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ABSTRACT

To determine the most appropiate zone for the emplacement of a nuclear repository, the National Atomic Energy Commission made an agreement with the Institute of Mining Research of the National University of San Juan. As a result, a sector of about 12 km^2 was preselected in Sierra del Medio (Chubut, Argentina) so as to perform the corresponding detailed analysis.

This paper presents the geostatistical study of the fracturation characteristics of the rock in above mentioned site. Treating "Number of joints per linear meter" and "Index of the surface rock quality" as variables led to the area of minor fracturation of 600 x 1000 m.

Finally, a tentative plan of drillings for the study of the body in a volume a about 600 x 1000 x 600 m was proposed.

1. INTRODUCTION.

In 1980 and 1981 the National Atomic Energy Commission requested the National University of San Juan to carry out a census of plutonic bodies in the Argentine Republic.

Four differents bodies that fulfilled all the CNEA's specifications for the emplacement of a nuclear waste repository were selected (1)(2). To begin the exploration, the body known as "Sierra del Medio", located in the north of the province of Chubut, was taken as the first alternative (Figure N°1).

In 1982 CNEA appointed the Institute of Mining Research to perform a new series of studies in order to investigate the granitic body of Sierra del Medio in detail. As a result, an area of about 12 Km^2 was selected, to situate the sector with less discontinuity and most suitable structural -petrographic characteristics for the emplacement of the repository.

Geostatistical techniques allowed define the above mentioned sector in a relatively short time and in a quantitive way.

2. METHODOLOGY USED.

The general methodology employed in the determination of the required area follows the following scheme:

a) First, primary data were obtained to define the sampling mesh.

Twenty-eigth approximateley isodistanced stations weretaken. They supplied values of the number of joints (N) for 2 meters intervals, the spacing among them. The obove mentioned measures were obtained along two lines of 10 m each, located at each station, normal to the global strike of the two principal systems of joints thataffect the rock mass.

Alfterwards, samples of the definite grid of 122 stations were obtained.

Besides, the geological study and the survey of the investigated area were developed (2).

The rock quality was measured, from the mechanical point of view, with the N/L and RQDS parameters. The latter was defined as the total length of spacings (more than 10 cm long) among discontinuits, per unit lenght. The N/L and RQDS values were estimated for each line. Different variables to be analysed were obtained, taking these primary data as basis.

b) The parameters that defined the definite grid of exploration were determined. Different forms and mesh densifications were proposed when the accuracy established for the knowledge of the considered variables was defined. This analysis was carried out only with the N/L parameter.

c) The distribution pattern to which the sampling of N/L and RQDS obey, was used in the selection of the type of semivariography to be estimated from them.

The chi-square criterion allowed to assess the adjustment of the N/L histography to the corresponding distribution.

The correlation between the N/L and RQDS parameters is shown at this point.

d) In order to carry out the geostatistical representation of the variables employed in the present study, the models of variability of the corresponding experimental semivariographies were obtained. These were estimated considering the estrikes N-S, NE-SW, E-W and NW-SE.

To Check the reliability of the N/L semivariography to be used in the krigeage operator, the Re-Use method was applied.

e) The determination of the minimum fracturation area was based on the kriging estimations of the mean values of the variables employed, for the units of surface in which the sampled area was assumed to be divided in.

At the same time, the geologic data was analysed in detail and it allowed to establish the reliability of the geostatistical model of the investigated area.

The estimations corresponding to this methodology were carried out with a IBM 4341 computation system, at the National University of San Juan.

3. LOCATION OF THE 600 x 1000 m AREA.

3.1 DETERMINATION OF THE DEFINITIVE SAMPLING GRID.

There was a 28 stations primary mesh with a minimum distance of 1000 m acording with the N-S direction and 350 min the E-W.

As the survey had not been carried out yet, this grid was assumed to be regular and it was situated in a same horizontal plane. The N/L values corresponding to each line were the only ones used in this study, taking them separately in order to get more information.

The parameters of the definitive mesh were obtained in accordance with the criterion that the size and orientation of the proposed grid are related with the accuracy established for the considered variable and with its corresponding semivariography.

SIZE OF THE MESH

In order to define the proposed grid, the N/L semivariography was obtained. Taking as an assumption a lognormal distribution for such variable, a variogram of relative local type was considered. This was corroborated by means of the statistical analysis carried out with the definitive sampling.

In Figure N°2 the experimental semivariograms are shown with the corresponding ellipse of range. The isotropy of sill was assumed for practical purposes. The high value obtained from the nugget affect are due to the minimum distance of the primary mesh, wich is too big to "detect" structures of variability of minor dimensions in the area under study.

According to the range values obtained - i.e.an ellipse of 1900 x 760 m - a 500 x 175 m grid was considered suitable for the interpretation of the semivariograms constructed on it.

In order to assess the adequacy of this size to the accuracy requirements established (20%), units of 150 m N-S x 50 m E-W were proposed which originated relative typical deviations similar to the accuracy previously mentioned.

ORIENTATION OF THE DEFINITIVE GRID.

To analyze the reliability of the anisotropy angle of range obtained in the N/L semivariography, two different methodologies were applied. They are based on the geostatistical estimations of typical deviations, corresponding to global assessments using the linear model that corresponds to the semivariography to be checked (Figure N°2). The proposed sampling is internal an established contour, determined only according to geometrical criteria. The methodologies are:

a) The variation of the typical deviation of kriging σ_K (%) for different anisotropy angles of range α (°) of the investigated semivariography, is show in Figure N°3. It can be seen that σ_K is minimun for α =15°. This fact allows to regard the anisotropy angle of range of the N/L semivariography (α =45°) as acceptable.

b) To corroborate the result of applying the previous methodology, different forms of the same 1000 x 500 m grid densification were proposed, getting the corresponding σ_K for each of them (Figure N°4).

It may be observed that the minimun σ_K is obtained for grid B, densificated in a North-South direction. This show that in such direction the variability is greater than along the others, since the assumed densification decreases in a major proportion the σ_K value corresponding to the primary mesh (Figure N°3). As the variability is greater in the N-S, the range is major in the same direction (Figure N°2), and anisotropy angle of range α = 0°was obtained.

The angles of anisotropy of ranges obtained α =45°, 15°and 0°, allowed to assign to the densified mesh the angle α =0°, keeping in this way the orientation of the primary grid.

In conclusion, a mesh of 500 x 175 m was proposed, according to the North-South and East-West direction, respectively.

3.2. STATISTICAL ANALYSIS OF THE N/L AND RQDS VARIABLES.

To determine the type of distribution to wich the N/L and RQDS samplings obey, they were classified by means of the corresponding histographies (Figure N°5). The mean of both units of length values was taken for the above mentioned parameters. Only the values resulting from the 100 stations available in this stage of the work were employed.

The N/L distribution seems to be in accordance with a lognormal pattern (Figure N°5). The presence of high frequencies in the RQDS histography, for values below 50%, is partly due to their reduction caused by those spacings among the discontinuities of less than 10 cm long, which are not considered in the RQDS computation. Besides, other fractions of unit length are discarded because of the width of discontinuities (some of them are affected by factors such as erosion). A lognormal distribution revolved according to a vertical axis has been superposed onto the RQDS histogram in Figure N°5.

LOGNORMALITY SIGNIFICANCE INDEX

The application of the chi-square criterion to the values of accumulated relative frequency of N/L, allowed to estimate their fitness to a lognormal law. Those values were drawn on a logarithmic-probabilistic graphic, in which the lognormal distribution is represented by means of a straight line. In a first attempt, as it is observed in Figure N°5, a group of points with a poor fitting to a straight line resulted. For this reason, and in orden to improwe it, a third parameter was added to the distribution (the addit on of a constant to the N/L variable) (3).

Two alternatives were tested, and the constant "5" which led to a good adjustment to a straight line, was selected. Then, this fitting with the chi-square criterion was evaluated. The separation of the experimental points with respect to the straight line that represents them, was determined by least squares. Thus, an index of significance of the 97% was obtained.

In accordance with this result, the N/L sampling supplied a valid proportional effect.

CORRELATION BETWEEN THE N/L AND RQDS PARAMETERS

Finally, the correlation existing between the 122 N/L and RQDS values is shown (Figure N°6). From it, a certain dependence between both parameters is deduced, and an extension of the correlation diagram to the N/L and RQDS high values is observed. This is originated because of the definition of the RQDS parameter (See 3.2).

3.3 LOCATION OF THE AREA OF MINIMUM FRACTURATION

The location of the area of minimum jointing was carried out with all the existing data resulting from the 122 stations sampling. The N/L and RQDS

parameters were considered. The mean of both line values was taken for the above mentioned variables. It was accepted that the values are placed in a same horizontal plane, although there is a difference among their elevations, due to the N/L fitness to a unique law of the lognormal type.

N/L AND RQDS SEMIVARIOGRAPHIES

The calculus of the experimental N/L and RQDS semivariographies was obtained according to the strikes N-S, NE-SW, E-W and NW-SE. The N/L variable was used instead of the N/L-5 (see 3.2), in spite of the lognormality characteristics of the last one. It was due to the fact that the constant substraction reduced remarkably the data to be used and consequent inconvenients emerge in order to establish the corresponding semivariography.

The experimental N/L and RQDS semivariograms are shown in Figures N°7 and N°8 together with the corresponding ellipses of range and total transition. The relative local type ones were considered because of the acceptable fit of the N/L parameter to a lognormal distribution and the existing correlation between N/L and RQDS. (See 3.2).

The semivariography data was introduced in the kriging operator by means of a linear type model.

$$\gamma(h) = Co + (C/a) \cdot h \quad \text{for } h < a$$
$$= Co + C \quad \text{for } h > a$$

There was a first attemps to assign through kriging, the N/L mean values to the area units assumed (rectangles of 150 x 50 m) (see 3.1), some negative values were obtained for the estimations and/or typical deviations of kriging, for the small values.

The origin of these inconvenients was assumed to be the high rate between the ellipse semiaxes corresponding to the total transition. This rate was descreased (table 1) correcting the above mentioned problem.

Range ellipse (meters)	a = 1,980	b = 825	α = 23.2°
Total transition ellipse	a = 0.228 x 0.9 = 0.205		
	b = 0.070 x 1.1 = 0.077		
	α = 29.1°		
	r = a/b = 2.66		

TABLE 1: Modified semivariography of N/L. Nugget effect Co = 0.112.

The same problem mentioned for N/L appeared for RQDS. It was solved with the semivariography shown in table 2.

Range ellipse (meters)	a = 2,025	b = 900	α = 21.8°
Total transition ellipse	a = 0.675 x 0.8 = 0.540	b = 0.185 x 1.2 = 0.540	
	α = 26.6°	r = a/b = 2.43	

TABLE 2: Modified semivariography of RQDS. Nugget effect Co = 0.116.

VALIDITY OF THE SERMIVARIOGRAPHIES (Re-Use Method).

Before using the semivariographies in the selection of the area of minimum jointing, they were checked to determine the reliability of their representativies.

This was performed applying the Re-Use Method, which allows to get statistical data about the differences among the sampling values and the corresponding estimations with kriging (see table 3).

Sempling	R = σ/σκ	Asymmetry	Flatness	Number of samples
N/L	1.68	- 1.17	4.58	120
RQDS	2.49	0.102	- 0.34	116

Di = Estimation of variable value by means of kriging at the sample point, minus the real corresponding value

σ = Typical deviation of Di

σk = Mean typical deviation of kriging

. From table 3 it is deduced that the R value of N/L is nearer 1 than that one corresponding to RQDS (the R value nearest to 1 show a better representativity of the sampling variability by the semivariography model).

. N/L shows a certain asymmetry as a consequence of having used that parameter without substracting the constant 5 (see 3.2).

. N/L produces a flatness (defined as -3) higher than that of the RQDS.

TABLE 3: Statistical parameters of the Re-Use Method application to the N/L and RQDS sampling values. The very small ones were discarded.

Selection of the area.

The mean values from N/L and RQDS kriging estimation with their corresponding typical deviations were assessed for the assumed units of area (see 3.1).

From the estimation and typical deviation isovalue curves analysis, the minimum N/L and maximum RQDS were determined, with the least error of estimation.

The isovalue curves corresponding to 5 joints per meter and 55% of RQDS are show in Figure N°9, with maximum errors of 25% and 30% respectively.

The geostatistical representation obtained with the N/L parameter was used for the final selection of the minimum fracturation area, due to the fact that the mencioned parameter provides a better representation of the characteristics of the soil.

. The RQDS histography shows values of frequency abnormally high below 50% (see 3.2).

. The N/L parameter represents the fracturation characteristics more properly, especially in the area of faults (see 3.2).

. The N/L parameter gives origin to a better fitting of the sampling values in the Re-Use Method (see tabla 5).

. In Figure N° 9 it can be seen that the N/L parameter leads to a most reliable representation of the rock quality (for instance ,the zone situated to the North-Northeast of the Las Chivas Hill, a sheared one with high N/L and RQDS values).

Figure N° 10 show the isovalue curve of 5 joints per meter, bounded by an error of 25%. These limits of estimation and error were chosen since such error affects the mean values in 1 discontinuity per meter at the most. In this way an area with the required dimensions of 600 x 100 meter resulted, with a good rock quality.

It is worthy to note the existing correspondence between the N/L geostatistical model and the petrographic characteristics.

The different lithologies existing in Sierra del Medio are acceptably reflected by such a representation.

It was also obtained a clear correlation between the mean values of joints per meter and the discontinuity characteristics resulting from the drilling (200 meters) carried out a different points of the sampling area.

4. RECOMMENDATIONS FOR THE GEOESTATISTICAL STUDY OF THE VOLUME OF INTEREST

Once the area of minimum fracturation was selected m the main purpose of this work, some recomendations were given for the study of the body of interest, superficially limited by the mentioned area and of about 600 m deep.

A series of configurations of 4 drillings within this area were proposed. The qrid thatr gives origin ti the minor kriging typical deviation is elongated according to the minor kriging typical deviation is elongated according to the East-West direction, with a relation major side to minor side of 5/3 (Figure N° 10).

The carrying out of a central drilling was proposed in order to consider to a certain extent, the influence of the possibli structural features.

Finally, it is recommended to investigate the behavioiur of the N/L oarameter deeply and the variability associated with it. If the constancy of the N/L relative variability can be accepted, it will allow to have the support of the surface relative semivariographies of the above mentioned parameter.

5. CONCLUSIONS

This study hasallowed to determine the location of a minimum fracturation area of about 600 x 1000 meters in the Sierra del Medio. Geostatistical techniques were applied to the parameters "The number of joints per linear meter (N/L)" and "Index of the rock quality in the surface (RQDS)".

For the previoisly mentioned determination, N/L was employed because it is the most representative one of the surface structural characteristics of the rock mass.

The minimum fracturation area obtaines has values of at most 5 joints per meter, with a maximum typical deviation of 25% (this error affects them at most in 1 discontinuity).

The reliability of this area location was established not only because of the good correlation existing with data resulting from the Geology in detail, but also of the drillings of 200 m in the sampling zone.

It is worthy to note that the application of Geostatistics in this type of problems is associated with a significantly time shorter than that required for the application of traditional techniques of exploration.

Finally, some recommendations were given for the prospective study, in depth, of the volumen of interest.

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Fig. 9 Isovalue curves corresponding to 5 joints per meter and 55% of RQDS.

Fig. 10 Correlation between the N/L geoestatistical model and the geological characteristics.

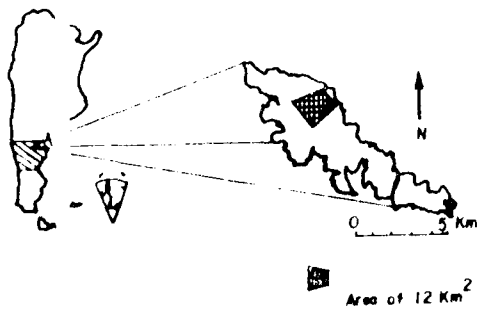
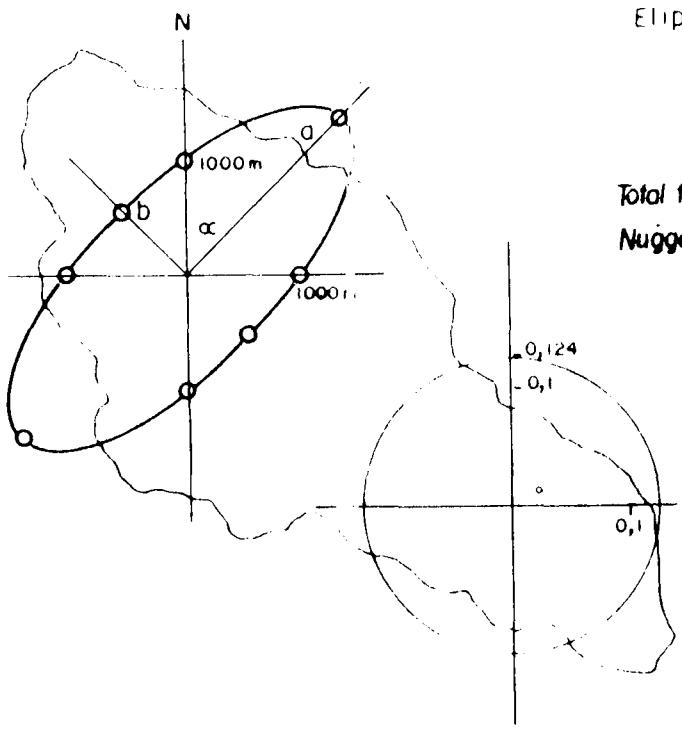


FIGURE 1 - Location sketch.



Elipse of range(m) a = 1900 m
b = 760 m
r = 2,5
α = 45°

Total transition 0,0335
Nugget effect 0,0030

FIGURE 2 - Semi-variography of the N/L primary sampling to be densified.

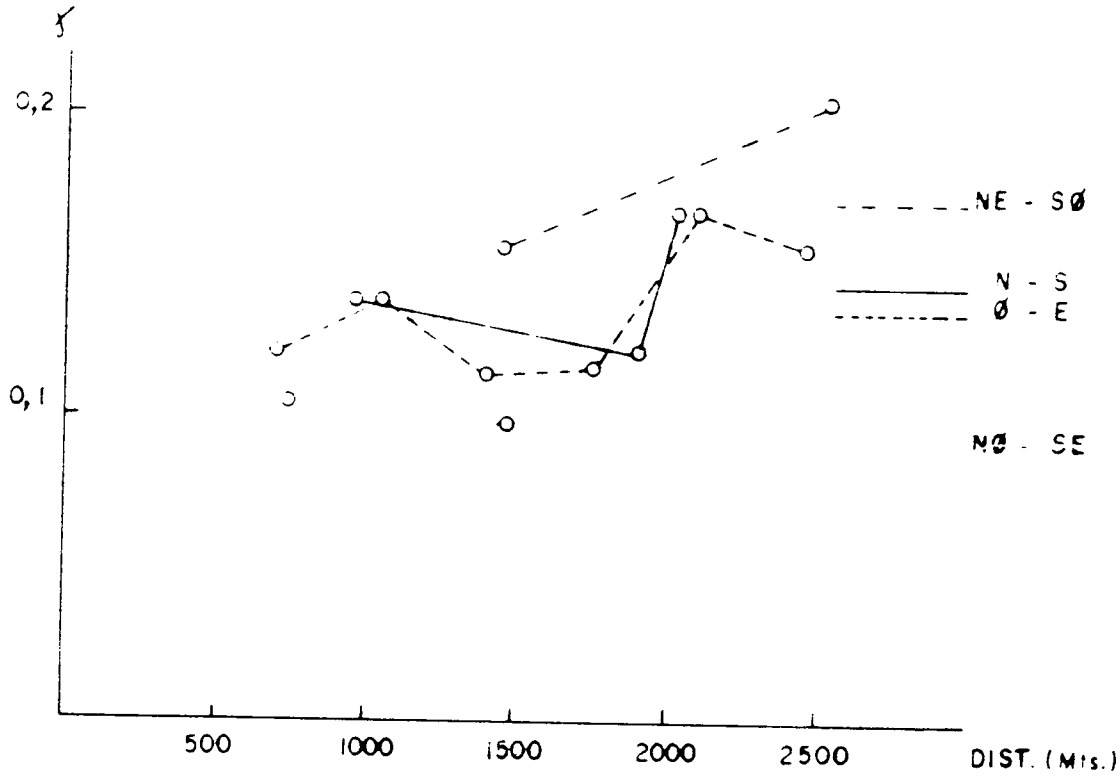


FIGURE 2- Semi-variography of the N/L primary sampling to be densified.

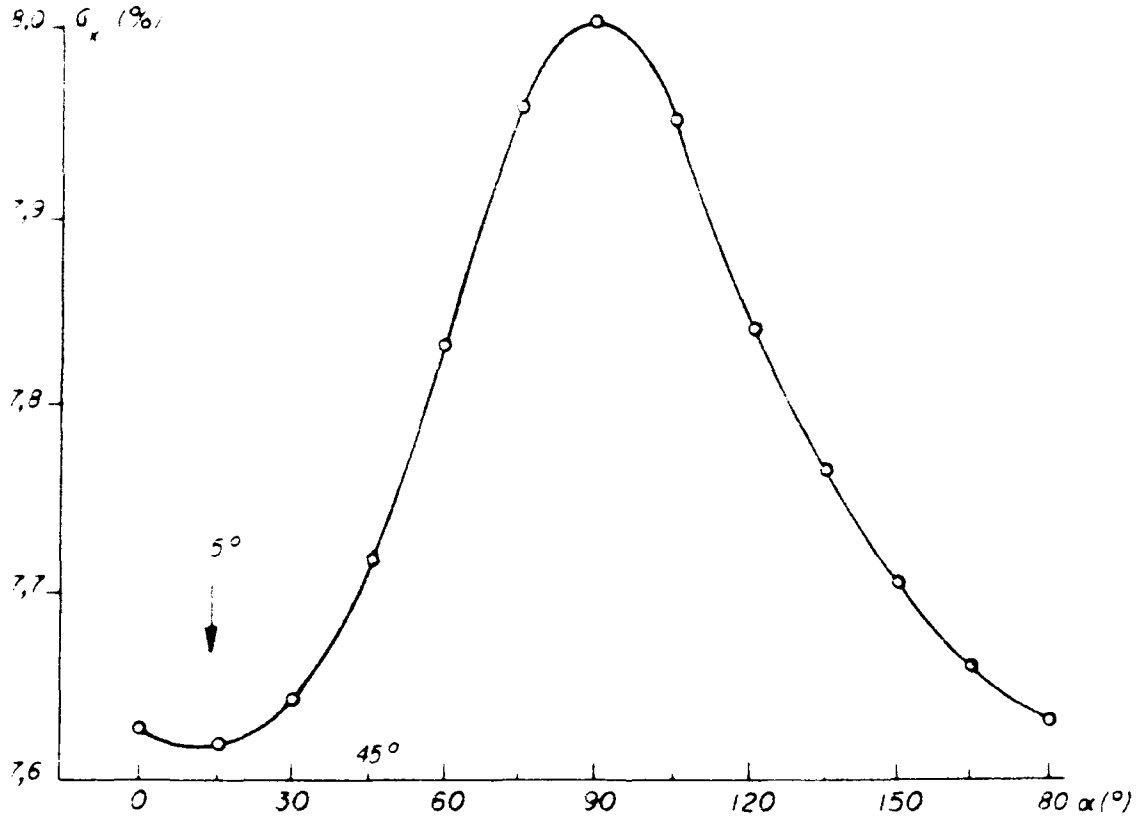


FIGURE 3- Effect of changes in the anisotropy angle of range α, on the σ_k of the N/L global estimation.

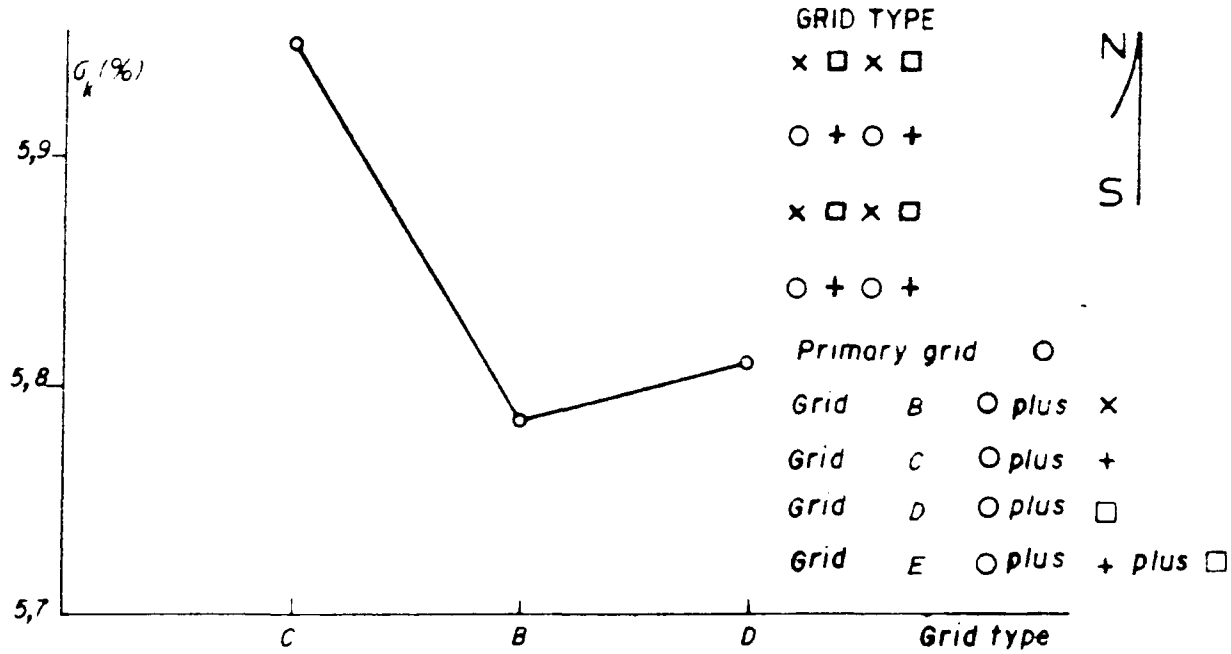


FIGURE 4- Effect of changes in the grid form, on the $\bar{V}_k$ of the N/L global estimation.

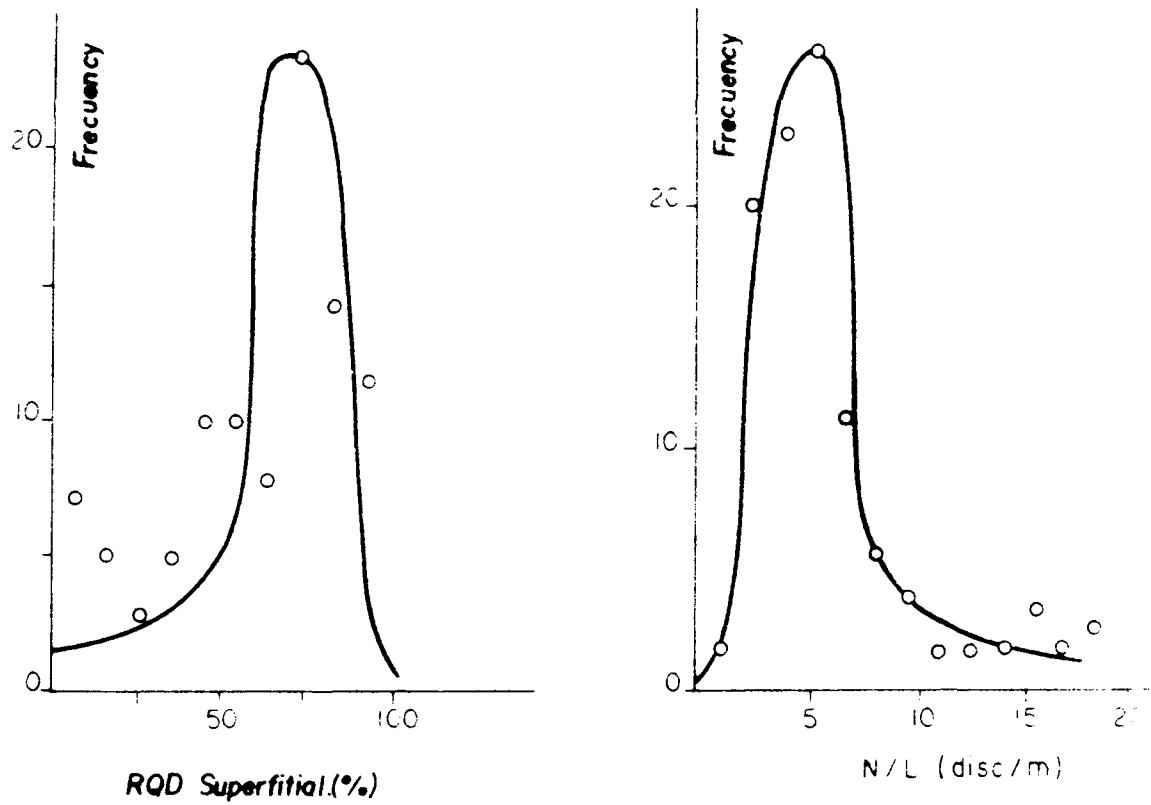


FIGURE 5- Lognormality analysis for N/L and two corrections of it (considering 100 stations)

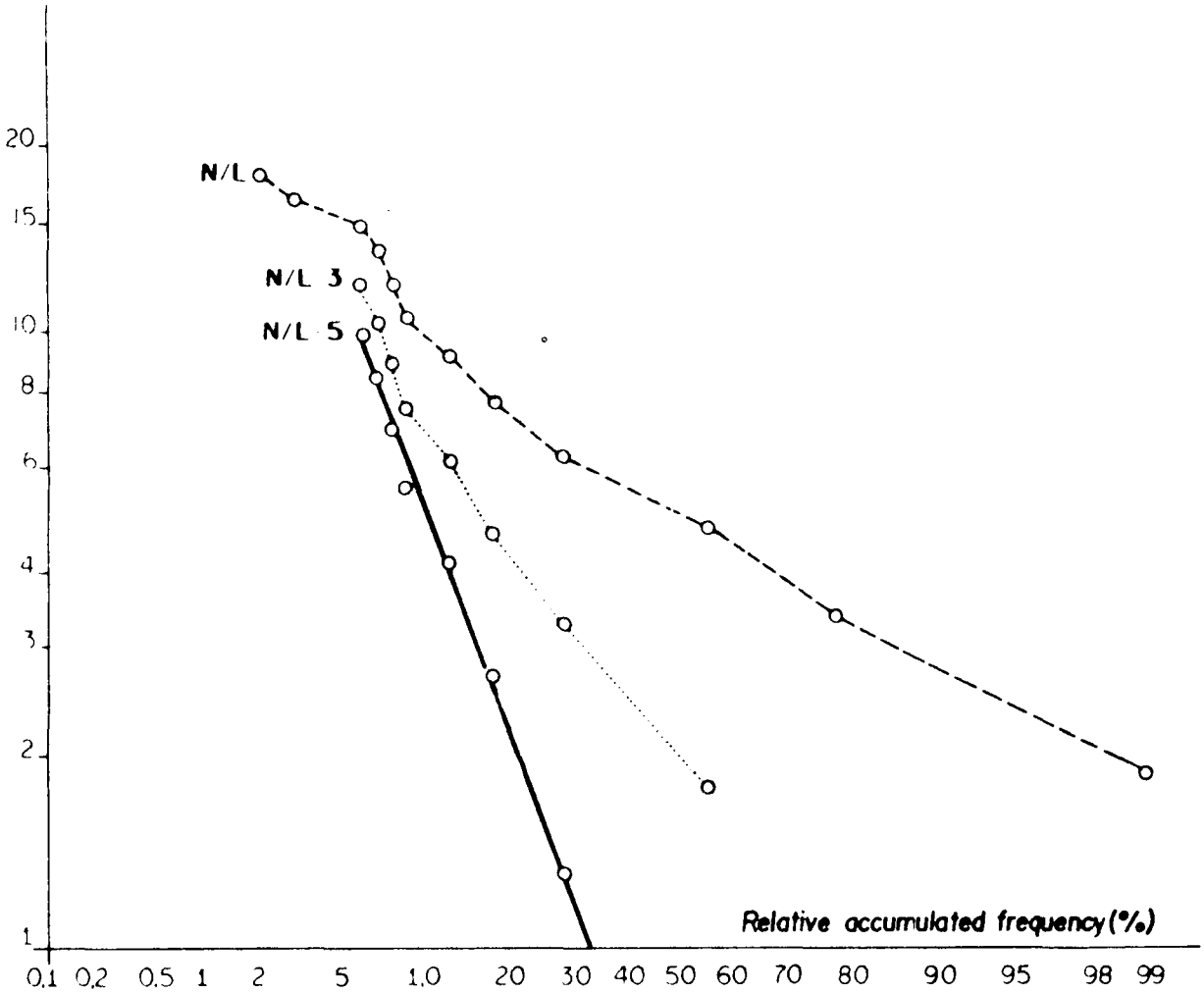


FIGURE 5- Lognormality analysis for N/L and two corrections of it. (considering 100 stations)

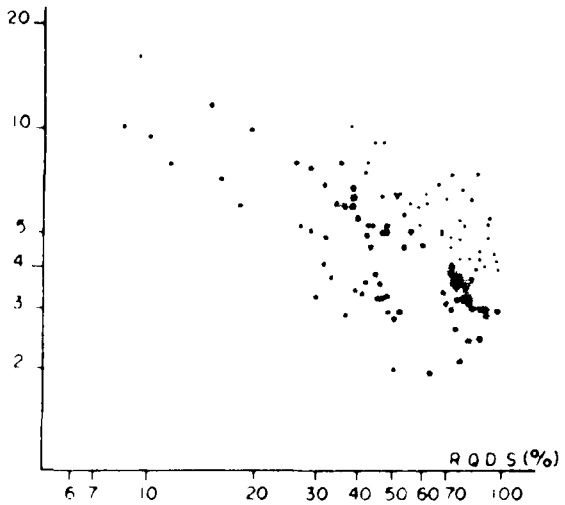
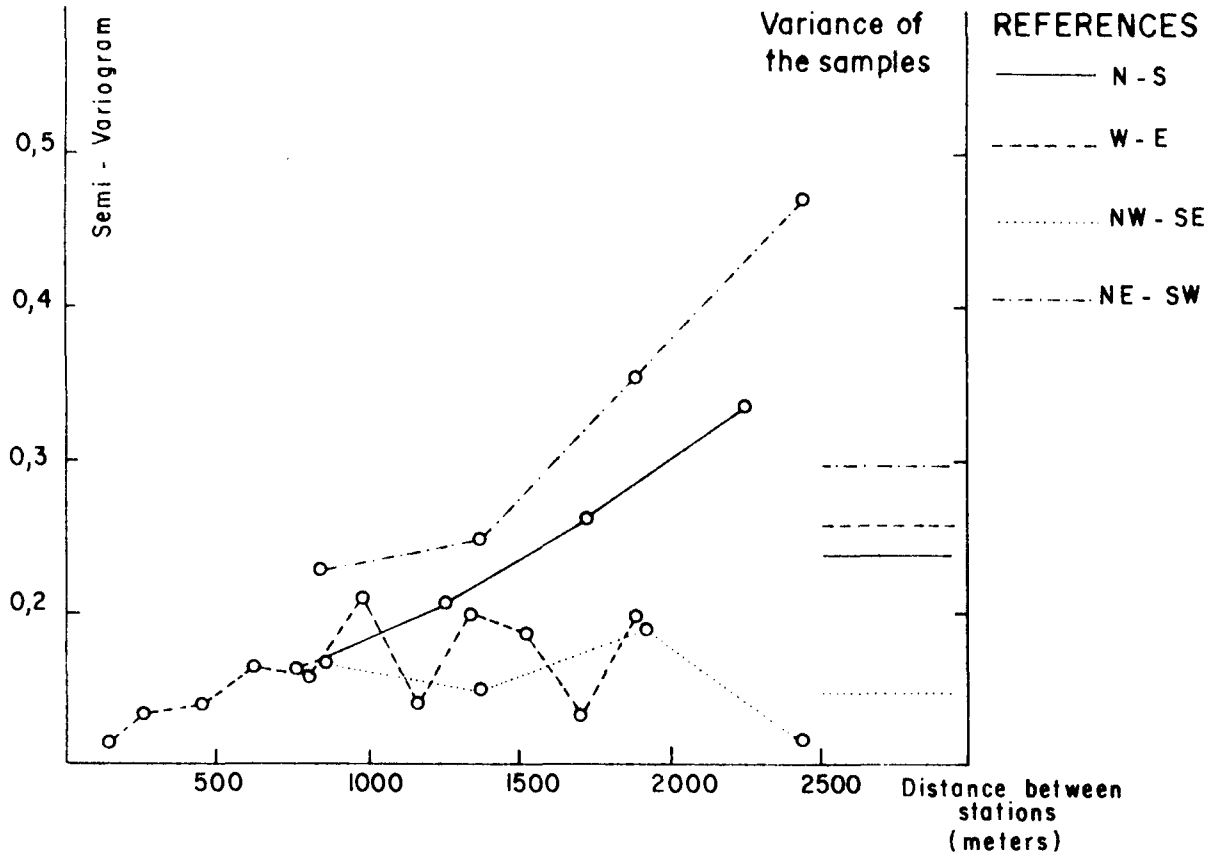
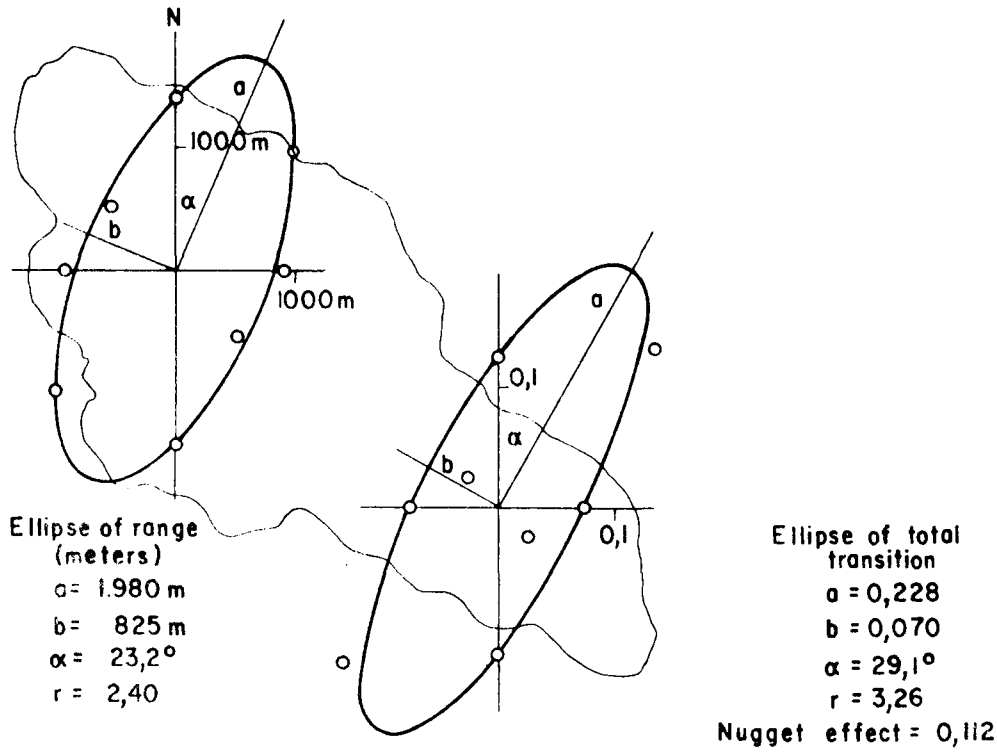


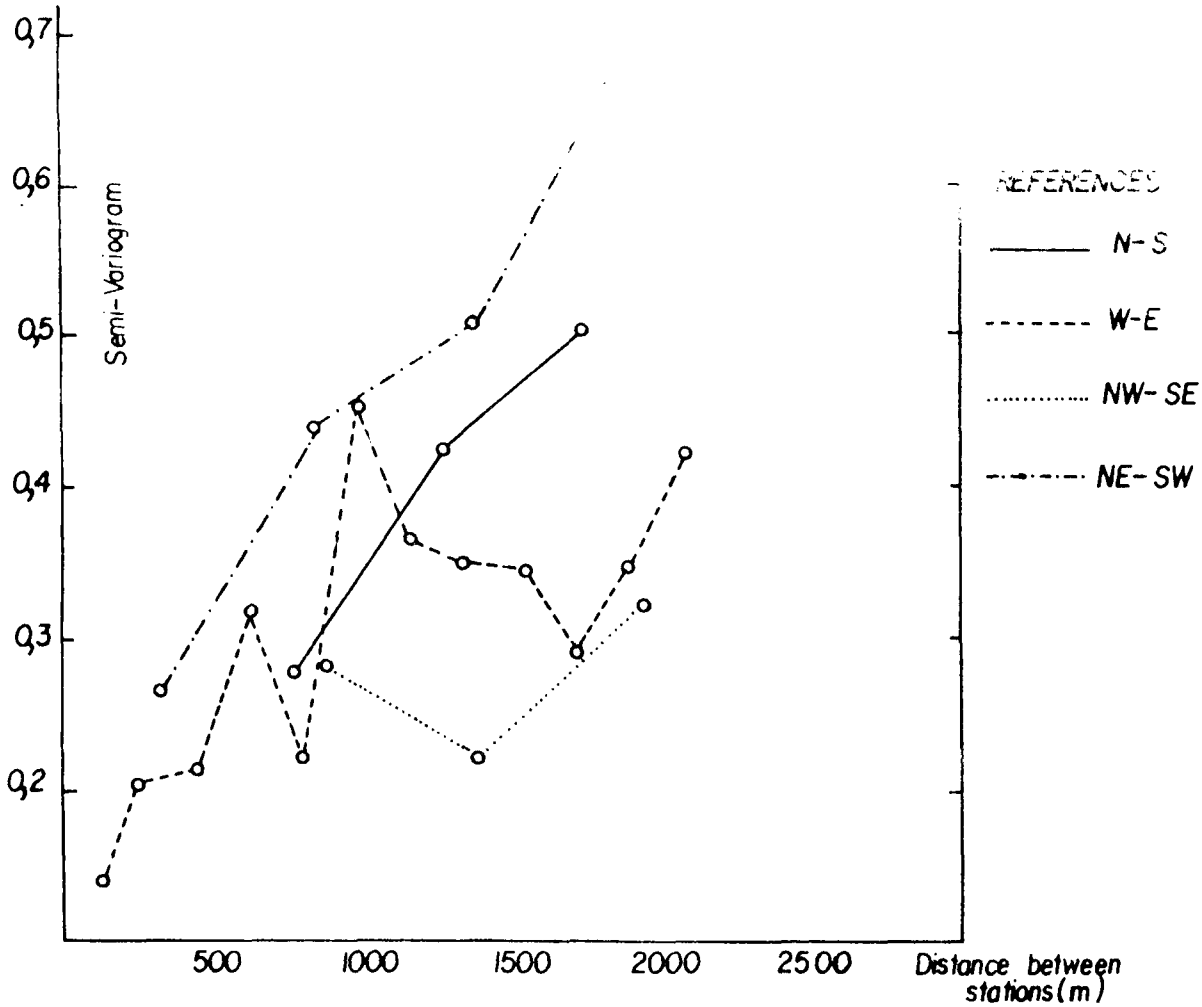
FIGURE 6- Correlation between N/L and RQDS sample values.

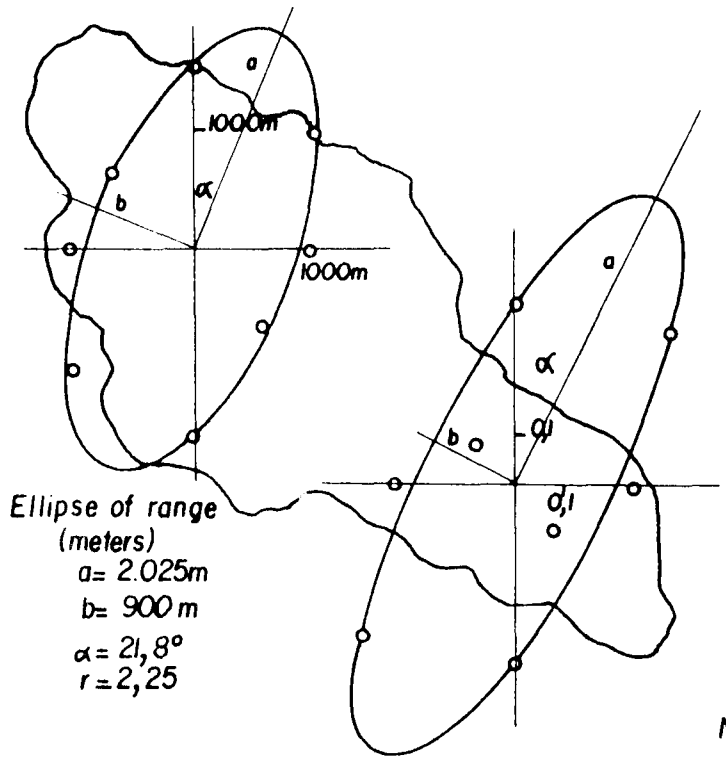




N/L Sampling Semi-variography to be considered in the determination of zones of minimun fracturation.

FIGURE 7.



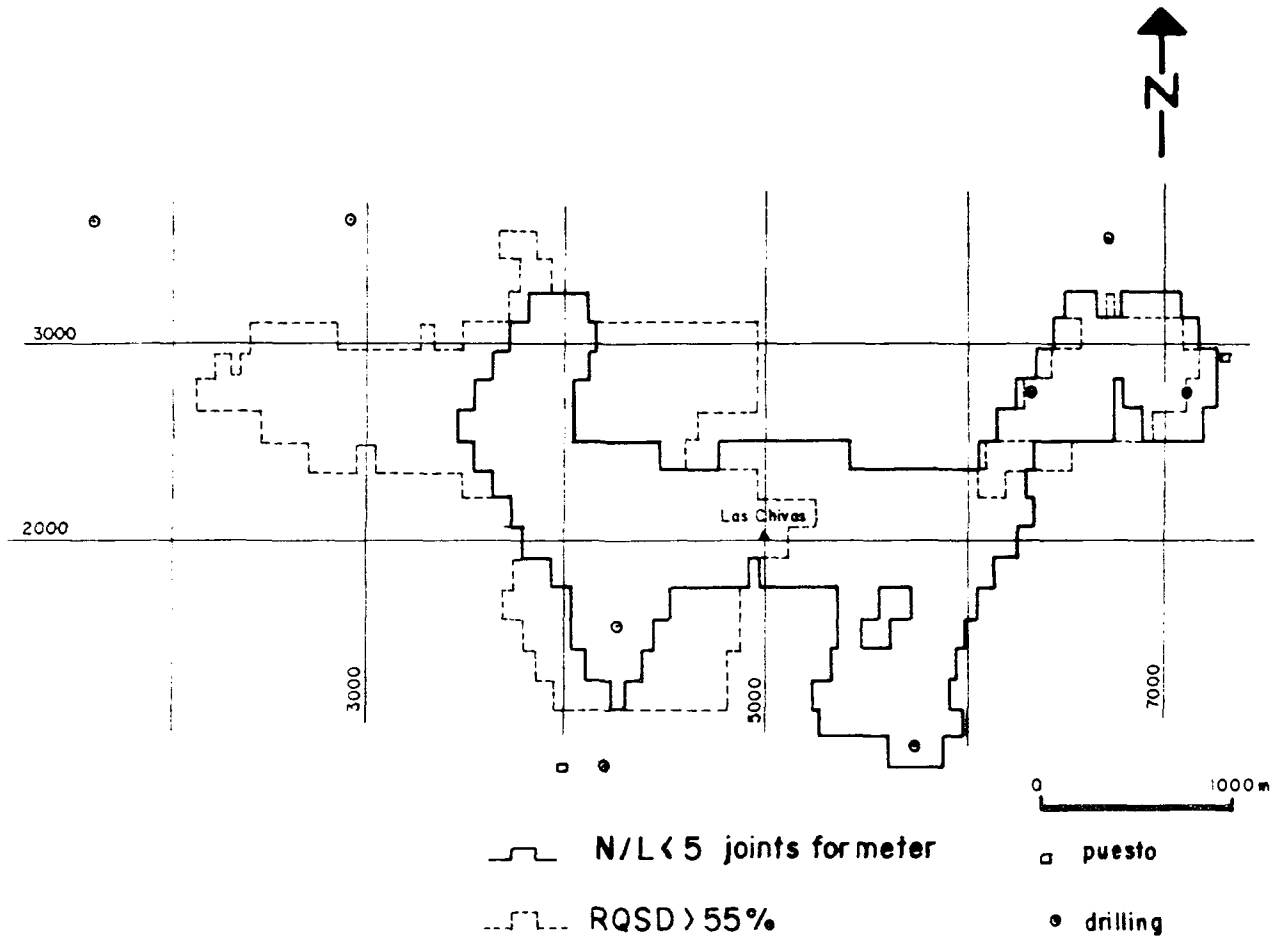


Ellipse of range (meters)
a= 2.025m
b= 900 m
α= 21,8°
r= 2,25

Ellipse of total transition
a= 0,675
b= 0,185
α= 26,6°
r= 3,65
Nugget effect= 0,116

FIGURE 8-

RQSD sampling Semi-Variography to be considered in the determination of zones of minimun fracturation.



Isovalue curves corresponding to 5 joints per meter and 55% of RQSD

FIGURE N°9

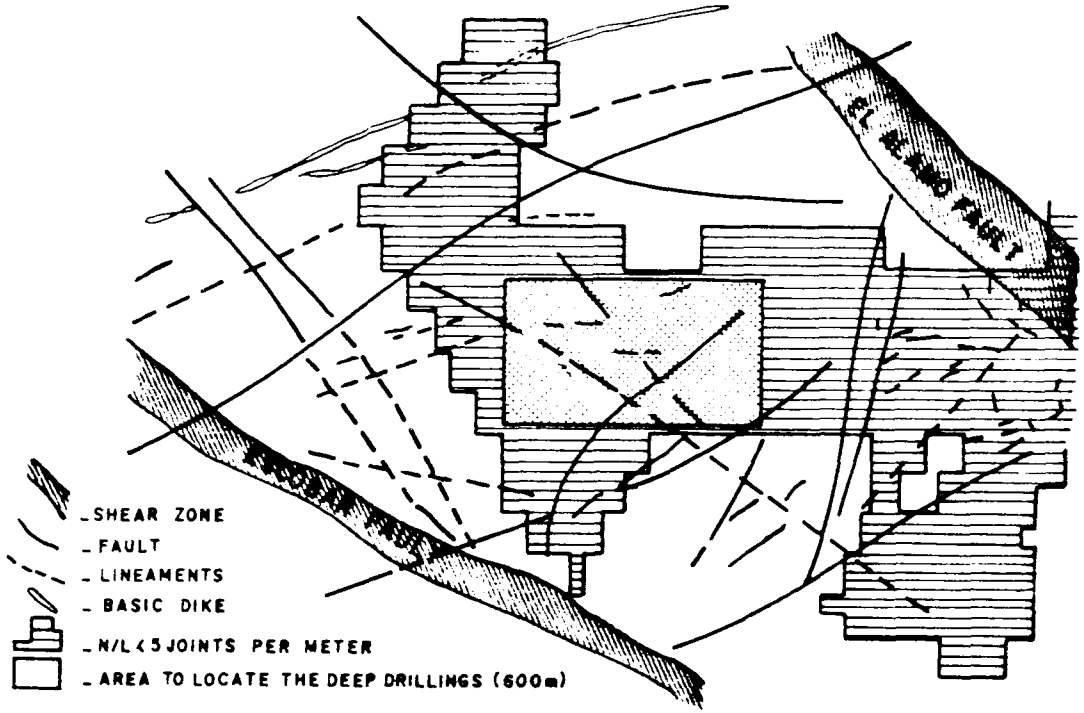


FIGURE 10- Correlation between the N/L geoestatistical model and the geological characteristics.

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REPO-02 Lucero Michaut, H.
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