Targeting fault aquifers on Cape Breton Island

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ABSTRACT
A wide variety of faulting is present on-Island, including thrust, strike slip, normal, transform, bedding plane detachment and crustal suture zones. Development of groundwater supplies from Fault Aquifers have focused on strike slip basin bounding faults cross cut with transform faults. Experience at Kellys Mountain and Eskasoni indicate these fault zones, developed within granites, are hydraulically active, acting as sources for major springs and potable groundwater supplies. Other fault aquifer systems are important in oil and gas exploration, base metal mineralization and geotechnical slope stability problems.

RÉSUMÉ
Une grande variété de formation de failles est présente sur l'île, incluant des zones de chevauchement, de rejet horizontal, de normal, de marge continentale transformante, de décollement du plan de stratification et de suture de la croûte terrestre. L'aménagement de sources d'approvisionnement en eau souterraine à partir des aquifères de faille a été ciblé sur des bassins de type rejet horizontal bornant des failles travers-banc et des failles de marge continental transformante. L'expérience acquise à Kellys Mountain et à Eskasoni indique que ces zones de faille, produites à l'intérieur des granites, sont actives hydrauliquement et sont à l'origine d'importantes sources d'eau de surface et de sources d'approvisionnement en eau potable souterraine. D'autres systèmes d'aquifères de faille sont importants dans l'exploration pétrolière et gazière, la minéralisation du métal commun et les problèmes de stabilité géotechnique des talus.

1 INTRODUCTION

Cape Breton Island forms the northern tip of Nova Scotia, along the eastern seaboard of Canada, encompassing some 11,700 km^2 (Figure 1).

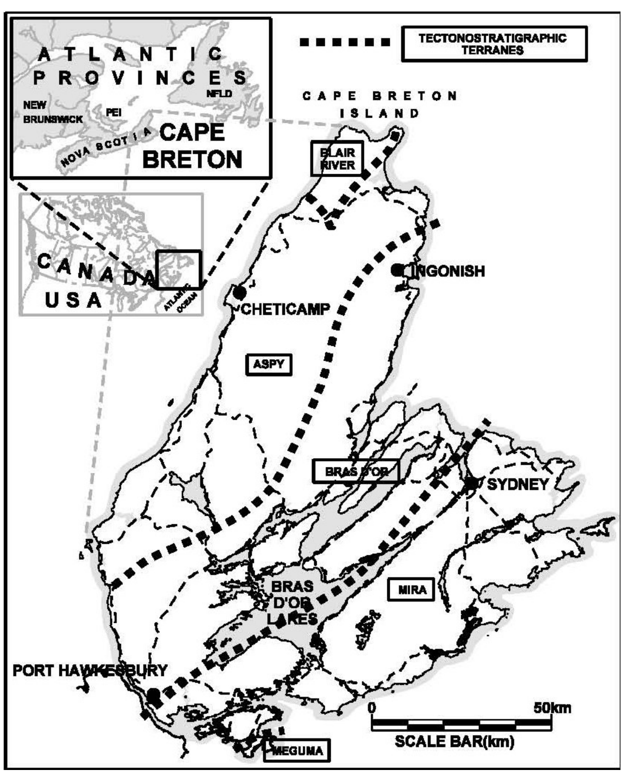

Figure 1: Location Map

Geological mapping has delineated a wide variety of faulting on-Island. These include thrust, strike slip, normal, transform, bedding plane detachment and crustal suture zones. They are associated with pluton un-roofing, highland fault blocks, sedimentary basin bounding faults, pull apart Carboniferous basins, salt diapirs, the Cabot Nappe thrust sheet, opening of the Atlantic Ocean and welding of five tectonostratigraphic terranes.

Hydrogeologically it was important to determine whether these approximate 400 to 65 million years (My) old faults were sufficiently hydraulically active to form targets for developing water supplies. This also necessitated understanding their role in base metal mineralization, and focusing oil/gas exploration.

This paper outlines the dominant fault types of the Island and summarizes the experience to date, with examples focusing on development for water supplies.

2 PALEOHYDROLOGY

The one billion year geological history of the Island is complex. Paleohydrologically it has been divide into six Atemporal streams@. The first two are pertinent to fault development.

Temporal Stream 1, between 1000 to 365 million years ago (Ma) included remnants of two mountain building episodes. During the closing of the Iapetus Ocean, a series of land masses were "docked" onto the North American continent along some 3000 km of the eastern seaboard of North America, forming the

Appalachian Mountain belt (Williams et al, 1999). Barr et al (1989) and White et al (2003) divided these basement rocks of the Island into five tectonostratigraphic terranes, including the Blair River Complex, as well as the Aspy, Meguma, Bras d'Or and Mira Terranes (Figure 1). The latter two form the Avalon Composite Terrane.

The Acadian Orogeny (400 to 370 Ma) resulted in the accretion of the Avalon Terrane. During the collision, Cape Breton Island found itself at the apex of the St. Lawrence Promentory. As a result, an off-shore volcanic island arc system was sandwiched between the promontory and Avalon zone, now classified as the Aspy Terrane, which underlies most of the Cape Breton Highlands. At this time the Bras d'Or Terrane was thrust over the Aspy, creating the Cabot Nappe (Lynch, 2001). Oblique collision between crustal blocks and mountain building created massive northeast-southwest trending predominately strike slip faults (Williams et al, 1999).

Temporal Stream 2 (370 to 65 Ma) incorporated a period of mountain erosion and basin infilling. After the initial closure of the Iapetus Ocean, it would take another 100 Ma to complete the final assemblage of terranes, forming Pangea. These continuous collision events created rifting and thrust faulting, as well as strike-slip, pull apart shear/wrench and oblique compressional forces within the Appalachian Mountain belt.

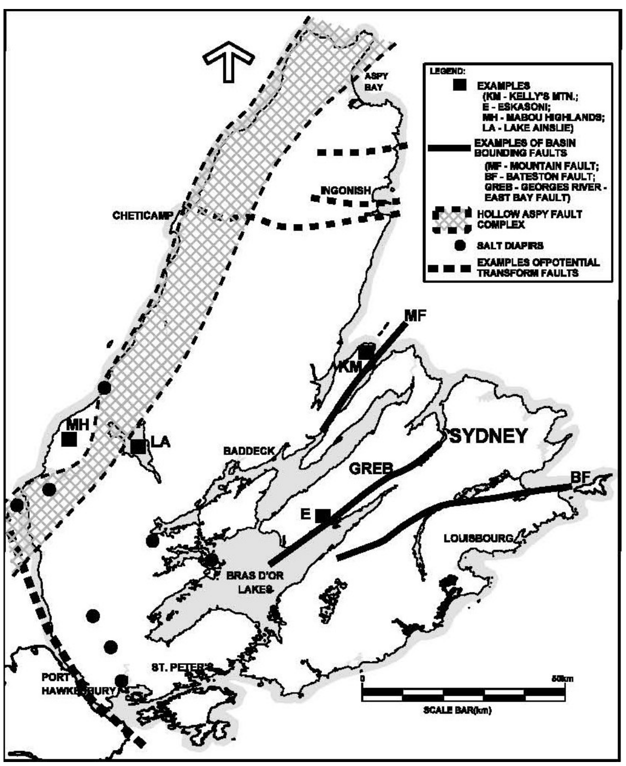

Figure 2: Pertinent Structural Features

The Maritimes remained in the interior of Pangea for over 100 My, until near the end of the Triassic (180 Ma), when crustal movement started to fragment the continent forming the present day Atlantic Ocean. As fragmentation continued into the Cretaceous (140 to 65 Ma), a proto ocean started to form in the Newark Rift Valley system, the northern extension of which trended along the Bay of Fundy - Cobequid - Chedabucto Fault system, extending just southeast of the Island. This period of extension allowed pre-existing strike-slip faults to be reactivated as normal faults. This system failed to develop, with the spreading center moving farther to the east along the present Mid Atlantic Ridge (Atlantic Geoscience Society, 2001). During this period, northwest-southeast trending transform faults extending out from the spreading center cross cut the strike slip faults (Faure et al, 2006).

3 STRUCTURAL HYDROSTRATIGRAPHIC UNIT

A Structural Hydrostratigraphic Unit (HU) was defined on-Island, which comprises zones where massive folding and faulting of bedrock occurred that were kilometres in scale. Although the forces that created these zones were responsible for widespread fracturing in the bedrock, this HU focuses on the "epicentre" of tectonic activity, where there may have been sufficient change to warrant a special designation.

Fault zones forming this HU consist of three major architectural components (Caine et al, 1996). The center is the "Fault Core", most highly influenced by stresses associated with displacement. It may undergo mylonitization, cataclasis, brecciation, geochemical alteration and development of clay-rich fault gouge. All contribute to a decrease in porosity and permeability by one to three orders of magnitude with respect to the "Protolith" (unaltered rock). The "Damage Zone" extends outward to the Protolith, being comprised of secondary structures, primarily fractures and other small faults, but also including veins, clevage and folds. It exhibits primarily fracture permeability. It tends to exhibit an increased permeability that promotes flow of fluids parallel the fault plane adjacent to the more impermeable Fault Core barrier (Bruhn et al, 1994). The juxtaposition of highly fractured Damage Zone materials with undeformed Protolith and generally unfractured Fault Core materials forms major permeability contrasts within a fault zone (Caine et al, 1996).

This HU can exhibit a wide variety of hydraulic characteristics (Evans et al, 1997), including: Flow Fault (hydraulic connection from one side to the other), Conduit Fault (permeable zone of preferential flow), Barrier Fault (an impermeable barrier) and Obstruction Fault (the character of both flow and barrier faults).

No intensive research had been undertaken within this HU on-Island. Therefore, whether these 400 to 65 My old faults were hydraulically active was initially unknown. Field experience suggested many were active, at least in the near surface. This was thought to be a function of "progressive exhumation", where deeply buried fault zones are gradually brought to the surface as a result of erosion over time scales of several My. The resultant reduction in temperature and confining pressures promote brittle phenomena, such as mesoscale fracturing and microscale cataclasis, combined with groundwater assisted reactions (Cowan, 2003).

Cape Breton Island is presently not tectonically highly active, so the creation of new faults or rejuvenation of old systems is not expected. The Island is positioned between three seismo-tectonic zones (Nolan Ertec, 1983). Although seismic activity on the eastern American seaboard is well known, the large majority of shocks are very small. With the exception of the Grand Banks earthquake of 1929 (7.2), all instrumentally determined earthquakes in Atlantic Canada have had magnitudes less then 5.2 (Rast et al, 1979).

Six broad types of potentially hydrologically active faults are present on-Island, as summarized below.

4 BASEMENT CRUSTAL ZONE FAULTS

The Cape Breton Highlands (Figure 2) provides a "window" exposing basement rocks and faults of the Canadian Appalachian Mountain belt (Lynch, 2001). These faults are not restricted to present day valleys and have undergone greenschist facies metamorphism (Raeside et al, 1992**).**

The main suture zones marking the boundaries where tectonic plates were welded together trend northeast and include the Eastern Highland Shear Zone between the Bras d'Or and Aspy Terrane, the Blair River and Wilke Faults separating the Aspy Terrane from the Blair River Complex, the MacIntosh Brook Fault, separating the Mira and Bras d'Or Terrane, as well as the Chedabucto Fault complex (Force et al, 2006) separating the Mira and Meguma Terranes (Figure 1). The boundaries of the terranes are composite structures formed during a long history of development and reactivation in which they were active both as shear zones and brittle faults (Williams et al, 1995).

One of the regional scale fault structures, which accommodated this orogenic cycle, includes the Highlands Shear Zone (HSZ). During the initial closure of the Iapetus Ocean, early Devonian thrusts toward the northwest along the HSZ emplaced the Cabot Nappe over the Cape Breton Highlands. It consists of a number of northeast striking shear zones consisting of very thick mylonite within a mainly ductile defomation zone generally 50 to 500 metres wide, but up to 5 km wide. It represents a deeply rooted, folded thrust fault at the base of the Cabot Nappe (Lynch, 2001).

These thrust faults and crustal sutures have not been hydrogeologically evaluated to-date due to their deep sedimentary cover, or remote highland exposures**.**

5 AINSLIE DETACHMENT AND SALT DIAPIRISM

Late Carboniferous block faulting in the basement and uplift of Cape Breton Island as a horst triggered a regional evaporite controlled, flat lying, bedding-parallel gravity slide near the base of the Windsor Group which defines the Ainslie Detachment fault. Locally, it allows locally up to 2 km of stratigraphic Windsor succession to be removed (Lynch et al, 1995). It is noted as a zone of intense shear at the top of the basal limestone (Giles et al, 1993). The front end of the gravity slide is characterized by compressional structures and a broad salt dipair field west of Cape Breton in the Gulf of St Lawrence. The onshore is characterized by extensional structures, listric normal faults and stratigraphic gaps in succession directly above the Ainslie Detachment (Lynch, 2001).

There is a link between the Ainslie Detachment and regional lead-zinc mineralization. At the Jubilee deposit, the underlying Horton Group acted as a principal lower basin aquifer, with the thick evaporite successions in the overlying Windsor Group providing an effective aquitard. The detachment fault likely affected basin hydrology, effectively increasing the permeability of the basal limestone along which fluid migration occurred. The deposit is stratabound to the brecciated limestone and occurs at the same stratigraphic level as the Ainslie Detachment (Lynch et al, 1996).

Salt diapirs within the Windsor Group extend upward some 0.9 to 1.5 km penetrating, warping and fracturing overlying Carboniferous clastic strata. Where measured on-Island the drag and intense fault zones adjacent the diapirs extend outward varying distances depending upon the nature of the strata. Massive brittle faulting, shearing and fracturing characterize competent sandstones, while shales exhibit non-ductile warping, changing to mudstones, with minor fracturing, infilled by gypsum precipitate. Intense fracturing extends outward for some 600 metres from the diapir margins creating high permeability in competent formations; with folding of strata extending up to 2 km from the margins (Davison, 2005).

On-Island there are 10 localities of salt dome activity (Figure 2), as mapped out by Giles (2004, 2003, 1981) and Alsop et al (2000).

Faulting along the periphery of salt diapirs form targets for oil and gas exploration (Davison, 2005). The proximity of evaporite sequences and mineralization sometimes associated with the Ainslie Detachment suggests a low probability for obtaining potable water and, therefore, has not been a target for water supply investigations to date.

6 HOLLOW-ASPY FAULT COMPLEX

This is the largest Structural HU system on-Island with a long and complex movement history. It is defined by Hall et al (1998) as a "zone of complex structure" covering the western half of the Island (Figure 2). It is interpreted as a late Carboniferous northeast striking, predominately dextral strike slip fault zone, dipping to the south with a throw of approximately 1.6 km. However, movement is very complex with different components at different times.

Under Saint Georges Bay it is mapped as a 1500 to 2500 metres wide deformation zone (Durling et al, 1995). It comes ashore on-Island as the Colindale Fault near Mabou, then trends northeast throughout the western region of the Island. It presents itself as a complex deformation zone with parallel and sub-parallel splays that become more numerous toward the northeast. Many are interpreted as strike slip and wrench faults, the largest being the Aspy. It may be related to stresses developed by movement along the Cobequid fault system, which created a series of half grabens in a large intra-continental pull apart system (Mukhopadhyay, 2004). To the northeast it becomes the Cabot Fault System, extending through Newfoundland as the Long Range Fault, as part of a massive San Andreas style fault system. To the southwest it extends onto the Mainland, joining up with the Cobequid-Chedabucto fault complex (Redfern, 2001).

To date, no detailed hydrogeological studies have been undertaken within this fault system for potable water. The southern portion of the system in the Mabou/ Lake Ainslie (Figure 2) area has been the subject in the early 1900's for oil and gas plays. Numerous oil seeps and presence of hydrocarbons in domestic wells have been documented around Lake Ainslie. Between 1864 and 1880 thirteen wells were drilled in the Mabou/Lake Ainslie area with oil and gas shows (McMahon et al, 1986). Most wells were less than 200 metres deep; seven to depths greater than 300 metres. Additional work took place between 1940 to 1960 with wells drilled to 1500 to 3000 metres, however, no commercial deposits were discovered.

A localized portion of the system just north of Cheticamp within the Cape Breton Highlands Park, formed a target for geotechnical investigations and remedial activities for reducing the impact of rockslides on the Cabot Trail.

7 PLUTON UNROOFING

In the southwest region of the Hollow-Aspy Fault complex, within the Mabou-Ainslie Subbasin, are a series of en-echelon, broad synclines separated by narrow, probably faulted anticlines and domes. This is considered to be a result of differential compaction over basement highs, of which the Mabou Highlands (Figure 2) exemplifies one partially exhumed dome (Giles et al, 1997).

The Mabou Highlands consist of a large, isolated horst block exposing basement units through the Carboniferous cover. Abundant and thick steeply dipping mylonite zones occur. The shear zones define moderately to steeply dipping faults, which strike north to northwest transporting blocks upward and toward the south. Large scale, folded mylonitic shear zones are detached along and were apparently transported by adjacent faults (Lynch, 2001). Erosion along these fault zones have resulted in an extremely dissected highland plateau, which distinguishes it from all the other highland areas on-Island.

A small (1.3 km^2) spring fed watershed developed within one of these dissected stream valleys forms part of the water supply for the Village of Inverness. Springs in an adjacent 9.6 km^2 watershed support cooling water for a commercial establishment. The 450 Lpm flow of one spring (Table 1) exhibits a fresh (TDS 50 mg/L), soft, non-colored, corrosive mixed sodium-bicarbonate/chloride type water and a near neutral pH of 7.4. Nutrients were present only in small concentrations predominately as carbon 1.2 mg/L. Iron and manganese were non-detectable.

TABLE 1 REPRESENTATIVE GROUNDWATER CHEMISTRIES ASSOCIATED WITH FAULTS

PARAMETER	UNITS	Kellys Mtn Spring 5	Kellys Mtn Spring 7	Eskasoni PW Christmas Brook	Eskasoni PW Spencer Lane	Mabou Highlands Spring 3
Sodium	mg/L	2.8	2.8	24	43	6.1
Potassium	mg/L	<0.1	<0.1	0.3	0.5	0.7
Calcium	mg/L	5.8	26	10.7	14	7.5
Magnesium	mg/L	1.8	4.2	2.17	5	2
Alkalinity (as $CaC0_3$)	mg/L	19.3	81.8	30	29	19
Sulphate	mg/L	5	5.6	6.4	6.5	6
Chloride	mg/L	4.6	5.2	38	83	10.6
Silica	mg/L	4.3	3.9	8.8	14	4.8
Ortho-Phosphate (as P)	mg/L	<0.01	<0.01	<0.02	<0.01	<0.01
Nitrate+Nitrite (as N)	mg/L	0.07	<0.05	<0.05	0.08	<0.05
Ammonia (as N)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	mg/L	<0.02	<0.02	0.03	<0.02	<0.01
Manganese	mg/L	<0.01	<0.01	0.01	<0.01	<0.002
Copper	mg/L	<0.01	<0.01	,0.01	<0.01	<0.002
Zinc	mg/L	<0.01	<0.01	<0.01	0.01	<0.002
Color	TCU	2.5	2.5	2.5	<3.0	6
Turbidity	NTU	0.3	0.2	0.81	0.12	0.07
Conductivity	uS/cm	62.7	175	185	340	88.8
pH	Units	7.8	7.8	7.5	7.4	7.4
Total Organic Carbon	mg/L				0.7	1.2
Hardness (as $CaC0_3$)	mg/L	21.9	82.2	35.7	55.5	29.3
Total Dissolved Solids	mg/L	36.2	84	117	184	50

8 TRANSFORM FAULTS

Regional structural analysis by Keppie (1976) noted the presence of a complex network of deeply incised lineaments trending northwest-southeast across the general structural grain of the Island. These notably cross cut the highlands, being associated with large canyons and river valleys, exemplified by Cheticamp, Ingonish, Clyburn, North and Skye-Lake Ainslie (Figure 2). It may also include the Canso fault, which trends northwest- southeast, potentially offset the terranes of southern New Brunswick from Cape Breton Island (Lori et al, 2007). In many areas less incised gorges and valleys are also present.

Williams et al (1995) interpreted these northwest trending faults throughout the Atlantic Provinces and into Maine as Transform faults associated with the opening of the Atlantic Ocean. This may have been associated with the proximity of the Newark Rift Valley system (Withjack et al, 2005) They are normal to the ocean-continent boundary. Since the generalized boundary is curved approximately 90 degrees, the transform faults fan sympathetically through a similar angle.

The persistence of the fault lineaments for tens of km, in some cases crossing tectonostratigraphic terrane boundaries, indicates that they are relatively young features, post Carboniferous (Triassic-Cretaceous). Wherever the faults are seen in outcrop, they overprint all other structures. The faults cut the youngest rocks in the areas wherever they occur and can be traced into the Carboniferous strata. These northwest striking faults are mostly sinistral and the west striking faults are mostly dextral, but both vary and the sense of displacement can vary even within a single fault. Mostly appear to be of Mesozoic age (Williams et al, 1995).

While no detailed hydrogeological studies have been undertaken, the more easily erodible nature of the fault zones is manifested by significant incision within the landscape, creating large scale canyons and gorges. The smaller gorges have been used to focus the target areas for groundwater supplies where they intersect Basin Bounding faults, as discussed below.

9 BASIN BOUNDING FAULTS

The closing of the Iapetus Ocean created continued slippage between opposing adjacent continental land masses, resulting in some 2500 km of transport past each other. As a consequence, margins were greatly disrupted, distorted and partly destroyed resulting in intense deformation and megashear along northeast trending strike slip faults (Redfern, 2001).

These linear, northeast trending faults are positioned along the edge of the Carboniferous basins. Linear bounding faults are best exemplified by the Mountain and Bateston Faults forming the western and southern boundaries of the Sydney Basin (Figure 2). They are inferred to have substantial dextral strike slip motion in the order of 10's km, dip slip offset in the order of more than 1000 metres, and are accompanied by steep dips of adjacent sedimentary strata (Boehner et al, 1986, Bradley et al, 1986). These faults were reactivated as dip-slip normal faults during the Mesozoic as part of extensional dynamics created by development of the Atlantic Ocean

One of the earliest implications of this faulting occurred during deep Permo-Triassic burial during which time it is suspected that the intrusion of hypersaline brines from the Windsor Group moved along faults (possibly the Mountain Fault) and were intruded into the overlying Sydney Mines Formation of the Cumberland Group (Martel et al, 2001). These brines have been documented at depth below the fresh groundwaters of important present day bedrock aquifers. Their saline chemical signature was investigated by ADI (1993) in the Phalen coal mine workings 2.5 km off shore at 600 metres below sea level. They are characterized as a hypersaline brine (TDS 162,600 to 169,000 mg/L), extremely hard (50,000 to 60,000 mg/L), sodium chloride type water with a pH of 5.0 to 7.6 and no measurable alkalinity or sulphate. Ammonia is characteristically large (32 to 60 mg/L). Of the metals monitored for higher concentrations were noted for strontium (860 to 1460 mg/L), iron (18 to 112 mg/L) and barium (421 to 780 mg/L).

Present day hydrogeological water supply studies have focused on the near surface areas of these fault zones given their proximity to existing population centres. Two case studies are summarized below.

9.1 Kellys Mountain

The Kellys Mountain pluton (Figure 2) is bounded on the east and west by northeast trending basin bounding faults, termed the Mountain Fault and North Shore Lineament, respectively. Boreholes drilled in proximity to the latter intersected zones of open, vertical fracturing and shearing at varying depths with hydraulic conductivities averaging 10^{-4} cm/sec. Fracturing was not found to decrease over a least 100 metres of depth (Nolan Davis, 1989).

Springs issuing from the eastern flank of the Mountain are positioned along the trace of the Mountain Fault. The largest (Spring 5) is associated with the intersection of an east-west trending lineament, possible transform fault.

A total of 10 springs were identified over an approximate 2 km length of fault trace (Nolan Davis, 1987). These springs were monitored up to 10 times between March and July 1987. During peak flows in April the total flow from nine springs was 7500 Lpm; with Spring 5 being the largest producer at 3,000 Lpm at the source. The lowest flows were recorded in July after a three week drought with a total of 510 Lpm. At this time, Spring 5 at source had dropped to 60 Lpm, resulting in the greatest variability of 236%. The combined average flow was 2,400 Lpm.

The springs recorded a generally similar type of chemistry, two examples of which are presented in Table 1. The analyses indicated a fresh (TDS 24 to108 mg/L), very soft to moderately hard (7 to 114 mg/L), non coloured, corrosive, mixed calcium/magnesium/sodium-bicarbonate type water with an alkaline pH range from 7.0 to 8.1 and alkalinity of 5.5 to 103 mg/L. Nutrient concentrations were at very low and usually non-detectable concentrations. Of the seven metals monitored most were less than detectable with the exception of sporadic, but low concentrations of iron (<0.01 to 0.02 mg/L) and manganese (<0.004 to 0.01 mg/L; uranium was non detectable. No precipitate was noted on the bed of the springs. Water temperatures indicated a constant 5 to 6 degrees C.

In summary the springs were classified as Class IV (Meinzer, 1927), Hillslope (Springer et al, 2009) non-thermal with variable flow. All 28 parameters monitored for met the maximum acceptable concentrations set out in the Guidelines for Canadian Drinking Water Quality. Therefore, the fault and transecting lineaments were found to be hydraulically active and contributing potable water quality.

9.2 Eskasoni

Eskasoni's groundwater supply is developed from wells drilled into a highly fractured granite fault zone of the Boisdale Hills Pluton, where the George River-East Bay basin bounding fault is intersected with cross cutting, potential transform faults. The fault zone at the base of the upland escarpment is bounded by granitics on the upgradient side and the argillaceous-evaporite sequences of the Windsor Group on the downgradient side.

The initial supply was from springs discharging at 200 to 300 Lpm, from a heavily fractured, granular textured, hornblende granodiorite.

Nolan Davis (1984) drilled test wells ranging in depth from 35 to 62 metres in three different locations along the fault trace where it intersected transform faults. One site, where bedrock was heavily fractured to depth, was chosen for a production well drilled to 26 metres with 1.5 metre #60 slot screen. Pump testing indicated a transmissivity (T) of 320 m^2/day, storage coefficient (S) of of 0.001 and a 20 year well (Q_{20}) safe yield of 1020 Lpm.

Two additional wells drilled at the location of the springs (Nolan Davis, 1989) to depths of 62 to 68 metres encountered both hard, competent non fractured, as well as highly fractured zones. A pump test provided a lower T of 7 m^2/day, an S of 0.003 and a Q_{20} safe yield of 114 Lpm.

Further test drilling (Nolan Davis, 1990) occurred at a third site (Spencer Lane) to depths of 40 to 50 metres, encountering broken granite and major fracture zones with flowing artesian conditions. Pump testing resulted in T of 216 m^2/d, and Q_{20} safe yield of 680 Lpm plus.

The wells noted similar water to depths up to 50 metres. It was characterized as a fresh (TDS 63 to 184 mg/L), soft to slightly hard (34 to 55 mg/L), corrosive, predominately sodium/calcium-bicarbonate type water with a pH range of 7.4 to 8.5. One well noted a trend toward higher sodium chloride with depth, thought to be a function of formation waters moving along the fault from adjacent Windsor Group and/or saline formation waters deep within the pluton. Metals were also mostly non detectable except for iron at 0.02 to 0.04 mg/L. Radiological indicators taken on one well noted low concentrations with Gross Alpha and Beta at <0.04 and <0.14 Beq/L, respectively; uranium was <0.005 mg/L and radon at 29 Beq/L.

10 CONCLUSIONS

Cape Breton Island exhibits a wide variety of faulting created predominately between 400 to 65 Ma. These faults have played critical roles in development of mineralization, hydrocarbon migration and intrusion of hypersaline brines into present day aquifers. Progressive exhumation has allowed at least the near surface zones of these faults to be hydraulically active, providing targets for the development of potable groundwater supplies.

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