with distinct types of mutations (*su* or *sh2*) differ in terms of soluble glucan content, which is higher only in *su1* genotypes. Such differences are attributed to finer biochemical differentiation among sweet corns for soluble glucans (16.54 to 59.55 mg/kernel) and could be understood and comprehended in the context of earlier information relating to effects of different mutations. Hence, this technique could easily differentiate the sweet corn genotypes into *su1* (with higher value of soluble glucans) versus non-*su1* types (with lower value), even on the basis of individual kernel. Similar to field corn and sweet corn as a group, QPM also conformed to a characteristic range of values in terms of content and composition of soluble and insoluble polysaccharides. Results can be extrapolated and applied to other major cereals (wheat, rice barley, jowar, etc.), considering their common core pathway of starch metabolism[12,13]. Some insights into apparent variations and consequent specialized utilization are evident in crops like barley, sorghum and wheat.

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Importance and sensitivity of variables defining throw and flyrock in surface blasting by artificial neural network method

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Rock breakage by explosives is followed by throw or heaving the broken material and occasional flyrock. Heaving is a desired feature of blasting for efficient mucking. However, flyrock is a rock fragment that travels beyond the designated distance from a blast in surface mines, and poses a threat to adjacent habitats. Here, we decipher the importance and sensitivity of the variables and factors used to establish the predictive regime of throw with more emphasis on flyrock. The data collected were modelled using artificial neural network approach. The importance and sensitivity of variables and factors were delineated so that they are in tune with the rationale of the outcome of the blast. A combinatory approach was devised to arrive at minimal variables and factors to reduce the statistical redundancy, and to propose a rational predictive regime for throw and flyrock in surface mines.

Keywords: Artificial neural network, blasting, flyrock, throw, surface mines.

BLASTING is an integral part of excavation in mines and continues to be a major method of rock fragmentation due to the economy of operation. Blasting, in addition to fragmentation, is associated with throwing the muck generated, vibrations, air overpressure and flyrock. While fragmentation and throw are desired effects, flyrock is an undesirable outcome. Flyrock is a fragment of rock that travels greater distances than desired, in comparison to throw which is limited to a few multiples of bench height. Flyrock is not only a threat to nearby habitats, but poses a challenge to miners as all sorts of 'Objects of Concern' (OC)[1] are affected by it. Flyrock is one of the major causes of blast induced fatalities and accidents[2].

There are several reasons for flyrock which belong to the domain of rockmass including structural discontinuities[3], blast design and explosive variables. Several attempts were made by different authors to identify the reasons for flyrock and several equations have been proposed to predict flyrock distance. However, there is a disparity between cause of flyrock and the variables identified that have been used in prediction regime[4]. Such a disparity is reflected in Tables 1 and 2 and a comparison is shown in Figure 1.

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Table 1. Causes of flyrock identified by different authors

Reference	Cause													Total variables identified
	Insufficient burden	Geological anomalies	Insufficient stemming	Excess explosive	Improper blast layout	Inadequate delay	Poor confinement	Poor quality stemming	Drilling accuracy	Explosive density	High specific charge	Misfire	Spacing	
Fletcher and D'Andrea[9]	√	√	√	√										4
Gupta[10]	√			√				√		√				4
Workman and Calder[11]		√			√									2
Davies[12]	√	√	√		√	√						√		6
Schneider[5]	√	√	√	√	√	√		√	√		√			9
Adhikari[13]	√		√			√					√		√	5
Richards and Moore[14]	√		√				√	√						4
Bajpayee *et al.*[2]	√	√					√							3
Kecojevic and Radomsky[15]	√	√	√	√	√									5
Little[16]	√	√		√		√	√							5
Verakis and Lobb[17]	√	√	√		√	√								5
Little and Blair[18]	√	√	√											3
Amini *et al.*[19]	√	√		√			√							4
Ghasemi *et al.*[20]		√	√											2
Kricak *et al.*[6]		√												1
Mishra and Mallick[21]	√	√	√			√			√			√		6
Total citations	13	13	10	6	5	6	4	3	2	1	2	2	1	

Table 2. Variables used in different flyrock distance prediction models

Reference	Factors used																No. of parameters used
	Rock conditions	Specific drilling	Total charge length	Hole depth	Burden	Spacing	Blast-hole diameter	Stemming length	Density of rock	Density of explosive	Specific charge	Explosive weight/m	Fragment shape	Charge per blasthole	Charge per delay	Drill hole angle	
Lundborg[22]							√				√						2
Roth[23]			√						√			√					3
Gupta[10]					√			√									2
St George and Gibson[24]									√	√							2
Richards and Moore[14]					√			√				√				√	4
McKenzie[25]			√				√	√		√			√				5
Monjezi *et al.*[26]				√			√	√	√		√				√		6
Stojadinović *et al.*[27]									√	√			√				3
Amini *et al.*[19]		√		√		√	√	√			√						6
Rezaei *et al.*[28]		√		√		√		√	√		√				√		7
Ghasemi *et al.*[20]				√	√	√	√	√			√			√			7
Ghasemi *et al.*[29]				√	√	√		√			√			√	√		7
Monjezi *et al.*[30]		√		√	√	√	√	√			√						7
Khandelwal and Monzeji[31]		√		√	√	√		√			√						6
Total citations	0	4	2	7	6	6	6	10	5	3	8	2	2	2	3	1	

Schneider[5] identified nine and Kricak *et al.*[6] identified only one parameter responsible for causing flyrock (Table 1). From the various influencing factors as given in Table 1, insufficient burden, geological anomalies and insufficient stemming emerge as the most important causes of flyrock generation. Improper blast design, excess explosive and inadequate delays assume a lesser role among the reported causative factors. This can help redefine strategies for modelling contributory variables of flyrock generation.

A similar compilation of variables used in models that predict distances travelled by flyrock is shown in Table 2.

As seen in Table 2, variables namely stemming length, blasthole depth, specific charge, burden and blasthole diameter emerge as the principal ones in predicting the distance which a flyrock can travel.

A comparison of top seven causative factors (Table 1), and those used in predictive equations (Table 2) are given in Figure 1.

From Figure 1 we infer that principally two variables, namely burden and rock, differ with regard to cause and prediction, probably due to the difficulty in assessing rock mass and burden. Other variables closely follow each other in cause and prediction citations, establishing their importance.

Accordingly, it was found pertinent to ascertain the importance and sensitivity of variables ranging from rock mass to blast design. For this purpose, artificial neural networking (ANN) method was deployed as it is a better predictive tool in situations like blasting[7], where complex interactions with variables take place. Since this method yields both the importance and sensitivity of variables with regard to output, without going into the details of interactions, it is suitable without actual prediction, which could be specific to different geo-mining conditions. ANN, neurogenetic and evolutionary algorithms have been used to predict flyrock[8]. The direct prediction of flyrock using genetic algorithms poses a problem

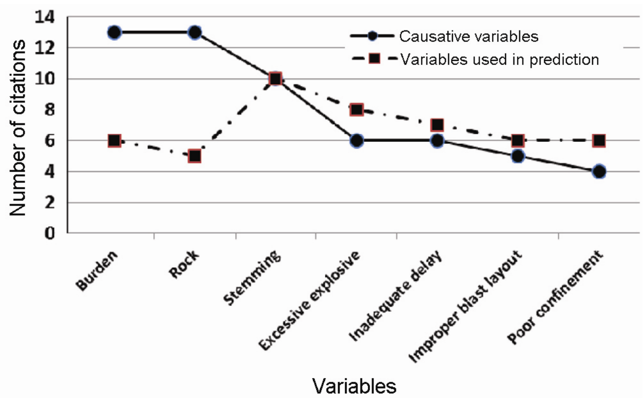

Figure 1. Departure in causative and predictive variables cited in literature.

of being site-specific and does not reveal the interrelationships and interactions within the variables in simple terms. However, the analysis is very good in providing other details like relative importance and sensitivity of the independent variables, with respect to the dependent variable.

Surface blasting involves several variables and factors that are used in design and estimation of other parameters while predicting different outcomes of blasts. The variables and parameters used in this work are defined in Table 3.

Data on different variables and factors of blasting from 10 mines, was generated to create a reasonable database. The variables included those pertaining to rock mass and blast design along with dependent variables like throw and flyrock. The basic statistics of the data thus generated is provided in Table 4.

The entire data from field blasts was analysed with EasyNN-Plus©, an ANN software, which has in-built routines to design a network, train and validate the ANN model. It uses a backward propagation method to minimize errors. Trimming, cloning and exclusion of data are inbuilt in the software to attain minimal error and to avoid overtraining. The software can suggest the number of input and output nodes for training a network. The type of network used in our study is shown in Figure 2.

Figure 3 shows progressive training of the network. Initially both throw and flyrock were included as output while using all input variables (Table 3), for simultaneous training of the network. However, the training continued and resulted in overtraining as validation did not work properly, as is evident from high scatter in the validation (Figure 3). This was because two different output variables, viz. throw (regular) and flyrock (random nature) were treated together. The problem could be solved by treating the output variables separately.

The values were thus independently analysed by ANN. The training results of ANN analysis of throw and flyrock when treated independently are shown in Figures 4 and 5 respectively.

The importance and sensitivity of different variables on throw and flyrock distance for combined and independent treatments of throw and flyrock obtained from ANN analysis are shown in Table 5.

In order to reduce variables entering into the scheme, a combinatory approach was evolved and used for furthering the results. The combinations of variables defined earlier that compensate several variables, are shaded in Table 5 and further elaborated in Table 6.

The variables adopted from Table 5 for defining a predictive regime for throw and flyrock distance were normalized. In order to retain the significance of parameters, the original ranking of the variables (Table 5) was maintained and the relative importance and sensitivity of the factors identified (Table 7).

Table 3. Definition of variables and factors used

Name	Nature	Symbol	Definition
Compressive strength	x_i	σ_c	Uniaxial compressive strength of rock estimated with Schmidt Hammer
Joint spacing	x_i	S_j	Spacing of the major joint set as observed in field
Joint orientation	x_i	O_j	Orientation of the major joint set with respect to blast face
P-wave velocity	x_i	c_{Pi}	*In situ P*-wave velocity of rock mass from geophysical survey
Density of rock	x_i	ρ_r	Density of rock specimen measured in lab
Acoustic impedance of rock	F_i	Z_r	Product of *in situ P*-wave velocity of rock and its lab density
Blastability Index	F_i	I_{BI}	Empirical estimation of blastability using method[32]
Drill diameter	x_i	d	Blasthole diameter as measured in field
Burden	x_i	B	Minimum burden observed in the blast
Spacing	x_i	S	Drilled spacing between two adjacent holes measured in field
Stemming length	x_i	l_s	Minimum stemming length applied to blastholes
Specific charge	F_i	q	The explosive charge per unit volume of rock used in blast
Explosive density	x_i	ρ_e	Density of explosive used as measured in blasts
Deck length	x_i	l_{sd}	Length of solid or air deck used to separate the charges in a single blasthole
Charge diameter	x_i	d_c	Explosive diameter in case of cartridge explosives used in blasts
Bench height	x_i	H_b	The height of bench being blasted
Hole depth	x_i	l_{bh}	Depth of the blasthole drilled
Charge length	x_i	l_c	Length of the explosive charge placed in the blasthole
Charge length to drill depth ratio	F_i	l_c/l_{bh}	Ratio of the charge length to the blasthole depth
Charge/hole	x_i	Q	Total weight of explosive used in a blasthole
Effective in-hole explosive density	F_i	ρ_{ee}	The weight of explosive used per unit volume of a blasthole
Throw	x_o	R_m	Distance of broken material from the bench blasted
Flyrock distance	x_o	R_f	Distance of flyrock fragment thrown from the blast

x_i is input variable, F_i is input factor, x_o is output variable.

Table 4. Statistics of different variables and factors investigated

Group	Name of the variable/factor	Units	Data sets	Mean	Minimum	Maximum	Standard deviation
Rock mass properties	Compressive strength (Schmidt)	MPa	145	52	17	105	24
	Joint spacing	m	145	0.53	0.10	1.30	0.26
	Joint orientation	Å	145	36	1.00	115.00	26.59
	P-wave velocity	m/s	145	2960	473	4690	1009
	Density of rock	kg/m^3	145	2455	1720	4100	295
	Blastability Index	×10	145	6.12	1.00	9.00	1.58
Basic blast design variables including modifications within the hole and explosive properties	Drill diameter	mm	145	128	100	165	24
	Burden	m	145	3.20	0.68	5.00	0.78
	Spacing	m	145	4.36	1.50	7.30	1.13
	Stemming length	m	145	3.19	0.30	6.50	1.38
	Specific charge	kg/m^3	145	0.50	0.08	1.50	0.30
	Explosive density	g/cm^3	145	1.06	0.77	1.30	0.12
	Deck length	m	145	0.58	0.00	4.70	0.77
	Charge diameter	mm	145	119	83	165	32
	Bench height	m	145	7.71	0.90	14.00	3.16
	Hole depth	m	145	8.17	0.90	14.50	3.28
	Charge length	m	145	4.44	0.60	8.95	2.15
	Charge length to drill depth ratio	–	145	0.57	0.19	0.94	0.15
	Charge/hole	kg	145	57.6	1.9	203.7	52.9
	Effective in-hole explosive density	kg/m^3	145	429.3	123.7	720.8	133.1
Rock movement descriptors	Throw	m	145	11.6	4.3	16.6	2.3
	Flyrock distance	m	27	69.3	32.0	137.0	28.7

Table 7 reveals that ρ_r, ρ_{ee}, B, c_{Pi}, S are the most important variables/factors that determine throw whereas B, c_{Pi}, ρ_r, ρ_{ee}, l_q/l_d and S are important to flyrock respectively.

Figure 6 shows that burden, density of rock, effective in-hole density of explosive, and *P*-wave velocity of rock assume significant importance in all types of rock displacement. However, the ratio of charge length to blasthole depth becomes more prominent for flyrock distance compared to throw. From this analysis, the parameters affecting the flyrock distance get outlined. This also conforms to the general trend in variables identified in the

Table 5. The relative importance and sensitivity of variables, factors

Variable/factor		ρ_{ee}	ρ_r	B	c_{Pi}	I_{BI}	ρ_e	O_j	S_j	d	l_{sd}	S	l_c/l_{bh}	q	l_c	l_{bh}	H_b	σ_c	d_c	l_s	Q_h
R_{all}	Imp.	1	8	4	2	9	12	6	3	10	16	14	7	13	15	20	19	5	18	11	17
	Sens.	1	10	5	4	3	18	11	2	9	7	12	15	8	13	6	19	17	14	16	20
R_m	Imp.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Sens.	3	1	2	17	4	8	9	16	10	6	11	19	5	12	18	15	13	14	7	20
R_f	Imp.	1	3	2	5	9	4	17	19	14	11	16	12	18	6	15	8	20	7	13	10
	Sens.	16	17	1	3	2	15	12	20	4	11	18	9	13	8	7	6	19	5	10	14

See Table 3 for symbols; the shadowed variables are combined later.

Table 6. Combination of variables and compensation of factors

Group	Name of the variable/factor	Combinatory variable, factor or compensatory factor/description	Comments
Rock mass properties	Compressive strength (Schmidt) Joint spacing Joint orientation *P*-wave velocity Density of rock Blastability Index	1. *P*-wave velocity of rock, and 2. Density of rock	Can be further combined into acoustic impedance of rockmass
Basic blast design variables including modifications within the hole and explosive properties	Drill diameter Burden Spacing Stemming length Specific charge Explosive density Deck length Charge diameter Bench height Hole depth Charge length Charge length to drill depth ratio Charge/hole	Included in ρ_{ee} 3. Included as design variable 4. Included in design variable Included in ρ_{ee} Included in ρ_{ee} and B, S, H_b Included in ρ_{ee} Included in ρ_{ee} Included in ρ_{ee} Included in ρ_{ee} Included in ρ_{ee} Included in ρ_{ee} Treated separately Included in ρ_{ee}	5. ρ_{ee} designed by Raina[1] incorporates several variables as shown here and is a better descriptor in comparison to specific charge The burden and spacing represent the design of blast. 6. The charge length to drill depth ratio is treated separately as it emerged out as an important linear factor controlling flyrock. (Note: Numbers indicate the variable identified after combination)

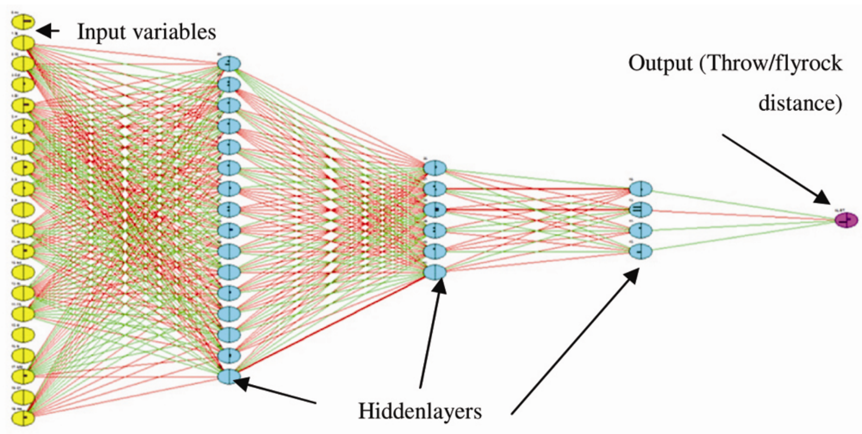

Figure 2. Network architecture for ANN analysis of the data.

cause of flyrock. Finally, the following functions (eq. (1)) and (eq. (2)) can be defined for throw and flyrock.

$$R_m = f(\rho_r, \rho_{ee}, B, c_{Pi}, S), \quad (1)$$

$$R_f = f(B, c_{Pi}, \rho_r, \rho_{ee}, l_q/l_d, S). \quad (2)$$

These functions assume use of a similar explosive since velocity of detonation of explosive was not considered in the analysis. An exercise can be made to further reduce the parameters entering into equations by considering the following: (a) The product of c_{Pi} and ρ_r constitutes the acoustic impedance of rock mass (Z_r); (b) The product of

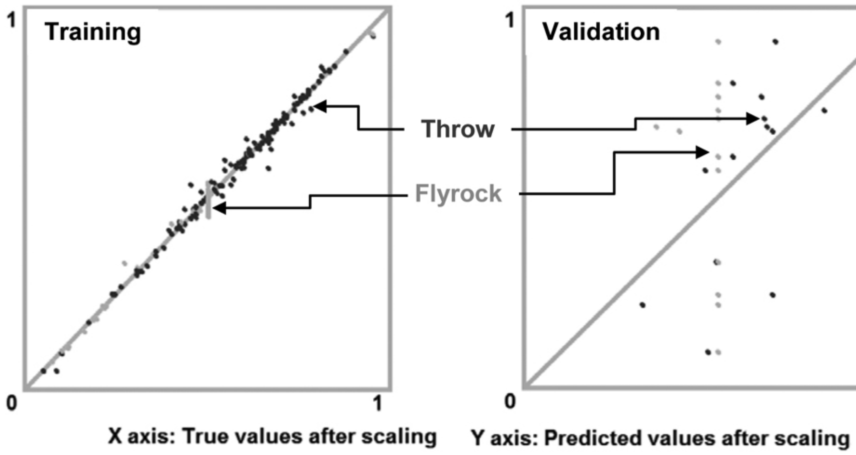

Figure 3. Training of the network.

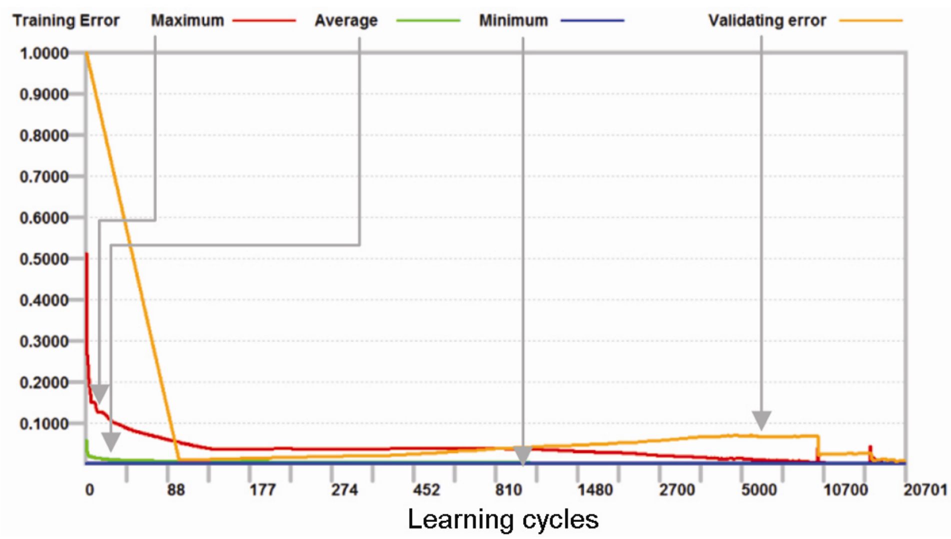

Figure 4. ANN Training and validating results for throw only.

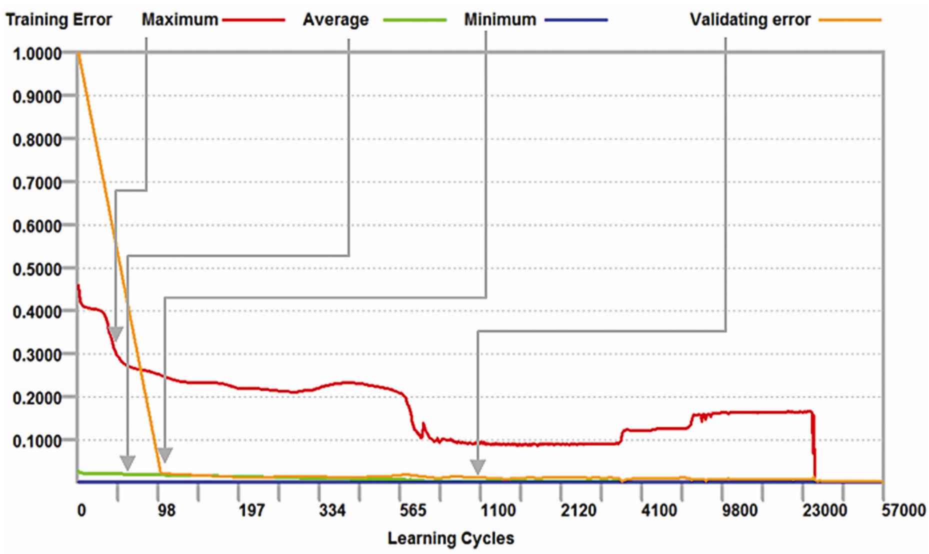

Figure 5. ANN training and validating results for flyrock only.

Table 7. Importance and sensitivity of final variables identified from ANN analysis

		Relative importance (imp.)			Relative sensitivity (sens.)			imp. × sens.		
Variable group	x_i, F_i	All	Throw	Flyrock	All	Throw	Flyrock	All	Throw	Flyrock
Rock	c_{Pi}	0.189	0.176	0.179	0.183	0.136	0.191	0.035	0.024	0.034
	ρ_r	0.156	0.188	0.188	0.157	0.196	0.147	0.024	0.037	0.028
Explosive	ρ_{ee}	0.194	0.194	0.158	0.196	0.189	0.150	0.038	0.037	0.024
	B	0.178	0.182	0.192	0.179	0.192	0.197	0.032	0.035	0.038
Blast design	l_q/l_d	0.161	0.127	0.133	0.136	0.128	0.172	0.022	0.016	0.023
	S	0.122	0.133	0.150	0.149	0.158	0.144	0.018	0.021	0.022

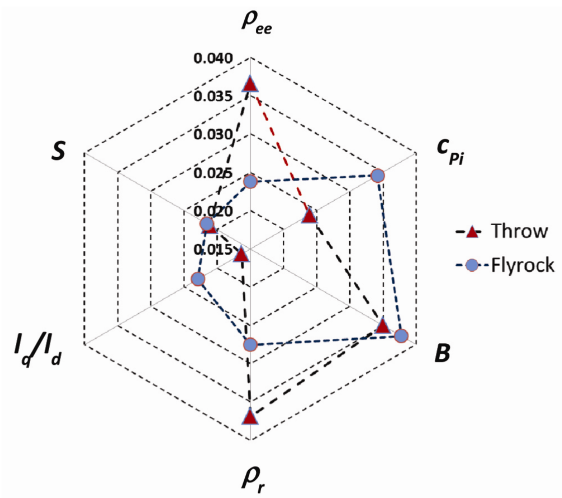

Figure 6. The relative importance and sensitivity of the variables for throw and flyrock.

ρ_{ee} and in-hole velocity of detonation (c_{dc}) relates to the acoustic impedance of the explosive (Z_e) and (c) the burden and spacing for a given bench height constitutes the blast pattern b_P.

Replacing the variables in eq. (1) and (2) by the factors mentioned above, the final form of the functions is given as

$$R_m = f(Z_r, Z_e, b_P), \quad (3)$$

$$R_f = f(Z_r, Z_e, b_P, l_q/l_d). \quad (4)$$

It is thus possible to define the parameters as mentioned in (eq. (1)) and (eq. (2)) in a particular mining condition without compromising on the variables. Equations (3) and (4) will thus require an estimation of least number of parameters to define the throw and flyrock distance.

We have enumerated a scheme consisting of variables in blasting that define the throw and flyrock distance. The method based on a significant database and importance of variables through artificial neural network, defines a new paradigm in the estimation of important outcomes of a blast. A combinatory approach has been devised to minimize parameters for estimation of throw and flyrock. It is evident from the developed functions that the basic factors defining throw and flyrock distance are similar, except for the charge length to drill depth ratio, which has a strong influence on flyrock distance. The crisp functions defined here can be used to work out independent parameters of the functions influencing throw and flyrock distance for a given mining condition, while considering that the explosive is similar.

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New occurrence of albitite from Nubra valley, Ladakh: characterization from mineralogy and whole rock geochemistry

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We report here the occurrence of albitite in Nubra valley of Ladakh region in the Trans-Himalaya area within Indian Territory at 34°44′46″N and 77°33′8″E before Panamik (in the Wish Pond, local name of the area). The albitite has been characterized by petrography, mineral chemistry, X-ray diffraction and whole rock geochemistry (i.e. major, trace and rare earth elements (REE)). The albitite comprises 85–96% albite and amphibole, whereas apatite, zircon and ilmenite occur as accessory minerals. The textural relationship and geochemical data indicate its igneous origin. The albitite contains about 5–6 ppm U and Th which may possibly host U-REE mineralization.

Keywords: Albitite, Karakoram, mineral chemistry, XRD, whole rock chemistry.

A number of albitite occurrences have been described in India within the Archaean basement and the Meso-Proterozoic cover rocks of Delhi Supergroup in north-central and northern Rajasthan[1–3]. Till now, there is only one known occurrence of albitite from Himalayan terrain, i.e. Swat valley of Pakistan in association with Mingora ophiolitic mélange[4]. However, such a rock type was not reported from Indian Himalayan or Trans-Himalayan region. Here, we present a detailed account of new occurrence of albitite from the Nubra valley of Shyok Suture Zone (SSZ) in trans-Himalayan region, based on petrography, XRD, mineral chemistry and whole rock geochemistry. The significance of albitite in Trans-Himalaya is important due to its peculiar occurrence in subduction-related tectonic setting (i.e. Shyok Suture Zone), whereas the albitites generally occur along the intercontinental rift zone[1–3].

The SSZ is characterized as structural boundary which separates Ladakh magmatic arc in the south from the Karakoram terrain in the north. The SSZ runs parallel to Shyok river[5] (Figure 1). The Karakoram terrain contains a suite of rocks covering mélanges, ophiolites, sedimentary and metamorphic rocks. These rock sequences crop out in the Karakoram Range: the Nubra Formation[6], the Karakoram leucogranite batholith (the Baltoro Plutonic Unit

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