOND EXPLOITS	Dilational Veins	7.5 g/t Au	Au,Gn,Sp,Hem,Pyr	Granite	Sil, Epi
2	WOODS LAKE	Dilational Veins	11.93 g/t	(Au),Asp	Metasediments	Seri
3	PATS POND	Dilational Veins	1.9 g/t Au	(Au,Ag),Cp,Gn,Sp	Felsic Volc	Sil
4	ROAD (CAMP)	Dilational Veins	5.5 g/t Au	(Au),Gn,Sp,Pyr	Felsic Volc	Seri, Pyr
5	WEST TULKS	Dilational Veins	N/A	(Au),Gn,Pyr	Felsic Volc	Seri, Sil
		Disseminated	N/A	(Au),Hem		Sil, Hem
6	MIDAS POND	Shear-Controlled	7.3 g/t Au	(Au),Pyr,Tour	Mafic Volc	Fe-carb, Pyr, Intense Argillic
7	GLITTER POND	Dilational Veins	2.55 g/t Au	(Au),Ba,Pyr	Felsic Volc	Seri
8	LONG LAKE	Dilational Veins	N/A	(Au),Pyr	Granite	Sil
9	VALENTINE LAKE	Dilational Veins	24 g/t Au	Au,Pyr,W,Tour	Trondhjemite, Conglomerate	Seri, Alb, Sil, Pyr
10	BOBBYS POND	Epithermal		Pyr,S,Pph,Ser,	Felsic Volc	Sil
11	VICTORIA MINE WEST/INCO	Veins	2.2 g/t	(Au),Asp	Felsic Volc	Sil
12	VICTORIA BRIDGE	Dilational Veins	32.5 g/t	(Au),Pyr	Trondhjemite	?
13	GUANO PIT	Dilational Veins	20.0 g/t	(Au),Pyr	Trondhjemite	?
14	SOUTH QUINN LAKE	Dilational Veins	N/A	(Au),Asp,Pyr,Po	Metasediments	Sil
15	RATTLING BROOK	Dilational Veins	6.5 g/t Au	(Au),Bi,Mo	Schist	
16	BOWERS TICKLE	Dilational Veins	13.7 g/t Au	(Au),Sb,Ag	Schist	Sil
17	LONG JACKS BIGHT	Disseminated	12.34 g/t Au	(Au,Ag),Pyr,Po,Ar,Gn	Schist	Sil
	LITTLE RIVER (18-22)				Felsic Volc	
18	WOLF POND	Dilational Veins	6.51 g/t	(Au),Asp,Pyr,Po,Sb	Felsic Volc	Sil
19	22 WEST/LITTLE RIVER	Disseminated	4.11 g/t	(Au),Asp,Pyr,Po,Sb	Felsic Volc	?
20	22 WEST/TILLICUM	Disseminated	4.9 g/t	(Au),Asp,Po,Pyr,Sb	Felsic Volc	Carb, Seri
21	38 WEST/42 WEST	Disseminated	3.09 g/t	(Au),Asp,Po,Pyr,Sb	Felsic Volc	?
22	89 TO 97 WEST/ESSO	Disseminated	3.8 g/t	(Au),Po,Pyr,Asp,Sb	Felsic Volc	Carb, Seri
23	LE POUVOIR	?	1.9 g/t	(Au),Asp,Sb	Schist	?
24	KIM LAKE #1	Veins	20.52 g/t	(Au),Gn,Sp,Cp	Felsic Volc	?
25	KIM LAKE #2	Veins	9.7 g/t	(Au),Sb,Asp	Felsic Volc	Carb, Seri
26	TRUE GRIT	Veins	30.2 g/t	(Au),Asp	Siltstone	?
27	GOLDEN GRIT TRENCH 4	Dilational Veins	16.9 g/t	(Au),Pyr	Pelite	Seri

KEY (to Figure 1, Continued)

	OCCURRENCE	STYLE	GRADES	MINERALOGY	HOST ROCK	ALTERATION
28	GOLDEN GRIT TRENCH 5	Dilational Veins		Sb,Pyr	Pelite	Seri
29	GREAT RATTLING Bk	Shear-Controlled	2.3 g/t Au	(Au),Pyr	Ultramafic, Metasediments	Sil, Seri
30	LIZARD POND	Shear-Controlled	12.6 g/t Au	(Au),Pyr,Asp	Ultramafic	Sil
31	CHIOUK BROOK	Disseminated	1.9 g/t Au	(Au),Pyr,Asp	Altered Seds	Sil
32	BRECCIA POND	Shear-Controlled	< 2 g/t Au	(Au)	Ultramafic	Sil, Hem
33	AZTEC	Epithermal	<1 g/t Au	(Au),Pyr	Altered Seds	Pyr, Argillic
34	HORNET	Dilational Veins	9.7 g/t Au	(Au),Pyr,Asp	Granite	Sil
35	A-ZONE EXTENSION	Dilational Veins	2.6 g/t Au	(Au),Pyr,Asp	Siltstone	Chlor, Potassic
36	ROAD GABBRO	Dilational Veins	7.9 g/t Au	(Au),Pyr,Asp	Gabbro	Sil, Fe-Carb
37	GOOSE	Dilational Veins	1.3 g/t Au	Au,Pyr,Asp	Greywacke	Seri, Sil
38	LBNL	Dilational Veins	1.8 g/t Au	(Au),Pyr,Asp	Porphyry	Sil
39	PORTERVILLE	Shear-Controlled	2.12 g/t Au	(Au),Pyr,Asp	Gabbro	Fe-Carb, Leucoxene
40	POWDERHOUSE COVE	Dilational Veins	78.2 g/t Au	(Au),Pyr,Asp	Felsic Dyke	Sil
	MOUNT PEYTON (41-45)					
41	HURRICANE	Shear-Controlled	4.6 g/t Au	(Au),Pyr,Asp	Diorite	Seri
42	CORSAIR	Shear-Controlled	3.2 g/t Au	(Au),Pyr,Asp	Diorite	Seri
43	COMANCHE	Shear-Controlled	1.3 g/t Au	(Au),Pyr,Asp	Diorite	Seri
44	SABRE	Disseminated	2.1 g/t Au	(Au),Pyr,Asp	Aplite Dyke	Sil
45	APACHE	Shear-Controlled	1.3 g/t Au	(Au),Pyr,Asp	Diorite	
46	THE OUTFLOW	Epithermal	12.23 g/t Au	(Au),Pyr,Sb	Greywacke	Sil
47	BULLET	Shear-Controlled	83 g/t Au	Au,Pyr,Asp,Gn,Cp	Shale	Fe-Carb
48	THE KNOB	Shear-Controlled	155 g/t Au	Au,Pyr,Asp,Cp,Bou	Greywacke	Fe-Carb
49	BOWATER	Dilational Veins	<3 g/t Au	(Au),Pyr	Greywacke	Sil
50	BIG POND	Dilational Veins	440 g/t Au	Au,Pyr,Asp	Gabbro	Fe-Carb
51	THIRD POND	Dilational Veins	4.6 g/t Au	(Au),Pyr	Greywacke	Sil
52	KNOB HILL	Dilational Veins	2.7 g/t Au	(Au),Pyr	Greywacke	Chlor, Pyr
53	JONATHANS POND	Shear-Controlled	6 g/t Au	(Au),Pyr,Asp		
54	BURSEY'S HILL	Disseminated	3.5 g/t Au	(Au),Cr	Ultramafic	Talc-Carb
55	CRIPPLE CREEK	Epithermal	9.6 q/t Au	(Au),Pyr,Asp	Trondhjemite	Sil
56	WEIRS POND	Dilational Veins	2.5 g/t Au	(Au),Asp,Pyr	Gabbro	Fe-Carb
	DUDER LAKE (57-60)					
57	FLIRT	Dilational Veins	N/A	(Au),Pyr,Asp	Gabbro	Fe-Carb, Chlor
58	GOLDSTASH	Disseminated	12.5 g/t Au	(Au),Pyr,Asp	Gabbro	Sil, Seri, Fe-Carb, Leucoxene
59	CORVETTE	Disseminated	N/A	(Au),Pyr,Asp	Gabbro	Sil, Seri, Fe-Carb, Leucoxene
60	STINGER	Shear-Controlled	N/A	(Au),Pyr,Asp	Siltstone	Seri, Fe-Carb
61	BURNT LAKE	Dilational Veins	N/A	(Au),Pyr	Greywacke	Sil
62	CLUTHA	Shear-Controlled	N/A	Au,Pyr,Asp	Gabbro	Fe-Carb, Sil
	MORETON'S HARBOUR (63-65)					
63	STUCKLESS COVE	Dilational Veins	20.2 g/t Au	(Au),Sb,Asp	Felsic Dyke	Sil
64	TAYLERS ROOM	Dilational Veins	13.3 g/t Au	(Au),Sb,Asp	Felsic Dyke	Sil
65	STEWARTS MINE	Dilational Veins	10.9 g/t Au	(Au),Asp,Pyr,Sp	Felsic Dyke	Sil
66	CHANGE ISLANDS	Dilational Veins	164.1 g/t Au	(Au),Pyr,Po,Cp	Felsic Dyke	Sil
67	INDIAN ISLANDS	Dilational Veins	8 g/t Au	(Au),Pyr,Asp	Felsic Dyke	Sil
68	CANN ISLAND	Shear-Controlled	3.1 g/t Au	(Au),Pyr,Cp,Sp	Mafic Volc	Chlor
69	POND ISLAND	Dilational Veins	<1 g/t Au	(Au),Cp,Sp,Sb,Bi,Ag, Asp,Tet	Granodiorite	Sil, Seri
70	CHARLES COVE	Dilational Veins	6.2 g/t Au	(Au),Pyr,Asp,W,Cp,Mo	Granodiorite	Sil
71	MIDDLE RIDGE	Shear-Controlled	1 g/t Au	(Au),Pyr,W	Granite	Seri, Sil
72	HUNAN	Dilational Veins			Greywacke	Seri, Carb
73	MORETONS HR. HEAD	Veins	9.11 g/t	(Au),Pyr,Asp,Sb	Mafic volc	?
74	PIERCE HR. EAST	Veins	4.79 g/t	(Au),Pyr,Asp,Sb	Mafic volc	?
75	SHOAL POINT	Shear-Controlled	4.67 g/t	(Au),Asp,Pyr,Cp	Gabbro	?
76	GANDER AIRPORT	Epithermal (?)		Pyr	Slate	Sil
77	HAND CAMP	Disseminated	10.6 g/t Au	(Au,Ag),Pyr,Gn,Sp	Sericite schist	Seri
	FLOAT					
A	PARADISE LAKE	Epithermal			Sandstone(?)	Sil
B	MOOSEHEAD	Dilational Veins	N/A	Au,Pyr,Asp	Sandstone(?)	Sil
C	SALMON RIVER	Dilational Veins	N/A	(Au),Asp,(Ag),Sp,Gn,Cp, Pyr,Po	Diorite	Sil
D	PANHANDLER	Dilational Veins	161 g/t Au	Au	Greywacke(?)	

( ) parentheses indicate that the mineral/commodity is present in minor or trace amounts or indicated by an assay.

Figure 1. *Regional geology of the eastern Dunnage Zone, central Newfoundland, showing the locations of significant gold occurrences (numbers are keyed to Table 1; geology modified after Tuach* et al., *1988). Abbreviations include: DG-Davidsville Group; BG-Botwood Group; DM-Dunnage Melange; EG-Exploits Group; WBG-Wild Bight Group; VLG-Victoria Lake Group; BNG-Bay du Nord Group; BG-Baie d'Espoir Group; PPC-Pipestone Pond Complex; CPC-Coy Pond Complex; GBC-Great Bend Complex; GRC-Gander River Complex; MPIS-Mount Peyton intrusive suite; T-Thwart Island (after Evans, 1993).*

the Gander Zone to include three metaclastic sequences termed the Gander Lake, Mount Cormack and Meelpaeg subzones.

The Dunnage Zone records the development and subsequent destruction of the early Paleozoic Iapetus Ocean. The zone can be subdivided into the Notre Dame and Exploits

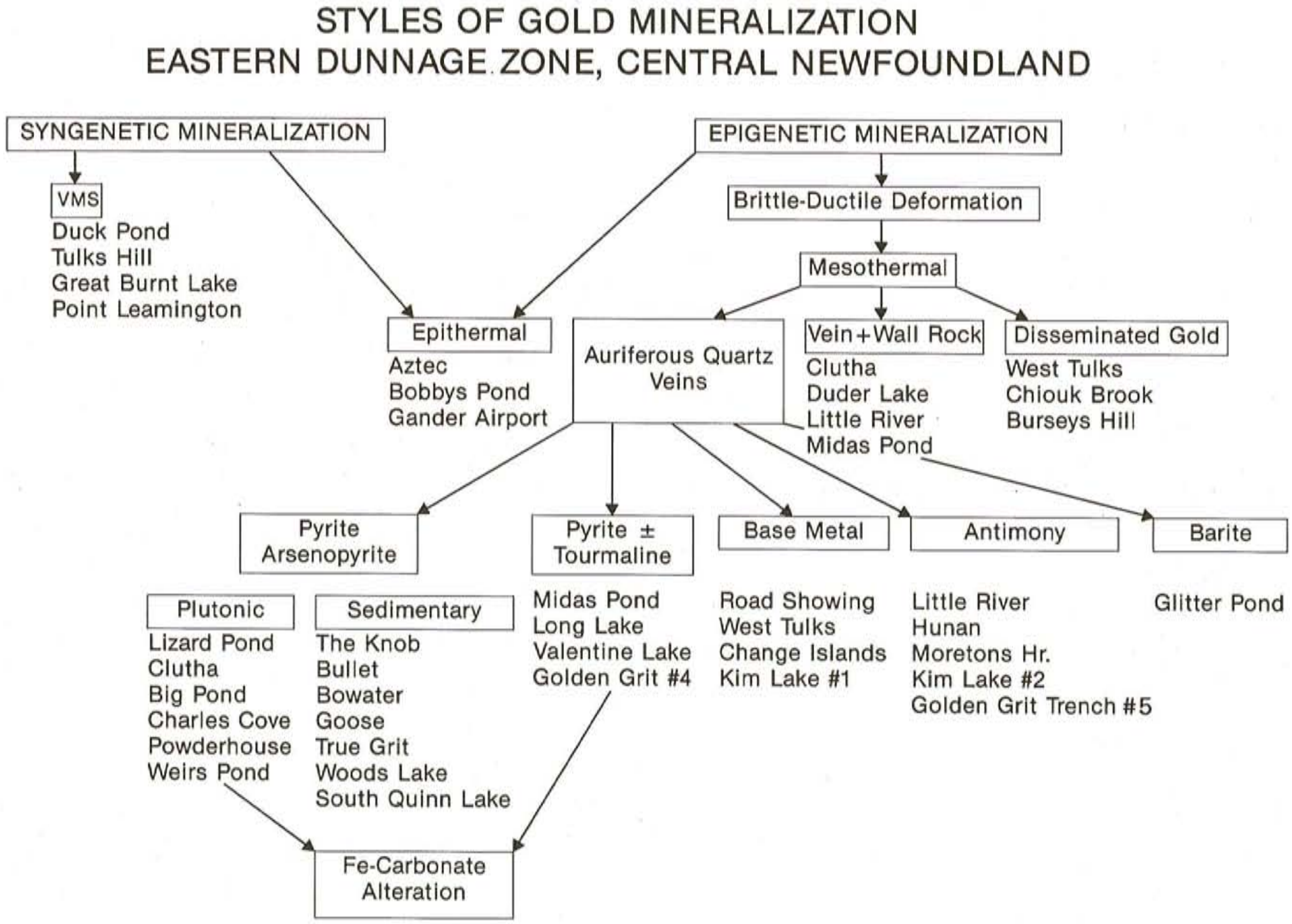

Figure 2. *Classification scheme for gold mineralization within the eastern Dunnage Zone. Included are possible gold-related alteration zones and antimony mineralization that may or may not contain anomalous gold (after Evans, 1993).*

subzones (Williams *et al.*, 1988), which are separated by the Red Indian Line.

The geological evolution of the Central Mobile Belt can be divided into two broad stages. The first stage includes pre-accretionary volcanism and pre- and syn-accretionary sedimentation in a series of Cambrian to Middle Ordovician island arcs and back-arc basins (Swinden, 1990). Closure of Iapetus, during the Early Ordovician, resulted in the emplacement of the Taconic and Penobscot allochthons along the western and eastern margins of Iapetus, respectively (Colman-Sadd *et al.*, 1992). In the eastern Dunnage Zone, allochthon emplacement involved thrusting of Exploits Subzone rocks over rocks of the Gander Zone. Allochthon emplacement was followed closely by cessation of island-arc volcanism. Continued closure of Iapetus during the Late Ordovician and Early Silurian was accompanied by the deposition of extensive flyschoid sequences in fault-bound basins in the central and eastern Dunnage Zone (Dean, 1978; Kean *et al.*, 1981). Full closure of Iapetus was complete in Newfoundland by the Late Ordovician or Early Silurian (Williams and Hatcher, 1983).

The second stage of geological evolution includes a Silurian orogenic phase, termed the Salinic orogeny (Dunning *et al.*, 1990), marked by crustal thickening. This produced regional metamorphism, plutonism, activation or reactivation of major fault systems, epicontinental-style volcanism and fluviatile sedimentation (Williams, 1967, 1969; Coyle and Strong, 1987).

Classification

Evans (1991) recognized both mesothermal and epithermal styles of gold mineralization within the eastern Dunnage Zone (Figure 2). Mesothermal lode-gold occurrences, particularly within the Archean, are probably the most studied and best documented style of gold mineralization. Recent workers include Colvine *et al.* (1984, 1988); Groves *et al.* (1988); Colvine (1989); Hodgson (1989); Kerrich (1989a, 1989b) and Kerrich and Feng (1992). Although these occurrences vary considerably, with respect to host rock and gangue mineralogy, many mesothermal gold deposits share a number of common characteristics including an alteration assemblage dominated by Fe-carbonate–

Table 1. Summary of the major characteristics of Archean lode gold mineralization

MESOTHERMAL VEINS

SETTING

-spatially related to major structural breaks formed in part by tectonic shortening
-localized along 2nd order or higher structures where brittle/ductile deformation predominates
-irregular distribution of Au deposits along these structures indicating focussed fluid flow due to local extensional features
-shear zone must exhibit little displacement, be active and permeable for an extended period, and open to a large volume of fluids
-late syn- to post- regional metamorphism

HOST ROCKS

-mineralization occurs in all rock types; mafic rocks (i.e., Fe-rich) favoured
-some are spatially associated with felsic intrusives

VEIN GEOMETRY

-simple shear strain predominates, resulting in
(1) shear fracture veins within R (low angle Riedel shears), R′ (high angle Riedel shears), P (pressure shears), D (central shears)
(2) extensional fractures, T (tensional) veins
-geometry of veins controlled by shear zone orientation and style, and by host lithology orientation and rheological properties
-1 to 10s of m wide with strike lengths of 10s -100s of m
-part of larger anastomosing structure (km long and up to 2 km in depth) with individual shears hosting a vein system
-vein formation and deformation synchronous
-overall vertical extent of mineralizing system may be on the order of 10 to 15 km in depth

VEIN CHARACTERISTICS

-coarse, milky white to grey quartz, often chert-like
-laminated, indicating multiple fluid injections
-gangue minerals (albite, Fe-carbonate, tourmaline, sericite, chlorite, pyrite, pyrrhotite, arsenopyrite, galena, sphalerite, chalcopyrite, molybdenite, stibnite, tellurides and tungsten)
-CO_2-rich, low salinity fluid inclusions
-hydrothermal fluid temperatures between 250 and 400°C

ALTERATION

-an extensive outer chlorite/calcite zone, often linear due to shear zone control
-inner carbonate zone comprised of Fe-dolomite, sericite, pyrite and quartz
-forms haloes 1 to 10s of m around vein systems, often overlap and merge to produce a broad zone
-intensity of Fe-carbonate alteration depends on the availability of Fe in the host rock

sericite–pyrite, and a spatial association with major shear zones, commonly terrane-bounding structures, which provide potential conduits for deep-crustal fluids. The fundamental characteristics of mesothermal gold systems are reviewed in Table 1.

Within the eastern Dunnage Zone, mesothermal gold deposits can be broadly divided into three main styles or classes (Evans, 1993) (Figure 2): 1) auriferous quartz vein systems, 2) altered wall rock (± auriferous veins), and 3) disseminated gold. Characteristics of these classes are outlined in Table 2. The style of mineralization is mainly dependent upon host-rock characteristics, rheological properties and permeability, and a great degree of overlap may exist between the styles, particularly in the altered wall-rock class. The altered wall-rock class is adapted from Dubé (1990), who described a similar altered wall-rock style of gold mineralization from western Newfoundland. Examples of each style from the eastern Dunnage Zone are included in Figure 2 and Table 2.

Table 2. Characteristics of the three classes of mesothermal gold mineralization from the eastern Dunnage Zone

Class 1: Auriferous Quartz Veins	
Host Rock	serpentinite, gabbro, diorite, granite, felsic dykes, felsic and mafic volcanic rocks, greywacke, sandstone and shale
Wall-rock Alteration	ultramafic rocks—silica and hematite (e.g., Lizard Pond and Breccia Pond) mafic rocks—strong Fe-carbonate, disseminated pyrite and arsenopyrte, and silica and chlorite (e.g., Big Pond) felsic rocks—sericite, silica, pyrophyllite and kaolinite (e.g., Powderhouse Cove, Charles Cove, Change Islands and Midas Pond) sedimentary rocks—weak to moderate silica, disseminated pyrite and arsenopyrite (e.g., The Knob, Bullet and the Bowater)
Vein Style	shear hosted and extensional vein styles width 1 cm to 2 m strike length from < 1 m to almost 1 km exhibit pinch and swell textures, banding, angular wall-rock fragments, open-space filling textures (comb textures and vugs), milky white quartz with abundant CO_2-rich fluid inclusions
Gangue Minerals	carbonate, sericite, chlorite, pyrite, arsenopyrite, stibnite, boulangerite, scheelite, tungstite, barite, hematite, tetrahedrite, sphalerite, chalcopyrite, galena and tourmaline
Size	variable Powderhouse Cove 2 cm wide, up to 15 cm long Big Pond 20 cm wide, exposed strike length 8 m Charles Cove up to 2 m wide, strike length in excess of 1.2 km The Knob up to 50 cm wide, strike length in excess of 75 m
Gold	-elemental, rarely as electrum or telluride -typically as inclusions in pyrite and arsenopyrite -locally as free gold in quartz veins

The mesothermal auriferous quartz vein class can be subdivided into five subclasses based on gangue mineral content (Figure 2): 1) pyrite-rich; 2) pyrite–arsenopyrite-rich; 3) base-metal sulphide-rich; 4) barite-rich; and 5) antimony-rich (Evans, 1993). Base-metal sulphide-rich veins may contain significant concentrations of silver.

Epithermal-Style Gold Mineralization

In contrast to mesothermal deposits, epithermal gold deposits form in shallow crustal settings, not necessarily in regional structures, commonly associated with meteoric-dominated fluids in fracture systems (Field and Fifarek, 1985). Epithermal-style alteration and mineralization have been reported from a number of areas in the eastern Dunnage Zone (i.e., Bobbys Pond, Aztec and The Outflow; Evans, 1991, 1992). These epithermal systems exhibit intense hydrothermal brecciation, pervasive silicification, quartz veining and strong argillic alteration. Gold values associated with these occurrences are typically low, from 1 to 3 g/t. The characteristics of the epithermal style of mineralization are outlined in Table 3.

Setting of Gold Mineralization in the Eastern Dunnage

Most of the gold occurrences within the eastern Dunnage Zone cluster within four areas 1) Victoria Lake–Millertown, 2) Bay d'Espoir, 3) Great Bend–Pauls Pond, and 4)

Table 2. *Continued*

Class 2: Altered wall rock (± quartz veins)	
Host Rock	sheared gabbro, mafic and intermediate volcanic rocks
Wall-rock Alteration	gabbro—intense Fe-carbonate, disseminated pyrite and arsenopyrite, silica, chlorite and leucoxene (e.g., Duder Lake and Clutha) mafic volcanic rocks—Fe-carbonate, disseminated pyrite, ± arsenopyrite, chlorite and silica (e.g., Midas Pond) intermediate volcanic rocks—silica, sericite, disseminated pyrite, arsenopyrite and minor Fe-carbonate (e.g., Little River and Kim Lake)
Gangue Minerals	pyrite, arsenopyrite, quartz and carbonate
Size	Clutha gabbro dykes 2 to 20 m thick with strike lengths up to 400 m, mineralized sections up to 2 m wide with strike lengths of 2-20 m Midas Pond 10 to 15 m wide, strike length of approximately 700 m Little River 1 to 4.5 m thick, strike length of approximately 450 m
Gold	inclusions within pyrite and arsenopyrite

Class 3: Disseminated Gold	
Host Rock	serpentinite, felsic volcanic rocks and sandstone
Wall-rock Alteration	serpentinite—talc-carbonate (e.g., Burseys Hill) felsic volcanic rocks—silica and hematite (e.g., West Tulks) sandstone—silica and disseminated pyrite and arsenopyrite (e.g., Chiouk Brook)
Size	unknown
Gold	inclusions within pyrite and arsenopyrite (?)

Glenwood—Eastern Notre Dame Bay (Figure 1). The presence of gold occurrences appears to be independent of the type or age of the host rock. Like the mesothermal examples, the epithermal-style occurrences are associated with regionally extensive structures. The structures include complex networks of northeast-, north-northeast- and northwest-trending linears that are visible on topographic and orthophoto maps.

Most of mesothermal gold occurrences in the eastern Dunnage Zone appear to have formed at shallower depths than typical mesothermal systems because: 1) they are associated with dominantly brittle features in a brittle—ductile setting; 2) some quartz veins exhibit comb-and-vuggy textures indicative of open-space filling; 3) alteration associated with some occurrences is similar to that typically associated with epithermal alteration (i.e., intense argillic); and 4) epithermal and mesothermal types of mineralization occur proximal to each other (e.g., the epithermal Aztec prospect and the mesothermal A-Zone Extension showing). The mesothermal occurrences may have formed in an environment transitional between epithermal and mesothermal styles of mineralization commonly described in the literature. A shallower depth of formation compared to Archean mesothermal ductile—brittle quartz vein deposits was also suggested by Dubé (1990) for quartz vein systems in western Newfoundland.

Table 3. Characteristics of epithermal-style gold mineralization and alteration in the eastern Dunnage zone

Epithermal-Style Mineralization and Alteration	
Host Rock	felsic volcanic rocks, sandstone and shale
Alteration	felsic volcanic rocks—silica, alunite, pyrophyllite, sericite, orpiment, realgar, native sulphur and pyrite (e.g., Bobbys Pond) sedimentary rocks—silica, pyrophyllite, kaolinite and pyrite (e.g., Aztec and The Outflow)
Style of Alteration	felsic volcanic rocks—pervasive silicification (pyrite forms semi-massive patches associated with pyrophyllite) sedimentary rocks—multiple-stage hydrothermal brecciation accompanied by silica flooding (textures include cockade textures, chalcedonic banding)
Size	Bobbys Pond mapped portion up to 750 m wide and 4 km long, extent unknown Aztec strike length approximately 600 m, drill tested to a vertical depth of approximately 75 m The Outflow strike length approximately 3 km
Gold	associated with pyrite, typically low grade 1-3 g/t

Significant gold mineralization has not been identified from within metasedimentary rocks of the Gander Zone (i.e., Meelpaeg and Mount Cormack subzones), which are exposed within the study area. This may have some bearing on the source or sources of the hydrothermal fluids responsible for the gold mineralization.

Stable-Isotope Studies

Stable-isotope analyses were initiated in 1993 in order to characterize the oxygen, carbon and sulphur isotopic compositions of hydrothermal minerals and host rocks associated with the major gold occurrences in the eastern Dunnage Zone. To date, 18 gold occurrences have been studied for which 72 isotopic analyses have been completed (Table 4). Additional analyses of these occurrences are in progress.

Oxygen isotope results of co-existing mineral pairs can yield estimates of the temperature of mineralization, and can discriminate between fluids derived from deep-crustal sources (i.e., metamorphic or magmatic fluids implicated in mesothermal deposits) and near-surface meteoric sources (i.e., epithermal deposits). Carbon and sulphur isotope data can discriminate between organic (sedimentary) and crustal sources that may have contributed solutes, including gold, to the occurrences (Figure 3). Furthermore, because the hydrothermal systems that form mesothermal gold deposits commonly occur over large geographic areas (i.e., gold districts) and are typically isotopically homogeneous, an important aspect of this study is to assess the isotopic variability of the fluids in the eastern Dunnage Zone and compare them to other known large gold camps. A large degree of isotopic variability could be interpreted as inhomogeneity of the source area(s), and suggest that the hydrothermal system was a localized event.

Results to date show the substantial variability in the oxygen, carbon and sulphur isotopic compositions of quartz, carbonate and sulphide minerals. The $\delta^{18}O$ values for quartz from gold-bearing veins have a wide range from 10.8 to 17.9. The $\delta^{18}O$ values for carbonate varies from 6.6 to 22.5, although the most extreme values are for early and late generations of carbonate in the host rock and are not associated with the gold. Few vein samples with co-existing hydrothermal minerals have been analyzed to date. Future work will focus on mineral pairs in order to determine oxygen isotope equilibration temperatures for the mineralizing event.

The $\delta^{13}C$ values for carbonate vary widely among the different gold occurrences, from -4.5 to -15.3, but are generally consistent within individual showings. The wide range of $\delta^{13}C$ values suggests that there are more than one isotopically distinct source of carbon for the different gold showings. In particular, a substantial organic source (i.e., sediment) is indicated by the low values, even in showings hosted by gabbro (i.e., Clutha). The oxygen and carbon isotopic variability seems mainly independent of host rock, suggesting that the fluids depositing the gold were not affected by local conditions, but reflect a deeper, heterogeneous source reservoir. For example, the Clutha and Big Pond showings are hosted by gabbro, yet they have hydrothermal minerals

Table 4. Preliminary stable isotopic data from gold occurrences in the eastern Dunnage Zone

Sample	rock/mineral	$\delta^{18}O$	$\delta^{13}C$	$\delta^{34}S$
Glenwood-Eastern Notre Dame Bay				
Clutha (gabbro-hosted)				
1	gabbro	17.6		
2	gabbro	17.3		
3	pyrite			0.9
3	pyrite			1.7
4	dolomite	16.6	-13.7	
5	pyrite			1.0
5	dolomite	16.1	-14.0	
7	calcite	15.1	-12.9	
8	gabbro	16.7		
8	calcite	14.9	-13.3	
Big Pond (gabbro-hosted)				
1	gabbro	16.6		
1	pyrite			1.2
1	dolomite	14.3	-6.9	
2	dolomite	15.0	-5.9	
3	gabbro	14.1		
3	pyrite			-1.9
Pond Island (granodiorite-hosted)				
1	galena			-2.7
1	pyrite			-0.1
Change Islands (felsic dyke-hosted)				
1	felsic dyke	12.2		
1	pyrite			-0.7
1	chalcopyrite			1.8
1	galena			-0.2
Charles Cove (granite-hosted)				
1	quartz	11.7		
1	arsenopyrite			2.8
Mt. Peyton (gabbro-hosted)				
1	arsenopyrite			1.0
2	arsenopyrite			0.2
The Knob (greywacke-hosted)				
1	quartz	17.9		
2	greywacke	11.5		
2	calcite	8.9	-13.6	
2	pyrite			0.5
3	calcite	13.5	-10.1	
3	pyrite			0.2
Bullet (shale-hosted)				
1	quartz	16.9		
1	calcite	6.6	-14.6	
1	pyrite			0.1
2	dolomite	17.5	-15.3	
2	calcite	10.1	-13.4	
2	shale	16.6		

Sample	rock/mineral	$\delta^{18}O$	$\delta^{13}C$	$\delta^{34}S$
Glenwood-Eastern Notre Dame Bay (continued)				
Bullet (shale-hosted) (Continued)				
2	pyrite			0.34
Great Bend-Pauls Pond				
Lizard Pond (serpentinite-hosted)				
1	serpentinite	11.2		
1	dolomite	16.9	-9.5	
2	quartz	15.2		
2	serpentinite	15.2		
2	magnesite	22.5	-7.5	
3	pyrite			4.3
3	quartz	11.9		
Goose (greywacke-hosted)				
1	calcite	16.4	-8.5	
Aztec (sandstone-hosted)				
1	pyrite			-5.4
Bay d'Espoir				
Little River (intermediate volcanic rock-hosted)				
1	tuff	14.2		
1	tetrahedrite			-3.1
2	tuff	17.0		
2	calcite	19.3	-14.1	
2	arsenopyrite			-0.7
Victoria Lake-Millertown				
North Pond (felsic volcanic rock-hosted)				
1	quartz	10.9		
1	pyrite			-2.7
Bobbys Pond (felsic volcanic rock-hosted)				
1	tuff	11.6		
1	native sulphur			-0.9
Midas Pond (mafic volcanic-hosted)				
1	pyrite			4.0
1	dolomite	11.4	-4.5	
Road Showing (felsic volcanic rock-hosted)				
1	quartz	12.1		
1	sphalerite			2.9
1	pyrite			4.8
1	galena			2.0
Valentine Lake (quartz monzonite-hosted)				
1	quartz	10.8		
2	quartz	11.3		
3	quartz	11.0		
3	tourmaline	8.4		
3	pyrite			10.7
South Quinn (metasediment-hosted)				
1	metasediment	10.4		
2	quartz	15.8		
2	arsenopyrite			3.5
2	dolomite	13.8	-7.0	

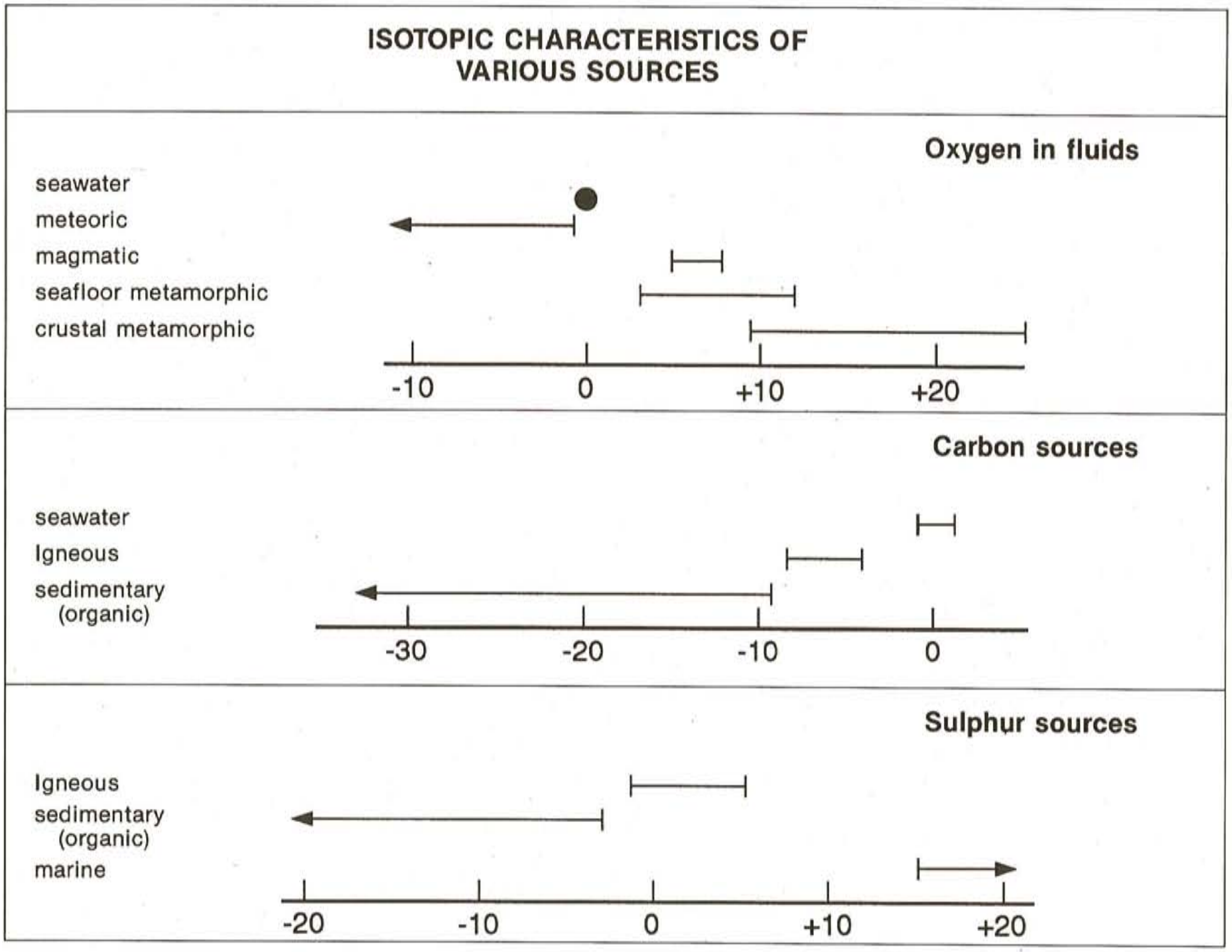

Figure 3. *Stable isotopic compositions of oxygen, carbon and sulphur from different sources (Kyser, 1986; Kerrich, 1989b).*

with $\delta^{18}O$ values as high as the sediment-hosted Knob or Goose showings (Table 4). Within individual showings there can be substantial isotopic variation (i.e., the Knob and Bullet), or very little variation (i.e., Clutha and Valentine Lake).

Twenty-eight analyses of sulphide minerals from the eastern Dunnage Zone show comparatively little variation relative to the oxygen or carbon isotopic values. The $\delta^{34}S$ values range from -3.1 to 4.8, with one anomalous value of 10.7 from Valentine Lake and of -5.4 from the Aztec showing (epithermal). As was the case for oxygen and carbon, there is no apparent distinction between gabbro-, volcanic-, or sediment-hosted gold occurrences based on the sulphur isotopic results.

The amount of oxygen and carbon isotopic variability in gold occurrences in the eastern Dunnage Zone is much greater than is typically observed in other major gold camps in Archean, Proterozoic and Mesozoic terranes (Figure 4). In particular, the source of carbon for prospects in the Eastern Dunnage, including those hosted by gabbro, is dominated by a sedimentary (organic) reservoir, a major contrast with the other gold camps.

Future Stable Isotope Work

The gold occurrences in this study were selected because they were considered to have formed in either mesothermal or epithermal systems, or were of questionable geological origin. To date, limited data for occurrences considered to be epithermal have been completed. Future isotopic work will contrast the mesothermal and epithermal occurrences, and regionally important source rocks, so that the importance of these different sources in forming the different types of gold occurrences can be constrained.

The stable isotopic work in the eastern Dunnage zone will be integrated with a similar ongoing study of gold occurrences in the western Dunnage zone (Baie Verte area) by M. Wilson, P. Cawood and G. Dunning of the Department of Earth Sciences at Memorial University. The Baie Verte project is part of a Natural Science and Engineering Research Council (NSERC) Strategic Grant to assess the role that

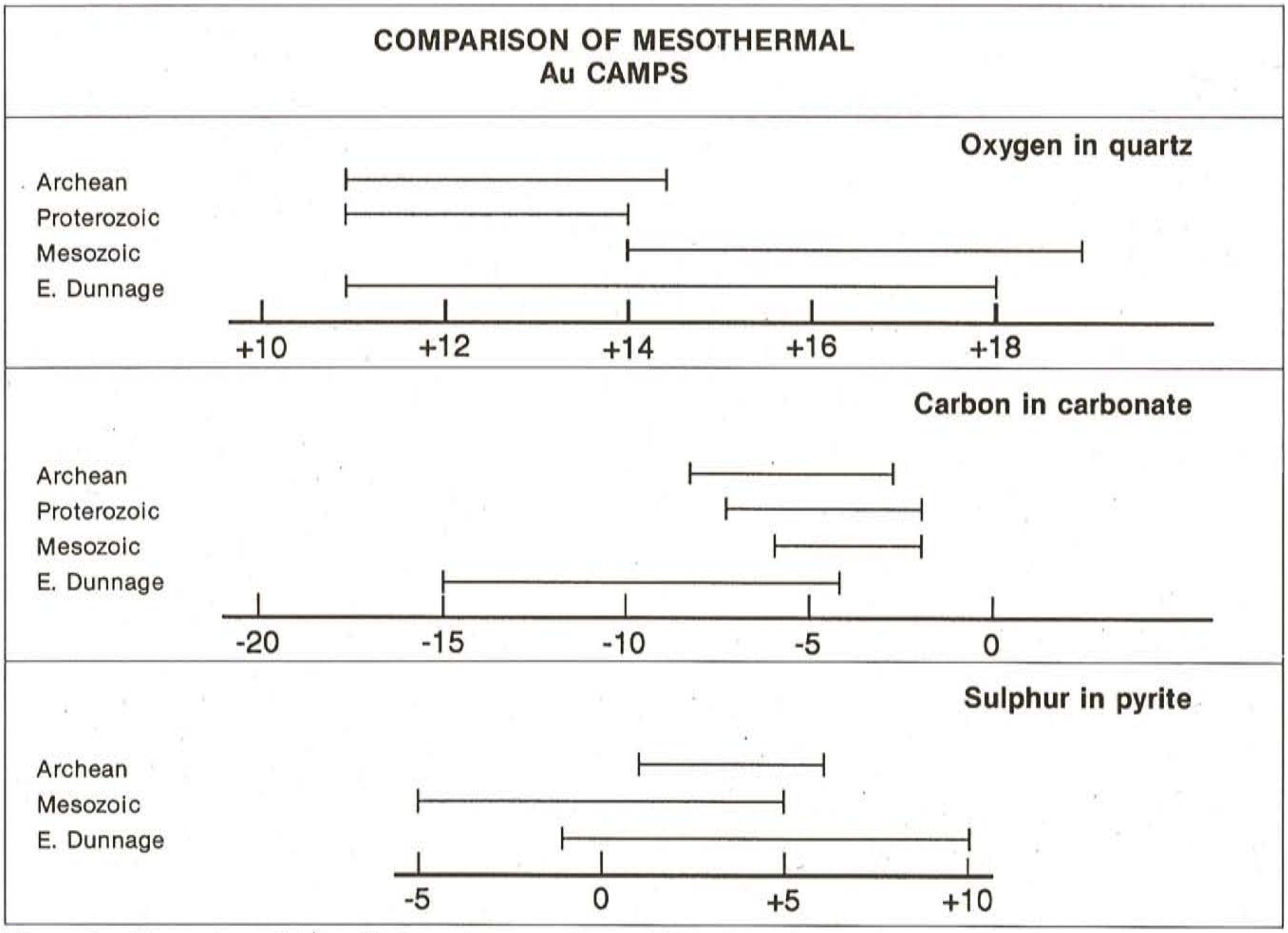

Figure 4. *Comparison of the stable-isotopic compositions of hydrothermal minerals from the Eastern Dunnage zone with those from other major gold camps (data from Table 4 and Kerrich, 1989b).*

accretion of the Appalachian orogen played in the formation of gold mineralization. Although there are numerous ophiolitic complexes throughout Newfoundland, only a few appear to be associated with epigenetic gold mineralization. Geochronological studies in progress by G. Dunning and P. Cawood and graduate students suggest that a principal difference between barren and mineralized ophiolites may be the timing of metamorphism and plutonism of the continental margin onto which they were accreted. Our working hypothesis, to be tested in the NSERC study, is that accretion boundaries that preserve Ordovician metamorphism and plutonism are not substantially gold-bearing (i.e., Coy Pond Complex); instead, gold occurs in association with continental-oceanic suture zones that have been affected by later Silurian metamorphic and igneous events. If a clear geochemical and temporal link can be established between gold and specific orogenic events that affected rocks of the continental margin and the accreted oceanic terranes, then the orogenic framework of exploration prospects can become a predictive tool in regional exploration programs throughout Newfoundland. The work in the western Dunnage Zone will be linked to the study of gold occurrences in the eastern Dunnage Zone so that a broader framework can be presented.

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