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PHYSICAL, ELECTRICAL AND MECHANICAL PROPERTIES OF GRANITIC AND LIMESTONE ROCKS WITH EMPHASIS TO THEIR CHEMICAL COMPOSITION

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ABSTRACT

The mechanical, physical and electrical properties in addition to the chemical constitution have been measured for some samples of the most common rocks; granite and limestone. Besides, factor analysis was applied giving rise to four specific factors controlling the mechanical behaviors of each rock type. In granite; the two most common factors measure the degree of rock compactness in terms of density, porosity and chemical constitution (Fe, Ca, K and Cr) and correlate the relation between mechanical, electrical and chemical constitution. Also, the limestone rock exhibits two most common factors. The first one measures the electrical properties in terms of porosity and other chemical elements such as: Ti and K, while the second factor measures the degree of silicification in terms of both Ca and Si.

INTRODUCTION

The mechanical behaviour is one of the rock features which is of prime importance to drilling, mining works and other civil construction. Two types of rock samples were selected for the purpose of present study. These include granitic, and limestone samples. Granitic samples were taken from El–Missikat pluton midway along Qena–Safaga asphaltic road, where Nuclear Materials Authority is currently developing an exploratory mine for uranium exploration. It is a coarse grained pink granite of Gattarian type. Limestone samples were obtained from Helwan quarriers, few kilometers south of Cairo, and it is mainly used for archaeological restoration. The rock is white and has a clastic texture which varies greatly in porosity.

The mechanical and physical properties of these two types of rocks were measured (Kamel, 1989), where at that time, some samples were selected for the electrical measurements before the destructive mechanical loading. Moreover, these samples were also chemically analysed for some selected major and trace elements (Si, Al, Fe, Ca, K, Ti, Mn, S, V, Cr, Zr, and Rb) which may eventually affect rock behaviour. Meanwhile, these two collection of data were statistically treated for the purpose of extracting the main factors controlling the mechanical behaviour of rocks in terms of their physical, electrical and chemical composition.

SPECIMEN PREPARATION

Specimens are prepared according to "ISRM" standards and recommendation as follows:

— Test Specimen is straight circular cylinder having a length to diameter ratio 2.00.

— The ends of the specimen are cut parallel to each other and at right angles to the longitudinal axis.

— The ends of specimen are perpendicular to the axis of the specimen with 0.001 radian or 0.05 mm in 50 mm.

— The sides of the specimen are smooth and free of abrupt irregularities at straight to within 0.30 mm the full length of the specimen.

PHYSICAL PROPERTIES

Electrical and mechanical properties of rocks are usually dispersed. This is mainly due to presence of heterogenity and discontinuities (cracks and voids). In order to study certain rock phenomena, this dispersion must be taken into consideration to be set at minimum. Such operation is hardly achieved specially when a limited number of samples are available.

In the present work, the physical properties are taken as parameters to ensure the homogeneity of the selected specimens for electrical and mechanical investigations. Only specimens within certain range of some physical properties are used for testing. Density and porosity are the main two physical properties according to which specimens are selected for electrical and mechanical tests.

MECHANICAL PROPERTIES

Uniaxial Test:

In an ideal uniaxial test, there would be, at all points in the specimen, one finite principal stress, directed parallel to the loading and sample axis. The compressive strength of the material is related to the maximum load at failure and equal in magnitude to the applied load divided by the cross–sectional area of the tested sample.

Double Shear Test:

A prismatic specimen is placed horizontally in a fixture providing two supports. Normal pressure along the longitudinal axis of the specimen is provided from one side by a hydraulic jack. Double shear is achieved by a square plunger occupying the entire space between the supports. The fixture with the specimen is placed between the platens of a testing machine, which provides the shearing force to the plunger.

The shear strength (S) of the specimen along the two shear planes is thus calculated:

$$S = P / 2A \tag{1}$$

where:

P: load, Kg.

A: cross sectional area of the rock specimen, cm^2

ELEMENTAL COMPOSITION

An EG & G ORTEC 6110 / 26 Tube Excited Fluorescence Analyzer (TEFA–III) was utilized for the quantitative analysis of the rock samples (Ashry et al., 1989). It is a reliable method of quantitative non–destructive multielemental analysis of rock and soil samples. Usually a relative method is used, in which the sample and a set of standards from the same environment are analyzed under identical conditions. The use of synthetic multielement standards is laborious and introduces additional errors during the preparation, mixing and dilution. For this reason many authors have used standard reference materials (SRM) as multielement standards in XRF. Beside being now available in adequate amounts, these (SRM) have been analyzed for many elements during various analytical methods. The (SRM) used for the elemental analysis of rock samples are the seven certified international geological standard samples (NBS, 1981): AGV–1, G–1, G–2, PCC–1, SOIL–5, GSP–1 and BHVO–1 and the local standards: ST–4 and ST–10 (Abdel Magiid, 1986). The samples were ground to a very fine powder, five grams of powder from each sample and standard were backed with spec pure boric acid and then pelletized at a pressure of 15 tons / in^2.

Different instrumental conditions were utilized in this analysis to obtain the optimum excitation conditions for the simultaneous analysis of each element. The standard calibration curves for Si, Al, Fe, Ca, K, Ti, Mn, V, S, Cr, Rb, Sr and Zr were determined by linear regression of the intensities versus concentration. In all cases, the correlation coefficients for the fitted values are greater than 0.97.

Because of the absence of limestone (SRM) the AGV–1, PCC–1, G–1, G–2, SOIL–5 and BHVO–1 were used also for the analysis. However, the values obtained for the major elements; Ca and Si in limestone seem to be reliable.

ELECTRICAL PROPERTIES

For measuring the electrical properties, the rock samples were provided with circular or rectangular films of carbon–dag electrodes on their opposite faces. To ensure good electrical contacts, a thin silver wires were fixed to each electrode with special silver dag.

The resistance of the rock sample (R) was measured by applying the condenser discharge technique shown in Fig. (1), (Khazbak and Soliman, 1991). This permits measuring wide range of resistance values simply by varying the value of the used polystryrene capacitor (C) and using suitable recording instrumentation. The discharge formula is given by Lawcer and Wright, (1969):

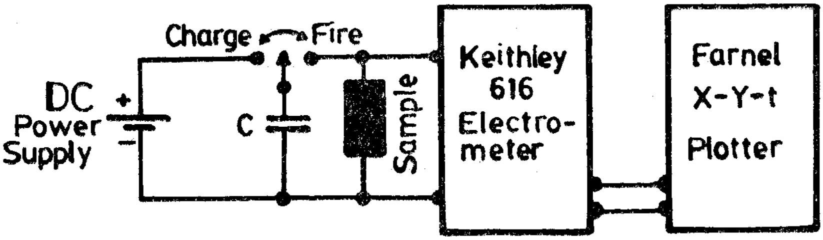

Fig.1: Schematic Diagram of the Condenser Discharge Circuit.

$$V = V_0 \ \mathrm{EXP}\ (-t / RC) \tag{2}$$

where:

V_0 : voltage at time $t = 0$

C : polystyrene capacitor

t : discharge time

Typical discharge curves are shown in Fig. 2 for both types of rock samples. In theory, if R is independent of V and thus independent of "t", a plot of ln (V_0 / V) versus "t" should be linear with a slope $1 / RC$, from which the sample conductivity is calculated:

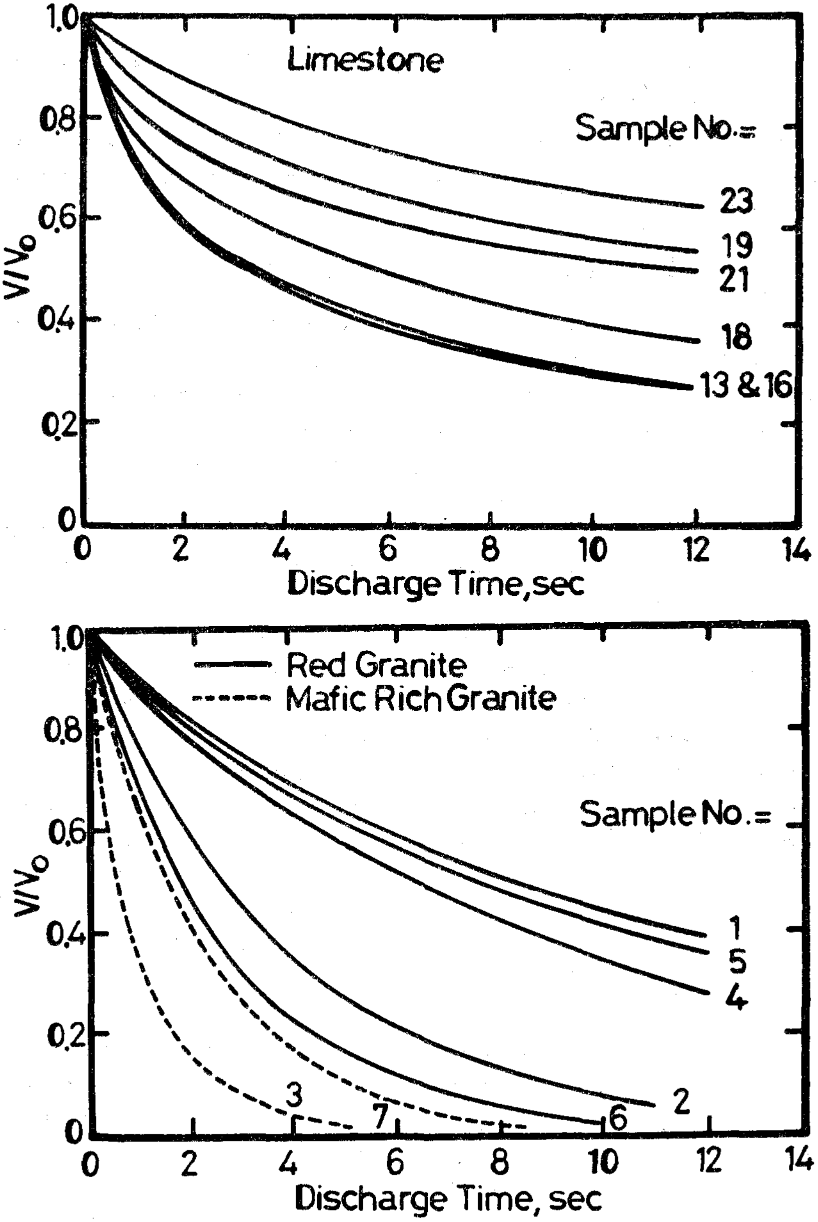

Fig. 2: Discharge Curves for Some Rock Samples •

$$\sigma = L / RA \tag{3}$$

where:

σ : conductivity

L : sample length

The time required for the charge to fall to 1 / e of its initial value is called the relaxation time.

In order to get the calculation easy, the slope (1 / RC) is calculated using the method of least squares; while the correlation coefficient measures the degree of fitting.

DATA PROCESSING AND COMPUTATION

Two data matrices are used, one for granite and the other for limestone samples. Standard statistics is applied to the raw data to compute means and measures of dispersions. Factor analysis as a multivariate technique is applied. A detailed discussion of factor analysis is referred to Comrey (1973). The purpose of factor analysis is to interpret the structure within the correlation matrix of a multivariate collection of data. Ho wever, it is a technique by which variables measured on a set of samples are linearly combined giving rise to a new set of fundamental quantities (factors) which can be named and simply interpreted in the light of sound geologic reasoning. In other words, one may say that the measured data along arbitrary axes is rotated to occupy symmetric position with reference to a set of new axes which do have meaning. Meanwhile, the data structure when rotated to refer to the new axes decomposes into simpler and interpretable structures. The used computer program was partially based on a subprogram named "TRED2", intended to extract the eigenvalues and eigenvectors from the correlation matrix using. Householder method as well as two other subprograms, designated "LUDCMP" and "LUBKSP", for matrix inversion (Press et al., 1986; Mostafa, 1986).

DISCUSSION AND CONCLUSION

Single variate statistics (Tables 1, 2) of both rock types shows that all variable possess coefficient of variability, Cv (S / X) x 100, less than 100. Thus, according to Sarma and Koch (1980) one can proceed computation on the original data with no need for any type of transformation. This also reflects the rather homogenity of the dealt with populations since all samples pertain to two strict rock units.

Table 1. Statistics of physical, mechanical, electrical and chemical properties of granite samples.

Var.	No.	Range		X	Sd	Cv	Se	Skw	Kurt	Conf.	Interval
		From	To							From	To
DENS	25	2.45	2.85	2.57	.08	3.18	.02	2.08	7.79	2.32	2.81
PORS	25	.00	.01	.01	.00	44.85	.00	.65	2.03	.00	.02
RS	11	302.78	320.48	313.71	5.61	1.79	1.69	-.59	2.03	296.87	330.56
SEG	19	1.00	15.50	6.75	4.38	64.90	1.00	.67	2.54	-6.39	19.89
T	19	.10	14.00	4.05	3.76	92.85	.86	1.31	3.88	-7.24	15.35
Si	19	23.01	34.15	30.82	2.12	6.89	.49	-2.39	10.06	24.45	37.19
Al	19	6.19	9.56	7.70	.78	10.11	.18	.59	3.78	5.36	10.03
Fe	19	.74	2.89	1.67	.90	54.20	.21	.50	1.32	-1.04	4.38
Ca	19	.35	.79	.56	.15	28.44	.04	.26	1.46	.08	1.04
K	19	2.10	5.99	4.29	1.22	28.50	.28	.16	1.64	.62	7.95
Ti	19	.14	.23	.18	.03	16.43	.01	.32	1.50	.09	.26
Mn	19	.04	.58	.11	.15	134.11	.03	2.35	7.07	-.33	.55
S	19	.01	.30	.08	.08	99.20	.02	1.14	3.20	-.17	.34
V	19	.02	8.31	6.17	1.78	28.81	.41	-1.97	7.84	.84	11.50
Cr	19	24.30	81.20	55.89	11.90	21.29	2.73	-.39	3.97	20.19	91.60
Zr	19	45.50	140.78	111.78	29.47	26.37	6.76	-1.05	2.87	23.36	200.20
Rb	19	398.00	831.20	617.64	138.15	22.37	31.69	-.21	1.87	203.20	1032.09

Table 2. Frequency table, physical, mechanical, electrical and chemical properties of limestone samples.

Var.	No.	Range		X	Sd	Cv	Se	Skw	Kurt	Conf.	Interval
		From	To							From	To
DENS	47	2.14	2.31	2.25	.04	1.61	.01	–.66	3.13	2.14	2.35
PORS	47	.02	.05	.03	.01	20.50	.00	–.15	1.69	.01	.03
RC	15	164.33	261.04	191.85	28.76	14.99	7.43	1.65	4.46	105.57	278.15
RS	19	24.56	56.01	43.84	10.28	23.44	2.36	–.85	2.27	13.01	74.67
SEG	20	10.40	110.00	41.73	29.39	94.37	8.81	.95	2.12	–76.42	159.89
T	20	5.80	49.50	23.00	17.09	74.32	3.82	.50	1.68	–28.29	74.28
Ca	15	25.14	36.18	30.53	3.06	10.04	.79	.55	2.54	21.34	39.73
Fe	15	.67	1.93	.89	.30	34.13	.08	2.56	9.19	–.02	1.80
Si	15	1.00	11.95	7.55	2.49	32.95	.64	–.60	4.30	.09	15.02
Ti	15	.04	.24	.12	.05	43.47	.01	.78	2.92	–.04	.27
Al	15	.30	.94	.71	.19	26.29	.05	–.89	3.09	.15	1.26
K	15	.05	.08	.07	.01	14.82	.00	.02	1.92	.04	.10

Fig. (3) shows the bar diagrams of the different measured variables for limestone and granite. The position of the mean values within the absolute range defines the degree of symmetry of the distribution. Salient features of variables will be discussed. It can be observed that the density of granite is symmetrically distributed while that of limes-

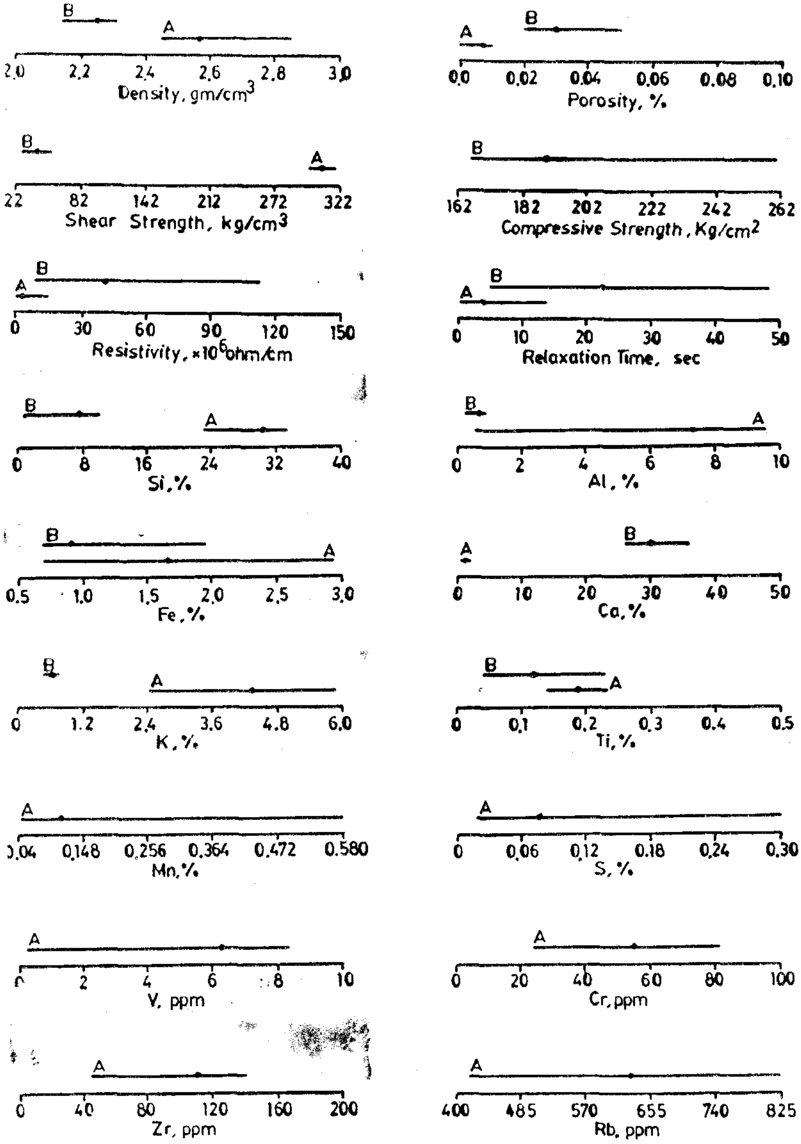

Fig. 3. Bar Diagrams of the Different Variables for Granite (A) and Limestone (B).

tone is more biased to one side (high values). The density of the limestone samples ranges between 2.15 and 2.3 gm / cm^3 with standard deviation of 0.0 715, while that for the granite it ranges between 2.45 and 2.86 gm / cm^3 with standard deviation of 0.709.

The porosity is the second physical property taken as a measure of homogenity. The bar diagrams show that the porosity of limestone is biased to the left (lower values) and ranges between 0.02 % and 0.05 % with standard deviation of 0.01, while the porosity of the granite is more or less symmetrically disposed about the mean and it ranges between 0.0 % and 0.01 %.

The shear strength for granite varies from 02.78 to 320.48 Kg / cm^2 (X = 1 .71 Kg / cm^2) and for limestone from 24.56 to 56.01 Kg / cm^2 (X = 4 .84 Kg / cm^2). The compressive strength is only measured for limestone and it ranges from 164.33 to 261.04 Kg / cm^2 (X = 191.85 Kg / cm^2).

The electrical properties is expressed in terms of the relaxation time and resistivity of the rock samples. The resistivity of limestone ranges from 10.40 x 10^6 to 110 x 10^6 ohm / cm (X = 41.73 x 10^6 ohm / cm) and that for granite ranges from 1.00 x 10^6 ohm / cm to 15.50 x 10^6 ohm (X = 6.75 x 10^6 ohm / cm).

The electrical behaviour of the rocks can be described in terms of the properties of their elemental constituents. Tables (3, 4) show the electrical conductivity of the detected elements in granite and limestone samples (Sargent–Welch, 1982). The detected elements can be conveniently grouped according to their influence on the electrical properties with respect to the major elements of the investigated rock type.

For granitic rock samples where the major element is Si (conductivity = 0.1 x 10^{-6} siemens), the presence of Fe, K, Ca and Al even with appreciable amounts (more conductive than Si), markedly affects the increase of conductivity. Meanwhile, decrease of conductivity is associated with the presence of Cr, Rb, Mn, Rr, Zr, and Ti.

For limestone rock samples where the major element is Ca (conductivity = 0.281 x 10^{-6} siemens), the presence of Al (more condictive than Ca) in high concentrations markedly increases the conductivity. This is also noticed by Ashry et al., 1989 in the analysis of the electrical properties of some beach black sands. Meanwhile, the decrease of conductivity is associated with the presence of K, Fe, Si, and Ti.

Statistics of the other chemical analysis are given in Tables (1, 2) and Fig. (3).

Table 3. Conductivity property of the detected elements in granitic rock samples.

Element	Fe	K	Ca	Al	Si	Cr	Rb	Mn	Sr	V	Zr	Ti
Conductivity, Microsiemens	0.100	0.143	0.218	0.382	0.100	0.078	0.060	0.054	0.043	0.040	0.024	0.024
Efects on Electrical Properties	Increasing Conductivity				Major	Decreasing Conductivity						

Table 4. Conductivity Property of the Detected Elements in Limestone Rock Samples.

Element	Al	Ca	K	Fe	Si	Ti
Conductivity, Microsiemens	0.382	0.218	0.143	0.100	0.100	0.025
Effects on Electrical Properties	Increasing Conductivity	Major	Decreasing Conductivity			

In multivariate statistics, instead of discussing the mutual relation, the correlation matrix is used to get the factors controlling the rock behaviour in terms of the measured variables (Tables 5, 6). In case of granite (Table 5), the reduction of 17–D space into 4–D gives rise to four factors accounting for 73.7 of the total system information (TSI):

Table 5. Varimax rotated factor matrix, granite samples.

	FACTORS			
	F1	F2	F3	F4
DENS	.387	–.067	.512	.032
PORS	–.497	.292	.103	.467
RS	.146	.391	.465	–.642
SEG	–.108	.903	–.157	.223
T	–.123	.900	–.173	.230
Si	.061	.143	–.351	.682
Al	.055	–.720	.358	.339
Fe	.987	.076	.013	–.045
Ca	.923	–.090	–.020	–.208
K	.947	–.195	.080	–.120
Ti	.907	.228	–.075	.073
Mn	.076	–.118	–.255	–.683
S	.125	.812	.001	.087
V	–.324	.485	.336	–.195
Cr	–.600	.190	–.344	–.122
Zr	.061	.145	–.852	–.023
Rb	–.040	.479	–.626	.346

Table 6. Varimax rotated factor matrix, limestone samples.

Var.	FACTORS			
	F1	F2	F3	F4
DENS	.188	.694	.050	–.341
PORS	.466	–.793	–.051	–.157
RS	.388	.945	–.374	–.067
SEG	.966	–.075	–.174	.002
T	.931	–.221	–.180	.077
Ca	.127	.065	–.722	.453
Fe	–.238	.622	.173	.396
Si	.282	–.033	.054	.829
Ti	.545	.046	–.024	.142
Al	–.006	.019	.882	.351
K	.771	.306	.292	.069

1– The first factor, F1 contributes 30.6 of TSI. It is positively loaded with DENS, Fe Ca, K, and Ti which indicates that the density of the rock is closely related to each of Fe, Ca, K and Ti. On other hand, F1 is negatively loaded with PORS and Cr. Hence, F1 can be re-called as a factor which measures the degree of rock compactness.

2– The second factor, F2 contributes 23.240 of the TSI. It is negatively loaded with RS, SEG, T, S, V, and Rb. However, this shows that shear strength, electrical conductivity and other elements, S, V and Rb, are correlated to each other.

3– The third factor, F3 contributes 14.74 of the TSI. It is positively loaded with PORS and Al which indicates the direct relation between porosity and Al. The negative load with Rs and Mn shows that shear strength and Mn are correlated.

4– The fourth factor, F4 contributes 11.150 of the TSI. It is positively loaded with DENS and RS which indicates the dependency between the density and shear strength. F4 is also negatively loaded with PORS, Si, Zr and Rb and simply shows the dependency between porosity and Si in particular.

In case of limestone rock samples (Table 6), the reduction of the 12–D into 4–D gives rise to four factors accounting for 79.7 of TSI:

1– The First factor, F1 contributes 30.580 of TSI. It is positively loaded with PORS, SEG, T, Ti and K which shows the dependency between the porosity and the measure of electrical properties SEG and T and some other chemical elements (Ti and K).

2– The second factor, F2 contributes 23.24 of TSI. It is positively loaded with DENS, RS, Fe and K which again confirm the correlation between density and shear strength. F2 is only negatively loaded with PORS. Thus, F2 can be recalled as a factor measuring mainly the mechanical behaviour of rocks.

3– The third factor, F3 contributes 14.740 of TSI. It is positively loaded with Al and negatively loaded with RS and Ca. This leads to the fact that the shear strength increases with increasing Ca and decreases for the presence of Al which may be eventually found in the argillaceous state.

4– The fourth factor, F4 contributes 11.15 of TSI. It is positively loaded with Si which may account for the degree of silicification. F4 is also negatively loaded with Al and Fe, which might be found in the form of clayey minerals. The inverse relation between these group of elements and the density suggests that the increase of clayey minerals is associated with decrease in density.

REFERENCES

ABDEL-MAGHID, A.A. (1986). Geologic and radiometric study of urnaniferrous granite in Um Ara-Um Shilman area, South Eastern Desert, Egypt, Ph.D. Thesis, Suez Canal Univ., p. 222.

ASHRY, H.A., SOLIMAN, F.A.S. and KHAZBAK, A.E., (1989). Influence of the elemental composition of zircon and collophane minerals on their electrical conductivity. Jour. Electrostatics, 23, pp 197-206.

ASHRY, H.A. and SOLIMAN, F.A.S., (1989). Computer Programming for matrix effect correction in X-Ray fluorescence spectrometry, Isotopenpraxis, 25, 11 / 12, pp. 485-489.

COMREY, A.L., (1973). A First Course in Factor Analysis. Academic Press, New York and London, p. 316.

KAMEL, A.I., (1989). Rock material characteristics and their impact on evaluation of stress-deformation behaviour with special reference to El-Missikat Granite pluton and Helwan Limestone. M. Sc. Thesis, Faculty of Science, Cairo Univ., Cario, p. 71.

KHAZBAK, A.E. and SOLIMAN, F.A.S., (1991). Electrical conductivies of some Egyptian beach sand minerals and their effects in electrical separation. Arabian Journal for Science and Engineering, 16, 2A, pp. 143-151.

LAWVER, J.E. and WRIGHT, J.L., (1969). Transactions of S.M.E., 244, pp. 78-92.

MOSTAFA, M.E., (1986). An Integrated Peackage for Computational Geology (IPCG). Internal Report, Nuclear Materials Authority, Egypt.

PRESS, W.H., FLANNERY, B.P., TEUKLOSKY, S.A. and VETTERLING, W.T., (1966). Numerical recipes; The art of scientific computing. Cambridge Univ. Press, pp. 817-826.

SARGENT-WELCH., (1982). Periodic Table of the Elements.

SARMA, D.D. and KOCH, G., Jr. (1980). A statistical analysis of exploration geochemical data four uranium, Math. Geol., 12, pp. 99-114.