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FIELD STRESS DETERMINATIONS AT THE NIOBEC MINE, CHICOUTIMI, QUEBEC

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by

B. Arjang*

ABSTRACT

As part of a stability evaluation project, field stresses were determined at the Niobec Mine Ltd., Chicoutimi, Quebec. Elastic strain recovery measurements were carried out at 260 m and 305 m below surface, with an overcoring technique using triaxial strain cells.

Stress determinations indicated a vertical stress gradient, σv, of about 0.0286 ± 0.0106 MPa/m, and an average horizontal stress gradient, σHa, of 0.0595 ± 0.0168 MPa/m, with a stress ratio, $\sigma Ha/\sigma v$, of 2.1. The magnitude of the horizontal E-W stress ranged between 1.3 to 2.3 times the horizontal N-S stress.

The maximum pre-mining stress is horizontal in the northeast to easterly direction, and acts perpendicular to the complex ore-bearing deposit of the mine.

The orientation of principal compressive stresses and the measured stress gradients followed the trend observed for the Canadian Shield, particularly Northern Ontario.

Key words: Niobec Mine; Strain recovery; Triaxial strain cell; Pre-mining stress.

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MESURE DES CONTRAINTES IN SITU À L'EMPLACEMENT DE LA MINE NIOBEC À CHICOUTIMI AU QUÉBEC

par

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RÉSUMÉ

Dans le cadre d'un projet d'évaluation de la stabilité du terrain, on a déterminé les contraintes in situ à l'emplacement de la mine Niobec Ltée, à Chicoutimi au Québec. On a effectué à 260 m et 305 m au-dessous de la surface du sol, des mesures de la recouvrance ultérieure à la déformation élastique, en employant une technique de surcarottage avec cellules d'essais de déformation triaxiale.

Les mesures des contraintes ont indiqué l'existence d'un gradient vertical de contrainte, σv, d'environ 0,0286 ± 0,0106 MPa/m, et l'existence d'un gradient horizontal moyen, σHa, de 0,0595 ± 0,0168 MPa/m, avec un rapport des contraintes, $\sigma Ha/\sigma v$, de 2,1. La contrainte horizontale E-W était de 1,3 à 2,3 fois supérieure à la contrainte horizontale N-S.

La contrainte maximale, avant les travaux d'exploitation minière, est horizontale dans la direction nord-est à est, et se manifeste perpendiculairement au gîte minéral complexe faisant l'objet de l'exploitation minière.

L'orientation des principaux efforts de compression, et les gradients des contraintes tels que mesurés, suivent la tendance observée dans le Bouclier canadien, en particulier dans le nord de l'Ontario.

Mots-clés : Mine Niobec; recouvrance; cellule d'essais de déformation triaxiale; contraintes avant les travaux d'exploitation minière.

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INTRODUCTION

In 1985, a cooperative research project was established between CANMET and Le Centre de Recherches Minerales, Ministere de l'Energie et des Ressources, Gouvernement du Quebec with the active participation of the Niobec Mine. The main purpose was an assessment of mine stability and the determination of basic input parameters for a numerical modelling of the various mining stages in order to provide guidelines for mine design and ground control.

The evaluation of the surface crown pillar (1), and the instrumentation for the stress monitoring on the selected sites, using vibrating wire stress rings, have been carried out. Numerical modelling for the preliminary assessment of a proposed large span stope has been conducted (2).

As part of the research project, field stress measurements were performed in selected development drifts on the 850 and 1000 levels. The pre-mining stresses were determined using an overcoring testing procedure. Eight tests were attempted at three sites.

GEOLOGICAL SETTING AND MINING BACKGROUND

The Niobec Mine is located about 13 km northeast of Chicoutimi, Quebec. The niobium (Nb_2O_5) deposits occur within the St. Honore Carbonatite Complex of the Saguenay Graben Structure in the pre-Cambrian Grenville Province of the Canadian Shield. The ore-bearing Carbonatite formations are covered by a capping of Paleozoic limestone. The main structural features are northeasterly oriented sub-horizontal and sub-vertical joint sets. No major faults have been distinguished within the mine property. Figure 1 shows the regional geological setting of the Chicoutimi area and a section of the Carbonatite Complex. The mine and regional geology have been studied in

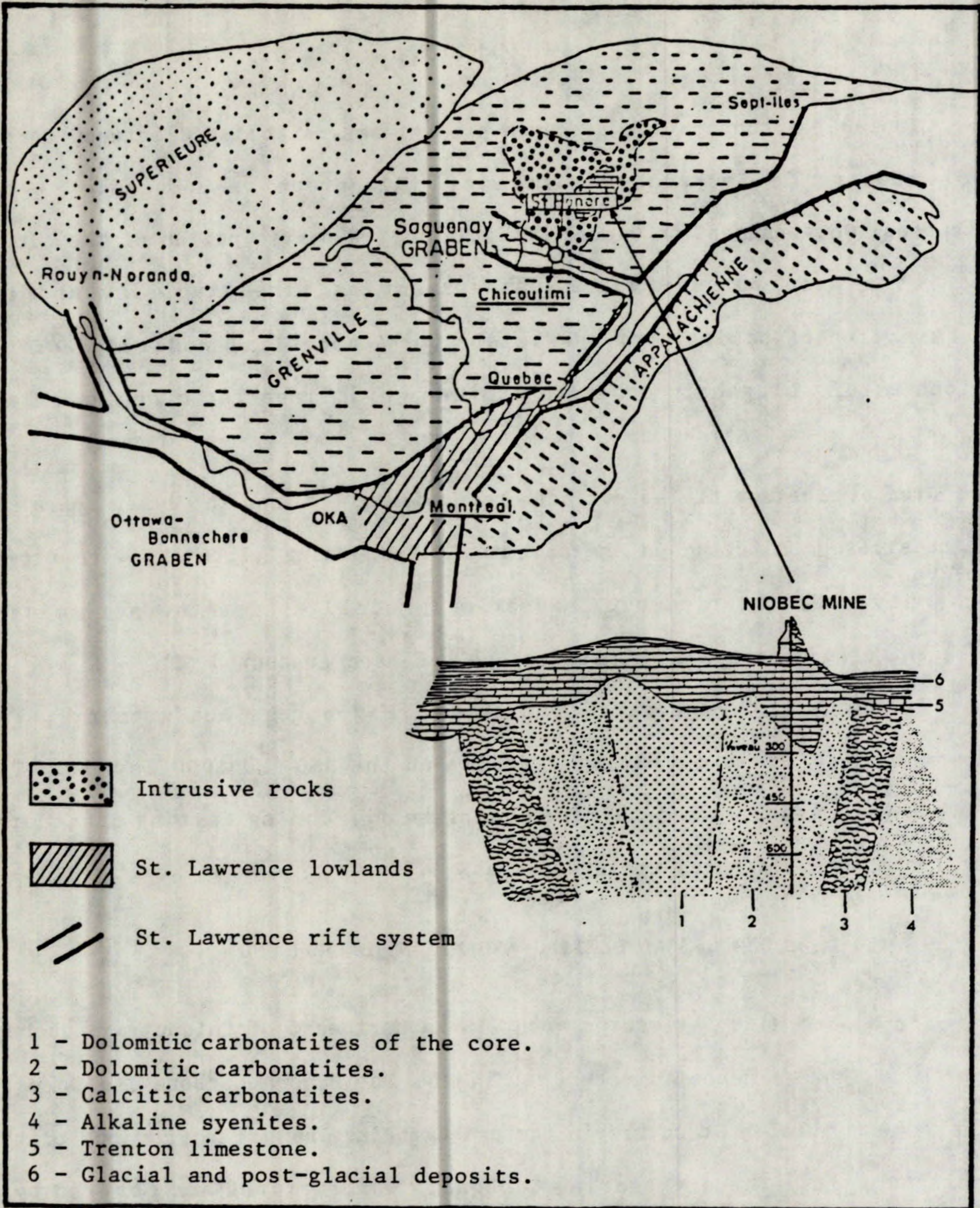

Fig. 1 - Regional geology of the Chicoutimi area and a section of St. Honore Carbonatite Complex.

detail elsewhere (3,4).

The orebody comprises a massive deposit of disseminated, irregularly shaped zones defined by grade as opposed to structure. It is bounded by a general cylindrical form, approximately 1000 m in diameter, extending some 300 m below surface.

The mine develops stopes using blasthole methods. In primary stoping, an irregular room-and-pillar mining method with about 50% extraction rate is used. The sequence of secondary stoping extraction involves the sill and crown pillars. The current practice is to mine the crown pillar and upper 75 m stope simultaneously, with development proceeding from 300 level. Figure 2 shows a longitudinal section of the mining layout with typical upper and lower stopes and the location of the stress measurement sites.

So far the mine has experienced some minor structurally-controlled instability problems.

FIELD STRESS MEASUREMENTS AND LABORATORY TESTING

Three-dimensional strain recovery measurements were carried out on the 850 and 1000 levels, 260 m and 305 m below surface. The measurements were taken in a carbonatite rock, away from the influence of mining. The coarsely grained carbonatites were composed of crystalline calcite with bands and fragments of syenite containing numerous vugs.

The test holes, having a diameter of 153 mm and inclination of 3^{o} to 8^{o} from horizontal, were drilled with a thick wall core barrel which yielded a core of 120 mm diameter. For the overcoring process a thin wall core barrel was used yielding a core of 144 mm diameter. On the 850 level, test holes were drilled at two sites. The first test hole, on the 1000 level, had to be abandoned at a depth of 10 m because of continuous core breakage. Only one test was attempted which was unsuccessful. The successful tests were obtained

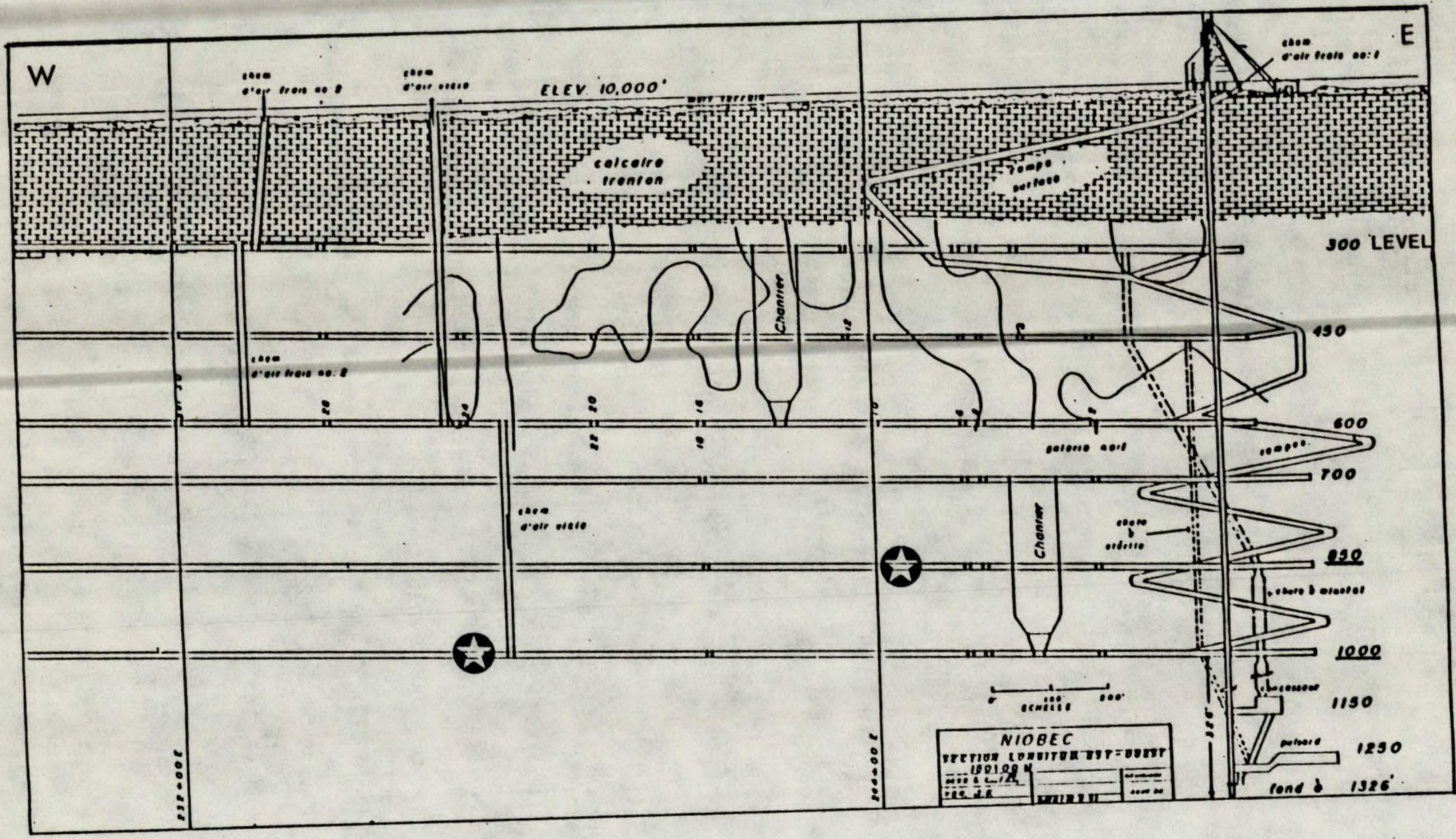

Fig. 2 - Longitudinal section of Niobec Mine showing mining layout and the locations of stress determination sites ✪.

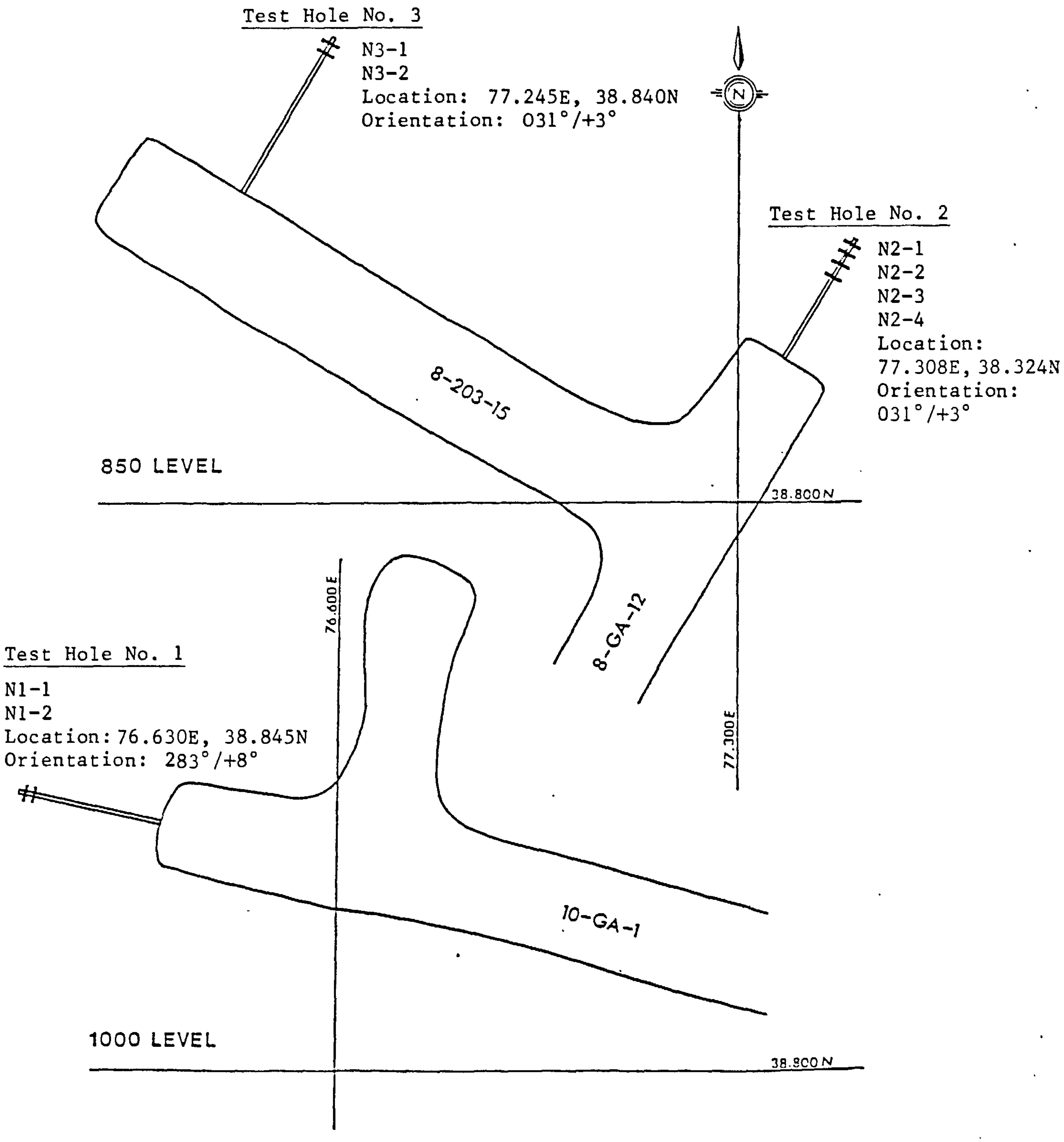

Fig. 3 - Stress determination sites and test hole locations on the 850 and 1000 levels, Niobec Mine.

in the second hole on this level. The orientations and location plans of test holes are shown in Figure 3. The measurements commenced at distances greater than 4.5 m from the wall of the drifts, which were about 3.5 x 4.9 m.

No major structural weakness planes were exposed in the vicinity of the stress measurement sites.. Some continuous sub-horizontal fractures were encountered, which resulted in core breakage. The selection of suitable locations to install the strain cell in fractured vugular rock hindered the field work. Many pilot holes had to be attempted to obtain a competent test location.

For the stress determinations, both Australian hollow inclusion triaxial strain cells (CSIRO) and South African triaxial strain cells (CSIR) were used. Details of the overcoring test procedure and the specifications of the strain cells are given in references 5 to 7. A total of five CSIRO and four CSIR overcoring tests were performed. The elastic strain recoveries from triaxial strain cell measurements are given in Table 1. The plots of gauge responses from strain recovery during overcoring (CSIRO strain cells) and the biaxial loading test on available overcored test specimens are shown in Appendix A.

In the laboratory, the hollow overcored specimens containing the strain cells were checked for cell-rock bonding. All tests containing the CSIRO strain cells were sectioned. The quality checks indicated poor bonding in test N2-1, which was consistent with the strain loss and the low strain recovery obtained during the overcoring. The epoxy in tests N1-2 and N3-1 contained minor air bubbles. Outlier gauge readings were observed, in the field and the laboratory, from test N2-4 on No. 3 rosette (CSIR cell).

Bonding problems observed from some CSIRO strain cell measurements can be related to the composition of rock type, which contained crystalline calcite, as well as to the quality of the epoxy provided by the manufacturer.

Table 1 - Strain recovery from triaxial strain cell (CSIRO and CSIR) measurements, Niobec Mine.

Location	Test No.	Test Depth (m)	Elastic Strain Recovery (με)											
			Gauge No.: 1	2	3	4	5	6	7	8	9	10	11	12
	Test Hole No. 2:													
850 Level	N2-1(1)	4.70	225	-32	110	20	70	6	107	-40	6	CSIRO Hi-Cell		
	N2-2*	5.70	210	370	300	170	465	215	60	330	350	375	120	95
	N2-3*	6.45	50	100	170	85	640	125	225	740	60	145	270	200
	N2-4*(2)	7.00	240	190	25	115	280	135	40	160	310	-	-	-
	Test Hole No. 3:													
	N3-1(3)	8.45	250	95	140	130	130	115	175	85	125	CSIRO Hi-Cell		
	N3-2	9.45	260	60	180	110	225	50	150	105	120	CSIRO Hi-Cell		
1000 Level	Test Hole No. 1:													
	N1-1	6.75	185	160	130	210	75	150	255	115	200	CSIRO Hi-Cell		
	N1-2	7.30	180	195	115	300	50	125	40	180	150	CSIRO Hi-Cell		

* CSIR triaxial strain cell.
(1) Test unsuccessful.
(2) Poor cell-rock bonding on rosette No. 3, strain readings from gauge No. 10, 11 and 12 rejected.
(3) Large air bubbles.

Apparently, creep of the epoxy layer on the rock surface resulted in inadequate bonding and subsequent low strain recoveries. In comparison, good bonding quality was achieved in CSIR triaxial strain cell measurements. Probably, the strain cell rosettes which were installed under pressure on a limited surface of the rock resulted in better bonding compared with CSIRO strain cells.

The elastic constants were determined from the available intact core specimens in the laboratory and from the biaxial compression tests on the stress measurement sites. The results are given in Table 2. The mean values for the elastic moduli and Poisson's ratios were used for stress tensor calculations. For the individual stress determination sites, differences in the elastic constants were insignificant.

STRESS DETERMINATIONS

For the stress determinations, the data were processed by computer programs which calculate the stress components, magnitudes and orientation of the principal stresses, and provide relevant statistical information (8,9). The calculation results in the tensor of the best fit according to a least squares solution. Calculated values for the stress components in E-W, N-S, vertical and shear stresses are given in Table 3. The principal stress magnitudes and orientations with regard to the true north (= Mine grid north) are given in Table 4. Figure 4 illustrates the orientation of principal compressive stresses in an equal area net, lower hemisphere projection.

To calculate the principal stresses for the CSIR triaxial measurements, tensor components (E, N, V, EN, VE, NV) related to the mine grid system are used.

Table 2 - Determination of elastic modulus (E) and Poisson's ratio (ν) from uniaxial and biaxial compression tests.

Location	Test No.	Core Height (mm)	Core Diam. (mm)	Ratio Hgt./ Diam.	E (GPa)	ν	Remarks
850 Level	N2-1*	355	144	2.46	76.89	0.25	
	N2-2**	355	144	2.46	72.89	0.30	
	N2-3	-	-	-	-	-	Overcored specimen broke under load
	N2-4*	280	144	1.94	72.55	0.24	
	N3-1	-	-	-	-	-	Overcored specimen fractured, broke under load
	N3-2*	355	144	2.46	75.86	0.26	
			Mean value:		74.55 ±2.15	0.26 ±0.02	
1000 Level	N1*	258	120	2.15	73.86	0.33	
	N2*	300	120	2.5	73.31	0.36	
	N3*	296	120	2.46	75.03	0.20	
	N1-1**	350	144	2.43	74.48	0.46	
	N1-2**	300	144	2.08	77.24	0.40	
			Mean value:		74.78 ±1.51	0.35 ±0.09	

* Uniaxial compression tests: obtained from strain gauge readings during unloading cycle in intervals of 12 to 25 MPa; maximum load 37 MPa.

** Biaxial compression tests: obtained from strain reading of the axial and circumferential gauges of the strain cell.

Note: Rock type: carbonatite, some core samples porous or contained vugs.

Table 3 - Stress tensor components from strain recovery measurements, Niobec Mine.

Location	Test No.	Stress Components (MPa) (Standard errors in brackets) * σ_{N-S} ** σ_X	σ_{E-W} σ_Y	σ_V σ_Z	$\tau_{NS/EW}$ τ_{XY}	$\tau_{EW/V}$ τ_{YZ}	$\tau_{V/NS}$ τ_{ZX}	Elastic Modulus (GPa)	Poisson's Ratio ν
850 Level	Test Hole No. 2:								
	N2-1	* 5.64	3.45	-0.07	3.74	-1.15	-1.64	74.55	0.26
		(0.51)	(0.36)	(0.23)	(0.28)	(0.13)	(0.26)		
	N2-2	** 17.15	13.92	20.31	-1.17	1.16	-3.38	74.55	0.26
		(2.41)	(2.41)	(3.95)	(1.39)	(1.79)	(1.79)		
	N2-3	** 16.72	7.70	23.30	-6.46	3.45	-4.78	74.55	0.26
		(2.68)	(2.68)	(4.40)	(1.55)	(1.98)	(1.98)		
	N2-4	** 12.02	10.91	8.52	0.42	1.10	0.21	74.55	0.26
		(0.35)	(0.31)	(0.64)	(0.20)	(0.28)	(0.36)		
	Test Hole No. 3:								
	N3-1	* 12.37	8.05	4.60	4.58	-0.47	-0.58	74.55	0.26
		(0.29)	(0.21)	(0.13)	(0.16)	(0.08)	(0.15)		
	N3-2	* 16.77	10.06	5.50	8.23	-1.49	-3.17	74.55	0.26
		(0.99)	(0.50)	(0.49)	(0.52)	(0.32)	(0.59)		
1000 Level	Test Hole No. 1:								
	N1-1	* 8.21	19.40	7.30	-2.32	0.22	-0.53	74.78	0.35
		(0.34)	(0.71)	(0.30)	(0.28)	(0.30)	(0.17)		
	N2-2	* 7.17	22.17	9.43	-0.12	1.11	0.02	74.78	0.35
		(0.13)	(0.51)	(0.15)	(0.12)	(0.16)	(0.07)		

*) CSIRO hollow inclusion strain cell.

**) CSIR triaxial strain cell; X, Y, Z are coordinates of an orthogonal coordinate system: X^+ is on right-hand side when looking down the drill hole; Y^+ is vertical; Z^+ is parallel to the drill hole direction and points towards the collar.

Table 4 - Magnitude and orientation of the principal stresses from elastic strain recovery measurements, Niobec Mine.

Location	Test No.	σ_1 MPa	Brg./Dip*	σ_2 MPa	Brg./Dip	σ_3 MPa	BRG./Dip
850 Level	N2-2	22.76	064/08	15.10	156/15	13.53	308/73
	N2-3	27.76	064/15	15.70	160/21	4.26	301/64
	N2-4	12.30	314/24	11.10	083/54	8.10	212/24
	N3-1	15.32	212/04	5.15	303/08	4.55	276/-81
	N3-2	23.00	214/11	5.20	110/50	4.12	132/-37
1000 Level	N1-1	19.85	281/-02	8.05	012/-32	7.00	009/58
	N1-2	22.26	270/-05	9.35	280/85	7.17	180/01

* Bearing in degrees clockwise from Grid North (Grid North = True North); dip is the angle in degrees positive down from horizontal.

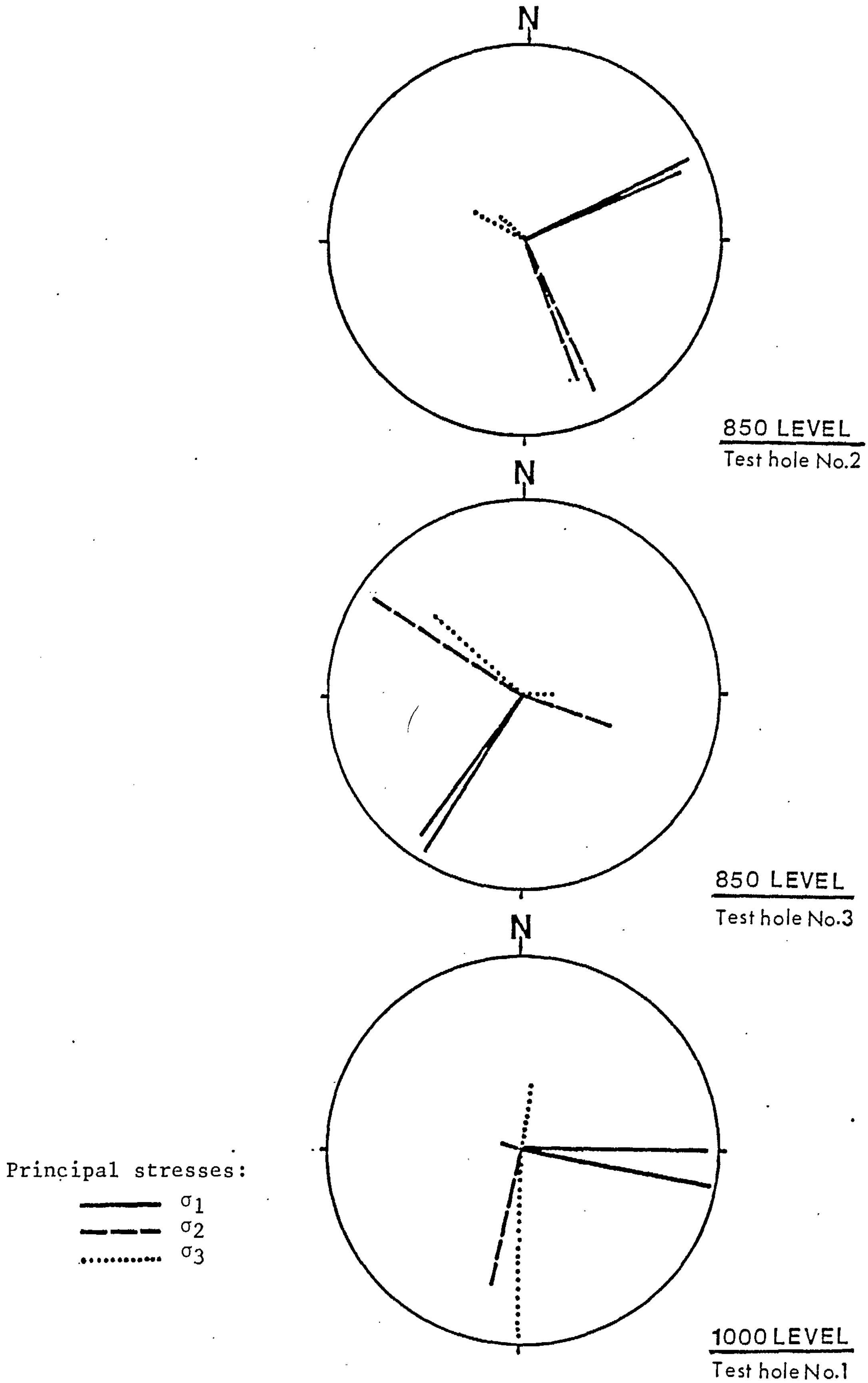

Fig. 4 - Orientation of the principal compressive stresses from Grid North (= True North) in an equal area net, lower hemisphere projection.

DISCUSSION OF RESULTS

The results presented a good correlation between the individual measurements and comparable stress values on three test sites. The high coefficient of correlation of the regression line and, in most cases, the low standard deviations suggest that acceptable stresses were determined. However, with regard to test performance and the analysis of the validity of measurements, the questionable and unsatisfactory data were excluded from the final evaluation. The most representative results are summarized in Table 5. For comparison, the values obtained from stress gradients in the Canadian Shield (10) are also included in Table 5.

Mean stresses, $(\sigma_1 + \sigma_2 + \sigma_3)/3$, of 10.7 and 16.5 MPa on the 850 level, and 11.6 MPa on the 1000 level were determined. This indicates a close agreement between the stress values obtained in test holes No. 1 (1000 level) and No. 3 (850 level), whereas about 30% higher stresses were measured in test hole No. 2 (850 level).

The magnitude of the horizontal E-W stress, 1.3 to 2.3 times the horizontal N-S stress, was determined on the 1000 and 850 levels (test hole No. 2). However, the results from test hole No. 3 (850 level), when compared with the remaining data indicated a higher N-S than E-W horizontal stress with some deviations in the orientation of principal compressive stresses. Also the stress magnitudes were found to be 35% lower than from test hole No. 2, located only 30 m away. If the tests in No. 3 hole are considered as valid, such distortions in the stress field are probably indicative of the local structural features at the stress determination site.

Based on results, the mean vertical stress (σ_V) gradient amounted to 0.0286 ± 0.0106 MPa/m, and the average horizontal stress (σ_{Ha}) gradient was 0.0595 ± 0.0168 MPa/m. A stress ratio, σ_{Ha}/σ_V, of about 2.1 was determined.

Table 5 - Results of field stress determinations on the 850 and 1000 levels, Niobec Mine.

Depth Below Surface	Test No.	Stress Components and Principal Stresses (MPa)								Reference Data** (MPa)
		σ_{EW}	σ_{NS}	σ_{V}	σ_1	σ_2	σ_3	σ_{Ha}*	σ_{Ha}/V	
260 m (850 L)	N2-2	22.00	17.00	10.60	25.30	15.40	8.90	20.35	1.9	σ_{Ha} = 15.10
	N2-3				064°/12°	160°/18°	305°/69°			σ_v = 7.00
	Comb.									σ_{Ha}/σ_v = 2.2
	N3-2	10.00	16.80	5.00	23.00	5.20	4.10	14.10	2.5	
					214°/11°	110°/50°	312/37°			
305 m (1000 L)	N1-1	19.40	8.20	7.30	19.85	8.05	7.19	14.00	1.9	σ_{Ha} = 17.70
					111°/02°	192°/32°	009°/58°			σ_v = 8.20
										σ_{Ha}/σ_v = 2.1

* Average horizontal stress, $\sigma_{Ha} = \frac{\sigma_1 + \sigma_2/2}{\sigma_V}$

** Canadian Shield data, obtained from stress gradients defined as (10):

Vertical stress, σ_V = 0.027 MPa/m (obtained from overburden weight)

Average horizontal stress σ_{Ha} = 0.0581 MPa/m (0-800 m depth below surface)

Stress ratio, σ_{Ha}/σ_V = 267/depth (m) + 1.25.

Some variations were observed with regard to the vertical stresses, but in most cases the measured vertical component of the in situ stress approximates the overburden weight.

The maximum pre-mining stress lies in a horizontal plane with northeast to easterly direction. For the individual test sites, the orientations of principal compressive stresses are consistent. However, the direction of maximum principal compressive stress on the 850 level shows a rotation of about 50^{0}, when compared with the 1000 level. The intermediate principal compressive stress is sub-horizontal, while the minor principal compressive stress is vertically oriented.

The stress magnitudes and orientations are comparable with the values established in the Canadian Shield, particularly Northern Ontario. The measured average horizontal stress gradient, as well as stress ratio, agrees well with referenced ground stress data.

ACKNOWLEDGEMENTS

The cooperation of Niobec Mine Ltd., especially the Geology Division, is appreciated. M. Betournay, Mining Research Laboratory, CANMET, acted as liaison officer on this project and maintained good communication. D. Labrie, Le Centre de Recherches Minerales, Ministere de l'Energie et des Ressources, Government de Quebec, assisted during the field work. The necessary laboratory tests were performed by G. Vaillancourt, Elliot Lake Laboratory, CANMET.

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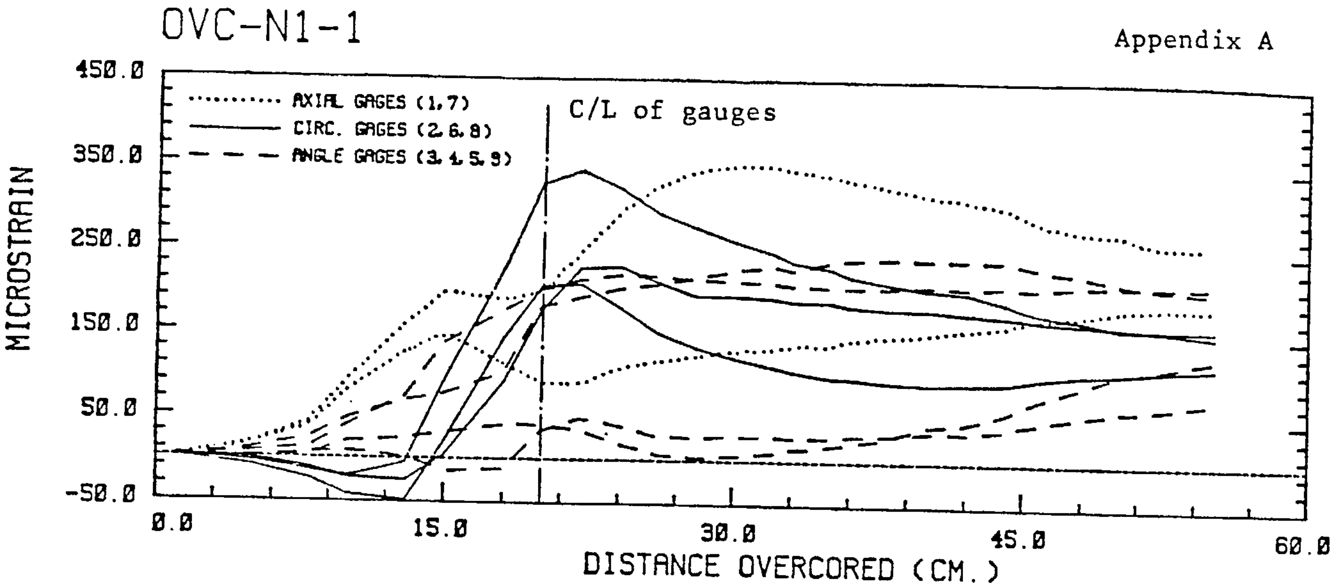


Fig. A-1a - Overcoring response of gauges.

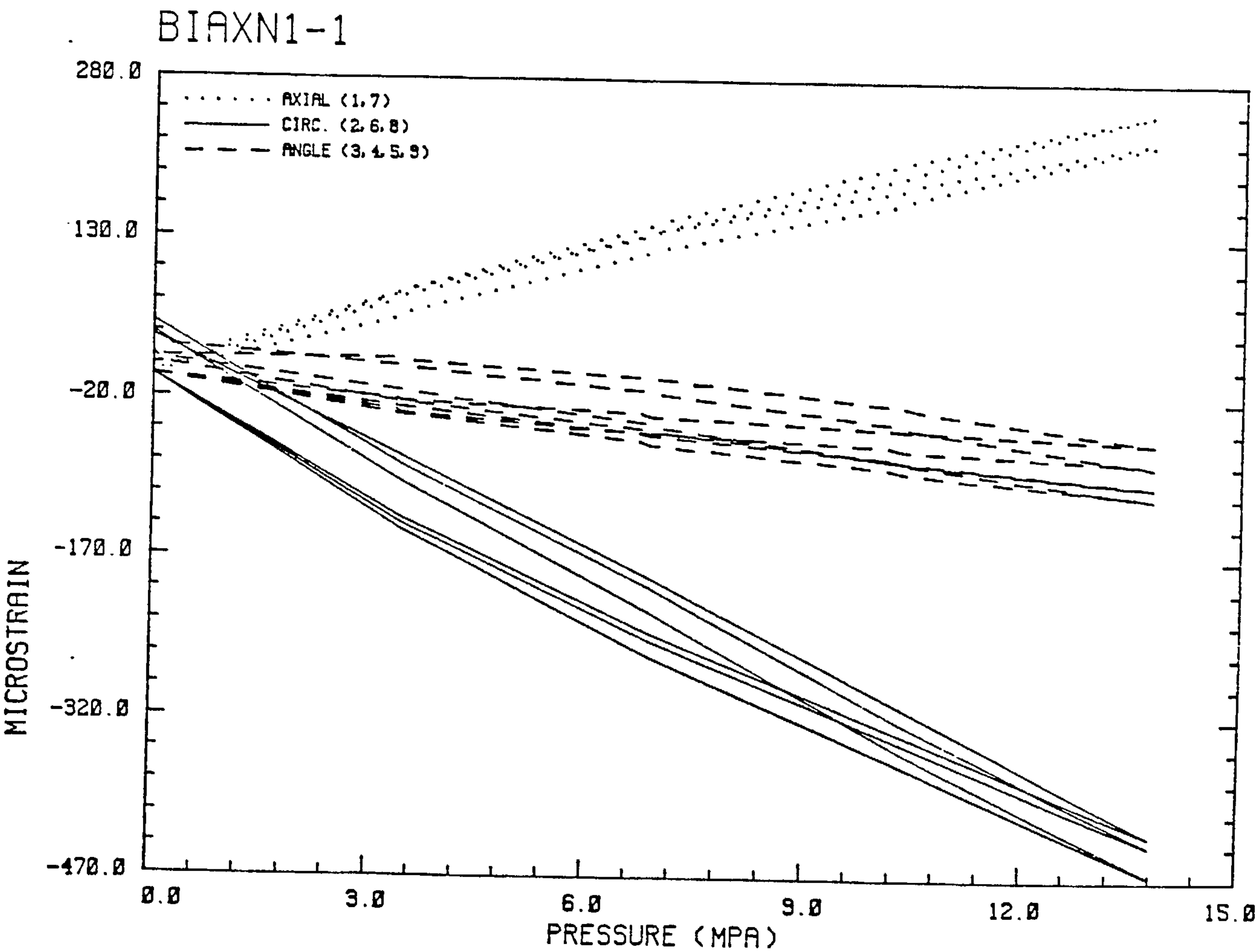


Fig. A-1b - Gauge response and linearity from loading cycle in biaxial compression in test N1-1, 1000 level.

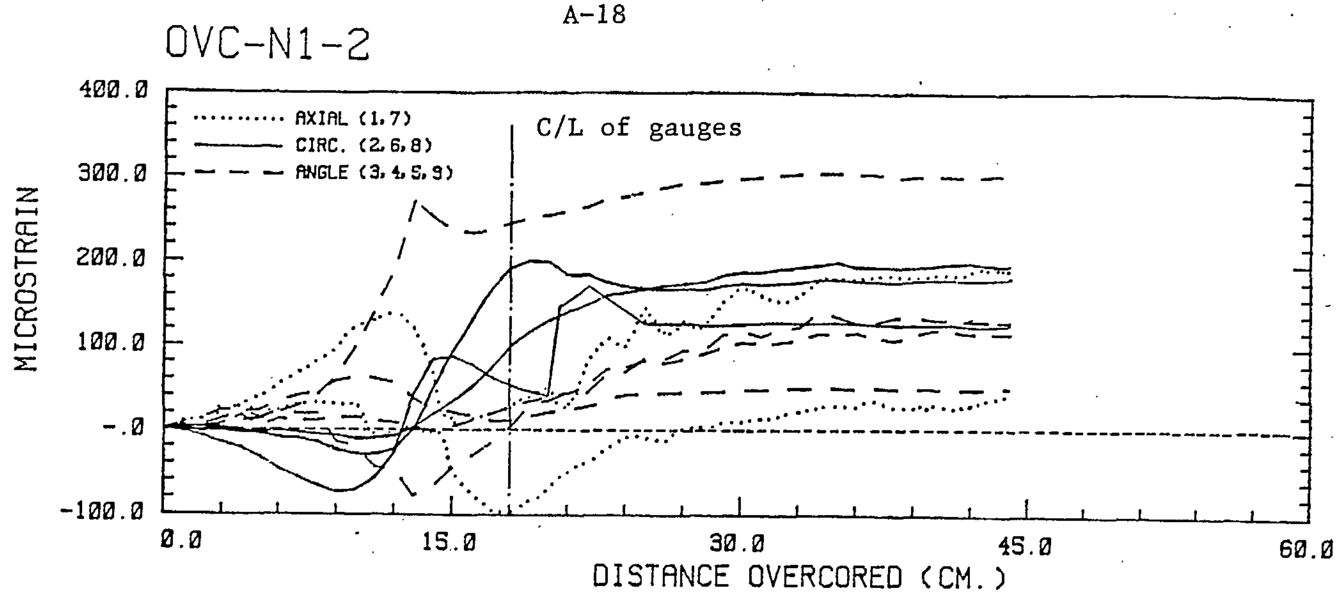


Fig. A-2a - Overcoring response of gauges.

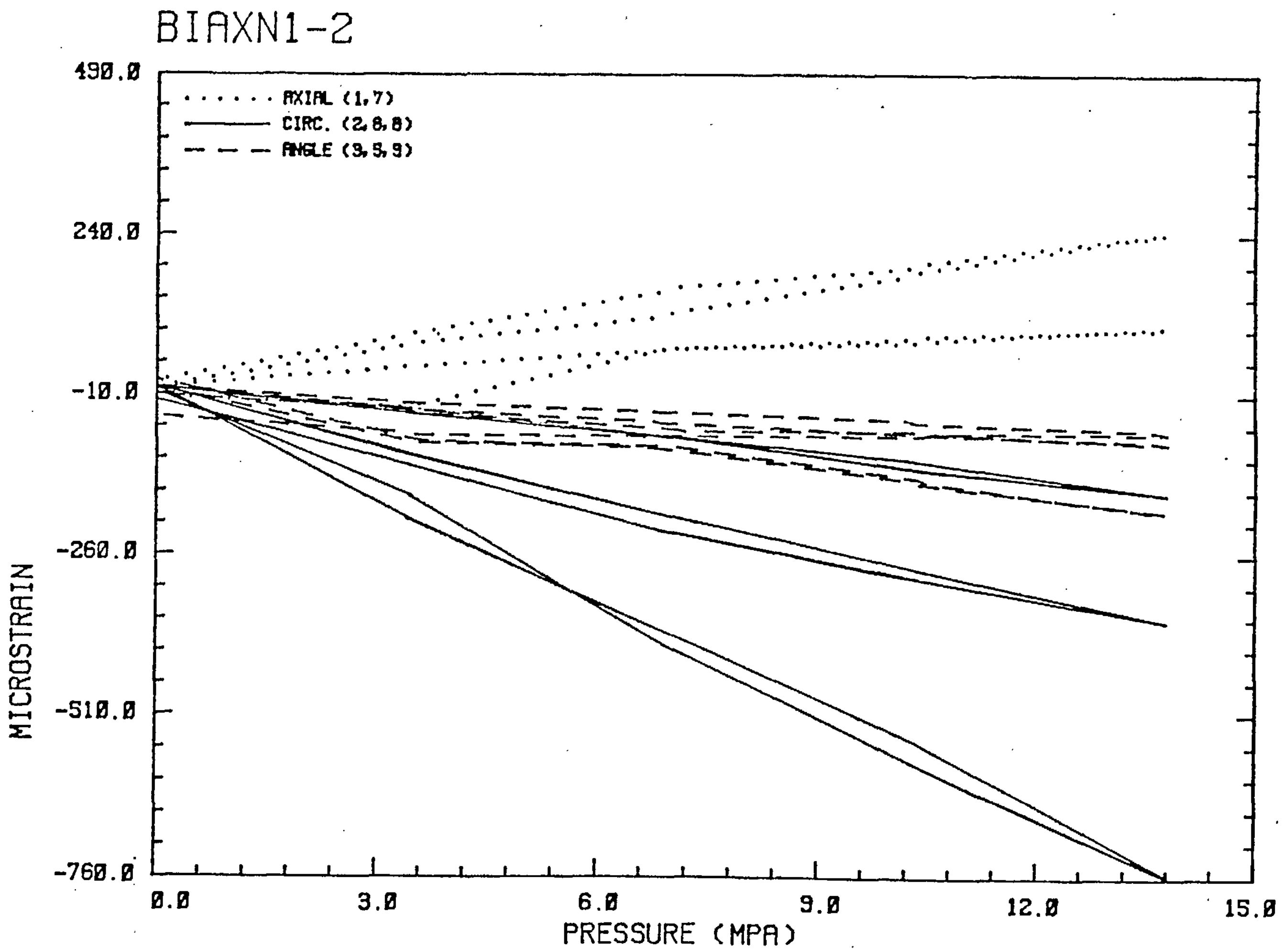
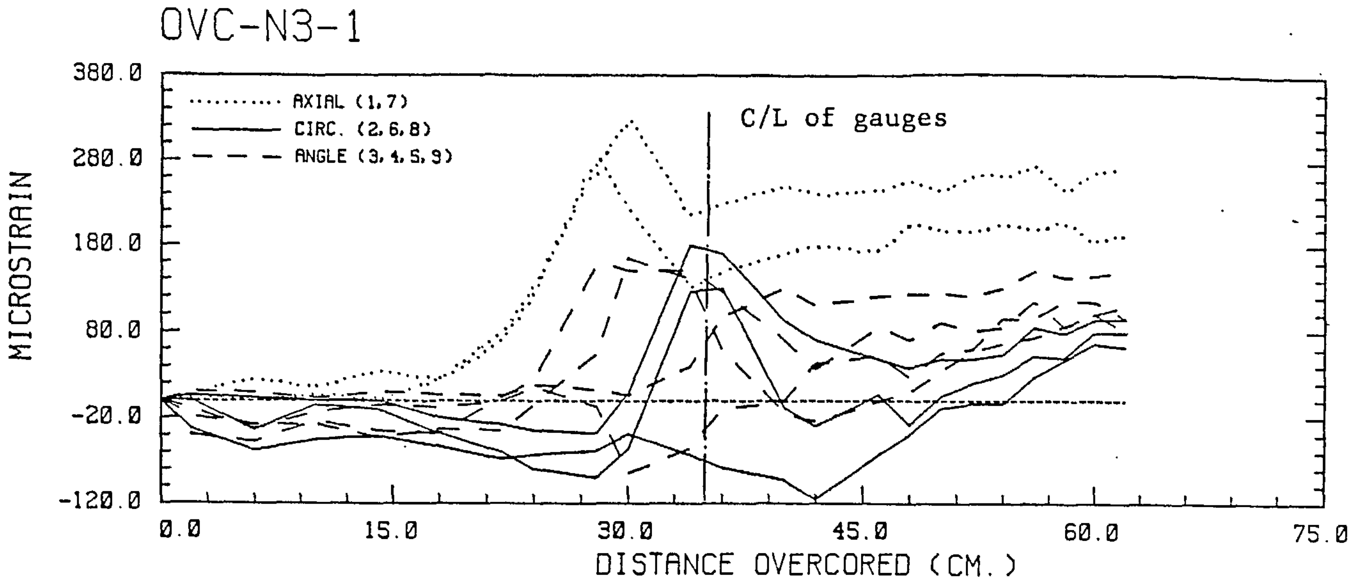


Fig. A-2b - Gauge response and linearity from loading cycle in biaxial compression in test N1-2, 1000 level.



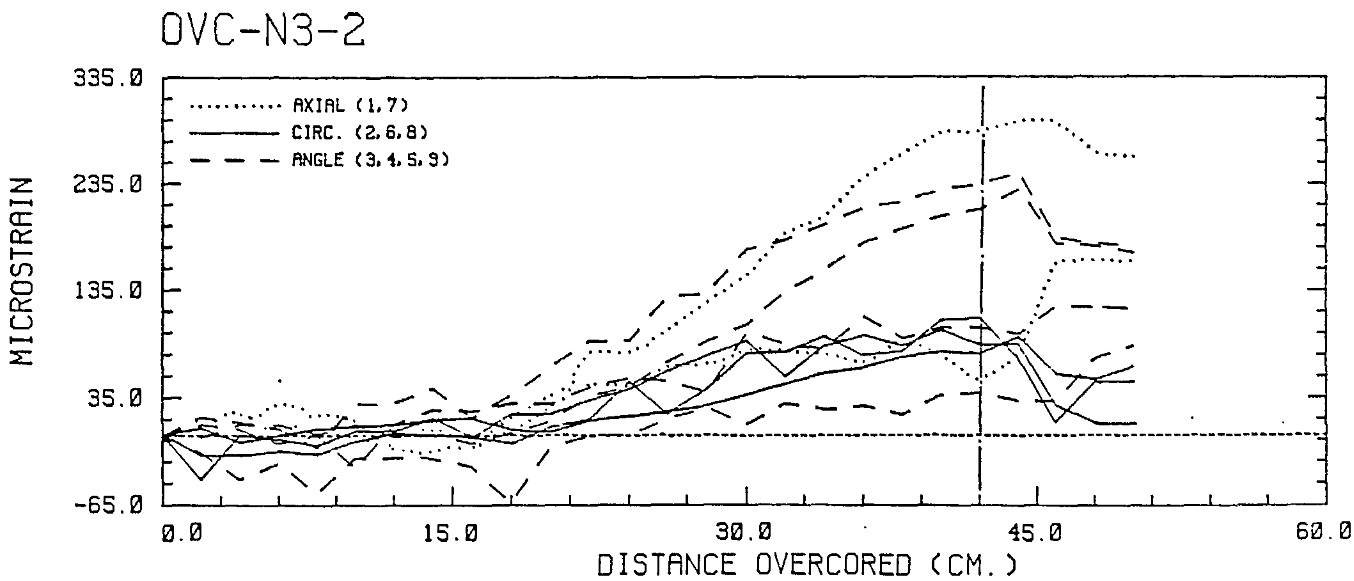


Fig. A-3 - Overcoring response of gauges in tests N3-1, and N3-2, 850 level.

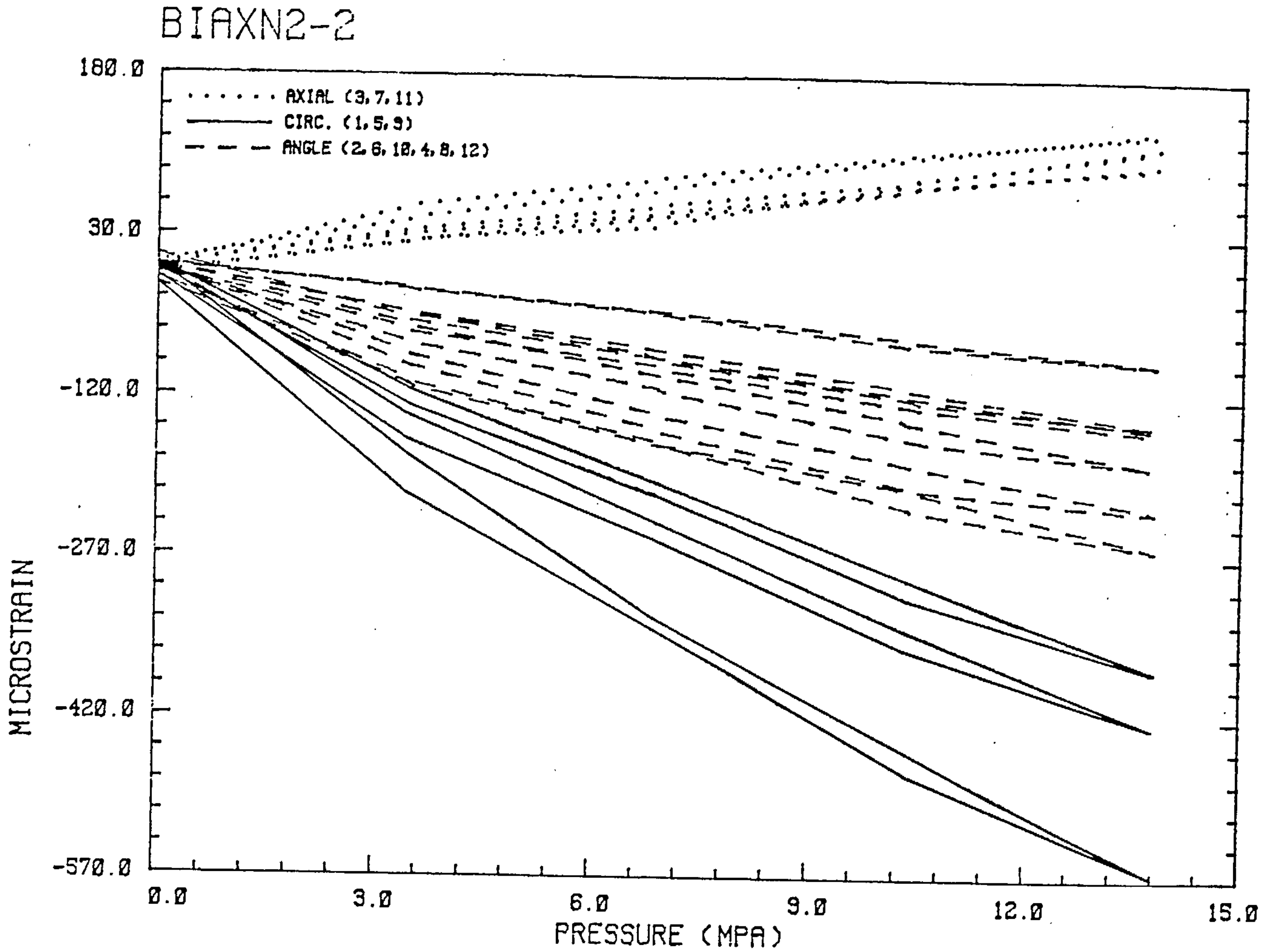


Fig. A-4 - Gauge response and linearity in biaxial compression in test N2-2, 850 level.