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PRE-MINING GROUND STRESSES AT THE BOUSQUET/DUMAGAMI MINES, CADILLAC, QUEBEC

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CONTRAINTES DANS LE SOL AVANT LES TRAVAUX D'EXPLOITATION AUX MINES BOUSQUET/DUMAGAMI, À CADILLAC (QUÉBEC)

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RÉSUMÉ

À des fins d'évaluation de la stabilité, des mesures extensométriques par surcarottage ont été effectuées aux mines Bousquet/Dumagami, à Cadillac (Québec).

D'après les mesures des contraintes dans le sol avant les travaux d'exploitation, effectuées à une profondeur de 900 m, les contraintes de compression horizontales maximale et minimale (σHmax, σHmin) sont orientées dans les directions nord-est et sud-est respectivement. Le gradient de contrainte de compression horizontale moyen était de 0,0505 MPa/m, et le rapport σHmax/σHmin était de l'ordre de 1,5. Par rapport aux zones minéralisées (N 105° E/87° S), σHmax a une orientation perpendiculaire alors que σHmin est orienté dans la même direction que les zones minéralisées et les principaux éléments structuraux.

Les valeurs des contraintes sont compatibles avec la plage de valeurs obtenues à des profondeurs comparables dans le Bouclier canadien.

Mots-clés : cellule de déformation triaxiale; mesures extensiométriques par surcarottage; contraintes avant exploitation minière.

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ABSTRACT

For the purpose of stability evaluations, overcoring strain relief measurements were conducted at the Bousquet/Dumagami Mines, Cadillac, Quebec.

Results of pre-mining ground stresses determined at a depth of 900 m, indicated that the maximum and minimum horizontal compressive stresses (σHmax, σHmin) are oriented in northeast and southeast directions, respectively. The average horizontal compressive stress gradient amounted to 0.0505 MPa/m, with a ratio of σHmax/σHmin in the range of 1.5. In relation to the ore zones (~N 105^{o} E/87^{o} S), σHmax acts perpendicular while σHmin is oriented on-strike to the ore zones and the main structural features.

The stress values fit within the range of data observed at similar depths in the Canadian Shield.

Key words: Triaxial strain cell; Overcoring strain relief measurements; Pre-mining stress.

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INTRODUCTION

At the request of Lac Minerals Ltd, in the context of Lac-Dumagami Geotechnical Committee, underground stress measurements were conducted at the Dumagami Mine of Agnico-Eagle Mines Ltd.

At the Bousquet 2 Mine, currently about 400 m of the projected 1300 m deep production shaft is completed. For the purpose of stress determinations, access to deeper mining excavations was only possible by the adjacent Dumagami Mine, where the strain relief overcoring measurements were taken at a depth of 900 m.

The results of previous stress determinations carried out at a depth of 190 m (1), and the present stress data will provide additional background information for the purpose of mine design and stability evaluations at the Bousquet/Dumagami Mines.

The Bousquet/Dumagami Mines are situated about 50 km east of Rouyn-Noranda, Quebec, close to the town of Cadillac. The mine sites, located within the southern margin of the Abitibi greenstone belt are shown in Figure 1 (2). Steeply dipping gold-bearing zones (~N 105^{o} E/87^{o} S) occur within a fine to medium grained volcanoclastic rock sequence.

STRAIN RELIEF MEASUREMENTS AND LABORATORY TESTS

The stress measurement site was located on the 21 level, as shown on a generalized longitudinal E-W section in Figure 2, and the location plan, Figure 3. The selected site was away from the influence of mine workings, however, some remote mining openings (drifts) existed above the location of the stress measurement site.

The horizontal test hole, nominal diameter of 150 mm, yielding a core diameter of 142 mm, was drilled nearly perpendicular to the structural plane

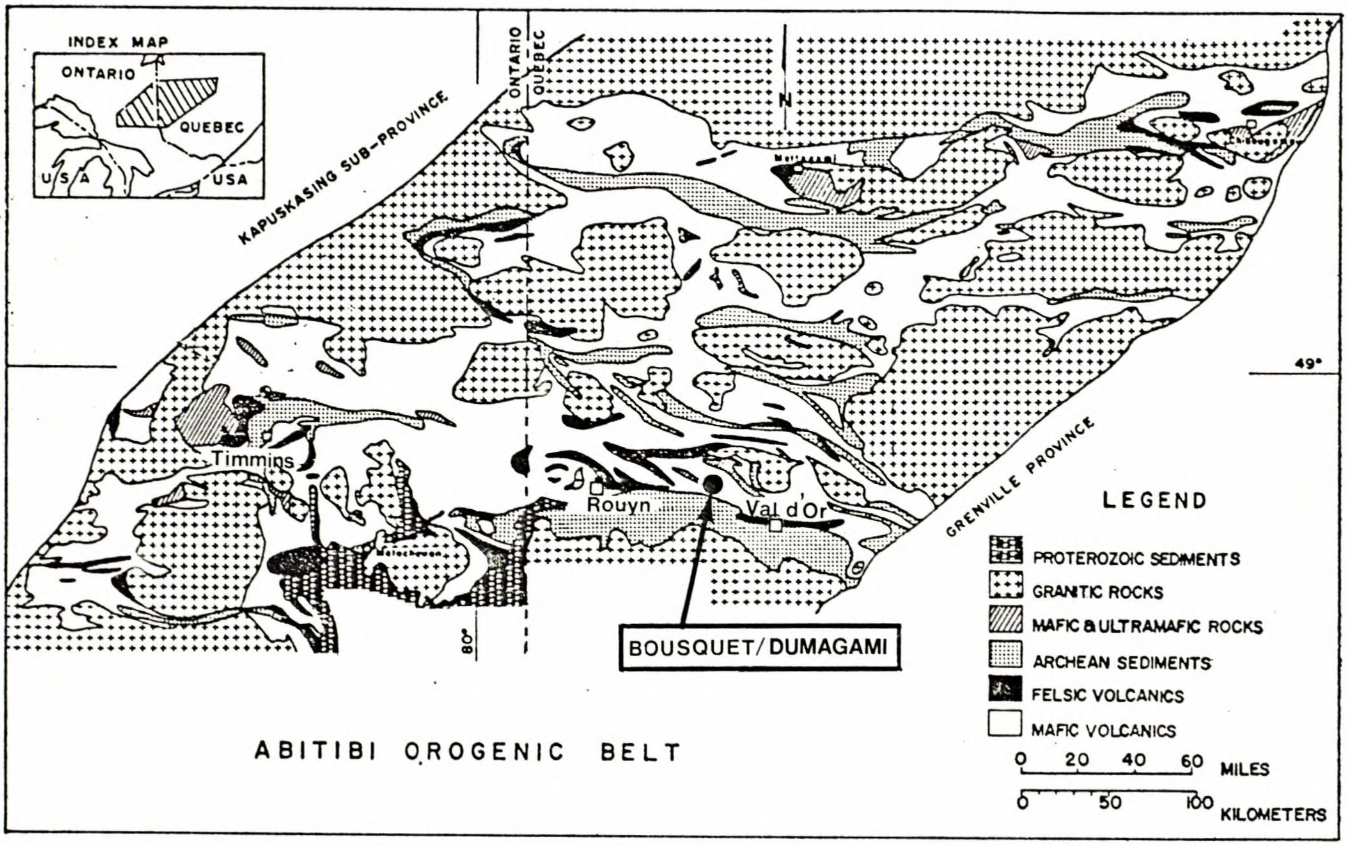

Fig. 1 - Regional geology and the location of Bousquet/Dumagami Mines (1).

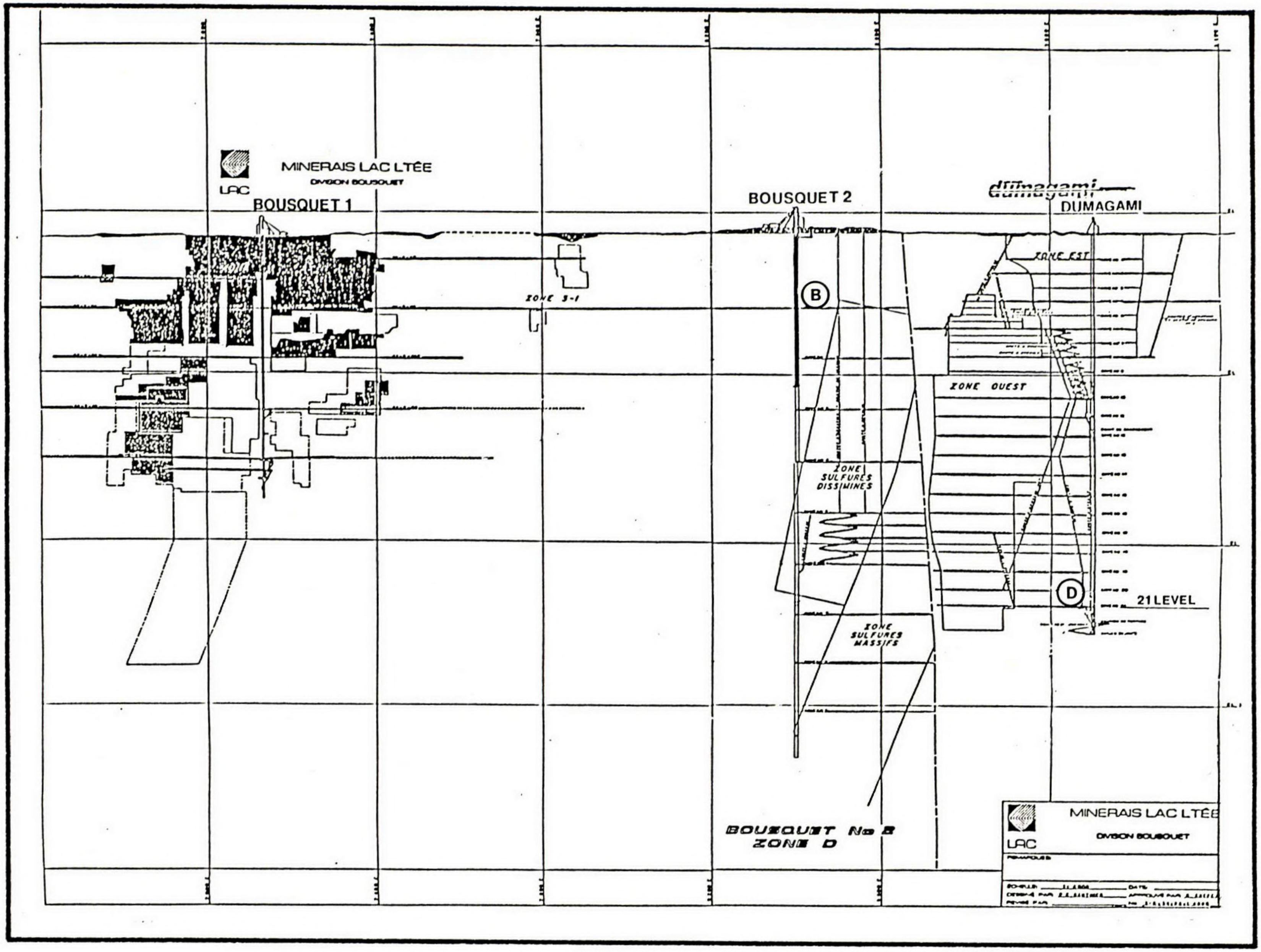

Fig. 2 - Longitudinal east-west section showing the location of the stress determination sites at the Bousquet 2 Mine (B), and the Dumagami Mine (D).

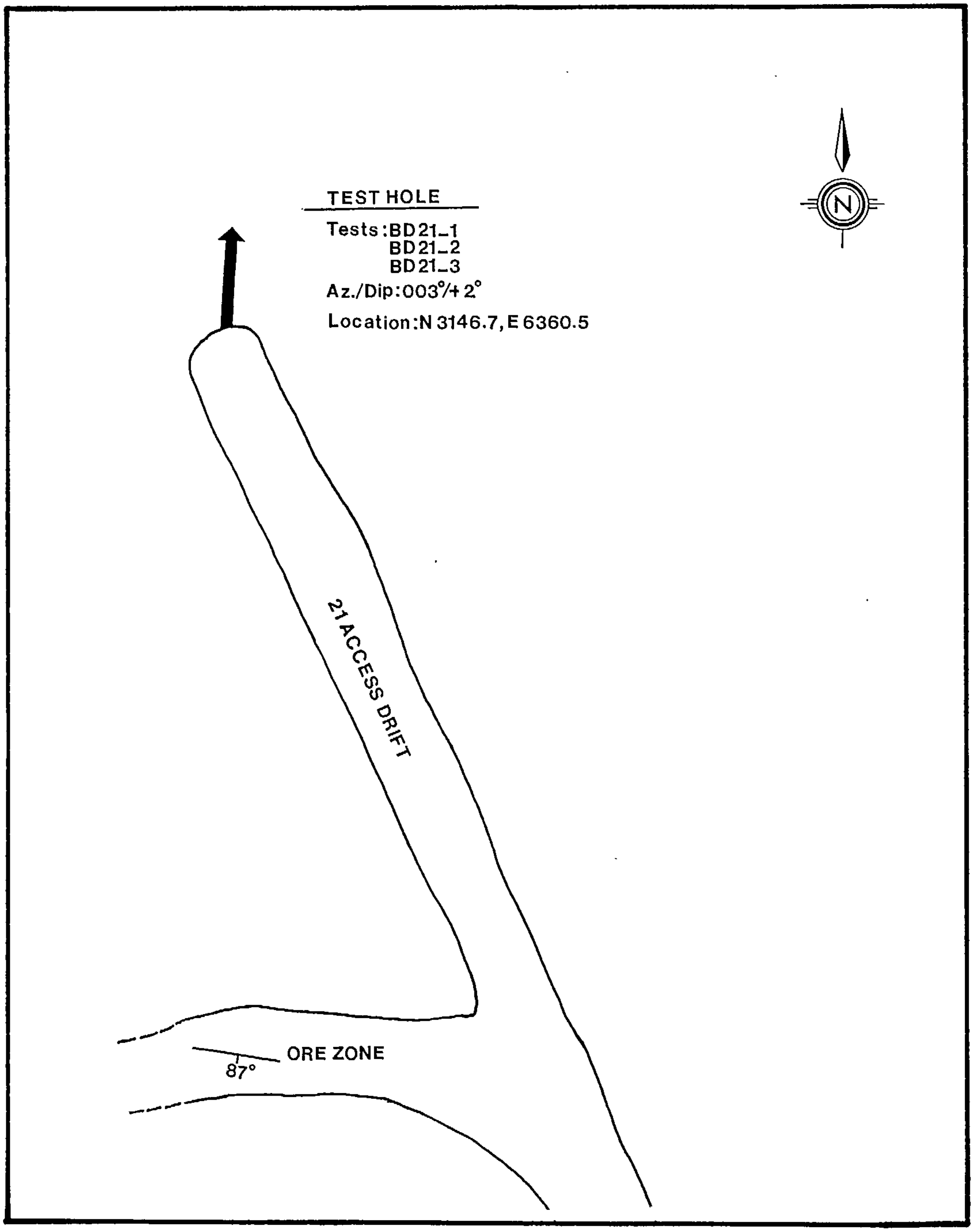

Fig. 3 - Stress determination site and test hole location (not to scale).

and schistosity. Core breakage occurred along the schistosity planes as well as sub-vertical discontinuities intersected in the drill hole. Strain relief overcoring measurements using CSIR triaxial strain cells were taken in a fine-medium grained, mainly banded ('bedded') porphyry tuff of the footwall strata. Three successful measurements: tests BD21-1, BD21-2 and BD21-3 were conducted at locations of 3.75 m to 4.70 m from the drift boundary (dimension: 3 m^2). The elastic strain recoveries and strain invariances for the individual tests are given in Table 1.

Following the standard procedure, rock property values were determined from uniaxial compression testing on the limited core specimens available. The elastic modulus and Poisson's ratio were obtained at a maximum load of about 30.0 MPa using the 60 ton press. The uniaxial compressive strength was determined at failure load on the same core specimens using the 2000 ton press. The results are given in Table 2. (According to the standard rock testing procedure, a height to diameter ratio of 2.5 is recommended. As a result of short core specimens, lower ratios were obtained, therefore, a possible 'size effect' on the values cannot be excluded.)

For the stress tensor calculations of tests BD21-1 and BD21-2, average elastic constants obtained from two solid core specimens, and for BD21-3, the values determined from overcored test specimen were used.

RESULTS OF STRESS DETERMINATIONS

For the stress determinations, the data were processed by a computer program which calculates the stress components and principal stresses, and provides relevant statistical information (3). The tensor of best fit is calculated according to a least squares method. The results of stress determinations are provided in Table 3. The stress components in E-W, N-S and vertical directions, and the orientation of principal compressive stresses are

Table 1 - Strain recovery from triaxial strain cell measurements

Location (Depth)	Test No.	Test Depth (m)	Microstrain ($\mu\varepsilon$) Gauge No: 1	2	3	4	5	6	7	8	9	10	11	12	SI* Rosette No. 1	2	3
21 Level (900 m)	BD21-1	3.75	-20	565	535	-50	1460	560	520	1400	715	770	925	890	0	20	20
	BD21-2	4.30	85	520	460	50	1740	580	450	1570	310	380	520	465	25	40	15
	BD21-3	4.70	70	460	740	380	1570	680	440	1325	1345	1270	580	655	30	5	0

* Strain invariance : sum of orthogonal strains ($\varepsilon_1 + \varepsilon_3 = \varepsilon_2 + \varepsilon_4$).

Test hole data : coordinates N3146.7, E6360.5; Bearing/Dip 003°/+2°.

Table 2 - Determination of rock properties from uniaxial compression testing

Sample No.	Core Specimen Height (mm)	Dia. (mm)	Ratio H/D	Elastic Modulus (GPa)	Poisson's Ratio	Uniaxial Compressive Strength (MPa)	Remarks
BD21-A	270	142	1.90	68.95	0.26	127.8	-
BD21-B	274	142	1.92	64.83	0.22	105.5	Specimen fractured
BD21-3	260	142	1.83	53.10	0.21	168.0	-

Note: Rock type: Porphyry tuff; fine-medium grained, banded ('bedded'). Loading perpendicular to the schistosity planes and 'bedding'.

Table 3 - Stress components and principal stresses from field stress determinations (stress in MPa).

Location (Depth)	Test No.	Stress Components (Standard errors in brackets) σ_{EW}	σ_{NS}	σ_V	τ_{EN}	τ_{NV}	τ_{VE}	STDV Error*	Principal Compressive Stresses Magnitude/Orientation σ_1	σ_2	σ_3
21 Level	BD21-1	45.6	59.0	16.6	6.6	-8.0	-6.3	1.14	63.8	43.2	14.3
(900 m)		(3.4)	(5.6)	(3.4)	(2.6)	(2.6)	(1.9)	17%	024/11	115/05	227/77
	BD21-2	41.2	45.8	17.7	7.8	-7.3	-14.4	0.72	57.2	36.8	10.5
		(2.1)	(3.5)	(2.1)	(1.6)	(1.6)	(1.2)	13%	044/21	138/11	256/66
	BD21-3	44.0	43.5	19.1	8.0	0.3	-1.1	0.71	51.8	35.8	19.0
		(1.7)	(2.7)	(1.7)	(1.3)	(1.3)	(1.0)	8%	046/00	136/03	300/86

* Percentage of average standard errors for stress components.

Note: Stress components and the principal stresses orientation (Bearing/Dip in degrees) related to the Mine coordinate system (Mine grid north = geographic north).

Elastic constants used for the stress tensor analysis:
BD21-1, BD21-2 : Elastic modulus = 66.9 GPa, Poisson's Ratio = 0.24
BD21-3 : Elastic modulus = 53.1 GPa, Poisson's Ratio = 0.21.

related to the mine coordinate system (Mine grid north = geographic north). The orientation of the principal compressive stresses and the overall trend of the ore zones are illustrated in Figure 4. For completion of data, orientation of stresses obtained from the previous measurement at the Bousquet Mine are also plotted in Figure 4.

The results of stress determinations show that the orientation of the principal compressive stresses are relatively consistent. The maximum and the intermediate principal compressive stresses are horizontal, prevailing overall orientation of N 37^{o} E and N 125^{o} E, respectively. The minimum principal compressive stress is oriented vertically. Comparing the stress magnitudes, insignificant variations were observed between tests BD21-2 and BD21-3, with differences of mean stress of about 2%. Test BD21-1, however, indicates a mean stress value 14% higher than the remaining data. Since the possibility exists that the measurements were influenced by the excavation geometry, results are not included in the final evaluations.

The magnitudes of measured vertical stress were about 70-80% of the estimated average overburden load (0.027 MN/m^3). Disturbance of the vertical in situ stress component can be explained by a possible effect of existing mining excavations (drifts) at the elevations above the stress determination site.

Figure 5 shows the variation of vertical, average horizontal stress and the ratio of average horizontal/vertical stress as a function of depth from the stress determinations in the Canadian Shield (4). For comparison, the data obtained at the Bousquet/Dumagami Mines are also plotted in this Figure. Data plots suggest that comparable values are obtained from the present stress determinations.

Based on the present data, evaluation of pre-mining horizontal compressive stresses and the vertical stress resulted in the following average

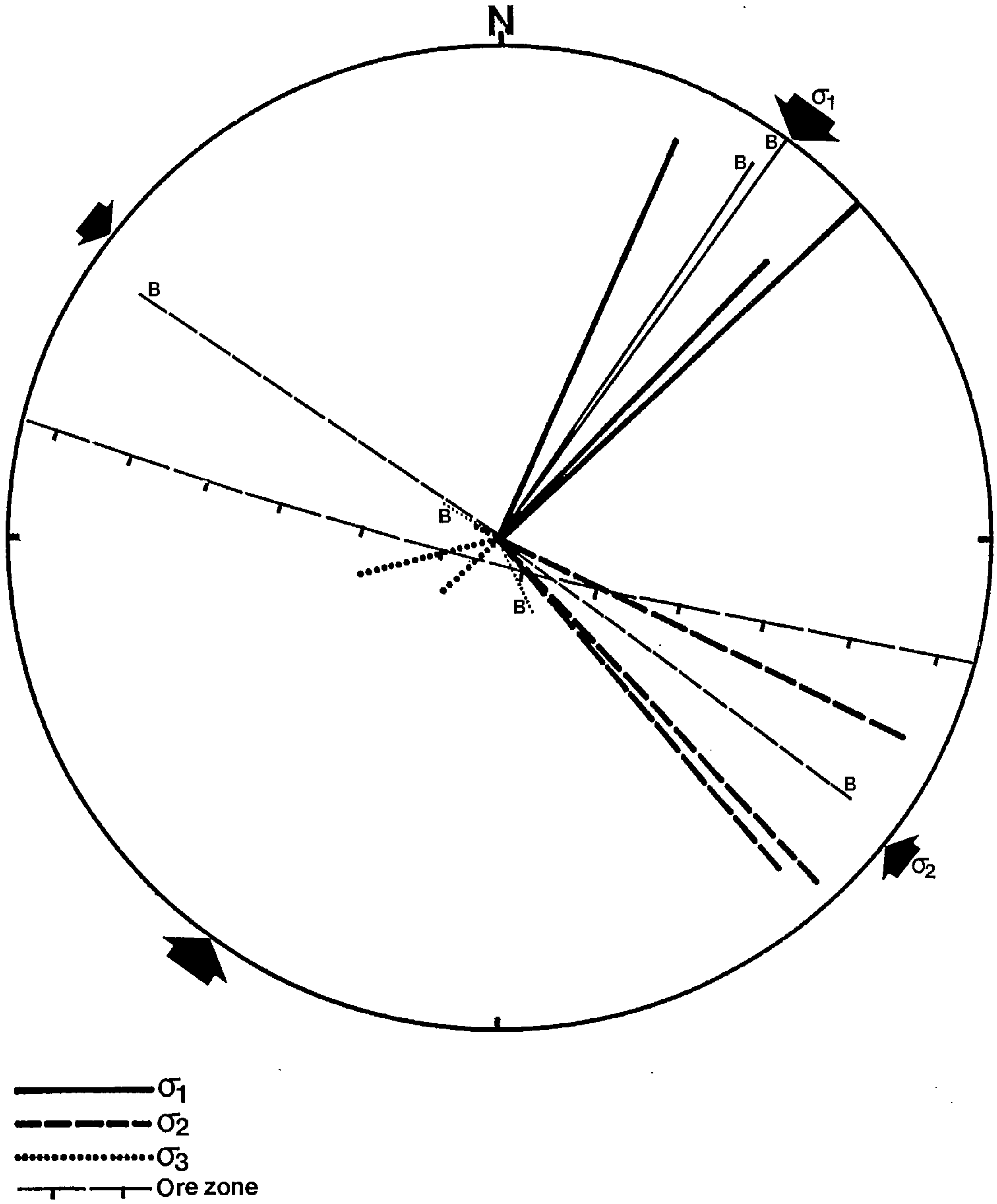

Fig. 4 - Orientation of the principal compressive stresses from Mine grid north (= geographic north) in an equal area net, lower hemisphere projection. (B) orientations obtained from stress determination at the Bousquet 2 Mine.

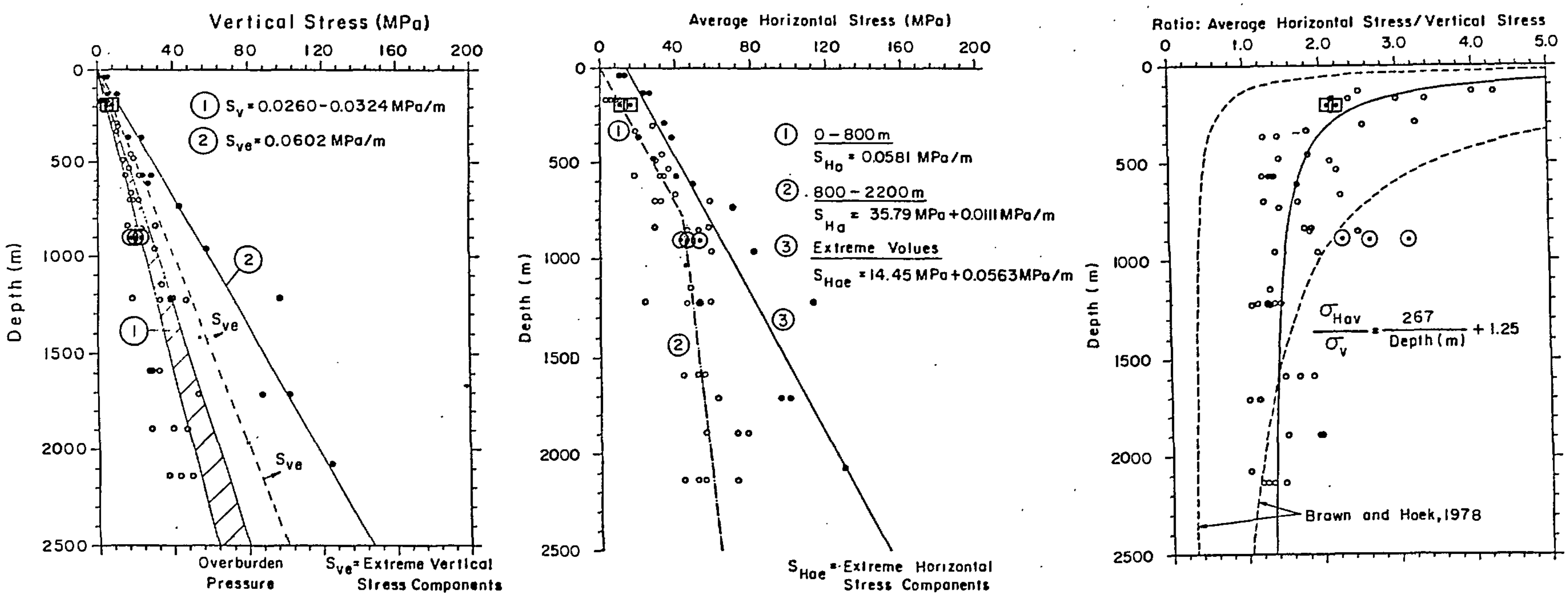

Fig. 5 - Variation of vertical, average horizontal stress and the ratio of average horizontal/vertical stress as a function of depth in the Canadian Shield. (⊙) values from stress determinations at the Dumagami Mine and the Bousquet Mine (⊡).

stress gradients and ratios:

Maximum horizontal compressive stress, $\sigma Hmax = 0.0605 \pm 0.004$ MPa/m

Minimum horizontal compressive stress, $\sigma Hmin = 0.0403 \pm 0.0008$ MPa/m

Average horizontal compressive stress, $\sigma Ha = 0.0505 \pm 0.003$ MPa/m

Vertical stress, $\sigma v = 0.0205 \pm 0.001$ MPa/m

$\sigma Hmax/\sigma Hmin = 1.50 \pm 0.08$

$\sigma Hmax/\sigma v = 2.97 \pm 0.36$

$\sigma Hmin/\sigma v = 1.97 \pm 0.14$

$\sigma Ha/\sigma v = 2.47 \pm 0.25$

For stability evaluations and mine design, the pre-mining vertical and horizontal stresses perpendicular and parallel to the ore zones can best be approximated as follows (stress in MPa):

Vertical stress, σv = 0.0212 MN/m^3 x Depth, m (0.027 MN/m^3 x Depth, m)

σH, perpendicular = 2.85 x σv (2.24 x σv)

σH, parallel = 1.90 x σv (1.50 x σv)

The above calculations are based on maximum measured vertical stress. For a comparison, values based on an estimated average overburden load are given in brackets.

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