Appendix A - Lecuyer 2001

PROCEEDINGS OF THE SIXTH INTERNATIONAL SYMPOSIUM ON MINING IN THE ARCTIC
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Mining in the Arctic

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Ground control monitoring at the Nanisivik Mine

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ABSTRACT: The Nanisivik Mine is located on the 73rd parallel in the Canadian Arctic. The mine began commercial production in 1976 and has since produced over 16 million tonnes. The Main Ore Zone stretches for 3.5 km west to east and has an average width of 80 m with a height of 5-20 m. The room and pillar mining method was employed in the Main Ore Zone with approximately 800,000 tonnes remaining in pillars. During 1999, post pillar recovery commenced as an integral part of the annual mine production. Preparation for post pillar recovery was initiated a decade ago with a three phase study that addressed ground stress determinations, ground stability evaluation and a pillar recovery trial. The major pillar recovery program commenced after Breakwater Resources acquired the mine in 1996. Tools such as the PIN (pillar index number) system and GMM (ground movement monitors) were developed and implemented to assist in the ground control aspect of post pillar recovery. This paper reviews the post pillar recovery plans as well as the monitoring systems utilized to ensure maximum pillar recovery coupled with maximum safety for the employees.

1 INTRODUCTION

The Nanisivik Mine is located 750 km north of the Arctic Circle at the north end of Baffin Island.
Located on Strathcona Sound, the mine has access to the Arctic Ocean by way of Admiralty Inlet and Lancaster Sound. A deep sea port allows for unloading of cargo and loading of concentrate stored at the dock area. (Figure 1)

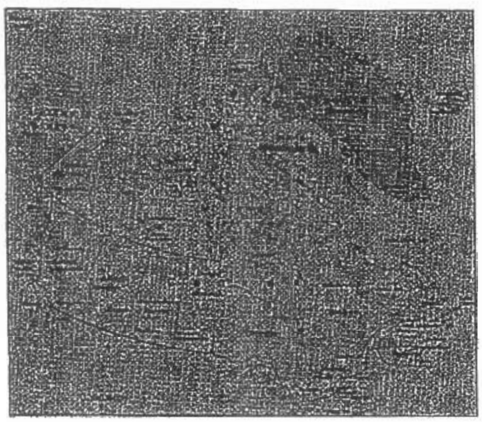

Figure 1-Location Map

The Nanisivik Mine has been in production since 1976 with over 16 million tonnes of ore mined to date. The present ore reserves indicate a mine life of approximately four years. The installation of a dense media separation plant, scheduled for start up in mid 2001, will permit mining and upgrading of diluted ore material offering an extension to the mine life.
The mine production is currently 2,500 t/day of zinc-lead ore with several mining methods utilized. The Main Ore Zone or MOZ was mined by the room and pillar method and is composed principally of pillars of good grade whose mixing is an important part of the annual mine production.

2. GEOLOGY

The mineralized deposits at Nanisivik are carbonate hosted, similar to Mississippi Valley type deposits in a block faulted sediment sequence of Proterozoic age. The main geological units are the dolostone of the Upper Society Cliffs formation which hosts the mineralization and the shale and dolostone of the overlying Victor Bay formation. (Figure 2)
Extensive faulting has resulted in a horst and graben structural setting. The mineralization formed by the replacement of the host rock in two main sulphide events, an early barren massive pyrite-dolomite event (uneconomic) and a later event, pyrite-

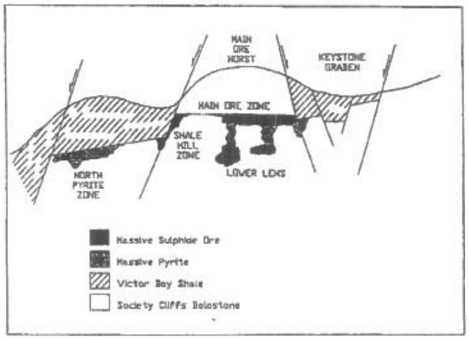

Figure 2 –Schematic Geologic Section looking east.

sphalerite-minor galena-dolomite, that produced the economic mineralization. The Nanisivik deposit is a major sulphide deposit with an estimated 50-100 million tonnes of massive pyrite of which about 15 million tonnes being economic due to zinc enrichment.

3. MINING OPERATIONS

In the Nanisivik area, the rock is permanently frozen to depths of 500 m or more, which contributes to mine stability. The MOZ is on average 80 m in width, over 3,500 m in length by 5-20 m in height. This primary mining method is room and pillar.
The room and pillar design includes pillars of 5 by 5 to 7 by 7 m on 25 m centers. The Main Ore Zone has been largely mined out with approximately 80% recovery on the first pass. The MOZ outcrops at the west and east ends of the orebody allowing access and egress via portals. The MOZ provided most of the production in the past, and consists mostly of post pillars today with about 75% of the MOZ ore reserves contained in the pillars.
Production comes mainly from the satellite zones located to the north of and beneath the Main Lens. Figure 3 illustrates the extent of the mine.

The mining methods utilized in the satellite zones include longhole , benching, slashing, and drifting, all of which make up 70% of the total mine production. Limited open pit mining is also carried out but this only amounts to about 5% of the total mineable ore reserves. All development and production drilling is done dry due to the permafrost. The rock temperature is a constant –12°C and the silica content is low, enabling maintaining respirable dust limits using dust collectors on the drilling equipment. Blasting is done using ANFO and non-electric detonators. ANFO is prepared on site with loading done using a mobile loading unit.

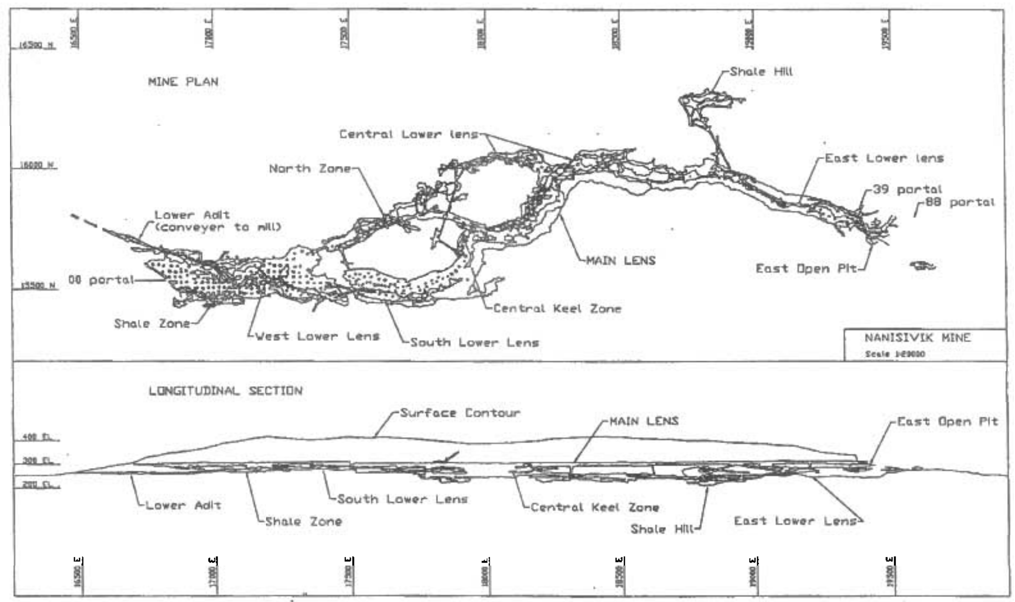

Figure 3- Mine plan & longitudinal section.

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4. PILLAR RECOVERY

The shallow depth of the orebody coupled with the permafrost present excellent conditions for post pillar recovery. Preparation for pillar recovery was started in 1989 with studies by CANMET. Pillar recovery operations ensued to some degree until 1994 when a large ground fall brought the program to a halt. Following this, a review of the pillar recovery program was carried out in 1997 and a revised program was developed that would provide a safe and economical method for pillar extraction. Presently some 24% of the total ore reserves are contained in the MOZ pillars, making successful recovery of the pillars essential for the viability of the mine.

5. ROCK MECHANICS STUDIES

In 1989, CANMET undertook rock mechanic studies with the objective to achieve pillar recovery without serious deterioration occurring in the roof (back) and wall strata. CANMET was retained to carry out a three- phase program between 1989 and 1991. Phase one, included field investigations and laboratory testing to determine ground stresses, insitu deformation modulii and borehole inspections. Measurements at the East Portal of the mine determined pre-mining vertical stress and stresses perpendicular and parallel to the horizontal orebody. These stresses can be expressed as follows:

Vertical Stress : 0.028 Mpa/m (1)
Stresses $\perp$ to Orebody : 3.2 x vertical stress. (2)
Stresses $=$ to Orebody : 1.4 x vertical stress (3)

Also, deformation modulii in the range of 50-60 Gpa for the dolomite and 20-30 Gpa for the orebody were recommended. Video inspection up to 6 m into the roof (back) indicated sound roof conditions aside from blast damage close to the roof line. From the modulii determined (elastic modulus and deformation modulii), the rock mass rating or RMR was evaluated at 79 for the dolostone and 60 for the sulphide ore.

Phase two consisted of ground stability evaluations utilizing finite element simulations to estimate overall mine stability. The parameters examined included crown pillar stability, sill pillar stability, pillar mining sequence and stope stability. These simulations showed that:

1.) The complete removal of the post pillars would be feasible without the use of backfill.
2.) The crown pillar was stable.
3.) The sill pillars were stable, but could require some ground control measures.
4.) From the point of view of access and ground control, pillar recovery from east to west was best.

Phase three included a pillar recovery trial carried out at the East Portal area of the mine. (Figure 4) In all, five pillars were extracted and observations and field instrumentation confirmed ground stability consistent with earlier analytical assessments. Back analysis and monitoring data were used to validate the model and input parameters used. Also, field abutment and pillar stresses determined using strain rings were compared with those predicted by the numerical model simulations and the results were in good agreement. The results supported the feasibility of extracting all of the remaining post pillars.
Another 11 pillars were removed in this location leaving an unsupported area of 350 m by 50 m.
Following the rock mechanics studies, instrumentation was installed between blocks 18 and 26. Between late 1992 and 1994 some 21 pillars were mined. In February of 1994 after six pillars had been removed in the 20 block area there was a large ground fall (approximately 12,000T) that halted pillar mining completely.

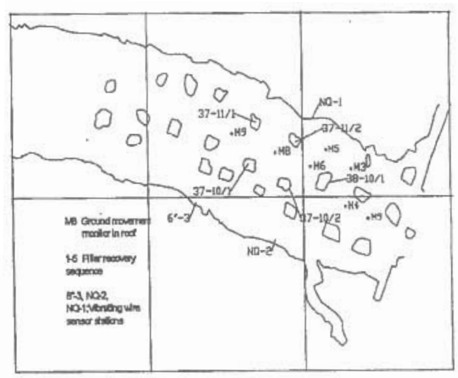

Figure 4 – Test site stope & monitoring layout.

6. PILLAR RECOVERY PLAN

Following the 1994 ground fall in the 20 block a review of the mine design was required in order to satisfy the Mines Inspection Services before pillar recovery could continue. During 1995 and 1996 no pillar mining was done and meeting grade objectives became difficult without the pillar tonnage.

In early 1997, the Nanisivik staff undertook a review of the mine design and the pillar recovery procedures under the direction of Dr. Chris Page, principle of the firm Steffen, Robertson and Kirsten(Canada) Inc.
Over the 24 years of mine operation, eight major ground falls have been documented and all, with the exception of the 20 block ground fall in 1994, have occurred in areas in which man entry was possible. Also, all of the ground falls had a visual structural explanation including exposure of a wedge or a shallow angle slip. There have been no ground falls due to failure of an intact beam. The conditions that had caused the ground falls were well understood. The pillar extraction program was therefore addressed with the critical strategy being that of two types of entry. These were defined as ENTRY: where conditions of geometry and rock mass quality allowed for the safe working of men within the current excavation and NON-ENTRY: where the conditions of geometry and rock mass were not sufficiently reliable for man-entry.
The primary concern for pillar extraction was safety, ensuring that men were only allowed in areas where the stability was reasonably certain. The major concerns included roof falls in Entry areas, collapses in Non-Entry areas that could overrun the last line of pillars, collapses in the Non-Entry areas that could trigger air blasts and caving in Non-Entry areas that could cause major collapses in Entry areas. The layout criteria for the room and pillar stoping was 5 x 5 to 7 x 7 m pillars on 25 m centers for the dolostone or mineralized backs and 5 m thick rib pillars on 20 m centers for the backs in the shale zone areas.
The evaluation of excavation stability was based on the use of the rock mass rating (RMR) as this was considered to be a good empirical procedure for assessing the excavation stability. (Figure 5)

Using the Hydraulic Radius, the RMR values could be calculated for Entry type excavations and the RMR at the possible start of caving. While the empirical relationship is approximate at best, with experience, it was considered a reliable tool. Therefore to provide limits to work with until more information could be acquired, the following criteria could be used to distinguish Entry from Non-Entry mining and also to limit the geometry of the pillar extraction areas.

1.) A Hydraulic Radius of approximately 30 could be developed with a competent dolostone back without large ground falls occurring.
2.) A Hydraulic Radius of approximately 10 could result in large failures with the shales, and
3.) Caving might occur at Hydraulic Radius of over 40.

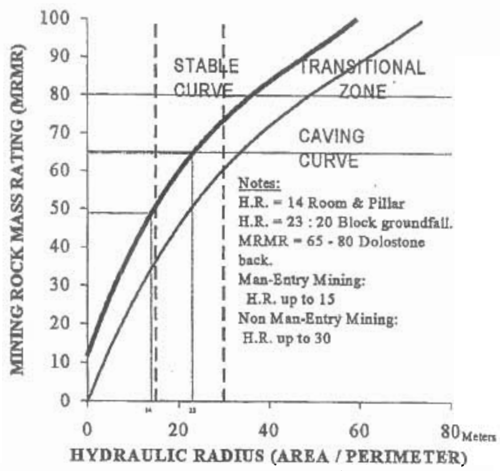

Figure 5- Stability Diagram (after Dr. D. H. Laubscher)

From this, the following controls were established. Entry mining, with average dolostone backs,could be defined by a Hydraulic Radius of less than 15. Entry mining in shale could be defined by a Hydraulic Radius of 5, as was presently being done.
The definition of an Entry Area was that within the limits of the present room and pillar design; only remote equipment beyond the last pillar line. Exemption from this would be approved on each individual occasion and only if the Hydraulic Radius and the RMR values would plot within the stable zone. Non-Entry mining with average dolostone backs was to be limited by a Hydraulic Radius of 30, while for shale backs this would be limited to 10.

7 PIN CLASSIFICATION

A pillar index number, or PIN system, was developed at Nanisivik during 1997 to compare different pillars and provide a measure for deciding the sequence in which pillars should be extracted and /or which might be left for a longer period or permanently. The PIN evaluation was based on the following factors with each factor having points assigned.

1.) Grade-%Zn -higher grade more points :max. 1 point.

2.) H/W Ratio-high
higher points to m
3.) Profile- above av
signed higher poi
4.) Jointing- massive
jointing assigned
5.) Weathering- non
assigned most poi
6.) Structure- none,
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2.) H/W Ratio-higher the height/width ratio higher points to max. of 2.
3.) Profile- above average to poor, with poor assigned higher points to max. of 1.5
4.) Jointing- massive, minor, major with major jointing assigned most points to max. of 1.5
5.) Weathering- none, minor, major with major assigned most points to max. of 1
6.) Structure- none, minor, major with major assigned most points to max. of 3

All of the 385 pillars in the Main Lens were evaluated and rated. Therefore, economic and geotechnical factors were used to rate the pillars. In general, a pillar with a high rating would be more attractive to recover before a similar pillar with a lower rating. The more competent pillars have a lower PIN and thus should be left in place as long as possible. In general terms, the average PIN was 2.5 with the interpretation that pillars with a PIN of less than 2 were not very attractive to recover and those with a PIN of over 3 were. From this information, plans could then be color-coded to aid in visualizing the pillar excavation priorities.

8 MONITORING

During the mine design review, it was decided to invest in real-time monitoring of areas to provide an additional tool to aid the rock mechanics program.
For this, ground movement monitors or GMM's (extensometers) were selected and CANMET was contracted to help Nanisivik in setting up the system. A system was installed, capable of having a total of 32 GMM units in the roof (back) to monitor any downward block movement. The GMM units consisted of Baytech Model ETT-204 electronic telltales. Four stations or slaves were purchased and installed underground with each slave capable of having 8 units operating from it. The GMM's consisted of 2.44m rockbolts (16mm diameter) coupled together to give a total length of 10 m. A standard 50 mm shell anchor was used at the end of the hole and the ETT-204 installed at the collar with a standard collar plate. (Figure 6)
A surface master and computer were set in the mine office. Software called LOOKOUT was installed which accesses the slaves via the master and monitors, displays, logs and provides alarms based on preset trigger levels. Movement beyond the trigger levels initiates the alarm, which can be verified. A log book is kept in the mine office which is used to record any changes that require follow-up by the electrical department. Also a ground control logbook is utilized for entry of any movement so that the proper protocol is followed. Alarm procedures are established so that any situation may be investigated immediately and corrective action taken.

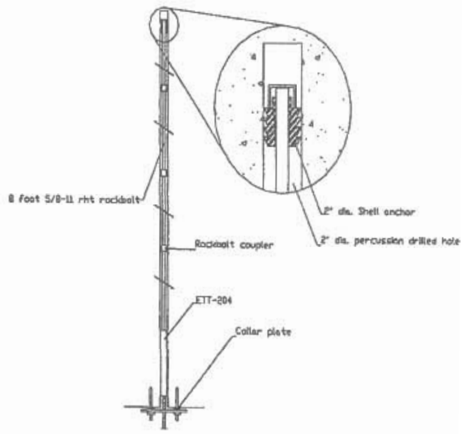

Figure 6- GMM Installation

The underground leaky feeder communication system serves to transmit the data through to the computer on surface. All stations are indicated on the computer monitor and readings can be verified over the last hour, 12hour and weekly periods. Also a plot of the displacement versus time can be viewed for any GMM via a push button.

9 RESULTS TO DATE

Since the review of the mine design and pillar extraction procedure in 1997, pillar recovery has progressed on a continuous basis. Pillar recovery has been very good, with 96% of the forecasted tonnage recovered in 1998, 90% during the 1999 period and to date 2000 about 75%. The 2000 program is on schedule because recovery of ore in the north wall (gouging) is also being done as final retreat operations are in progress.
While the GMM units are by no means trouble free, they provide continued monitoring. Installed initially in Entry areas, some units are now located in Non-Entry areas and provide ongoing monitoring of maximum span openings. Open spans have attained 80 m in the MOZ-Central area and 70 m in the MOZ-East area of the mine. Careful blasting has helped in maintaining the GMM units in open areas. The durability of these units over time remains to be seen. The data transmitted from the units is dependant on the mine radio (leaky feeder system) and electrical noise can be a problem.

Since 1997, several ground falls have occurred. In the MOZ-Central, a ground fall occurred in September of 1999 of about 5,000 tonnes. Another ground fall occurred in October of 2000, which was estimated at 10-12,000 tonnes. (Figure 7)

Both of these ground falls were a result of sulphides left in the roof (back) where it was known that low angle slips occurred. This particular area of the mine was also exposed to warmer air in the past as the main ventilation system downcasted the 17N ramp. The compressor station was installed in this area at the time resulting in a source of warm air. Geological features included the presence of vuggy ground as well as low angled slips. This area had not been mined to the dolostone contact. Both of the ground falls were contained in the Non-Entry areas hence there was no danger to mine personnel. The ground falls occurred shortly after pillar recovery in the immediate area. While not accurately predictable, the ground falls were anticipated due to the conditions mentioned.

While the GMM's did not indicate any movement prior to the September 1999 ground fall, the GMM B-4 did indicate 0.40 mm of movement the day prior to the October 2000 ground fall. In other areas such as 19 block where five pillars were recently removed the GMM did show slight movement but stabilized very quickly. Presently, eight GMM's are located in Non-Entry areas and eleven are located in Entry areas. These are located along travelways and therefore continue to provide information on the ground movement in these areas. The GMM's, while providing useful information, have to be utilized with caution since each only represents a measurement at a single point.

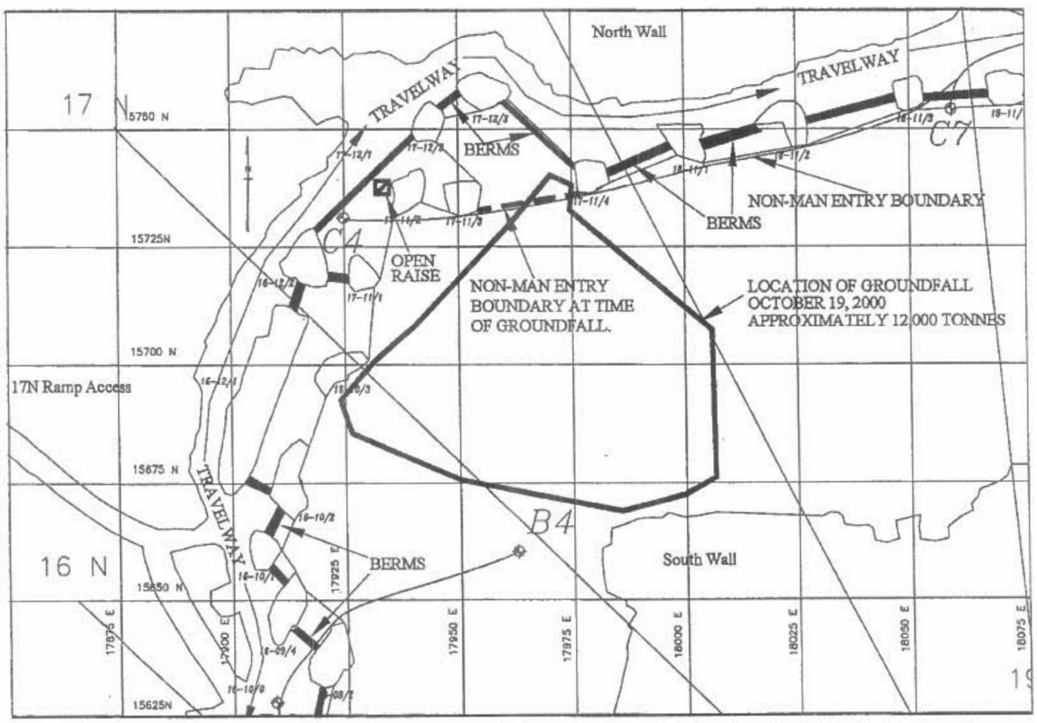

Figure 7- 17 Block Area Ground Fall

10 ADDITIONAL MON

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11 CONCLUSIONS

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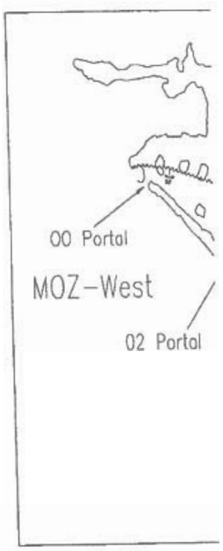

Figure 8- MOZ-West area.

10 ADDITIONAL MONITORING

For future pillar recovery in the MOZ-West part of the mine additional monitoring is being considered due to the presence of the Keystone faults. The MOZ-West has approximately 300,000 tonnes of ore in pillars grading over 11% zinc. (Figure 8)
Removal of pillars would mean removing support with potential downward movement. In order to monitor any movement, a program is being investigated with CANMET to utilize Time Domain Reflectometry or TDR. This would expand the surface based mine stability monitoring program with the addition of TDR cables to the existing GMM array. This would provide real-time monitoring of fault movement during and after pillar recovery, help decision making with respect to man entry and worker safety in pillar recovery areas and improve the pillar recovery program by enhancing the decision making processes. The TDR program is expected to require about six months to set up.

11 CONCLUSIONS

The experience to date has provided information that permits formulation of the following conclusions.

1.) The design guidelines for Hydraulic Radius have reached 30 with no indication of competent and regular roofs (backs) showing signs of beam failure. Therefore there is no need at the present time to change the guidel lines.

2.) No significant signs of stress related failure from pillar walls have been observed. The ground falls that have occurred are a result of exposure of a wedge of shallow angle slip. Any sulphides left in the roof (back) can be prone to a ground fall as the sulphides break away from the dolostone contact if the span becomes greater than the normal room and pillar spans.

3.) The GMM monitoring system provides real-time indication of ground movement. While it has not served to directly predict the ground falls that have occurred, the extensometers provide assurance that where installed, conditions in the roof (back) are monitored. These are point load type extensometers that serve more to monitor conditions over the longer term with respect to progressive deterioration of the roof (back) conditions. The system provides the operator with physical indications of movement.

4.) The use of Entry and Non-Entry pillar recovery procedures has proved to be successful at Nanisivik and will continue to be utilized, providing for maximum safety and post pillar recovery.

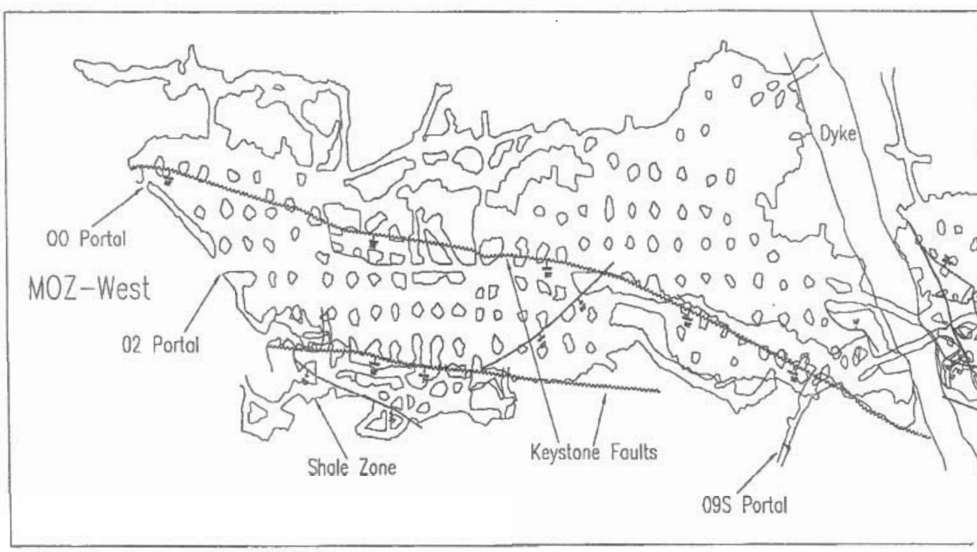

Figure 8- MOZ-West area.

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