A GEOLOGICAL OVERVIEW OF THE HEDLEY GOLD SKARN DISTRICT SOUTHERN BRITISH COLUMBIA (92H)

By G.E. Ray, I.C.L. Webster, B.C. Geological Survey Branch
G.L. Dawson, The University of British Columbia
A.D. Ettlinger, Santa Fe Pacific Mining Inc.

KEYWORDS: Economic geology, gold skarn, Hedley, Upper Triassic, Nicola, stratigraphy, back-arc basin, slump breccias, Mount Riordan, garnet skarn, industrial minerals.

INTRODUCTION

This paper presents an updated overview of the geology and mineral deposits in the Hedley mining district, south-central British Columbia. The district contains the Nickel Plate gold skarn deposit, which is currently being operated by Homestake Canada Ltd. (formerly Corona Corporation), as well as several past-producing gold skarns: the French, Canty and Good Hope mines (Figure 2-5-1). It also includes the Mount Riordan (Crystal Peak) skarn which is being evaluated as a potential industrial garnet deposit by Polestar Exploration Inc.

Early mapping of the district geology was completed by Bostock (1930) and Rice (1947, 1960), and more recently by Ray and Dawson (1987, 1988, 1993, in preparation), and Monger (1989). Studies on the various gold skarns include early work by Camsell (1910), Bostock (1930), Warren and Cummings (1936), Billingsley and Hume (1941), Dolmage and Brown (1945), and Lee (1951); recent investigations have been completed by Ray *et al.*, (1987, 1988), Webster (1988), Ettlinger and Ray (1989), Ettlinger (1990), Dawson *et al.*, (1990a, 1990b), Ettlinger *et al.*, (1992), and Ray and Dawson (1993 in preparation). In addition, details on the Mount Riordan industrial garnet deposit have been published by Mathieu *et al.*, (1991), Grond *et al.*, (1991) and Ray *et al.*, (1992).

REGIONAL GEOLOGY

The Hedley mining district lies within the allochtonous Quesnel Terrane of the Intermontane Belt. It is situated at the eastern edge of the Upper Triassic Nicola Group, close to its contact with Paleozoic and Triassic oceanic rocks of the Apex Mountain Complex (Figure 2-5-1), which is believed to be a deformed ophiolite (Milford, 1984). Elsewhere in south-central British Columbia, the Nicola Group unconformably overlies this package (Read and Okulitch, 1977), but at Hedley the contact is either faulted or occupied by the mid-Jurassic Cahill Creek pluton.

The Nicola Group consists largely of island-arc supracrustal rocks that were deposited in an elongate and rifted marginal marine basin associated with an easterly dipping subduction zone (Preto, 1979; Mortimer, 1986, 1987). West of the Hedley district, along the main axis of the arc, the group reaches 6000 metres in thickness and is dominated by mafic, subaerial to submarine volcanic flows and tuffaceous rocks in which limestones are uncommon (Preto, 1979). Farther east at Hedley, however, the group is thinner (maximum 3000 m), lacks volcanic flows, and is dominated instead by sedimentary rocks that include bedded tuffs, calcareous and turbiditic siltstones and thick, extensive limestones.

Immediately following the termination of the Late Triassic Nicola arc volcanism, a variety of intrusions ranging from dikes and sills to major batholiths were emplaced into the Nicola Group. These intermediate to high-level intrusions, which vary from gabbro to granodiorite and alkaline to calcalkaline in composition, range from 194 to 210 Ma in age, (Preto *et al.*, 1979; Monger, 1989; Parrish and Monger, 1992). Some of the alkalic intrusions (*e.g.*, Copper Mountain stock) are related to porphyry copper-gold deposits, while some of the calcalkaline plutons (*e.g.*, Brenda stock) are associated with gold-poor porphyry copper-molybdenum orebodies (Carr, 1968; Preto, 1972; Soregaroli and Whitford, 1976). In the Hedley district, the Bromley batholith, the Hedley intrusions and the Mount Riordan stock (Figure 2-5-1) were all emplaced during this Late Triassic to Early Jurassic plutonic episode.

DISTRICT STRATIGRAPHY

The Nicola Group at Hedley is a westerly thickening, late Carnian to late Norian calcareous sedimentary and arc-related volcaniclastic sequence that was deposited on a tectonically active, west-dipping paleoslope (Figures 2-5-2 and 2-5-3). Sedimentary facies changes and paleocurrent indicators suggest that the sediments in the group were derived largely from an eastern source, although the alkaline and calcalkaline pyroclastic rocks higher in the succession may have originated from the Nicola arc to the west. The Nicola Group in the Hedley area is believed to have been laid down across the structural hinge zone that marked the rifted margin of the westerly deepening, shallow-marine Nicola basin.

At Hedley, the Nicola Group sedimentary succession contains a number of newly recognized formations for which formal nomenclature is now proposed (Ray and Dawson, 1993, in preparation). The succession (Figure 2-5-2) includes an upper, widely developed and thick (at least 1200 m) unit, the Whistle Formation; the formation consists largely of alkalic and subalkalic tuffs and tuffaceous sediments, and its base is occupied by an extensive limestone-boulder deposit, the Copperfield breccia, which reaches 200 metres in thickness. The angular to well-rounded limestone clasts are commonly 1 metre in diameter although, rarely, they reach up to 15 metres across; they contain shallow-water bivalves, as well as conodonts that are slightly older (late Carnian to early Norian) than the early to middle Norian faunas in the underlying Chuchuwayha and Hedley formations (M.J. Orchard, personal communication, 1989) (Figure 2-5-3). One of the rare chert clast from the breccia yielded radiolarians of Permian age (F. Cordey, personal communication, 1985).

Limestone makes up 95 per cent of the clasts but rare clasts of chert, argillite, siltstone, and volcanic and plutonic rock are present. Many of the elongate argillite and siltstone clasts are deformed which suggests they were unlithified when they were incorporated into the breccia. Some appear to have been scoured from the immediately underlying sedimentary units, and many of these units show chaotically disturbed bedding, presumably caused when the breccia ploughed into the unconsolidated silty and argillaceous sediments.

The Copperfield breccia probably represents a chaotic gravity-slide deposit formed by the catastrophic slumping of an unstable accumulation of shallow-marine reef debris down the submarine paleoslope. This mass ploughed into, and was deposited on the unconsolidated deeper water sediments of the Hedley, Chuchuwayha and Stemwinder formations (Figure 2-5-4). The breccia is probably analogous to the modern megabreccias described along the Nicaraguan

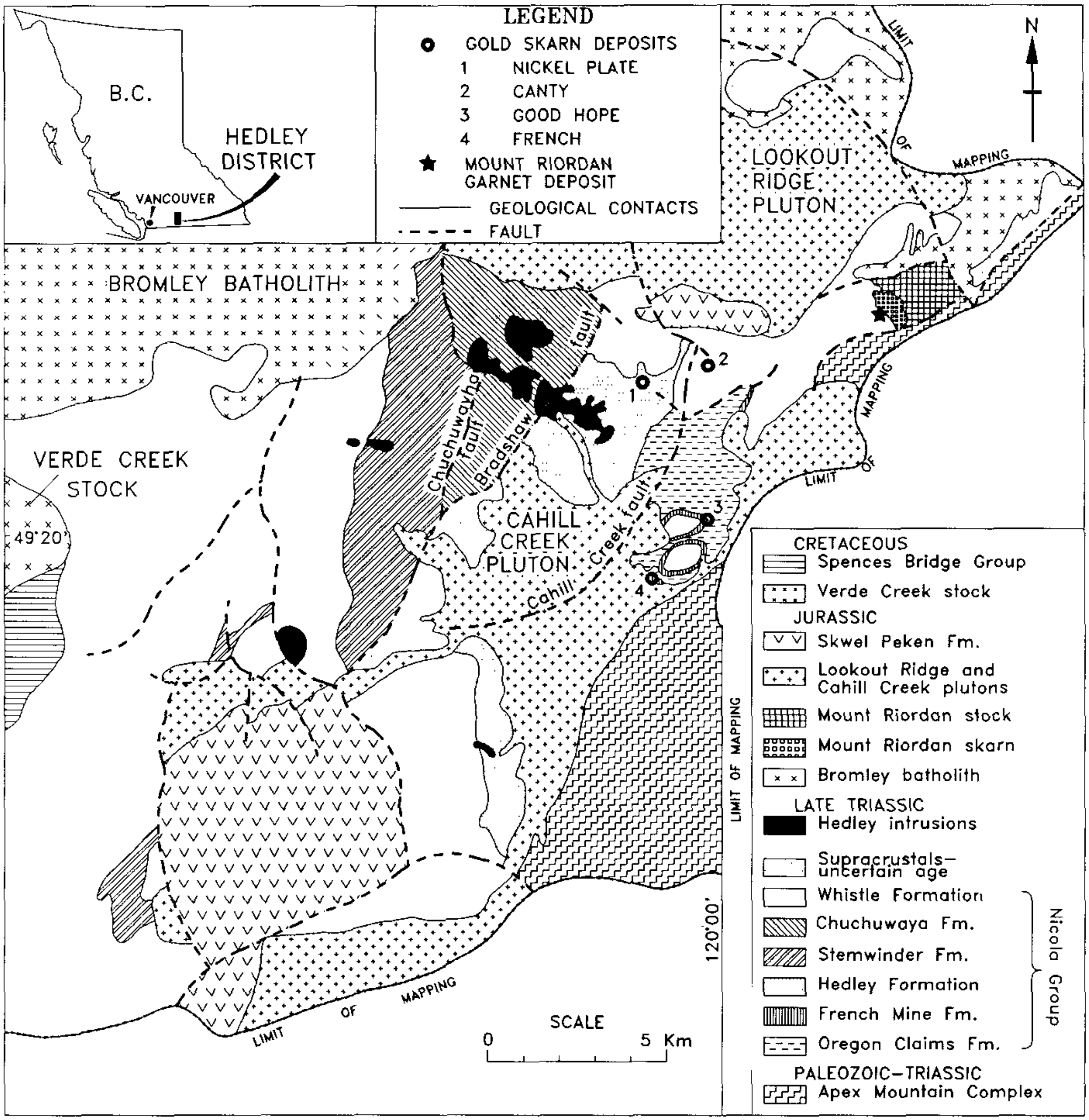


Figure 2-5-1. Geology of the Hedley district and location of the skarn deposits.

Rise in the Western Caribbean (Hine *et al.*, 1992). These megabreccias form thick (up to 120 m) and extensive (27 km by 16 km) units and are believed to represent seismically triggered bank-margin collapse features that took place along the edges of low-relief carbonate platforms (Hine *et al.*, 1992).

The Whistle Formation is underlain by a succession in which four sedimentary facies are distinguished from east to west: the thin (up to 200 m), shallow-marine, limestone-dominant French Mine Formation in the east, the thicker, siltstone-dominant Hedley and Chuchuwayha formations in the central part of the area, and the thick (up to 2200 m), deeper water and argillite-dominant Stemwinder Formation in the west. Conodonts from the French Mine, Hedley and Chuchuwayha formations indicate they are Late Triassic (Carnian-Norian) in age (M.J. Orchard, personal communication, 1989; Figure 2-5-3). The sedimentary facies were separated from one another, and partly controlled by northerly trending active growth faults (Figures 2-5-2 and 2-5-4); these fractures, which were probably related to the basin-margin rift structures, were precursors of the Chuchuwayha, Bradshaw and Cahill Creek faults.

The Chuchuwayha, Hedley and French Mine formations are underlain by a poorly understood sequence of mafic tuffs with minor flows, limestone and chert-pebble conglomerate, the Oregon Claims Formation (Figure 2-5-2; Ray and Dawson, 1993, in preparation). The age of this unit and its contact relationship with the overlying Nicola rocks are uncertain. It may represent the oldest exposed section of the Nicola Group, but it is more likely to be an older basement on which the Nicola Group was unconformably deposited, and could be a western extension of the Apex Mountain Complex.

A newly recognized mid-Jurassic unit, the Skwel Peken Formation, overlies the Nicola Group at Hedley (Figure 2-5-1). It has two members. The lower member, 1500 metres thick, is dominated by calcalkaline andesitic to dacitic lapilli and ash tuffs that commonly contain glassy, strongly embayed and fractured quartz crystals. Minor amounts of epiclastic sediments, welded tuffs and pyroclastic surge deposits are also present. The thinner (maximum 400 m) upper member is dominated by massive andesitic crystal tuffs.

We believe that the Skwel Peken Formation is the first mid-Jurassic supracrustal unit recognized in south-central British Columbia. The formation was laid down in a non-marine, subaerial to shallow-water environment and is believed (Ray and Dawson, 1993, in preparation) to represent extrusive volcanism related to the mid-Jurassic Cahill Creek and Lookout Ridge plutons (Figure 2-5-1). Zircons extracted from quartz-rich tuffs in the lower member give a maximum U-Pb age of 187±9 Ma (J.E. Gabites, personal communication, 1992). Minor amounts of Cretaceous Spences Bridge Group and Eocene Springbrook and Marron formations are also exposed in the area (Figure 2-5-1).

Several episodes of plutonism are recognized. The oldest resulted in the quartz dioritic and gabbroic Hedley intrusions that are associated with widespread gold skarn mineralization, including the Nickel Plate, Canty, French and Good Hope deposits. Field evidence and equivocal radiometric U-Pb dating suggest they were intruded during Late Triassic to Early Jurassic times, between 219 to 194 Ma (J.E. Gabites, personal communication, 1992). The intrusions occur as large and small stocks, as sill dike swarms and as isolated minor bodies; the swarms are preferentially developed in the thinly bedded Chuchuwayha and Hedley

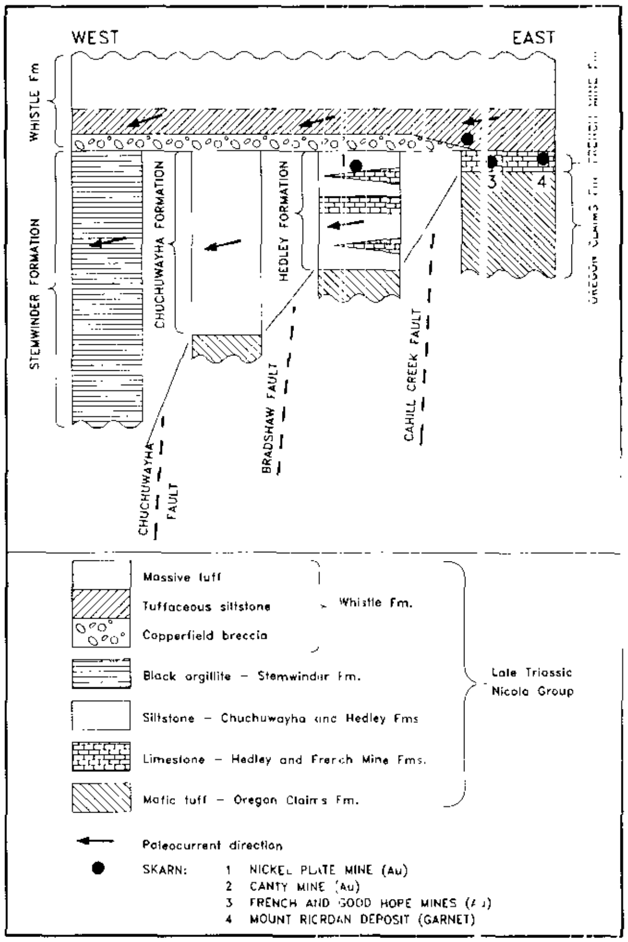


Figure 2-5-2. Schematic east-west section across the Hedley district showing sedimentary facies changes in the Nicola Group and stratigraphic location of the skarn deposits.

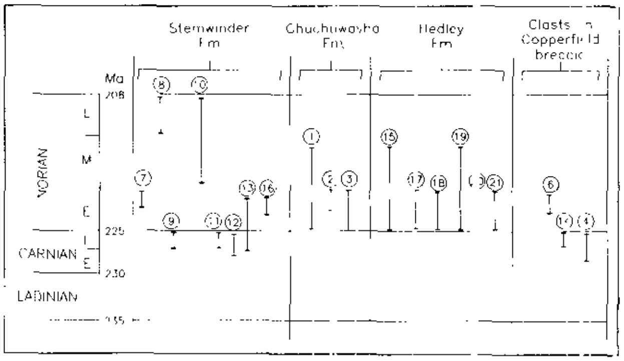


Figure 2-5-3. Age range of conodont microfossils collected from the Nicola Group, Hedley district Numbers in circles refer to fossil sample numbers listed in Ray and Dawson (1993, in preparation). (Fossils identified by M.J.Orchard, Geological Survey of Canada).

formations. Some elongate bodies, such as the Toronto stock, were intruded along easterly trending lineaments that may have been late Triassic transform faults related to the rifted basin margin.

A slightly younger plutonic episode resulted in the large, granodioritic Bromley batholith and a related marginal body, the granodioritic to gabbroic Mount Riordan stock. The latter is genetically associated with the large, garnet-rich Mount Riordan (Crystal Peak) skarn that contains minor tungsten-copper occurrences. A radiometric U-Pb zircon age of 194.6±5 Ma (Early Jurassic) is indicated for the Mount Riordan stock (J.E. Gabites, personal communication, 1992), and a similar age of 193±1 is obtained from the Bromley batholith (Parrish and Monger, 1992).

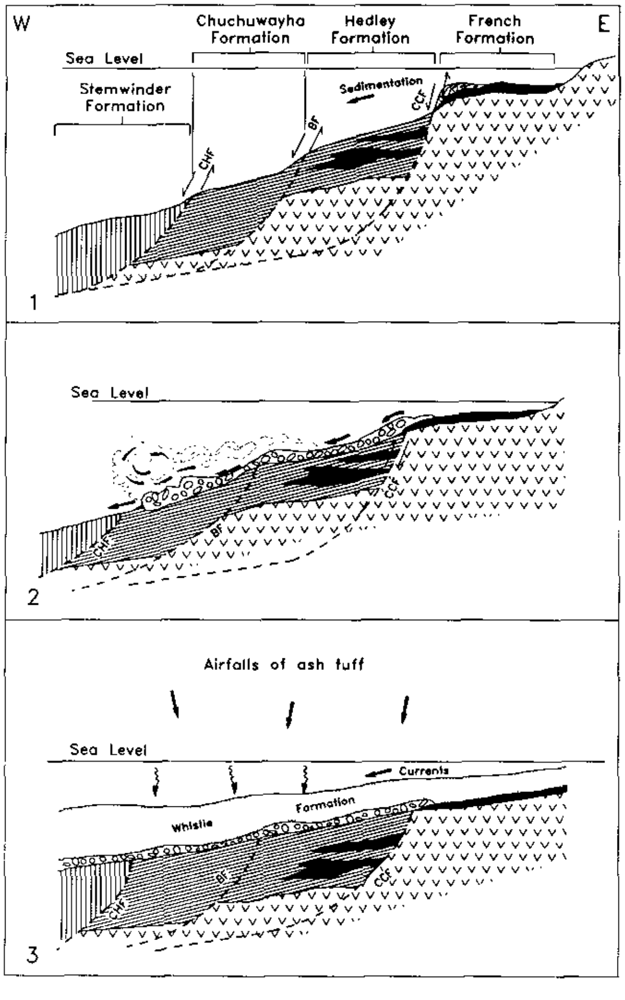
A subsequent phase of granodioritic to quartz monzonitic magmatism is represented by the Lookout Ridge and Cahill Creek plutons. The latter, which commonly separates the Nicola Group to the west from the Apex Mountain Complex farther east, yields a U-Pb zircon mid-Jurassic date of 168.8±9 Ma (J.E. Gabites, personal communication, 1992). These high-level plutons are spatially related to a suite of minor aplites and quartz porphyry intrusions that yield a Late Jurassic U-Pb zircon date of 154.5 +8 −43 Ma. The plutons are believed to be the magmatic source of the volcaniclastic package in the nearby Skwel Peken Formation (Ray and Dawson, 1993, in preparation).

The youngest major intrusion in the district is the granitoid Verde Creek stock (Dolmage, 1934) which is coeval with the Early Cretaceous Spences Bridge Group (Preto, 1972); it intrudes the Nicola Group in the western part of the district (Figure 2-5-1).

A rare, distinctive suite of leucocratic, calcalkaline minor intrusions (or possible volcanic flows) is spatially associated with the Skwel Peken Formation. These rocks contain magmatic garnet phenocrysts with almandine-rich cores and spessartine-rich margins that are chemically and optically distinct from the grossular-andradite garnets in the gold skarns.

STRUCTURAL GEOLOGY

Two deformational episodes are identified in both the Apex Mountain Complex and Nicola Group, although the temporal relationship of the episodes between one rock package and the other is unknown. The first and most intense episode identified in the Apex Mountain Complex resulted in tight to isoclinal minor folds with moderate to strong, northerly to northeast-striking and subvertically



LEGEND

☐ Tuff } Whistle Fm.

Copperfield breccia } Whistle Fm.

■ Limestone – French and Hedley Fms.

▨ Siltstone – Hedley and Chuchuwayha Fms.

▥ Argillite – Stemwinder Fm.

Tuff, volcanics, sediments – Oregon Claims Fm.

CCF = Cahill fault
BF = Bradshaw fault
CHF = Chuchuwayha fault

Figure 2-5-4. Depositional history of the Nicola Group in the Hedley area:

1. Carnian-Norian – deposition of the French, Hedley, Chuchuwayha and Stemwinder formations onto the Oregon Claims Formation adjacent to the rifted eastern margin of the Nicola basin. Sedimentation was from an eastern source and the facies were controlled by active, normal growth faults that were precursor structures for the Chuchuwayha, Bradshaw and Cahill Creek faults.
2. Late Triassic – catastrophic deposition of the Copperfield breccia into the basin as a chaotic mass-gravity slide from shallow-marine facies to the east. This was possibly triggered by earth movements associated with development of the main Nicola arc farther west.
3. Late Triassic – major airfalls of Whistle Formation ash and lapilli tuffs from an unknown source. Sedimentary currents were still from the east but conditions did not allow limestone deposition.

inclined penetrative axial planar fabrics; no major folds of this age are recognized. The second period of deformation is only locally developed in the Apex Mountain rocks. It resulted in northerly striking, subvertical open folds, but is not associated with any penetrative fabrics.

Both of the deformational episodes identified in the Nicola Group predate the Skwel Peken Formation and the Cahill Creek pluton which suggests they are pre-Middle Jurassic in age. The first episode, which was only locally developed in the Nicola Group, produced west to northwest-striking minor flexures that were probably related to the forcible emplacement of the Hedley intrusions. At Nickel Plate, these structures partly controlled the gold skarn mineralization (Billingsley and Hume, 1941).

The second deformation in the Nicola Group was the dominant structural event in the district. It resulted in easterly overturned minor and major asymmetric folds with northerly striking, steep westerly dipping axial planes. It produced a large anticlinal structure with its axis just east of the Nickel Plate deposit. Locally, argillites in the Stem-

TABLE 2-5-1
COMPARISON BETWEEN THE NICKEL PLATE AND MOUNT RIORDAN SKARNS

	Nickel Plate	**Mt. Riordan**
Host formation and age	Upper Triassic Hedley Fm.	?Upper Triassic French Mine Fm?
Hostrock lithology	Predominantly siltstone, minor limestone	?Massive limestone and carbonate breccia?
Associated intrusive rocks	Hedley intrusions (gabbro, diorite)	Mount Riordan stock (granodiorite-gabbro)
Age of intrusions	Post 219 and pre 194 Ma (Late Triassic - Early Jurassic)	194.6±5 Ma (Early Jurassic)
Initial $^{87}Sr/^{86}Sr$ of intrusions	0.7038*	0.7044*
Skarn mineralogy	Banded, clinopyroxene-dominant skarn with sulphides and scapolite. Garnets generally anhedral and brown coloured. No scheelite present.	Massive, garnet-dominant skarn. Coarse, euhedral garnets with highly variable colour. Generally low sulphide content. Minor pyroxene, actinolite, epidote. Scheelite present.
Opaque minerals	Pyrrhotite, arsenopyrite, minor chalcopyrite and rare pyrite	Magnetite, pyrrhotite, pyrite minor chalcopyrite.
Degree of skarn alteration	Original sedimentary bedding commonly preserved in skarn.	Virtually no primary structures preserved.
Approximate exposed area of skarn	4 km^2	0.3 km^2
Maximum thickness of skarn	300 m	At least 175 m
Geochemistry of mineralization	Anomalous Au,As,Cu,Co,Bi,Te,Ag,Sb	Anomalous Cu,W,Ag,Mo
Garnet composition	Low Mn (< 0.5% MnO) Grossularitic cores, andraditic margins Ad 15-80	Low Mn (< 1.0 % MnO Andraditic cores, grossularitic margins Ad 45-98
Pyroxene composition	Low Mn (< 1.0% MnO) Hd 40-95	Low Mn (<1.3 % MnO) Hd 41-51

* R.L Armstrong, personal communication 1989.

winder and Chuchuwayha formations contain a fracture cleavage related to this deformation, although elsewhere axial planar penetrative fabrics are absent.

In addition to the above two episodes, a younger period of folding has gently deformed the Skwel Peken Formation. This post-mid-Jurassic deformation resulted in open minor flexure folds with northeasterly striking axial planes.

ECONOMIC GEOLOGY

The Hedley district has important skarn deposits (Figures 2-5-1 and 2-5-2) as well as some minor gold-bearing quartz-carbonate veins. The skarns are separable into two types: older and more economically important gold skarns such as the Nickel Plate, Canty, French and Good Hope deposits that generally have low garnet/pyroxene ratios, and younger skarns that have high garnet/pyroxene ratios, and contain minor tungsten and copper but little or no gold. The Mount Riordan (Crystal Peak) skarn is the largest of this second type: it is a potential industrial garnet deposit with drill-indicated reserves of 40 million tonnes averaging 78 per cent by volume garnet (Mathieu *et al.*, 1991; Grond *et al.*, 1991). Differences between the gold skarns, represented by the Nickel Plate deposit, and the garnet-dominant Mount Riordan skarn are listed in Table 2-5-1.

TABLE 2-5-2
PRODUCTION FROM GOLD SKARN DEPOSITS – HEDLEY DISTRICT

Deposit	Ore milled (t)	Gold (kg)	Silver (kg)	Copper (t)	Grade (Au g/t)
Nickel Plate					
1904-1963[a] (Underground)	2 983 900	41 705	4 160	981	13.97
Nickel Plate* (Open pit)					
1987[b]	481 454	1512.4	832.4	0	3.14
1988[b]	879 645	2714.9	2955.7	0	3.08
1989[b]	1 065 026	2463.8	3246 0	0	2.31
1990[b]	1 141 255	2382.1	844.6	0	2.08
1991[b]	1 166 039	2842.7	677.7	0	2.43
Hedley Mascot (Underground) 1936-1949[a,b]	619 022	7 248	1 707	871	11.70
Total	8 336 341	60 868.9	14 423.4	1 852	7.30
French					
1950-1965[a]	29 450	786	NA	NA	26.68
1957-1961[d]	48 158	817	66	NA	16.96
1982-1983[a]	4 438	26	135	20	5.86
Total	82 046	1629	201	20	19.85
Good Hope					
1946-1948[d]	4 241	89	NA	NA	20.98
1982[a]	6 874	77	119	0.6	11.20
Total	11 115	166	119	0.6	14.93
Canty					
1939-1941[a,c]	1 483	16	NA	NA	10.78
Grand total from skarn	**8 430 985**	**62 679.9**	**14 743.4**	**1872.6**	**7.43**

NA = Data not available
*Note: includes some open pit production from the Canty deposit.

Sources
(a) MINFILE
(b) Mineral Statistics, EMPR Mineral Policy Branch
(c) Rice (1947,1960)
(d) National Mineral Inventory - NMI 92H/8

TABLE 2-5-3
PRODUCTION FROM VEINS – HEDLEY DISTRICT

Vein	Ore milled (t)	Gold (kg)	Silver (kg)	Copper (kg)	Lead (kg)
Maple Leaf; Pine Knot 1937	5 897	29.4	13.3	846	891
1982 (Banbury Mines Ltd.)	1 179	4.1	NA	NA	NA
Total	7 076	33.5	13.3	846	891

Gold skarns have produced over 62 tonnes of gold from 8.4 million tonnes of ore (Table 2-5-2); over 97 per cent of the gold was derived from the Nickel Plate deposit. By contrast, the quartz-carbonate veins, such as the Pine Knot, Maple Leaf and Gold Zone veins, have produced only 33 kilograms of gold (Table 2-5-3). The gold grade of the Nickel Plate ore, worked during the early underground operations, ranged from 12 to 14 grams per tonne gold, whereas the ore currently mined by open-pit methods ranges between 2 and 3.1 grams per tonne gold (Table 2-5-2). The overall grade of all the gold skarn deposits mined in the district is 7.43 grams per tonne gold.

The gold skarns are genetically and spatially related to diorite-gabbro stocks and dike-sill swarms of the Hedley intrusions. Economic gold skarns are hosted only in the Nicola Group, and on both a district and mine scale are structurally, stratigraphically and lithologically controlled. They favour areas where the Hedley intrusions cut the calcareous, shallower marine sedimentary facies of the Hedley and French Mine formations (particularly rocks that are flat lying or gently dipping) but are absent in the deeper water sediments of the Stemwinder Formation farther west (Figure 2-5-2).

Economic gold mineralization is almost wholly confined to the exoskarn, although locally the endoskarn is cut by late, thin veinlets of auriferous sulphides. Exoskarn alteration varies from narrow zones less than 10 metres wide to large envelopes hundreds of metres thick. The largest exoskarn envelope is at Nickel Plate where it outcrops over 4 square kilometres (Figure 2-5-5), is up to 300 metres thick, and is estimated to contain between 0.75 and 1.5 cubic kilometres of altered rock. Alteration is characterized by pyroxene-garnet-carbonate-scapolite assemblages, and mineralogical zoning is present in both the mineralized and barren skarns. This zoning generally consists of coarser grained garnet-rich proximal assemblages and finer grained pyroxene-rich distal assemblages (Figure 2-5-5). Gold-pyrrhotite-arsenopyrite mineralization is preferentially developed in the distal, pyroxene-dominant skarn, and is associated with a geochemical enrichment in arsenic, copper, bismuth, tellurium, cobalt, zinc, antimony, molybdenum, and nickel.

Significant geochemical and mineralogical variations are seen throughout the gold skarns. At Nickel Plate, chalcopyrite and Cu/Au ratios increase westwards towards the Hedley intrusion Toronto stock, and Au/Ag ratios are greater than 1 in the northern part of the deposit and less than 1 in the south.

Bismuth tellurides (hedleyite, tetradymite), arsenopyrite and high pyrrhotite/pyrite ratios characterize the gold ore;

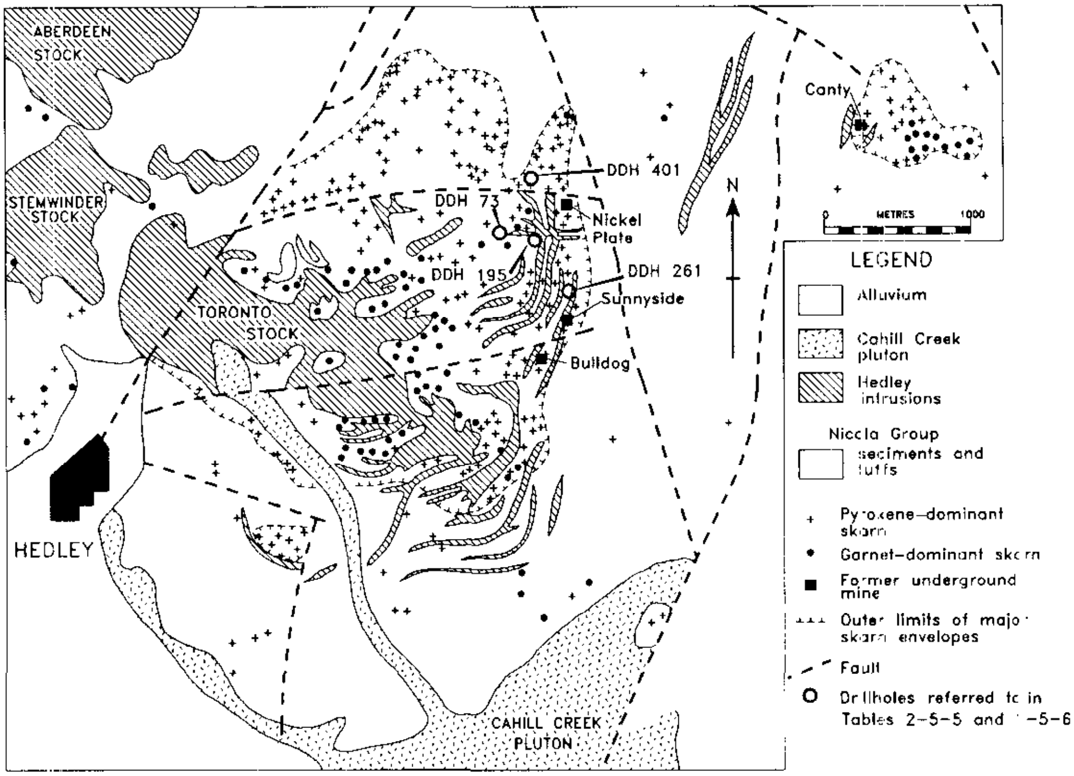


Figure 2-5-5. Outcrop distribution of the exoskarn envelopes surrounding the Nickel Plate and Canty deposits. Note: location of drillholes listed in Tables 2-5-5 and 2-5-6.

TABLE 2-5-4
CHEMICAL COMPOSITIONS OF THE HEDLEY INTRUSIONS COMPARED TO IGNEOUS ROCKS ASSOCIATED WITH BASE AND FERROUS METAL SKARNS

	SKARN DEPOSIT CLASSES													
	Au (Hedley)		Fe		Cu		Zn-Pb		W		Mo		Sn	
	mean	range	mean	range	mean	range	mean	range	mean	range	mean	range	mean	range
SiO_2	54.56	(48.27-59.48)	61.5	(47.2-74.7)	63.5	(55.2-73.7)	66.2	(57.1-76.3)	68.9	(62.6-72.8)	74.8	(73.1-76.0)	76.6	(75.4-78.0)
TiO_2	0.67	(0.51-1.04)	0.8	(0.2-3.1)	0.5	(0.0-1.0)	0.6	(0.2-1.6)	0.4	(0.1-0.7)	0.2	(0.1-0.3)	0.03	(0.01-0.04)
Al_2O_3	18.49	(15.51-20.24)	17.3	(13.1-22.3)	16.6	(14.3-20.4)	15.4	(12.1-16.3)	15.5	(14.0-16.8)	14.3	(13.0-15.1)	12.6	(10.5-13.8)
Fe_2O_3	1.39	(0.37-3.14)	2.0	(0.5-5.6)	1.9	(0.03-3.2)	2.1	(1.0-3.0)	1.3	(0.2-2.3)	-	-	0.[illegible]	(0.0-0.9)
FeO	5.86	(4.15-7.90)	3.8	(0.4-11.2)	2.8	(0.7-5.8)	2.4	(0.2-5.0)	2.0	(0.8-3.2)	0.5	(0.0-1.5)	1.[illegible]	(0.2-1.4)
Fe_2O_3T	7.85	(5.83-10.94)	6.2	-		5.0	-	4.7	-	3.5	-	-	-	1.5
MnO	0.14	(0.07-0.19)	0.1	(0.0-0.3)	0.2	(0.0-1.8)	0.1	(0.0-0.3)	0.1	(0.0-1.0)	0.03	(0.0-0.05)	0.[illegible]	(0.0-0.2)
MgO	4.00	(2.51-8.51)	2.3	(0.2-4.9)	2.2	(0.7-4.2)	1.8	(0.1-4.2)	1.1	(0.1-2.6)	0.5	(0.3-0.9)	0.[illegible]	(0.1-0.4)
CaO	8.56	(6.48-11.88)	5.7	(0.7-11.4)	4.3	(1.8-7.6)	4.0	(0.4-6.3)	3.2	(1.9-4.6)	1.2	(0.5-2.0)	0.[illegible]	0.4-0.7)
Na_2O	3.17	(2.04-4.79)	4.4	(2.9-7.7)	3.3	(1.0-5.3)	3.5	(1.6-4.3)	3.4	(2.7-4.0)	3.1	(1.9-4.2)	2.[illegible]	(0.8-3.6)
K_2O	1.40	(0.53-2.54)	1.7	(0.3-3.4)	3.4	(1.3-5.4)	3.6	(2.0-5.2)	3.5	(2.4-5.4)	5.0	(2.8-7.9)	4.[illegible]	(4.2-5.0)
P_2O_5	0.18	(0.14-0.26)	0.27	(0.0-0.4)	0.25	(0.0-0.4)	0.26	(0.0-0.6)	0.15	(0.1-0.3)	0.08	(0.0-0.1)	0.01	(0.0-0.03)
Fe_2O_3/FeO	0.24	(0.05-0.44)	0.53	(0.12-2.36)	0.68	(0.01-1.04)	0.87	(0.49-6.18)	0.65	(0.09-1.23)	-	-	0.[illegible]0	(0.01-1.35)
K_2O/Na_2O	0.44	(0.20-0.66)	0.39	(0.05-0.85)	1.03	(0.38-1.71)	1.03	(0.53-3.06)	1.03	(0.61-1.87)	1.6[illegible]	(0.67-4.16)	1.[illegible]4	(1.17-6.25)
Number of samples	28		18		17		9		17		3		9	

*Data for base and ferrous metal skarns compiled by Meinert (1983)
Fe_2O_3T = Total iron as Fe_2O_3

also present throughout the ore are chalcopyrite and trace sphalerite together with traces of bismuth, nickel and cobalt minerals (native bismuth, maldonite, breithauptite, gersdorffite and cobaltite). Native gold, intimately associated with tellurides, occurs as minute blebs (maximum 25 microns across) in arsenopyrite and less commonly in pyrrhotite (Warren and Cummings, 1936). The gold-sulphide mineralization is generally coeval with widespread scapolitization (Billingsley and Hume, 1941; Dolmage and Brown, 1945; Ettlinger *et al.*, 1992). The close temporal and spatial association between gold and scapolite suggests that chlorine-rich fluids may have been important in the transportation and precipitation of gold in the Hedley skarns.

The proposed model for the Nickel Plate deposit (Figure 2-5-6) involves metals being derived from the Hedley intrusions and transported by large volumes of reduced magmatic fluid into a strongly reduced calcareous sedimentary sequence. Formation of the large exoskarn envelope was accompanied by an early, high-temperature mineral sequence of (1) biotite and orthoclase, followed in turn by (2) manganese-poor, generally hedenbergitic clinopyroxene (Hd_{35-95}), and (3) grandite garnet (Ad_{15-100}). The overall compositional zoning in the larger Nickel Plate garnets is from grossularitic cores to andraditic margins, and both they and the pyroxene tend to have a low manganese content (<1 and 1.5 weight %, respectively). Garnets are mostly birefringent although some crystals have isotropic cores and birefringent margins. Subsequently, at lower temperatures, gold, sulphides, tellurides and scapolite, together with minerals such as prehnite, were deposited. Fluid inclusion studies (Ettlinger, 1990) indicate the main pyroxene-garnet skarn at Nickel Plate formed at temperatures (pressure corrected) between 460° and 480°C, with average fluid salinities of 18.3 and 9.7 weight per cent NaCl equivalent for garnet and pyroxene, respectively. Homogenization temperatures for scapolite associated with gold and sulphide minerals were in the range of 320° to 400°C.

Compared to other magmatic rocks related to either copper, iron, tungsten, zinc-lead, molybdenum or tin skarns, the Hedley intrusions are enriched in iron and have the lowest amounts of total alkalis and silica, and highest amounts of calcium, magnesium and iron (Ray and Webster, 1991; Table 2-5-4). The coarse porphyritic textures of some of the Hedley intrusions suggest these rocks were emplaced at shallow to intermediate depths. Low Fe_2O_3/FeO ratios and the presence of ilmenite and pyrrhotite in the unaltered Hedley intrusions, and high pyrrhotite/pyrite ratios in the ore indicate that both the intrusions and the skarn-forming fluids were strongly reduced. This conclusion is also supported by the presence of iron-rich biotite (Ettlinger, 1990), native bismuth and hedenbergitic pyroxene.

Skarn overprinting of the intrusions, to produce endoskarn, was accompanied by variable increases in the potassium and silica content and the K_2O/Na_2O ratios, decreases in magnesium and total iron, and sharp declines in the Fe_2O_3/FeO ratios (Table 2-5-5). Many of these chemical changes are related to the breakdown of the primary ferromagnesian minerals and their replacement by biotite, orthoclase, quartz and clinopyroxene. Initial skarn overprinting of the Nicola siltstones, with the appearance of orthoclase, biotite and lesser albite, leads to gains in potassium and sodium (*see* DDH401, Table 2-5-6). However, as skarn alteration increases, these minerals are replaced by clinopyroxene and garnet, leading to relative losses in potassium and sodium and gains in iron, magnesium and manganese, together with increased K_2O/Na_2O ratios (*see* DDH's 195 and 261, Table 2-5-6). The dramatic decrease of iron in the Nickel Plate endoskarn with progressive skarn overprinting is matched by a corresponding increase of iron in the adjacent exoskarn. This suggests that the destruction of the magmatic ferromagnesian minerals in the intrusions led to the iron enrichment in the nearby exoskarns. Thus, these minerals are probably the main source of the iron in the ore zones and may also be the source of the gold.

TABLE 2-5-5
COMPARATIVE CHEMISTRY (USING MEAN VALUES) OF THE UNALTERED HEDLEY INTRUSIONS AND MODERATELY AND INTENSELY ALTERED ENDOSKARN IN THE NICKEL PLATE DEPOSIT

Element	Unaltered Hedley intrusions	Moderately altered endoskarn DDH401	Intensely altered endoskarn DDH195 and DDH261
SiO_2	54.56	52.45	58.79
TiO_2	0.67	0.71	0.52
Al_2O_3	18.49	17.16	17.05
Fe_2O3	1.39	0.3	0.24
FeO	5.86	5.77	2.89
Fe_2O_3T	7.85	6.66	3.45
MnO	0.14	0.11	0.07
MgO	4.00	4.76	3.10
CaO	8.56	9.80	8.70
Na_2O	3.17	2.92	3.61
K_2O	1.40	2.54	3.33
P_2O_5	0.18	0.19	0.14
LOI	1.30	1.53	1.01
Fe_2O_3/FeO	0.24	0.05	0.08
K_2O/Na_2O	0.44	0.87	1.19
No. of samples	28	9	12

Fe_2O_3T = Total iron as Fe_2O_3
For drillhole locations see Figure 2-XX-5.

TABLE 2-5-6
COMPARATIVE CHEMISTRY (USING MEAN VALUES) OF THE UNALTERED NICOLA GROUP SEDIMENTARY ROCKS AND MODERATELY AND INTENSELY ALTERED EXOSKARN IN THE NICKEL PLATE DEPOSIT

Element	Unaltered limestone	Unaltered siltstone	Moderately altered exoskarn	Intensely altered exoskarn
			DDH401	DDH195 and DDH261
SiO_2	8.11	57.97	55.01	42.41
TiO_2	0.03	0.35	0.55	0.27
Al_2O_3	0.80	6.29	12.45	5.37
$Fe2O_3$	0.06	0.82	0.20	3.35
FeO	0.22	1.51	4.06	8.92
Fe_2O_3T	0.29	2.50	4.79	13.26
MnO	0.11	0.09	0.10	0.44
MgO	1.37	1.90	3.91	2.82
CaO	49.02	18.48	12.27	26.19
Na_2O	0.09	1.28	1.76	0.16
K_2O	0.15	1.17	3.76	1.30
P_2O_5	0.09	0.21	0.21	0.31
LOI	39.53	9.64	3.63	6.35
Fe_2O_3/FeO	0.30	0.63	0.07	0.83
K_2O/Na_2O	1.65	1.06	5.02	36.84
No. of samples	5	6	23	29

Fe_2O_3T = Total iron as Fe_2O_3
For drillhole locations see Figure 2-XX-5.

It is postulated that a large thermal cell formed around the Nickel Plate skarn (Figure 2-5-6). This probably resulted in the influx of cooler, more oxygen-rich meteoric waters into the bottom of the system which mixed with the magmatic fluids and resulted in the deposition of sulphides and gold. Consequently, ore horizons are preferentially developed near the base and lateral margins of the alteration envelope, close to its contact with underlying limestones. By contrast, the upper and middle portions of the skarn tend to be barren (Figure 2-5-6). This zoning has relevance regarding future exploration of other, apparently barren, skarn outcrops that may mask mineralization at depth.

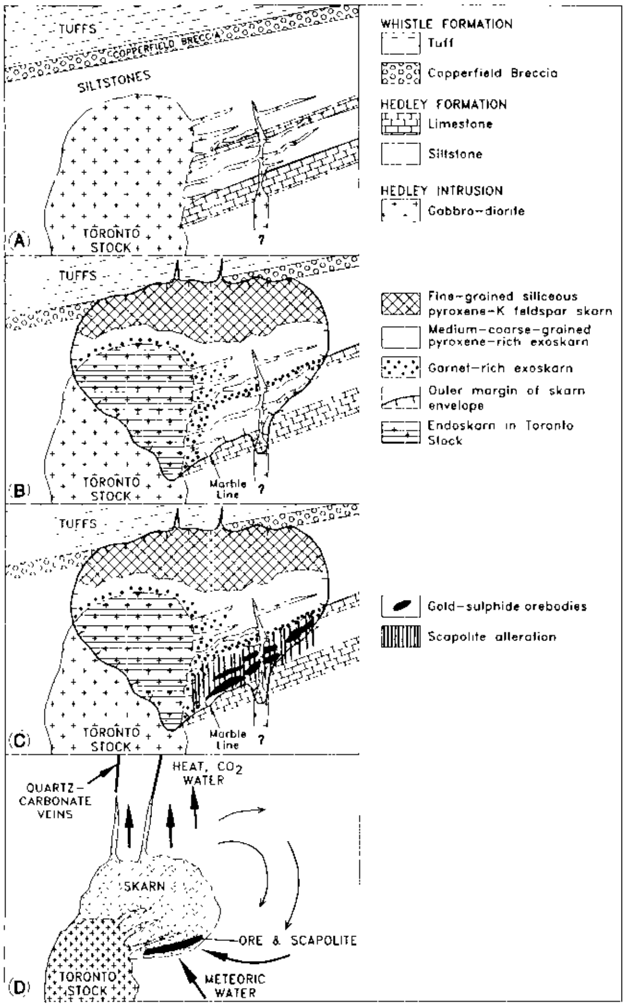


Figure 2-5-6. Schematic diagram showing postulated development of the Nickel Plate skarn envelope:

A: intrusion of the Toronto stock and associated sill-dike complex.

B: Infiltration of hydrothermal fluids to produce a 300-metre-thick, pyroxene-rich prograde skarn envelope with upper fine-grained siliceous zone. Coarser grained and garnet-dominant skarn developed adjacent to intrusions.

C and D: The formation of a large thermal cell around the skarn leads to an influx of meteoric water into the base of the system causing precipitation of the sulphide-gold-scapolite orebodies. Some quartz-carbonate veins develop along fractures above the envelope.

A district-wide, east-to-west change in the metallogeny, mineralogy and oxidation state of the skarns is suggested. Pyroxene-dominant and strongly reduced skarns containing gold, arsenopyrite and bismuth tellurides occur in the west and central parts of the district, while more oxidized tungsten-bearing and garnet-dominant skarns such as the Mount Riordan skarn occur in the east (Ray *et al.*, 1992). This zoning is partly due to the different sedimentary protoliths of the various skarns which reflect the original sedimentary facies changes in the Nicola Group across the district. It is also related to the different age and compositions of the associated intrusions responsible for the gold skarns and the Mount Riordan garnet skarn.

CONCLUSIONS

The Hedley district straddles the eastern tectonic edge of the Late Triassic Nicola back-arc basin, and its geology provides an insight into how rifting controlled the basin margin, the easterly derived sedimentation, and development of several economically important sedimentary facies. Dramatic evidence of syntectonic sedimentation is displayed in one distinct marker horizon, the Copperfield breccia, which represents a chaotic gravity-slide deposit of carbonate reefal debris. The breccia was probably derived from a shallow-marine, carbonate platform that originally lay immediately east of Hedley. Similar gravity-slide breccias could be expected to mark proximity to the eastern boundary of the Nicola basin elsewhere in British Columbia. The Copperfield breccia probably has a similar origin as the extensive modern megabreccia units that occur along the margins of low-relief carbonate platforms in the western Caribbean (Hine *et al.*, 1992).

In addition to several minor gold-bearing veins, the district contains some major gold skarn deposits as well as the Mount Riordan garnet skarn which has industrial mineral potential. The latter is associated with the 194 Ma (Early Jurassic) Mount Riordan stock whereas the gold skarns are genetically related to the slightly older Hedley intrusions. The Hedley intrusions, in comparison with other igneous rocks related to iron, copper, zinc-lead, tungsten, molybdenum and tin skarns, are the least differentiated and have the highest content of iron, magnesium, alumina and calcium. This chemistry reflects their derivation from primitive oceanic crust in an island arc environment.

In contrast to the rarer oxidized gold skarns, such as the McCoy deposit in Nevada (Kuyper, 1987; Brookes *et al.*, 1990), and the McLymont property in northern British Columbia (Ray *et al.*, 1991), the Nickel Plate, French, Canty and Good Hope deposits represent classical reduced-type gold skarn systems. Their reduced state is demonstrated by high pyrrhotite/pyrite and low Fe_2O_3/FeO ratios in the ore, and the presence of native bismuth, iron-rich biotite and hedenbergitic pyroxene. Progressive skarn overprinting of the intrusions and calcareous siltstones at Nickel Plate is accompanied by a sharp decrease in the iron content of the endoskarn and a corresponding increase in iron in the adjacent exoskarn. It is believed that the magmatic ferromagnesian minerals in the Hedley intrusions, which were broken down during skarn alteration, were the main source of the iron enrichment in the exoskarn.

The Hedley district still has good exploration potential for gold-skarn discoveries, particularly as the Nickel Plate model suggests that some of the larger, untested and apparently barren skarn envelopes in the district may overlie mineralization at depth. While underground mining would not be economically feasible on the Nickel Plate ore currently being worked by open-pit methods, it should be remembered that the ore extracted between 1904 and 1963 by underground mining graded 12 to 14 grams per tonne gold.

The deposit model and ore controls postulated at Hedley are applicable to other areas of the Cordillera. Tectonic hinge zones marking rifted margins of island-arc or marginal basins are considered to be highly favourable for gold skarns. Such areas containing abrupt facies changes with reduced calcareous sediments and porphyritic ilmenite-bearing dioritic to gabbroic intrusions are ideal for gold skarn development. In particular, exploration should be directed to intrusions that are iron-rich (greater than 7% total iron), have low Fe_2O_3/FeO ratios and are associated with pyroxene-dominant exoskarn systems containing early orthoclase-biotite alteration, high pyrrhotite/pyrite ratios, arsenopyrite, bismuth tellurides and scapolite.

ACKNOWLEDGMENTS

Part of the mapping and study costs were financed by the Canada - British Columbia Mineral Development Agreement 1985-1990. We wish to thank the management, staff and former staff of the following companies and organizations for their considerable assistance and co-operation: Homestake Canada Ltd. (formerly Corona Corporation and Mascot Gold Mines Ltd.), particularly J. Bellemy, A.H. Ransom, R. Simpson, W. Wilkinson, H.G. Ewanchuk and L.W. Saleken; Polestar Exploration Inc., particularly H.C. Grond and R. Wolfe; Banbury Gold Mines Ltd., particularly M.R. Sanford; Chevron Canada Resources Limited, particularly E. D. Dodson and L.A. Dick; and the Similkameen Indian Band, particularly Chief B. Allison and G. Douglas. M.J. Orchard and F. Cordey of the Geological Survey of Canada, identified the microfossils. The zircon U-Pb analyses were completed at the Department of Geology, The University of British Columbia, by J.E. Gabites, D. Murphy and P. Van der Hayden. Assistance in the field was given by M.E. MacLean, M. Mills and M. Fournier. Informative discussions with J.W.H. Monger, L.A. Dick, J. Hammack and the late R.L. Armstrong are appreciated. The figures were drafted by I.C.L. Webster, A.R. Pettipas and M.S. Taylor, and the paper was considerably improved by the editing of J.M. Newell.

REFERENCES

Billingsley, P. and Hume, C.G. (1941): The Ore Deposits of Nickel Plate Mountain, Hedley, B.C.; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume. 44, pages 524-590.

Bostock, H.S. (1930): Geology and Ore Deposits of Nickel Plate Mountain, Hedley, B.C.; *in* Summary Report 1929, Part A, *Geological Survey of Canada*, pages 198A-252A.

Bostock, H.S. (1940): Map of the Hedley Area, B.C.; *Geological Survey of Canada*, Map 568A.

Brookes, J.W., Meinert, L.D., Kuyper, B.A. and Lane, M.L. (1990): Petrology and Geochemistry of the McCoy Gold Skarn, Lander County, Nevada; *in* Geology and Ore Deposits of the Great Basin, Symposium Proceedings, *Geological Society of Nevada*, April 1990.

Camsell, C.(1910): Geology and Ore Deposits of the Hedley Mining District, B.C.; *Geological Survey of Canada*, Memoir 2.

Carr, J.M. (1968): The Geology of the Brenda Lake Area, *B.C. Minister of Mines and Petroleum Resources*, Annual Report 1967, pages 183-212.

Dawson, G.L., Godwin, C.I., Ray, G.E., Hammack, J. and Bordin, D., (1990a): Geology of the Good Hope - French Mine Area, South-central British Columbia, *in* Geological Fieldwork 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-1, pages 271-277.

Dawson, G.L., Godwin, C.I. and Ray, G.E. (1990b): Gold Skarn Mineralization Associated with a Sediment-sill Complex, French Mine, South-central B.C.; *Geological Association of Canada - Mineralogical Association of Canada*, Program with Abstracts, Volume 15, page A30, Annual Meeting, May 16-18 1990, Vancouver, B.C.

Dolmage, V. (1934): Geology and Ore Deposits of Copper Mountain, British Columbia; *Geological Survey of Canada*, Memoir 171.

Dolmage, V. and Brown, C.E. (1945): Contact Metamorphism at Nickel Plate Mountain, Hedley, B.C.; *Canadian Institute of Mining and Metallurgy*, Bulletin, Volume 48, pages 27-67.

Ettlinger, A.D. (1990): A Geological Analysis of Gold Skarns and Precious-metal-enriched Iron and Copper Skarns in British Columbia, Canada; unpublished Ph.D thesis, *Washington State University*, Pullman.

Ettlinger, A.D. and Ray, G.E. (1989): Precious Metal Enriched Skarns in British Columbia: An Overview and Geological Study; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-3.

Ettlinger, A.D., Meinert, L.D. and Ray, G.E. (1992): Skarn Evolution and Hydrothermal Fluid Characteristics in the Nickel Plate Deposit, Hedley District, British Columbia; *Economic Geology*, Volume 87, pages 1541-1565.

Grond, H.C., Wolfe, R., Montgomery, J.H. and Giroux, G.H. (1991): A Massive Skarn-hosted Andradite Deposit near Penticton, British Columbia; *in* Industrial Minerals of Alberta and British Columbia, Canada, Proceedings 27th Forum on the Geology of Industrial Minerals, Banff, Alberta, Hora, Z.D., Hamilton, W.N., Grant, B. and Kelly, P.D., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1991-23, pages 131-133.

Hine, A.C., Locker, S.D., Tedesco, L.P., Mullins, H.T., Hallock, P., Belknap, D.F., Gonzales, J.L., Neumann, A.C. and Snyder, S.W. (1992): Megabreccia Shedding from Modern, Low-relief Carbonate Platforms, Nicaraguan Rise; *Geological Society of America*, Volume 104, pages 928-943.

Kuyper, B.A. (1987): Geology of the McCoy Gold Deposit, Lander County, Nevada; *Symposium on Bulk Mineable Precious Metal Deposits of the Western United States*, April, 1987, Program with Abstracts, page 40.

Lee, J.W. (1951): The Geology of Nickel Plate Mountain, B.C.; unpublished Ph.D. thesis, *Stanford University*.

Mathieu, G.I., Boisclair, M.R. and Wolfe., R., (1991): Geology, Mineralogy and Processing of Mount Riordan Garnet Ores; *in* Industrial Minerals of Alberta and British Columbia, Canada, Proceedings 27th Forum on the Geology of Industrial Minerals, Banff, Alberta, Hora, Z.D., Hamilton, W.N., Grant, B. and Kelly, P.D., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1991-23, pages 135-145.

Meinert, L.D. (1983): Variability of Skarn Deposits: Guides to Exploration; *in* Revolution in the Earth Sciences – Advances in the Past Half-Century, Boardman, S.J., Editor, *Kendal/ Hunt Publishing Company,* pages 301-316.

Milford, J.C. (1984): Geology of the Apex Mountain Group, North and East of the Similkameen River, South-central British Columbia; unpublished M.Sc. thesis, *The University of British Columbia.*

Monger, J.W.H. (1989): Geology of Hope and Ashcroft Map Areas, British Columbia; *Geological Survey of Canada,* Map 42-1989.

Mortimer, N. (1986): Late Triassic, Arc-related, Potassic Igneous Rocks in the North American Cordillera; *Geology,* Volume 14, pages 1035-1038.

Mortimer, N. (1987): The Nicola Group: Late Triassic and Early Jurassic Subduction-related Volcanism in British Columbia; *Canadian Journal of Earth Sciences,* Volume 24, pages 2521-2536.

Parrish, R.R. and Monger, J.W.H. (1992): New U-Pb Dates from Southwestern British Columbia; *in* Radiogenic Age and Isotope Studies: Report 5; *Geological Survey of Canada,* Paper 91-2, pages 87-108.

Preto, V.A.(1972): Geology of Copper Mountain; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Bulletin 59.

Preto, V.A. (1979): Geology of the Nicola Group between Merritt and Princeton; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Bulletin 69.

Preto, V.A., Osatenko, M.J., McMillan, W.J. and Armstrong, R.L. (1979): Isotopic Dates and Strontium Isotopic Ratios for Plutonic and Volcanic Rocks in the Quesnel Trough and Nicola Belt, South-central British Columbia; *Canadian Journal of Earth Sciences,* Volume 16, Number 9, pages 1658-1672.

Ray, G.E. and Dawson, G.L. (1987): Geology and Mineral Occurrences in the Hedley Gold Camp; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1987-10, Scale 1:20 000.

Ray, G.E. and Dawson, G.L. (1988): Geology and Mineral Occurrences in the Hedley Gold Camp; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Open File 1988-6, Scale 1:25 000.

Ray, G.E. and Dawson, G.L. (1993, in preparation): The Geology and Mineral Deposits of the Hedley Gold Skarn District, Southern British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Bulletin.

Ray, G.E. and Webster, I.C.L. (1991): An Overview of Skarn Deposits, *in* Ore Deposits, Tectonics and Metallogeny in the Canadian Cordillera; *B.C. Ministry of Energy Mines and Petroleum Resources,* Paper 1991-4, pages 213-252.

Ray, G.E., Dawson, G.L. and Simpson, R. (1987): The Geology and Controls of Skarn Mineralization in the Hedley Gold Camp, Southern B.C.; *in* Geological Fieldwork 1986, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1987-1, pages 65-79.

Ray, G.E., Dawson, G.L. and Simpson, R. (1988): Geology, Geochemistry and Metallogenic Zoning in the Hedley Gold Skarn Camp; *in* Geological Fieldwork 1987, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1988-1, pages 59-80.

Ray, G.E., Grond, H.C., Dawson, G.L. and Webster, I.C.L. (1992): The Mount Riordan (Crystal Peak) Garnet Skarn, Hedley District, Southern British Columbia; *Economic Geology,* Volume 87, pages 1862-1876.

Ray, G.E., Jaramillo, V.A. and Ettlinger, A. D. (1991): The McLymont Northwest Zone, Northwest British Columbia: A Gold-rich Retrograde Skarn?; *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1991-1, pages 255-262.

Read, P.B. and Okulitch, A.V. (1977): The Triassic Unconformity of South Central British Columbia; *Canadian Journal of Earth Sciences,* Volume 14, pages 1127-1145.

Rice, H.M.A. (1947): Geology and Mineral Deposits of the Princeton Map-area, B.C.; *Geological Survey of Canada,* Memoir 243.

Rice, H.M.A.(1960): Geology and Mineral Deposits of the Princeton Map-area, B.C.; *Geological Survey of Canada,* Memoir 243.

Soregaroli, A.E. and Whitford, D.F. (1976): Brenda; *in* Porphyry Deposits of the Canadian Cordillera, Sutherland-Brown, A., Editor, *Canadian Institute of Mining and Metallurgy,* Special Volume No. 15, pages 186-194

Warren, H.V. and Cummings, J.M. (1936): Mineralogy at the Nickel Plate Mine, *The Miner,* Volume 9, pages 27-28.

Webster, I.C.L. (1988): Skarn and Ore Mineralogy at the Hedley Amalgamated Mine, Hedley, B.C.; unpublished B.Sc. thesis *Brock University.*

NOTES