APPLICATION OF MWD
TECHNIQUES TO MINE DESIGN

OCAK TASARIMINDA MWD TEKNİĞİNİN UYGULANMASI

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ABSTRACT

Technological advances now permit the continuous and automatic recording of drill performance data. Utilization of microprocessor-based Monitoring While Drilling (MWD) systems allows for rapid capture, processing and analysis of large quantities of data.

This paper evaluates the drilling parameters of significance for these studies such as instantaneous penetration rate, and thruat on the bit. The development of a microprocessor-based, automated drill monitoring system will then be reviewed. The design criteria for such systems involving sensors, data collection/transmission, treatment and application to various aspects of raining will be considered. Reference to recent field studies undertaken in a range of geological environments will focus on field and laboratory studies with percussive drilling to relate the potential of such monitoring to mine design.

OZET

Teknolojik ilerlemeler, günümüzde delici performans verilerinin sürekli ve otomatik olarak kaydedilmesini mumkun kılmaktadır. Mıkroıişlemcı esaslı delme sırasında kayıt (HWD) sistemlerinin kullanımı ile birçok verinin hızla kaydı, işlenmesi ve analizi mümkün olmaktadır.

3u bildiri,-bu tur çalışmalarda önemli olan enstantane delme hızı ve matkaba uygulanan baskı gibi delme parametrelerini değerlendirmektedir. Daha sonra bir mikroışlemcı esaslı otomatik delici kayıt sisteminin geliştirilmesi gözden geçirilmektedir. Olçucu, veri toplanması/iletişimi, derleyici gerektiren bu tUr sistemlerin tasarım kriteri ve çeşitli madencilik konularına uygulanımı Üzerinde durulmaktadır. Bu tUr kayıt sisteminin ocak tasarımında potansiyelini açıklamak için, bazı farklı Jeolojik koşullarda yürUtUlmUş son arazi çalışmalarından örnekler, darbeli delme ile saha ve laboratuvar çalışmaları Üzerinde yoğunlaşmaktadır.

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1. INTRODUCTION

Despite the increasing use of geophysical logging, the cost, time and effort of site evaluation can be considerably reduced using data obtained during drilling of exploration or production holes. The use of a drill monitoring device enables information regarding rock mass characteristics to be determined from the monitoring of drill performance parameters such as penetration rate, thrust on bit, and rotary speed and torque. Detailed information regarding rock type, lithology, rock strength, fracture location, width and whether open or closed, can all be potentially determined from the recorded drilling parameters. This data recorded with respect to depth in the borehole must however be interpreted by direct comparison, correlation and calibration with core logs.

1.1. Previous Drill Monitoring Studies

Rock drill monitoring was used in site investigations by Deveaux et. al. (1983) and Schneider (1983) for detecting weak and water bearing zones. Horner and Scherrel (1977) monitored rotary percussive rigs to establish bedrock levels for the required depth of penetration installation of piles and rock anchors. Multi-channel data logging by Brown and Barr (1978) demonstrated that monitored drill parameters could be used to locate fractures and discriminate between lithologies.

Monitoring by Leighton (1983), Lebel (1984) and Schedk et. al. (1982). on blasthole production rigs enabled improved blast design based on the location of weak and strong bands related to penetration rate peaks. The location of strong beds by drilling performance was also reported by Hojar (1987) in surface lignite mining. Montreal area investigations with the Automated Drill Monitor (ADM) by Peck (1986), Peck et. al. (1987), and Carter (1988) have Indicated effective correlation between lithological, geomechanical and drilling parameters.

1.2. Currant Montreal ADM Development

The system developed by Solroc Inc. Montreal, is a microprocessor-based drill monitoring device. This ADM (Automated Drill Monitor) records, measures and processes drill performance parameters. These variables when properly interpreted enable a precise definition of zones of changing rock properties at depth in a borehole, Clark (1982). These intervals can then be further defined in terras of variation in strength and/or fracturation.

The ADM system can be used with any kind of drill rig, whether percussion or rotary or a combination of these. Pressure, torque, flow arsd position/velocity transducers are the means of converting the mechanical drill parameters into electronic impulses which are then recorded and stored by the ADM. Parameters such as thrust on the bit, injection pressure, operating and feed air pressures, instantaneous rate of bit penetration, torque and rotational speed of the drill steel are all capable of being monitored. The particular set of parameters to be recorded during a drilling study would be dependent upon the type of drill rig employed and the information desired. Print-outs of this drilling information can be easily obtained in a readily interprétable graph format through use of an incorporated microcomputer.

In the recent studies, the monitoring of percussion drilling rigs was undertaken. The difference in time and cost between percussion and diamond drilling enables the ADM System to obtain additional information regarding the site geology by means other than core logging. The ADM devica allows more economical percussion holes to be drilled and correlated in tandem with a reduced diamond drilling program. Additionally the reliability and accuracy of subsurface data already collected can be greatly improved.

The parameters of penetration rate and thrust were the important variables for the percussion drill used in these investigations. As a result, the ADM device was configured to monitor only these parameters, subsequently described. The penetration rate of the drill ise the rate of advance of the drill bit, usually expressed in meters/hour or feet/hour. It is the most important of drill parameters to enable an assessment of ground conditions. This parameter is controlled by several factors:

i) the nature of the ground, ıe. hardness, strength, type and frequency of discontinuities; 11) type of drill used, eg. drill rig and bit type; iii) flushing media and pressures used; iv) the drilling personnel, ie. their experience and drilling habits controlling thrust on bit, rotary speed of drill stem, etc., Horner and Scherrel (1977). By standardizing the last three factors whenever possible, any variations in the first will be reflected by a characteristic variation in the penetration rate. As mentioned earlier, interpretation of this parameter with respect to depth can only be achieved by initial correlation with known geology.

The penetration rate is recorded as a function of depth in order to enable correlation between logs at the same scale from different holes. This also permits the width of the penetration rate peaks on the graphs to be used as a direct measure of fracture aperture Lutz (1982). Drillability studies have attempted to correlate this parameter with the classical properties of rock such as Young's Modulus, hardness, compressive strength etc., but further refinements of these concepts are required before this information can be used reliably, Clark (1982).

The thrust is the amount of weight upon the drill bit. This parameter allows breakage of the rock by a crushing mechanism and thus penetration of the drill. This mechanism operates in tandem with an indexing or rotation of the drill bit. This operation cleans away chippings from the bit-rock interface to produce a "clean" surface for the next bit impact. Therefore a good bit-rock contact and a minimum amount of drill energy attenuation r>er impact results. Penetration rate is directly influenced by this parameter and thrust is therefore recorded to check for any variations. 1'hrust levels will .-ary according to the drill rig and bit type, rock type and operator skill. The ADM data acquisition system is based on a compact, rugged and powerful datalogger device. The dimensions of the device are 8 inch x 6 inch x 3.b inch (203 x 152 x 89 mm), waiting 7 lbs (3.2 kg). This unit has a self contained power supply of 8 rechargMble D cell batteries capable of providing 2 months worth of scanning and processing of incoming signals from a maximum of 16 input channels. An 8 bit microprocessor is present to control the unit along with an internal memory capacity of 80 K (equivalent to 20,000 low resolution data points in final memory). An 8 digit LCD display provides the possibility of reviewing the settings of the various input channels and a keyboard allows changes to be made to these in terms of scan rates, thresholds etc. directly. The unit is very flexible in terms of its data storage and transfer capabilities and a wide range of possibilities are available depending upon the operating environment and location.

The transducers used with the ADM are all externally powered by a separate battery pack. The unit does have the capacity of providing the necessary power to run the transducers but this reduces the sampling rate and therefore the resolution of the system. Pressure transducers are linked to the hydraulic or air lines on the drilling rig in order to record such parameters as thrust on bit and operating air pressures. The most important transducer is the one enabling the combined recording of both displacement and velocity of the drill bit. Since the parameter of displacement sets the positions of the other parameter data points, it is crucial that this transducer be both accurate and reliable. The transducer operates via a steel cable attached to the drill head, which as drilling proceeds causes the rotation of a tachometer generator and potentiometer. The amount of rotation and speed of these components are therefore proportional to the velocity and linear displacement of the drill stem. The device can be used to monitor boreholes as long as (40 m) and is capable of withstanding sudden acceleration increases of the drill of up to 50 g's, as could be the case when intersecting a void. It is also resistant to vibratory stresses associated with drilling of maximum 10 g's and temperatures in the range of $- 40^{o}C$ to $+ 66^{o}C$.

In the event that drilling is in a remote area, modifications to the input instructions can be made directly by use of the built in keyboard. However, if telephone facilities exist the data can be reviewed and obtained directly via a modem transfer link between the datalogger and an off-site microcomputer. The potential exists therefore for instrumenting a drill rig in remote areas and accessing the recorded drill parameters via modem at a home base computer. Such a link would also enable the engineer at the central office to remotely emulate the programming of the unit if changes were required, without leaving his office for the field.

An additional option for data storage is the dumping of recorded and processed data from the datalogger onto a cassette tape. This would allow a further 180 K of information to be stored. Such a method would permit the monitoring and recording of data from a full day of drilling, with subsequent transfer from cassette tape to a micro-computer for additional data treatment back at the office. Under harsh operating conditions when data storage on tape is not possible, an expanded memory of 64 K can be achieved using a built in storage module. This modification permits the unit to operate reliably over the temperature range of -40 ^{o}C to + 66 ^{o}C. If suitable conditions exist, a direct link between logger and a portable computer is possible, enabling direct processing of the raw drill parameters in the field . The appropriate technique would again be dependent upon the needs of the operator and the geographical location of the drilling.

Once the data have been properly processed, presentation of the information on the computer screen is in the from of X-Y or bar graphs. These graphs of the raw drill parameters are plotted with respect to depth in the borehole. Using appropriate drillability algorithms the estimation of changing rock compressive strength with depth can be determined and plotted alongside the other logs. A "zoom" function incorporated into the system software, enables the expansion of any of the logs within a selected interval of interest. The scales, in addition to the units (Imperial or metric) of the graph axes can be selected at will.

The plots of these parameters can subsequently be examined alongside the borehole geologic log as given by core or previous work. This allows the isolation of the positions of fractures and zones of weak rock based upon the responses of the drilling parameters at the same depth locations.

Subsequently hard copies of the data logs can be obtained by outputting the configured data to a printer/plotter. Since the drilling data can oe digitally stored on floppy or r-Td disk, the information can be accessed at any tine in the iuture if additional stud> is desired.

Use of the ADM system can enable information regarding the rock mass characteristics to be determined f>om the monitored drill parameters of penetration rate and the thrust on Dit. The combination of these paraneters into a particular set of drillability equations, permits the estimation of the in situ geomechanical properties of the rock. Such information can be generated on-site and therefore be of immediate use towards the planning, design and production phases of a project. îhe ability of being able to generate such infci matron from faster and cneaper percussion drilling can result m considerable savings.

2. <u>WINING APPLICATIONS</u>

The extended capabilities of digitally recordea and processed information, enable the ADM system to be useful in many mining application areas. Applications of the ADM system to the mining industry include Mining Production *Control and* Blasting Design. The proposed capaoılıtıes *of* this device are thus outlined.

2.1. Mine Production Control

<u>Drilling surveillance</u> - Monitoring (with the options to directly transmit data to the mine office) of the drill performance parameters and hole depth purely to oversee the quality of blast hole drilling.

<u>Management information system</u> - This would provide routine drill performance reports, highlighting above or below norm statistics, ftoutinely reported data should relate to Drill Shift Statistics such as Date; Drill and Operator Identity; Scheduled and Actual Drilling Time; Shift % Dırıllıng/Propellıng/Idle Time; % Utilization; % Availability; Total Depth drilled; Bit Statistics (type, identity number, footage and condition per shift and cumulative). This is best presented alongside a graphical

représentation of rock characteristics data as interpreted from the actual monitored drill performance parameters. This information can be presented in a concise and graphical manner by computer which would aim to avoid data "overkill" and be visually attractive. The use of pie/bar charts and X-y graphs showing data history and trends would achieve this aim.

Depth control - This ensures accurate drill hole depths and maintain level pit floors. In surface mining environments, e.g. working inclined coal seams, this facility would be attractive to a mine operator where not all holes are required to the same depth and "stand off" distances may be required above seams or mineralized horizons. In wall control blasting, e.q. buffer or pre-split blasting, an operator may also have a particularly keen interest in blasthole depth and quality control.

2.2. **Mine Planning**

Reserve estimation, grade and dilution control - Drill monitoring offers the potential to differentiate between mineralization and waste rock in many geological settings i.e. where there is a sufficient consrast in absolute hardness or discontinuity spacing. This may well be an attractive feature of the ADM where the operator would be able to update reserve estimation, control grades and amend blasting strategies to minimize dilution.

Groundwater control - Mines experience groundwater flow patterns related to rock mass permeability. The latter may sometimes be inferred from rock density and strength, but more importantly from the presence of cavities and discontinuities (joints, bedding planes, faults). The ADM has sufficient sensitivity to characterize not only rock strength but also cavities, discontinuities or fractures. Many mines, it is felt, would appreciate an additional ability to monitor grondwater characteristics. The monitoring of the drilling circulating fluid pressure would provide valuable information regarding open fractures and groundwater flow.

Stope Planning - Monitoring of ITH blasthole drıl̇l̇3 is currently under study in Sweden, Shunneson (1988), as a means of locating ore-waste contacts and defining iron ore grade zones.

Surface Pillar Design - With the assistance of drill monitoring the definition of quality and geometry of both the surficial cover and rock mass can be evaluated.

Other important potential applications include the definition of: caved ;cnes; effective grout take; oackfill quality; deformation envelopes in pillar, stope and drift walls; and required depth for rock reinforcement,

2.3. Blasting Design

Fragmentation optimization - Identification of variations in blastability within mine benches is governed by rock strength. The ADM interprets rock strength variation based upon drill performance data. Since fragmentation is also strongly controlled by geological structure i.e. weakness planes, it was considered necessary to develop the ADM to be able to monitor performance data at depth increments of 1/8 inch (3,2 mm). This would provide the capability of precisely detecting fractures so as to assess their locations and intensity. Thus a strength and fracture log could be produced by the system per hole. Although explosives loading techniques do not require high precision', such a log would facilitate decisions on explosive selection, stemming, decoupling and decking ona hole by hole basis. The endpoint would be optimum fragmentation physically and economically, for the mine operator.

2.4. Machine Development and Autoaation

Drillability and drill performance optimization - It is the next step of development of the ADM, to serve to optimize drilling performance. It would indicate to the operator the optimum levels of drill parameters based upon interpretation of the ground conditions experienced in previous local holes. The system may in fact have the capability of forming the feedback control unit of automated drills or other mining equipment. The development of expert systems for automation in mining, forms the basis of current research at McGill.

dit selection and »t :r control - as in the previous function, the mte-cretation *of* ground coiru t-ons bv the ACM should serve as an indicator of optimum jit 'y;e. during the working life of Ihe bit, account can also be Tiade of the nature of ^\e tit wear and bit failure tyoes in oraer to relate this to lock ab^asıvıty, hardness and quality of operator treatment.

3. FIELD INVESTIGATIONS

Reference is now made to recent percussion drill monitoring studies at the Meloche Quarry, Francon Quarry and Northcrest development in the Montreal area. These aim to lllubtiate the capabilities of MWD systems to detect variations in lithology, structural and Tiechamcal properties in sedimentary, igneous and metamorphic rock masses. This was undertaken using the Automated Drill Monitor (ADM; system set to ' ecord drill parameters every 10 mm. This sampling intsrval [is] is been found ID provide the required sensitivity for grouna charactertzaticn. Monitoring was conducted in the Chazy and Trenton Limestone Groups, witn-n the Ordovıcıan tonrations overlying the Palaeozoic sedimen's and I.'ecamtrian mela-norrliK basement of the Montreal area, Clark (197?). P-ıJlıng wi; by percussion t-op harr-mer machines in the Meloche Quarry (Joy Pamtract MS-4£), Francon Quarry (Atlas Copco ROC 810H) and Northcrest Terrace (Joy RamtracK MS-4E), Figure 1.

In the Meloche Quarry, the Chazy Limestone comprises mainly crystalline and fossılıferous limestone beds, 0.15-1.2 m thick. These vary in shale content to nearly pure shale, with partings up to 60 mm thick. The Francon Quarry, in the Trenton Limestone Group, is characterized by regularly spaced, undulating *i*os3ilıîeroua shale partings beteten successive limestone bed3, up to 100 n.m thick. ;h ile i,ea-ns, 1 to 35 mm thick, contain fossil frigmentï up 'o 10 mm m size. *Tne* li-restone sequence is intruded by sills 'nu jvkee, 0.]r 1 n n-> ." » s < *l*^ transect the strata and are defler'-c -1 .v bedii- ; u ;'.J \r ench face. In both quarries the IHII'..I.? ^ ^ I 3i •• -, ux^i p"-t ucmmantly

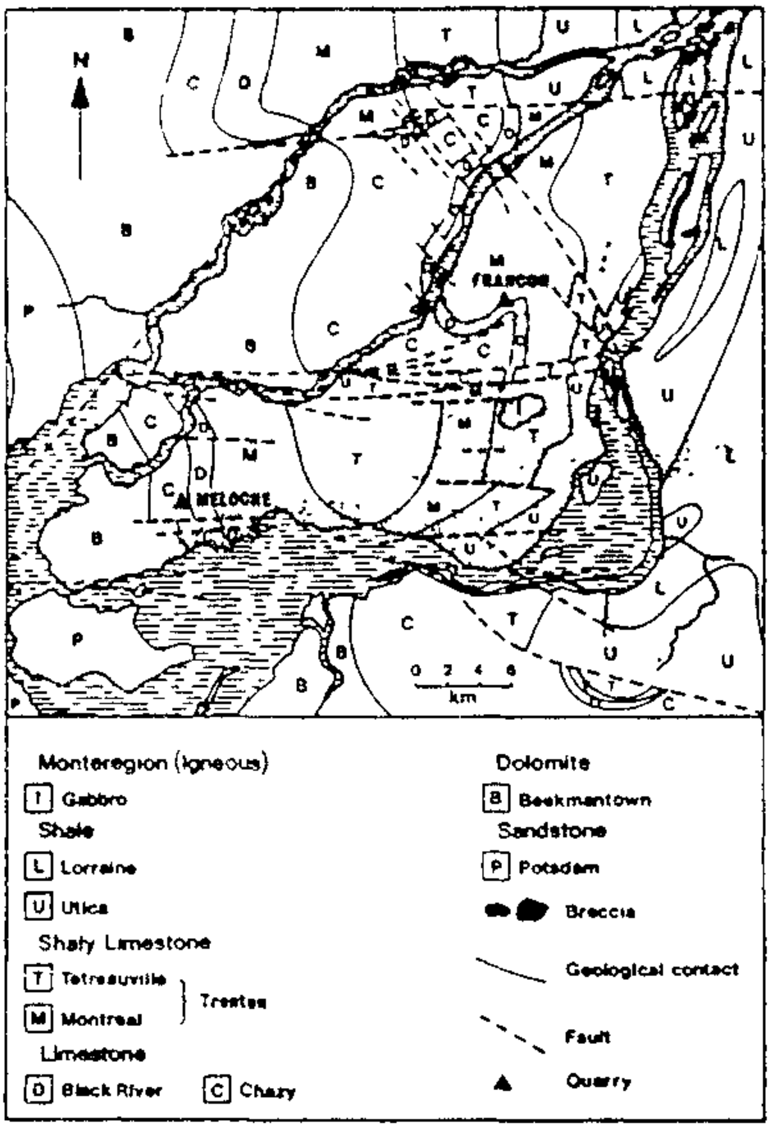

Figure 1. Field Site Locations, Montreal Area
(After Durand (1978))

suünorizontai. fractures found parallel to bedding and snale partings.

The Northcrest site comprises coarse rockfill on a limestone and igneous base. These Trenton Limestones are intruded by syenite, gabbro, breccia and lamprophyres associated with the Monteregıon ıntrusives. The lamprophyres are very fine grained with small phenocrysts averaging 1 mm in size. The syenites are homogenous and fine grained, whilts the gabbros are medium to coarse grained, with phenocrysts from 1-30 mm.The breccia is composed of 10-40 mm fragments of limestone, syenite and lamprophyre. Pervasive alteration of syenite and lamprophyre occurs locally and karstic features in the limestones range from 5 to 90 cm in depth and 1.5 to 3 m in width. Metamorphism of the limestones **to** marble occurs along several of the igneous/limestone contacts.

3.1. Drill **Performance Parameters**

As mentioned previously, the drill parameters of importance monitored during these studies were the penetration rate and thrust to the bit. The thrust levels in these studies were found on monitoring to be essentially constant. Penetration rate therefore proved to be the principal interpretive parameter.

3.2. Lithological **Identification**

Sample penetration rate logs from the Northcrest site, Figures 2 and 3, clearly show that penetration rate satisfactorily profiles the depth of backfill as well as the nature of the altered rock zones above the underlying unweathered horizons. The enlarged borehole intervals indicate how characteristic penetration rates identify different rock types. Small lamprophyre sills intruded into altered and fractured zones of limestone are readily identified by sharply reduced penetration rates. In such sections, penetration rates in lamprophyres averaged 30 m/hr. In the limestones these ranged from 35 to 45 m/hr, dependent upon degree of fracturation and alteration, together with the shale and fossil content. (These rates agreed closely with those monitored in limestones at the

Meloche and Francon Ouames). Areas of local alteration in the sills are indicated by sharp increases in peak height (see also Figure 4).

In contrast to the sedimentary sequences, the igneous rocks are identified by lower penetration rates. The syenites produced penetration rates of 15 to 31 m/hr, varying with the degree of alteration, while the gabbros ranged from 8 to 15 m/hr. Gabbros are differentiated from syenite in the igneous suite oy their characteristic "flat" segments of penetration rate peaks, related to increased homogeneity.

3.3. Structural Interpretation

Figures 2 and 3 show the locations of karstic zones, characterized on the penetration rate logs by prominent peaks with penetration rates exceeding 250 m/hr. Investigations by Lutz (1982* have shown that the width of penetration rate peaks can be used as a direct measure of the width of discontinuities. The penetration rate peaks in these cases therefore indicate discontinuities ranging from 13 to 24 cm in width. In the Francon Quarry study, the location of discontinuities by core logging and drill monitoring was supplemented by borehole T.V. (BHTV) surveys, Figure 4, Peck et. al. (1987). These were used to verify the position of in situ fractures located by the drill monitor and to eliminate those induced by drilling or mishandling.

Areas of high RQD and fracture frequency calculated for these three logging techniques coincide with positions of increased penetration rate peak amplitude and width. Although excessively high RQD values were calculated from standard core logging,the resultant of mechanical breakage and personnel mishandling of drillcore, more realistic RQD values were calculated from the ADM and BHTV surveys. These were generally within 10% of each other. Fracture logs generated from drill monitoring thus offer a potential means of estimating RQD. Initial studies indicate however, that drill response lacks sensitivity to fractures when these are steeply inclined to the borehole axis or if the sampling interval is too large.

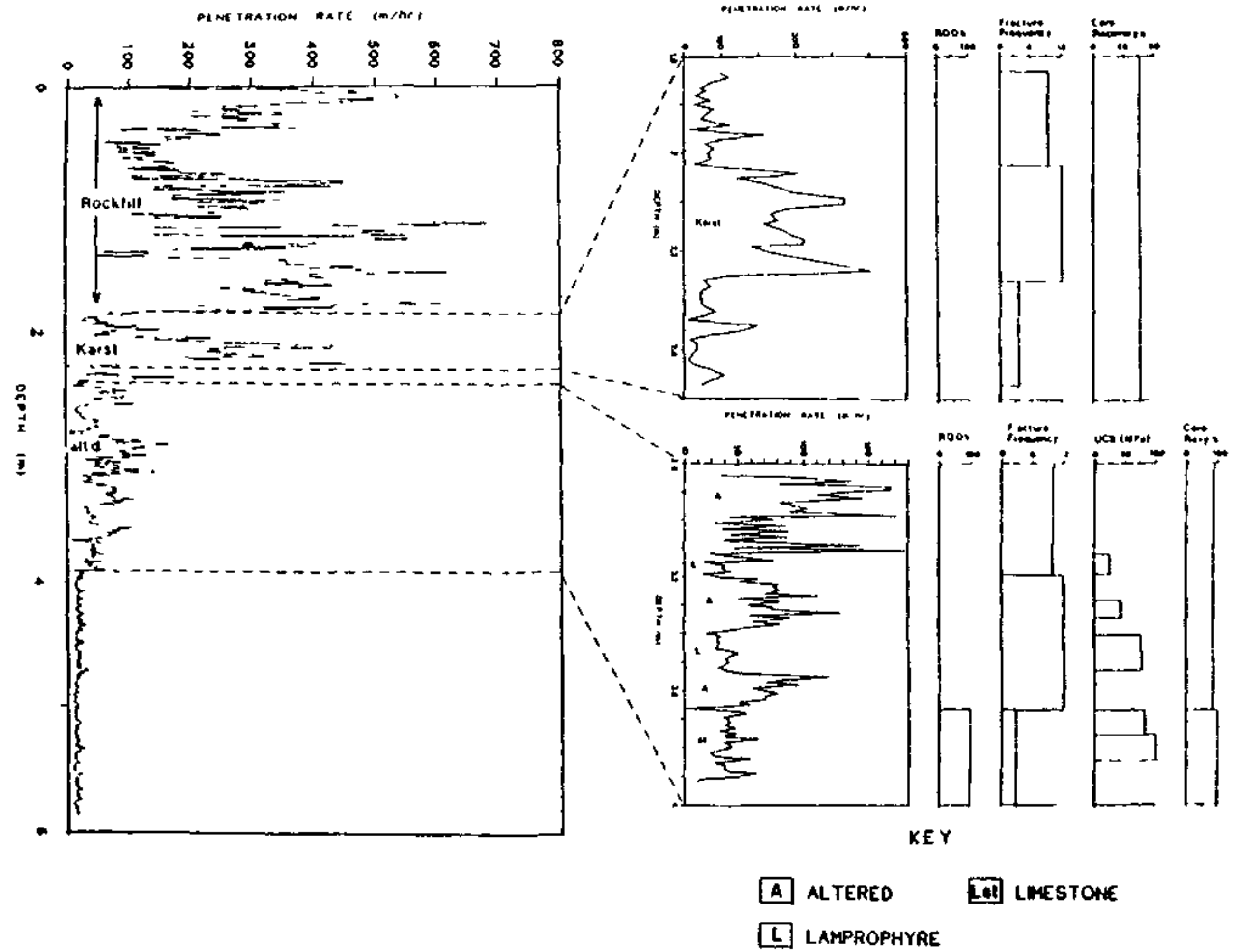

Figure 2. Drill Monitoring Data from Limestone-Lamprophyre Environment, Northcrest (Carter et al. (1988))

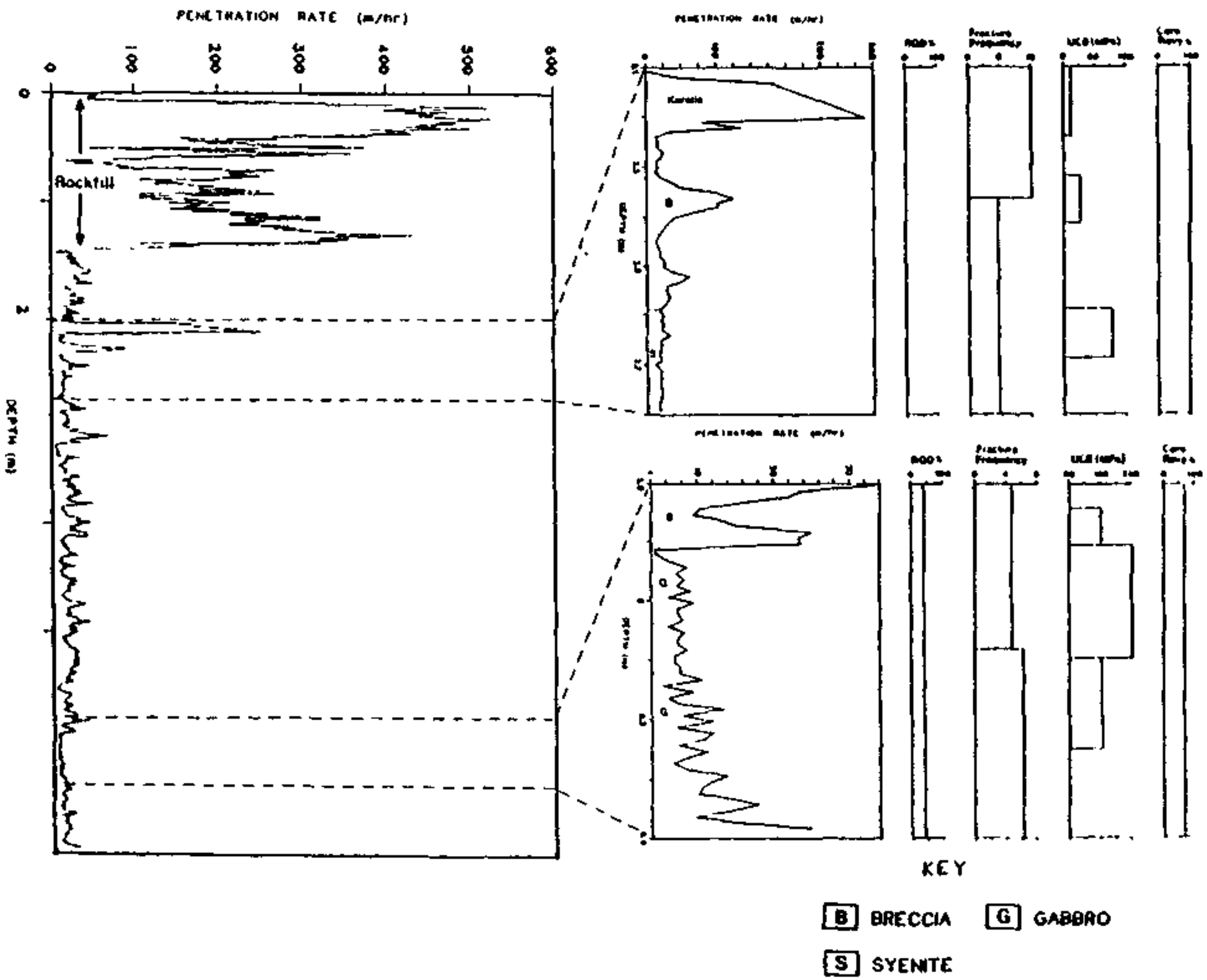

Figure 3. Drill Monitoring Data from **Igneous environment, Northcrest**
(Carter et al. (3988))

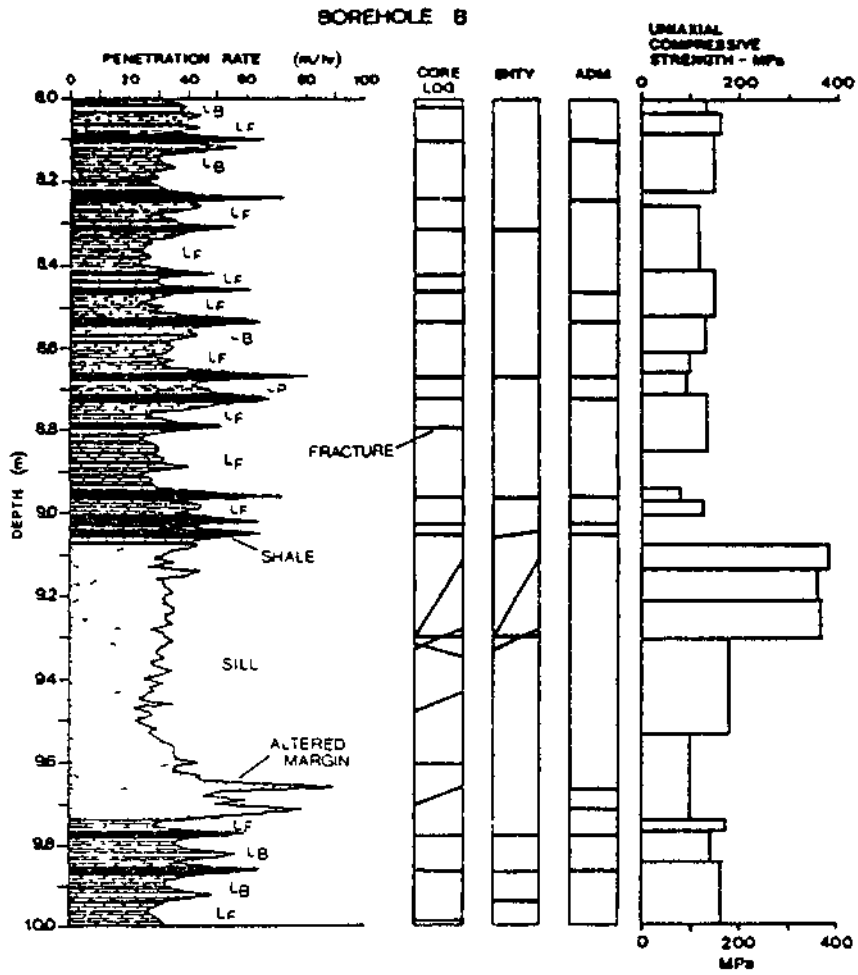

Figure 4. Drill Monitoring Data - Francon Quarry (Peck et al.(1987))

3.4. Estimation of Rock Properties

Drill response to cnanges in rocx mechanical properties, most notably strength, is reflected by variations in penetration rates on recorded logs. Figure 4. Factors affecting strength may include; alteration, fracturation, mineralogy and fabric. Figure 5 relates unconfined compressive strength to monitored penetration rate, for rock types drilled at the Northcrest site. The anticipated trend of decreasing penetration rate with increased rock strength is evident. The scattering of points and lower rock strengths of some of the igneous rocks are accounted for by local alteration, reducing the bulk rock strength and thus enhancing penetration rates. The influence of alteration and fracturation on penetration rates in limestone and the sills is also apparent in Figures 2 and 4, in which highly fractured and altered zones are typified by reduced rock strength and peneration rates well in excess of 70 m/hr.

In situ rock strength may be estimated by input of drill monitoring data into drillability algorithms. Based on measured penetration rates, predicted strength envelopes may be determined for a range of rock types and conditions at any site. Figure 6 shows such strength prediction for limestones based on Meloche Quarry drilling studies, using alternative U.S.B.M. drillability algorithms derived from laboratory and field studies, Schmidt (1973) and Tandanand and Linger (1973). Drilling rate, however is governed by bulk strength, which is related to both intact rock strength and discontinuities. In situ derivation of bulk (rockmass) strength by drilling could potentially advance the ability to characterize rockmass quality.

4. CONCLUSIONS

The interpretation of drilling performance parameters has been shown to provide detailed information about rock mass characteristics in a borehole. Provided a minimal knowledge of local geology exists and initial correlation with drill performance is undertaken, MWD systems provide the potential to provide accurate and reliable data for both absolute rock

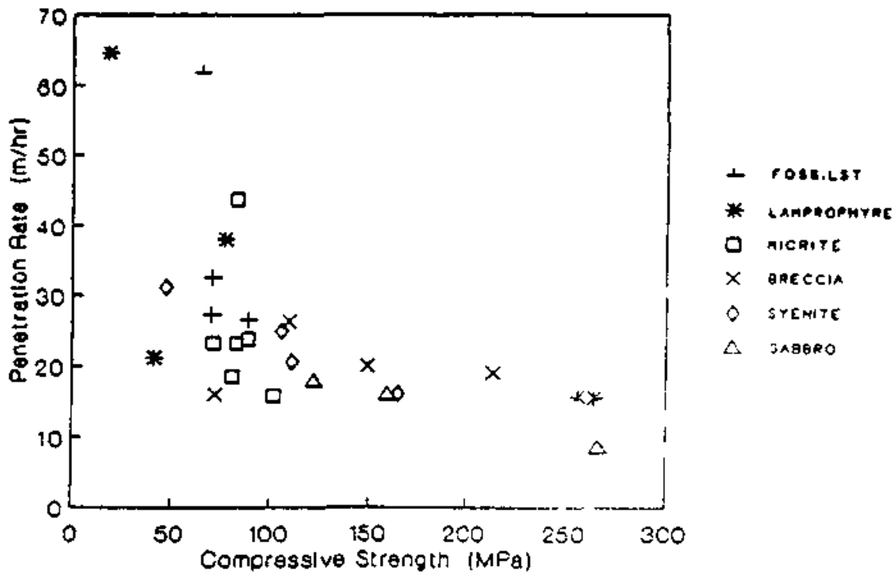

Figure 5. Penetration Rate, Unconfined Compressive Strength Relationship, Northcrest (Carter et al. (1988))

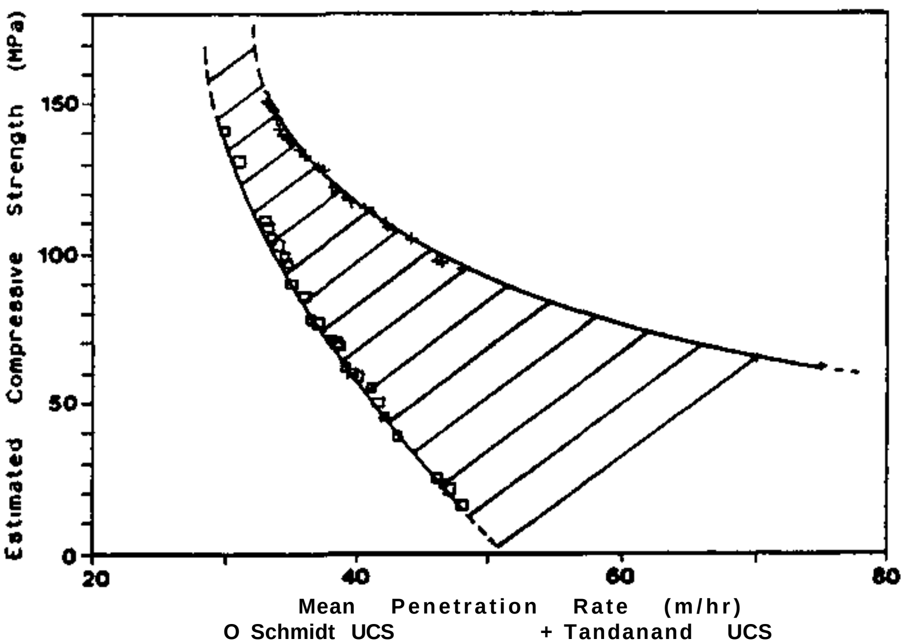

Figure 6. Estimated Compressive Strengths from Mean Percussive Penetration Rates, Meloche Quarry, (Peck (1986))

strength ana discontinuities.

Employment of MWD systems during routine production drilling and blasthole production drilling could result in savings of both time and expense, *hile lending greater insight into the complexities of ground conditions and rockmass quality.

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REFERENCES

Brown, E.T. and Barr, M.V., 1978; "Instrumented Drilling as an Aid to Site Investigations", Proc. 3rd Int'l. Congr., Int'l. Assoc. Engng. Geol., Madrid, Section IV, Vol. 1, pp. 21-28.

Carter, M.A., 1988; "Site Characterization for Mechanical Excavation", Unpub. MSc. thesis, McGill University.

Carter, M., Scoble, M.J., J. Peck and A. Bensoussan., 1988; "Rock Mass Characterization by Drilling", Proc. 15th. Canadian Conf. Rock Mechanics, Univ. of Toronto, pp. 11-20.

Clark, G.B., 1982; "Principles of Rock Drilling and Bit Wear" (Part 1), Colo. School of Mines Quarterly, Vol. 77 (1).

Clark, T.H., 1972; "Region de Montreal Area", Geol. Rep. Quebec Dept. Nat. Resour., No. 26-27, pp. 59-63.

Durand, M., 1978; "Classification des Phénomènes et Cartographie Geotechnique des Roches Rencontrées dans les Grands Travaux Urbains à Montréal, Canada", 3rd Int. Cong. Int. As3. Engng. Geol., Madrid, Spain, Sect. 1, pp. 45-55.

Deveaux, Martin et al., 1983; "Instantaneous Logging in Water Survey", Bull, of Int'l. Assoc. Of Engng. Geol., No. 26-27, pp. 59-63.

Hojar, *,., 1987, Toen ^it Mining of Lignite in Czechoslovakia ', .'rcc. Symp. Continuous Surface Mining, Edmonton, Alberta, GolosinsKi, ^.Z. and Boeh-n, '•".G. eds. (Clausthal-Zeılerfıeld Trans Tech Publications), pp. 183-92.

Horner, P.C. and Sherrell, F.*t., 1977, "The Applications of Air Flush rtotary-Percussive Techniques in Site Investigation", 0. *lour, oi* Engng. Geol., 10, pp. 207-221.

..ebel, J.R.G., 1984, 'An Investigation to Evaluate the Relationship **Between** Rock Quality Index and Powder Factor for Surface Mining", Unpub. MSc. thesis, Univ. British Columbia.

Leighton, J.C., 1983; "Correlating Rotary Drill Performance to Powder Factors for Improved Blasting Control", 36th Cdn. Geotech. Conf., Vancouver, B.C., June 1983, pp. 4.1.1-4.1.10.

Lutz, J., 1982; "Automatic Recording of Drilling Parameters - General Presentation", Jurançon, France.

Peck, J., 1986; "Application of Drill Monitoring to Rock Mass Characterization", Unpub. M. Eng thesis, McGill University.

Peck, J., Scoble, M.J., and Carter, M.A., 1987; "Interpretation of Drilling Parameters for Ground Characterization in Exploration and Development of Quarries", Trans. Instn Mm. Metall. (Sect. B: Appi. earth sei.), 96, August 1987, pp. B141-B148.

Scheck, D.E., Mitchell, L.H., and Mack, G.W., 1982; "Automated Blasthole Logging and Design", Open File Rep. U.S.B.M., 55-83, 126p.

Schmidt, R.L., 1973; "Drillability Studies", U.S.B.M. RI 7684.

Schneider, B. , 1983; "Drilling Logs for Earth Dam Leakage Location", Bull, of Int'l. Assoc. Of Engng. Geol., No. 26-27, pp. 123-128.

Shunneson, H., 1988; Personal communication, Div. Min. Equip. Eng., Lulea Univ., Sweden.

Tandanand, S. and Unger, H.F., 1973, "Drillability Determination - a Drillability Index for Percussion Drills", U.S.B.M. RI 8073.