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An Analytical Comparison of Various Egyptian Soils, Clays, Shales and Some Ancient Pottery by Neutron Activation*

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The term "clay" is usually used to describe an unstructured rock composed essentially of clay minerals. The physical attributes of clays that have been of most significance to man are, of course, the plastic properties they assume upon being mixed with an appropriate amount of water which permits them to be formed into pottery. Shales are also rocks formed primarily of clay minerals, but they have been metamorphosed by geologic forces into thinly layered or laminated structures. They are usually harder than clay although they were originally argillaceous sediments that accumulated in past geologic times. Many shales when ground and mixed with water regain the plastic properties of clay and serve well for pottery formation. The Egyptian shales we have analyzed have had this property, and hence should be considered among the potential pottery making materials in Egypt.

Some clays and shales contain components other than clay minerals and are described accordingly as sandy, limey, bituminous etc. Although river alluvium and cultivated soils, which are geologically Recent sediments, usually contain a preponderance of such non-argillaceous components, they often have sufficient clay minerals to be used successfully for pottery.

The characterization of a particular clay usually involves a study of its physical and chemical properties by a variety of techniques such as X-ray diffraction, electron microscopy, thermal analyses as well as chemical analysis. Chemical composition, particularly the pattern of trace impurity concentrations, can be used along with stratigraphy and petrography, particularly the identification of fossil inclusions, to confirm attributions of different outcrops to the same geologic formations and sometimes to infer the origins of these formations.

The use of clay in pottery making antedates recorded human history, and pottery remains are a major record of past civilization. In recent years, the deductions made by archaeologists with regard to pottery classification and provenance have been supplemented by modern methods of chemical analysis such as emission spectroscopy[1,2] and neutron activation analysis.[3-19] The latter technique has proved to be most valuable not only because it is highly sensitive but also because it allows the simultaneous quantitative determination of a large number of elements. However, most of the investigations reported have been concerned with the examination of the articles only, and few attempts have been made previously to examine the parent clays from which the ancient pottery might have been manufactured.

The present investigation is concerned mainly with the content of trace impurities in the clays and shales in Egypt. The patterns of trace impurities and minor components may be used as a basis for classification of clays and would be useful in tracing the origin of the parent materials used in pottery manufacturing. A number of clay samples, therefore, were collected from different sites throughout Egypt, to represent all extensive natural formations from the Recent deposits down to the lower Cretaceous levels, and were analyzed for sixteen elemental components by instrumental thermal neutron activation methods. Also a few specimens of ancient pottery were analyzed and compared in their minor components and trace impurities to the clays.

Clay and Shale Formations in Egypt

Geological evidence indicates that the course of the Nile through Egypt was established during the Pliocene epoch when a tectonic valley, to which the Mediterranean Sea at first had access, was formed.[20] Accordingly the rock formations through which the Nile valley passes are earlier than

Pliocene and the deposits occurring on the flood plain of the river are of Pliocene and later date. These later deposits are rich in clay and clay-like materials, while the surrounding earlier rocks contain considerable shales and some clays. Let us first consider the surrounding rocks through which the river flows.

At the apex of the alluvial delta the river encounters several limestone layers one of which, the Maadi formation, contains significant shale intercalations. This formation extends roughly from Cairo to slightly south of the Fayum. Further south in the region of Upper Egypt which extends roughly from Qena to Idfu the river valley cuts down through the upper relatively pure limestone layers into a series of more argillaceous layers many of which are rich in shale. These shale-rich layers can extend in all to a depth of from one to two hundred meters. The layers in this region which are particularly rich in shale are in order of increasing depth the Esna shales, the Dakhla shales, the Phosphate formation and the Quseir Variegated shales. They range in date of deposition from the upper Paleocene through the upper Cretaceous. From roughly Idfu to Aswan the river valley penetrates yet deeper into the Nubia sandstone layer which underlies these shale beds and which dates to the lower Cretaceous. The Nubia sandstone layer which is surface exposed in the Aswan region contains clay deposits which are used today for pottery manufacture.

Three distinctly different deposits lie on the flood plain of the Nile. The lowest lying of these layers accumulated during the Pliocene. It is thought to have been deposited under marine or estuarine conditions. Marine penetration into the valley had apparently ceased to be a major factor by the time of the Pleistocene epoch. During the Pleistocene North Africa was not arid as it is today but experienced periods of abundant rainfall.[21] Accordingly although today the tributary wadis of Egypt contribute practically no sediments to the Nile flood plain, during the Pleistocene epoch the wadis were relatively active, contributing significantly to the Nile sediments. The pluvial periods of the Pleistocene produced a distinctly separate second layer of deposition upon the Nile flood plain, which, as the analyses reveal, is distinctly different in chemical composition from the Pliocene layer which it covers. However it is basically similar in composition to the shale layers through which many of the contributing wadis cut. It would seem logical that the erosion of these shales contributed significantly to the formation of the Pleistocene clays.

The upper layer of Nile alluvium has been deposited during the Recent epoch and represents predominantly foreign sedimentary material carried by the Nile from Ethiopia and East Central Africa. The analyses show it to be distinctly different in composition from all other materials studied.

The occurrence of many of these formations and deposits throughout much of Upper Egypt is shown in Fig. 1. In this figure one sees that the recent alluvium deposit lies closest to the river with a strip of Pleistocene deposit usually occurring at its outer edges. Occasional areas of Pliocene deposition surface at the extreme outer edges of the valley beyond the Pleistocene strips. The surrounding outcrops of shale are particularly evident in the region shown in Fig. 1, as is the very low lying Nubia sandstone which particularly becomes a surface rock in the Aswan region.

In the great depressions of the Western Desert in which the major oases lie, many of the same formations, i.e., the lower lying shales and Nubia sandstone, surface. Also there occur at the oases Pliocene, Pleistocene and Recent deposits analogous to those in the Nile valley. A number of our specimens have come from these oases sites.

There are in addition some relatively pure kaolin clays which occur in Carboniferous Ataqa sands and Nubia sandstone on either side of the central-upper region of the Gulf of Suez and also underlie the Nubia sandstone at Aswan.

The Sources and Compositions of the Geological Specimens

The specimens of clays and shales we have analyzed were provided from the collection of the Geological Museum at Cairo through the kind permission of Dr. R. Said and the cooperation of Mr. A. Talaat. Dr. Said also generously advised and assisted in the provision of some of the samples for analysis. For the most part four or five samples of each formation considered in the previous discussion were analyzed. The samples of each formation were selected to represent, as a rule, geographically disperse sites in order that the compositional uniformity of the formations could be estimated. The source locations for the specimens analysed are all indicated in Fig. 2.

We recognize clearly that such limited sampling as we presently have cannot be regarded as being comprehensive of the extensive formations being studied. However, particularly because the different samples of the same formations have tended to be similar in composition, this sampling does serve to indicate in general terms the basic minor and trace component compositional characteristics of these various formations. We very much hope it will be possible to add to and refine these data.

For simplicity of presentation we shall consider together the specific geographic sources of the specimens and the analytical results obtained on them, leaving for later a description of the method of analysis. Notations of the source locations and numerical analytical data for the individual specimens are listed together in Tables I, III, IV, and V.

Recent, Pleistocene and Pliocene Clays and Soils

The analyses of the clay and soil specimens taken from Recent, Pleistocene and Pliocene deposits are grouped together in Table I. Specimens of Nile alluvium came from the Boulac section of Cairo, an island in the river at Assiout and several sites in and about Aswan. These alluvium specimens from three quite widely separated regions along the Nile are very closely similar in composition. Our results are also in close agreement with similar analyses of Nile alluvium from upper Egypt published by Perlman and Asaro.[16,13] Nile alluvium is outstanding in its very high manganese, iron and cobalt contents, as compared with all other clays analyzed. The average manganese concentration is about tenfold that in any of the other clays and the cobalt concentration is about twice as great. Conversely the thorium concentration in the alluvium is significantly low, being often about half that of the other clays and of most shales. These elements are particularly diagnostic for this material. The sodium content is also significantly high in alluvium but it is similarly high in Pleistocene clays and the shales which were found near the river.

Two other specimens of recent soils were analyzed. One came from the village of Dakhla at the Dakhla Oasis in the central Western Desert, and the second was from the Wadi El Natrun in the Western Desert south of Alexandria. The data on these specimens in Table I show that the Dakhla Oasis soil has all of the unusual compositional characteristics of the Nile alluvium. It is sufficiently similar to the alluvium in the concentrations of all components determined to suggest a common origin for the two deposits, and hence a probable early water connection between the river and the oasis. In contrast to this the soil from the Wadi Natrun does not have either the high manganese and iron concentrations or the relatively low thorium concentration that characterize Nile alluvium. Hence a different origin for this deposit is indicated.

A visual comparison is made in Figs. 3 and 4 between the standard deviation ranges of concentration of eleven of the components determined as they were found to exist in the different types of clay like material we have analyzed. One observes, for example, at the right of Fig. 3 how far the manganese content of the matching recent soils lies outside of the statistically probable ranges of its occurrence in other materials studied. Some of the components not plotted show similar separations. The only reason for not including them in the plots was to keep the visual display within modest and easily comprehensible limits.

The Pleistocene clay samples came from two regions along or near the Nile. The first region lies just south of Cairo where we have a sample from the village of Maadi and another from the Fayum. The second region is central Upper Egypt where the clay specimens came from Qena and Esna. It is worth noting that the Pleistocene clays of Qena and Esna are used extensively today for the manufacture of pottery.

Comparison of the analyzed results on these four specimens shows that although all four are basically similar in composition, the pair of specimens from south of Cairo show some consistent differences from the pair of specimens from Upper Egypt. Specifically they have more iron, cerium, europium and thorium and less barium and chromium than the clays from Qena and Esna. We have found these same differences to occur between the shales that outcrop in the region south of Cairo, i.e., the Maadi formation shales, and shales that outcrop in the vicinity of Qena and

Esna, the Esna shales. Table II displays side by side the average concentrations and group standard deviation ranges* of the compositions we have found in both the clay and shale samples from Maadi and the Fayum and in the clay and shale samples from Upper Egypt. In Table II the components whose concentration ranges are different in the two regions are underlined. It can be seen that upon the basis of these data the Pleistocene clays and Maadi formation shales from Maadi and the Fayum are indistinguishable from each other. The Pleistocene clay and Esna shale of the Qena-Esna region are not quite as closely matched in composition but are still very similar to each other. Considering the small number of samples analyzed it would be stretching statistics to distinguish between them. However, the Maadi formation shales show the same compositional differences from the Esna shales that Maadi Pleistocene clay does from Esna Pleistocene clay. Indeed the local clays of Pleistocene deposition do seem to have been derived to a predominant extent from the shales local to them.

This conformity to local conditions suggests that in other localities throughout Egypt the composition of Pleistocene clays might be characteristically different. For example, Pleistocene deposits occur along the edges of the

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*For simplicity of presentation the arithmetic means and standard deviations have been listed in Tables II and VII. Experience has convinced us that trace impurity concentrations tend to be logarithmetically distributed and hence geometric means and standard deviations in terms of logarithms of concentrations would be a more correct presentation of the data. However, because the differences between the two methods of data handling are small when the members of a group are reasonably closely similar to each other it is reasonable and practical to use the considerably more familiar linear data presentation in these instances.

delta. At Alexandria, situated at the western edge of the delta, there should be available Pleistocene clays as well as alluvium for pottery fabrication. It will be necessary to characterize these and other local Pleistocene clays not yet analyzed before one can consider this study to be at all complete.

Clays of the Pliocene epoch are widely distributed over the Nile Valley and the oases. They are commonly called "plastic clays" and are used for pottery making. The four specimens analyzed came from widely separated locations. The first was from the site of the Fom El Khalig which was a canal within Cairo with an entrance to the Nile just east of the island of Roda. The second Nile specimen comes from the former village of Korosco, which was located south at Aswan well into Lower Nubia. The remaining two specimens came from the Central Western Desert oases, Kharga and Baharia. These four specimens are all similar to each other in composition. It would seem probable that they were all formed under similar circumstances, presumably marine or estuarine conditions. Considering such conditions of formation it would seem more likely that the Pliocene deposits would be more generally uniform than the Pleistocene and hence that it is unlikely Pliocene clay from particular localities throughout Egypt can be differentiated upon the basis of their minor and trace impurity patterns.

The Pliocene clays are characterized by relatively high concentrations of cerium, hafnium and thorium and low concentrations of sodium, iron and cobalt, characteristics which they share with the kaolin clays. In general these two types of clay are very similar in the concentrations measured. However, the kaolins have significantly less potassium, iron and manganese than the Pliocene clays, so that the two are easily differentiated upon the basis of these elements.

Cretaceous Clays

Both the kaolin clays and Nubia sandstone clays are attributed to the Cretaceous period. The data on these clays are listed in Table III. We have analyzed three kaolin clay specimens, one from Kalabsha, south of Aswan in Lower Nubia and two from Abu Darag, near the head of the Gulf of Suez on its west coast. The specimens are reasonably similar to each other in composition, and at this stage we are considering them only as a group. Analysis of additional samples might provide some basis for differentiating the Nubian from the Suez Gulf kaolins.

As has already been noted, the kaolins are compositionally similar to the Pliocene clays but contain significantly less potassium, iron and manganese. They are characterized by their unusually low concentrations of these elements and of cobalt and by relatively high concentrations of cerium, hafnium and thorium.

All of our five Nubia sandstaone clay specimens come from the vicinity of Aswan. They include a group of three samples taken from an exploratory shaft near Aswan. They were selected for analyses in order to obtain an indication as to whether any significant changes would occur in concentrations as a function of depth from the surface. Recognizing that clays can undergo chemical exchange and also that a deposition or leaching out might occur at the surface of a clay deposit one feels that superficial samples, such as most of our specimens were, might differ from subsurface samples. There might also be natural nonuniformity throughout the deposit of course. The three specimens, T 21, T22, and T 23, taken respectively at the top layer of the clay deposit, near the shaft opening, and seventy-five meters within the shaft show a consistent change with distance in sodium, manganese, cobalt, and perhaps iron. Of these the relative change in sodium concentration was by far the most serious one. This confirms a general feeling one has that sodium would be among the least dependable of the components measured. Chemically, sodium and other alkali metal ions would be among the most labile toward chemical exchange and most likely to be present in soluble, and hence transferable, salts. It is interesting to note that the elements which show a diminution from the surface inward are ones which are present in significantly higher concentrations in the Nile alluvium than in the clay.

Despite the differences just noted the Nubia sandstone clays form a reasonably consistent group which is compositionally different from the others studied. The difference resides in the overall pattern of constituents, there being no single component present at a concentration level significantly different that is from all other clays and shales analyzed.

Shales from Near the Nile

The Maadi formation, the Esna, the Dakhla, and the Phosphate formation shales were all specimened at sites near to the Nile. As has been mentioned, the Maadi formation shale specimens came from Maadi and the Fayum. The three other shale containing layers were sampled in the El Sharawna District between latitudes 25° and 26° and longitudes 32° and 33° which is the central region of Fig. 1. Additional specimens from the Phosphate formation were taken from the Gebel Abu Had, the site of which is shown in the upper right corner of Fig. 1. Analytical data for all of these specimens are listed in Table IV.

The small but significant differences between the Maadi formation and the Esna shales were discussed when similar differences in the Pleistocene clays associated with them were considered. The Dakhla shale is little different from the Esna shale in composition, having perhaps somewhat less iron, manganese, and cobalt. The Phosphate formation is not a uniform layer and the shales from it show considerable compositional variation. All of these shales are roughly alike in composition, however, and can be distinguished compositionally from all the other clay-like materials analyzed except the Pleistocene clays.

Shales from the Kharga Oasis

The shale bearing layers that outcrop in the Sharawna District also outcrop at the Kharga Oasis. From the Gebel Abu Tartour there we have received specimens of Dakhla shale, Phosphate formation shale and of the yet lower lying Qusier variegated shales. Data for these specimens are listed in Table V. The Dakhla and Phosphate formation shales from the oasis are similar to those from the Nile with two very pronounced exceptions, both of which occur in the alkali metal elements. On the average there is only about one-twentieth as much sodium in the shales from the oasis as was in the corresponding shales from the Sharawna District and less than half as much cesium. Similar low concentrations of sodium and cesium are found in the variegated shale specimens from the Kharga Oasis. Whether these differences in alkali concentrations between shales of the two regions represent surface alterations of the type previously discussed or are basic to the shales and represent consistent differences in their conditions of deposition can be answered only through further investigation. It would be most helpful to have subsurface specimens of these shales for comparative analysis. Also it would be interesting and worthwhile to know if the Pleistocene clays at the oasis also have the low sodium and cesium of the shales which outcrop there. However this may be, surface shale material taken from the oasis can easily be distinguished from the other shales studied upon the basis of these elements.

In other respects the variegated shale specimens from the Kharga Oasis differed significantly from the other shales studied only in having a higher potassium content on the average than all other shales and as high an iron content as the Maadi formation shales

Archaeological Evaluation of the Clay and Shale Analyses

The analytical data on Egyptian pottery forming materials is just extensive enough at this stage to permit a reasonable evaluation of the potential of investigating ancient Egyptian pottery by means of comparative analyses. However, in order for extensive reliable inferences to be drawn from comparison of specific pottery compositions to that of the clays, the cataloging of clay compositions must be considerably more comprehensive and extensive than it now is. Also there is now need for a systematic analytical survey of ancient Egyption pottery itself to determine to what extent the various clays were used by themselves to produce pottery or in various combinations with each other and with the addition of tempering materials.

At present it looks as if it might be impossible to obtain an indication of the geographic source within Egypt of pottery made of pure Nile alluvium or Pliocene clay or mixtures of the two unless the analysis of a sufficient amount of pottery of known date and geographic provenance establishes that traditions of the use of these pure clays or particular mixtures of them were confined to specific localities at specific periods. The picture is much more encouraging with respect to other clays and the shales as there does appear to be some local compositional differentiation within the Pleistocene clays and shales. Also some of the clays which can be identified as to type through analysis, such as the Nubia sandstone and the kaolin clays, outcrop in only limited regions throughout Egypt.

It would seem likely that their use in pottery would have been similarly localized.

At this stage we have a better feeling for the consistency and diversity of clay compositions than of ancient Egyptian pottery compositions. A logical step at this time would be the undertaking of a reasonably comprehensive program of analysis of pottery of at least one historic period from known locations throughout Egypt. In this way hopefully an estimate of the consistency and degree of localization of the traditions of use of clays and tempers in pottery formation can be obtained. The insight that might be gained into the technology of the ancient Egyptian potters would itself justify such a study.

In summary, therefore, the fact that it now appears that one can distinguish between different types of clays that occur widely throughout Egypt through neutron activation analysis and in some instances one can identify clays that are local to specific regions establishes that there is potentially a reasonable likelihood that similar analyses of ancient pottery should in some instances provide indications of the geographic origins of that pottery. Because of the wide geographic distribution of some clays of nearly uniform composition it is to be expected that in many instances it may not be possible to infer such origins from the analytical data. As has been argued, the extent to which this is true will depend greatly upon the extent to which unique traditions of pottery formulation were observed in specific locations. Only analysis of the pottery itself can answer these questions. In any event it should, in many instances, be possible to interpret the compositions of the analyzed pottery in terms of the clays from which it might have been formed.

Analysis of Pottery

A small group of pottery specimens were analyzed as a very preliminary test of the potential of correlation between clay and pottery compositions. Only nine specimens in all were studied but they were all excavated material of known origin. They were selected to range in date from early Old Kingdom into the Islamic Period and they were supplied to us through the kind cooperation of Dr. Zaky Iskander.

Three of the specimens were from Sakkara and differed greatly in their date of burial. Two were of the Old Kingdom, one, P1, attributed to the Archaic period (32nd-28th centuries B.C.), the other, P9, attributed to the Pyramid Period (2723-2242 B.C.). The third Sakkara specimen, P8, was attributed to the relatively late 26th Dynasty (663-525 B.C.). Four specimens were of the Ptolemaic Period and were all from the Hadra excavations which were carried out at Alexandria in 1971. All four specimens P4, P5, P6, and P7 have been attributed to 140 B.C. Two specimens of yet later date, P3 and P2, were from Kom el-Dekka, also at Alexandria, and were respectively of the Coptic and Islamic periods. The data for these pottery specimens are given in Table VI.

The specimens can be divided rather well into but three compositional groups, a fact that lends credence to the concept that consistent traditions in pottery formulation did exist. The first compositional group includes both the oldest and youngest specimens which are separated by a time span of as much as four thousand years. This is not too surprising, however, as the composition of this particular group is essentially that of the pure Nile alluvium. A comparison between the average concentrations in this group of pottery and that in Nile alluvium is presented in Table VII. One can see that they differ significantly only in the sodium concentration which is somewhat higher in the ancient pottery. However, sodium chloride is known to accumulate as efflorescent deposits on the walls of tombs in Egypt and it is quite possible that some extra sodium could have accumulated in the pottery during burial. It is also possible, of course, that alluvium is slightly less rich in sodium today than it was millennia ago. In all other elements the compositions of these specimens are as close to that of Nile alluvium as one would expect them to be if indeed they had been made totally of this material. The specimens include all of the three from Sakkara and the Islamic specimen from Kom el Dekka at Alexandria. Perlman and Asaro[18] have also reported on a pottery group from a cemetery at Ballas in Upper Egypt which closely matches Nile alluvium.

The second group of matching specimens include a Ptolemaic specimen from the Hadra excavation and the Coptic specimen from Kom el Dekka, both at Alexandria. These specimens have many of the characteristics of Nile alluvium, e.g., relatively high manganese and cobalt and low thorium, but to a much less degree than the alluvium itself. It seems probable that this pottery contained Nile alluvium mixed significantly with one or more other components. We have not as yet been able to match this composition with a composite of the clays we have analyzed. It is possible the material we presume to have diluted the alluvium might be a tempering material or a clay, such as a Pleistocene clay unique to the delta region which we have not yet analyzed.

The third group includes three specimens, all of Ptolemaic date from the Hadra excavations at Alexandria. Two of these three specimens are closely matched in composition and have the characteristics of Nile alluvium diluted with other components. The third is more dilute than the first two in components that tend to be high in alluvium and could well be similarly constituted but with a lower alluvium content. All three are characterized by having definitely higher chromium than we have encountered in other materials studied except for a few of the very deeply lying shales.

These few analyses of pottery like the clay analyses encourage one to believe that more extensive studies of Egyptian pottery may often provide a basis for worthwhile inference but sometimes may only confirm an Egyptian origin for the objects studied. One considers future programs of neutron activation analysis of ancient Egyptian pottery with reserved optimism.

APPENDIX

Analytical Procedure

(i) Sampling: To insure representative sampling, at least 0.5 gram samples were ground and thoroughly mixed. In turn 40 mg samples of this more uniform material were packaged for activation. In the case of pottery, the surface of the sherd was cleaned with a tungsten carbide burr and a drill of tungsten carbide whose base could be placed in the chuck of an ordinary electric hand drill. The first portion of the powder drilled was discarded and then more powder removed to provide the amount required.

(ii) Irradiation: Activations were carried out at the Brookhaven High Flux Beam Reactor at fluxes of 1-4 x 10^{14} neutrons cm^{-2} sec^{-1}. A short activation of a few minutes preceded measurement of the short lived activities of manganese, sodium, potassium, and sometimes lanthanum, while an activation lasting for some hours followed by a decay period of a week to ten days preceded measurements of the longer lived activities. With every batch of samples each of the six U.S. Geological Survey Rock Standards were introduced to be irradiated under the same conditions. In this way each element is individually calibrated in each run. Agreement between the six standards confirms that conditions of activation and counting are uniform.

After irradiation and cooling, the samples and the standards were transferred quantitatively, using ethanol, into glass tubes provided with metal caps to allow them to be picked up by the magnet tipped arm of an automatic sample changer. An alternative more convenient procedure which does not involve the transfer of the activated samples is to use small sealed quartz tubes for packaging the samples instead of the usual aluminum cans. The main impurities in the quartz were Sb, Sc, Ce, Th, Cr, Fe, and Co, but their concentrations were negligible as compared with those encountered in the samples. Therefore the samples could be counted while still remaining in the pure quartz tubes.

(iii) Counting and Spectrum analysis: The gamma ray spectra were taken with a 35 cm^3 Ge(Li) detector coupled to a 3200 channel analyzer with magnetic tape output. An automatic sample changer would introduce the samples into a well in front of the detector where they were positioned in an exact geometry relative to the detector for the prescribed counting intervals. Counts from a precision pulser were fed through the entire electronics of the counting system during the period of counting, and recorded as an additional peak in the spectrum. The ratio of the number of counts collected in this pulser peak to the number of pulses emitted by the pulser during the counting period provided an exact measure of the percent live time of the entire electronic system.

(iv) Data processing: The data on the magnetic tape were processed by a Control Data 6600 computer in successive steps that 1) analyzed the spectra, 2) calculated calibration constants from the data on the six standards run with the samples, 3) converted peak data to concentrations and 4) produced comparative plots of specimen data or carried out statistical analysis on the data for groups of specimens as desired.

These analytical procedures have been described in detail by Abascal, Harbottle and Sayre.[22]

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TABLE I

CLAYS AND SOILS DEPOSITED AFTER THE FORMATION OF THE NILE

Epoch of Deposition		RECENT							PLEISTOCENE				PLIOCENE			
Source Locations		Boulac District Cairo	Islands in Nile Assiout	South of Aswan	Aswan	Agha-Khan Tomb Aswan	Dakhla Dakhla Oasis	Wadi Natrun	Maadi South-east of Cairo	Qena Upper Egypt	Esna Upper Egypt	El Fayum	Fom El Khalig Cairo	Korasco Nubia	Kharga Kharga Oasis	Baharia Oasis
		Matching						Non-matching								
Specimen No.		T2	T7	T24	T25	T26	T15	T1	T5	T8	T9	T14	T3	T11	T16	T17
									Concentrations of Oxides in Percent							
Sodium	Na_2O	1.22	1.26	1.44	1.51	1.65	1.55	0.59	1.52	1.16	1.94	1.80	0.190	0.084	0.065	0.097
Potassium	K_2O	1.21	1.33	1.55	1.24	1.29	1.25	0.52	1.53	1.06	1.07	1.30	1.35	1.13	1.02	0.69
Iron	Fe_2O_3	11.3	10.8	11.4	11.2	11.4	10.1	6.9	8.16	6.39	6.64	7.68	1.43	1.90	1.80	2.24
									Concentrations of Oxides in Parts Per Million							
Rubidium	Rb_2O	76	44	43	46	41	109	90	78	55	74	65	35	31	21	30
Cesium	Cs_2O	0.7	1.0	1.4	1.8	1.5	1.4	2.7	4.7	3.8	5.7	3.6	1.3	1.9	1.3	3.0
Barium	BaO	510	460	540	520	520	620	640	380	450	720	240	560	------	------	330
Scandium	Sc_2O_3	41	40	40	40	38	38	46	35	29	33	36	30	36	36	36
Lanthanum	La_2O_3	58	------	42	37	36	35	------	62	107	68	66	88	82	95	65
Cerium	CeO_2	150	138	90	84	78	145	155	144	67	73	183	480	440	500	320
Europium	Eu_2O_3	2.7	2.9	3.1	2.8	2.9	2.5	3.0	3.1	2.0	2.9	2.8	2.7	2.8	3.8	2.5
Hafnium	HfO_2	6.8	6.9	8.5	6.8	7.6	7.6	7.3	5.9	3.2	3.1	7.4	22.6	19.8	22.6	15.3
Thorium	ThO_2	7.7	6.5	7.0	6.2	6.0	6.4	12.3	17.3	13.7	14.6	13.7	21.0	25.5	26.3	16.8
Tantalum	Ta_2O_3	3.5	3.7	2.2	2.1	2.5	2.9	4.8	3.7	2.4	2.8	3.9	3.8	4.7	3.6	5.5
Chromium	Cr_2O_3	208	195	250	218	235	223	195	194	241	281	208	157	176	175	171
Manganese	MnO	1740	1840	1660	1520	1540	1520	104	168	295	165	112	102	88	90	139
Cobalt	CoO	47	47	46	47	46	43	36	18	22	20	15	5	9	15	6

TABLE II

COMPARISON OF PLEISTOCENE CLAYS WITH SHALES FROM THE SAME SOURCE REGIONS

		Specimens from Nile Region South of Cairo		Specimens from the Qena-Esna Region of Upper Egypt	
		Pleistocene Clay	Maadi Formation Shale	Pleistocene Clay	Esna Shale
		Average Concentrations in Percent*			
Sodium	Na_2O	1.66 ± 0.20	1.70 ± 0.05	1.55 ± 0.55	2.43 ± 0.25
Potassium	K_2O	1.42 ± 0.16	1.21 ± 0.12	1.07 ± 0.01	1.09 ± 0.11
Iron	Fe_2O_3	7.9 ± 0.3	7.8 ± 1.1	6.5 ± 0.2	6.1 ± 0.3
		Average Concentrations in Parts Per Million*			
Rubidium	Rb_2O	72 ± 9	66 ± 2	64 ± 13	60 ± 12
Cesium	Cs_2O	4.2 ± 0.8	3.8 ± 0.7	4.8 ± 1.3	5.4 ± 0.8
Barium	BaO	310 ± 100	270 ± 80	580 ± 190	450 ± 130
Scandium	Sc_2O_3	36 ± 1	32 ± 4	31 ± 3	27 ± 4
Lanthanum	La_2O_3	64 ± 3	66 ± 5	87 ± 27	49 ± 7
Cerium	CeO_2	164 ± 28	136 ± 17	70 ± 4	48 ± 10
Europium	Eu_2O_3	2.9 ± 0.2	2.7 ± 0.3	1.9 ± 0.1	1.6 ± 0.2
Hafnium	HfO_2	6.6 ± 1.0	6.4 ± 0.9	3.1 ± 0.1	2.9 ± 0.5
Thorium	ThO_2	15.5 ± 2.6	15.5 ± 0.5	14.1 ± 0.6	11.2 ± 2.8
Tantalum	Ta_2O_5	3.8 ± 0.1	3.2 ± 0.4	2.6 ± 0.3	1.3 ± 0.2
Chromium	Cr_2O_3	201 ± 10	199 ± 33	261 ± 28	254 ± 30
Manganese	MnO	140 ± 40	256 ± 101	230 ± 92	173 ± 28
Cobalt	CoO	16 ± 2	23 ± 5	21 ± 1	25 ± 4

*With group standard deviations.

TABLE III

EGYPTIAN CLAYS DEPOSITED BEFORE FORMATION OF THE NILE

		Kaolin Clays from Nubia and the Suez Gulf			Nubia Sandstone Clays from the Aswan Region				
Epoch of Deposition		Cretaceous			Lower Cretaceous				
Source Locations		Kalabsha South of Aswan	Abu Darag Gulf of Suez		Aswan dark grey clay	Aswan light grey clay	Specimens from a Shaft Near Aswan		
							top layer	near opening	75 meters inside
Specimen No.		T13	T18	T19	T10	T20	T21	T22	T23
					Concentrations of Oxides in Percent				
Sodium	Na_2O	0.16	0.38	0.76	0.10	0.11	0.58	0.42	0.06
Potassium	K_2O	------	0.15	0.10	1.19	1.15	1.00	1.08	1.13
Iron	Fe_2O_3	0.74	1.02	1.17	6.3	2.5	7.5	7.3	4.8
					Concentrations of Oxides in Parts Per Million				
Rubidium	Rb_2O	23	------	------	70	50	42	46	48
Cesium	Cs_2O	------	------	------	4.3	3.1	5.3	6.7	4.6
Barium	BaO	350	------	230	------	------	250	230	240
Scandium	Sc_2O_3	43	34	41	38	54	55	41	42
Lanthanum	La_2O_3	128	92	------	88	85	68	65	69
Cerium	CeO_2	480	371	417	186	160	164	145	152
Europium	Eu_2O_3	4.5	3.1	2.7	2.8	3.4	------	2.8	2.4
Hafnium	HfO_2	21.2	15.9	15.7	7.0	8.0	6.1	7.6	7.9
Thorium	ThO_2	38.1	20.7	30.8	14.9	15.8	14.9	16.7	17.8
Tantalum	Ta_2O_5	15.4	10.5	12.0	3.8	5.5	1.9	2.2	2.6
Chromium	Cr_2O_3	381	206	180	153	155	193	168	167
Manganese	MnO	11	43	25	111	36	244	165	72
Cobalt	CoO	6	3	5	33	6	22	17	14

TABLE IV

SHALES FROM OUTCROPS NEAR THE NILE

Formation		Maadi Formation			Esna Shale				Dakhla Shale		Phosphate Formation							
Epoch of Deposition		Upper Eocene			Upper Paleocene				Lower Paleocene		Campanian to Maastrichtian							
Source Location		El Fayum		Maadi south of Cairo	Gebel El-Shaghab Sharawna District				Gebel Aweina Sharawna		Gebel Abu Had Northeast of Qena				Gorayat		Gebel Aweina	
															Sharawna District			
Specimen No.		TK17	TK18	TK20	TS4	TS5	TS13	TS14	TS3	TS12	TA1	TA6	TA7	TA19	TS3	TS9	TS10	TS11
Concentrations of Oxides in Percent																		
Sodium	Na_2O	1.76	1.67	1.67	2.43	2.78	2.26	2.25	1.57	3.50	8.44	2.79	3.44	1.59	2.91	4.39	4.14	4.41
Potassium	K_2O	1.07	1.25	1.31	0.97	1.12	1.05	1.23	0.75	1.07	1.17	0.94	0.99	2.96	1.16	1.42	1.36	1.19
Iron	Fe_2O_3	5.24	8.62	6.39	5.92	5.82	6.45	6.19	5.20	4.77	5.08	4.98	5.48	8.06	9.17	7.04	7.26	5.70
Concentrations of Oxides in Parts Per Million																		
Rubidium	Rb_2O	68	66	65	72	43	65	58	57	48	51	53	49	83	65	73	55	50
Cesium	Cs_2O	4.5	3.9	3.1	6.5	5.1	4.7	5.4	5.5	2.5	2.6	3.2	3.2	2.2	7.0	2.7	3.2	2.3
Barium	BaO	340	180	280	600	520	300	390	——	190	600	230	330	——	270	390	310	340
Scandium	Sc_2O_3	35	32	28	33	23	26	27	37	24	23	30	29	32	33	28	37	21
Lanthanum	La_2O_3	71	64	62	59	42	46	47	41	47	30	44	38	44	50	53	44	57
Cerium	CeO_2	151	118	140	61	38	46	46	42	51	40	46	42	45	49	53	45	59
Europium	Eu_2O_3	2.9	2.8	2.3	1.9	1.4	1.6	1.6	1.3	1.6	2.4	0.9	1.7	1.8	2.0	2.0	1.7	1.8
Hafnium	HfO_2	5.9	7.0	5.4	3.5	2.3	2.8	3.0	3.7	3.0	2.3	2.5	2.2	3.1	2.9	4.7	3.9	8.0
Thorium	ThO_2	16.0	15.0	15.5	15.0	8.4	10.3	11.0	13.2	11.3	8.4	11.9	11.8	8.7	11.6	12.7	12.0	12.9
Tantalum	Ta_2O_5	3.7	2.9	3.0	1.5	1.4	1.1	1.3	1.4	0.9	0.8	1.1	0.8	1.0	1.4	1.3	1.1	1.1
Chromium	Cr_2O_3	221	215	161	290	217	255	255	222	190	245	227	333	177	329	396	402	193
Manganese	MnO	151	353	264	133	177	192	192	48	33	75	49	87	354	177	226	164	50
Cobalt	CoO	19	29	20	19	28	29	24	11	6	13	10	14	21	20	16	19	10

TABLE V

SHALES FROM GEBEL ABU TARTOUR AT THE KHARGA OASIS

Formation		Dakhla Shale			Phosphate Formation	Variegated Shales				
Epoch of Deposition		Lower Paleocene			Cretaceous	Upper Cretaceous (Cenomenian)				
Specimen No.		TK13	TK14	TK15	TK10	TK3	TK5	TK6	TK7	TK8
					Concentrations of Oxides in Percent					
Sodium	Na_2O	0.10	0.18	0.14	0.06	0.14	0.13	0.09	0.13	0.09
Potassium	K_2O	1.09	1.61	1.54	0.89	3.27	3.72	1.96	4.04	2.37
Iron	Fe_2O_3	5.58	6.09	8.69	4.83	9.09	9.05	8.52	9.31	7.99
					Concentrations of Oxides in Parts Per Million					
Rubidium	Rb_2O	43	46	52	28	95	76	62	62	66
Cesium	Cs_2O	2.2	1.8	2.5	1.5	1.5	1.7	1.3	1.5	1.6
Barium	BaO	------	460	------	330	------	190	520	220	400
Scandium	Sc_2O_3	26	22	35	31	29	32	20	30	31
Lanthanum	La_2O_3	46	52	61	52	44	50	77	48	58
Cerium	CeO_2	87	100	144	109	72	91	172	91	99
Europium	Eu_2O_3	1.8	1.8	1.7	1.3	1.6	2.2	1.3	2.0	2.3
Hafnium	HfO_2	2.4	12.6	4.2	3.1	4.3	5.6	15.8	5.0	5.6
Thorium	ThO_2	12.4	15.6	15.5	11.5	9.6	12.1	16.7	10.2	16.8
Tantalum	Ta_2O_5	1.4	1.5	1.8	1.1	1.5	2.4	2.0	------	0.7
Chromium	Cr_2O_3	192	196	245	195	139	157	113	149	188
Manganese	MnO	215	428	96	145	330	384	253	267	176
Cobalt	CoO	21	20	15	22	23	24	17	22	18

TABLE VI

ANALYSES OF SOME ANCIENT EGYPTIAN POTTERY

		Compositional Group 1				Compositional Group 2		Compositional Group 3		
Source Location		Sakkara			Alexandria	Alexandria		Alexandria		
Period		Archaic Period	Pyramid Period	26th Dynasty	Early Islamic	Ptolemaic	Coptic	Ptolemaic		
Specimen No.		P1	P9	P8	P2	P3	P5	P4	P6	P7
						Compositions of Oxides in Percent				
Sodium	Na_2O	2.28	2.25	2.60	1.80	1.75	1.25	1.21	1.34	0.63
Potassium	K_2O	1.80	2.18	1.50	1.50	1.92	2.01	2.37	2.71	1.27
Iron	Fe_2O_3	10.20	8.50	11.00	11.60	6.55	5.96	7.83	7.12	7.05
						Compositions of Oxides in Parts Per Million				
Rubidium	Rb_2O	70	57	60	-------	42	62	124	130	61
Cesium	Cs_2O	1.2	1.2	1.4	0.9	1.0	1.4	8.2	5.7	3.5
Barium	BaO	410	640	490	600	450	400	410	370	220
Scandium	Sc_2O_3	37	33	40	42	25	21	34	31	52
Lanthanum	La_2O_3	46	41	42	44	49	38	39	39	19
Cerium	CeO_2	97	83	92	92	92	76	81	77	47
Europium	Eu_2O_3	2.5	2.6	3.2	3.0	1.7	1.7	1.5	1.5	0.7
Hafnium	HfO_2	6.7	6.8	6.8	7.5	9.1	6.4	4.2	4.2	1.8
Thorium	ThO_2	9.2	7.1	7.8	8.0	8.8	7.4	12.3	11.6	6.6
Tantalum	Ta_2O_5	2.6	2.7	2.4	3.1	3.3	2.5	1.5	1.5	0.9
Chromium	Cr_2O_3	236	184	249	281	169	126	520	350	330
Manganese	MnO	2050	1180	1760	1880	950	960	1140	1510	890
Cobalt	CoO	46	38	48	54	31	26	40	39	37

TABLE VII

COMPARISON OF THE AVERAGE OXIDE CONCENTRATIONS IN THE NILE ALLUVIUM SPECIMENS AND IN FOUR ANCIENT POTSHERDS* OF SIMILAR COMPOSITION

		Nile Alluvium Specimens	Matching Ancient Pottery
		Average Concentrations of Oxides in Percent	
Sodium	Na_2O	1.42 ± 0.18	2.23 ± 0.33
Potassium	K_2O	1.32 ± 0.13	1.72 ± 0.32
Iron	Fe_2O_3	11.2 ± 0.3	10.3 ± 1.4
		Average Concentrations of Oxides in Parts Per Million	
Rubidium	Rb_2O	50 ± 15	62 ± 7
Cesium	Cs_2O	1.3 ± 0.4	1.2 ± 0.2
Barium	BaO	510 ± 30	540 ± 100
Scandium	Sc_2O_3	40 ± 1	38 ± 4
Lanthanum	La_2O_3	43 ± 10	43 ± 2
Cerium	CeO_2	108 ± 33	91 ± 6
Europium	Eu_2O_3	2.9 ± 0.2	2.8 ± 0.3
Hafnium	HfO_2	7.3 ± 0.7	7.0 ± 0.4
Thorium	ThO_2	6.7 ± 0.7	8.0 ± 0.9
Tantalum	Ta_2O_5	2.8 ± 0.8	2.7 ± 0.3
Chromium	Cr_2O_3	220 ± 22	238 ± 40
Manganese	MnO	1660 ± 130	1720 ± 380
Cobalt	CoO	46 ± 1	46 ± 7

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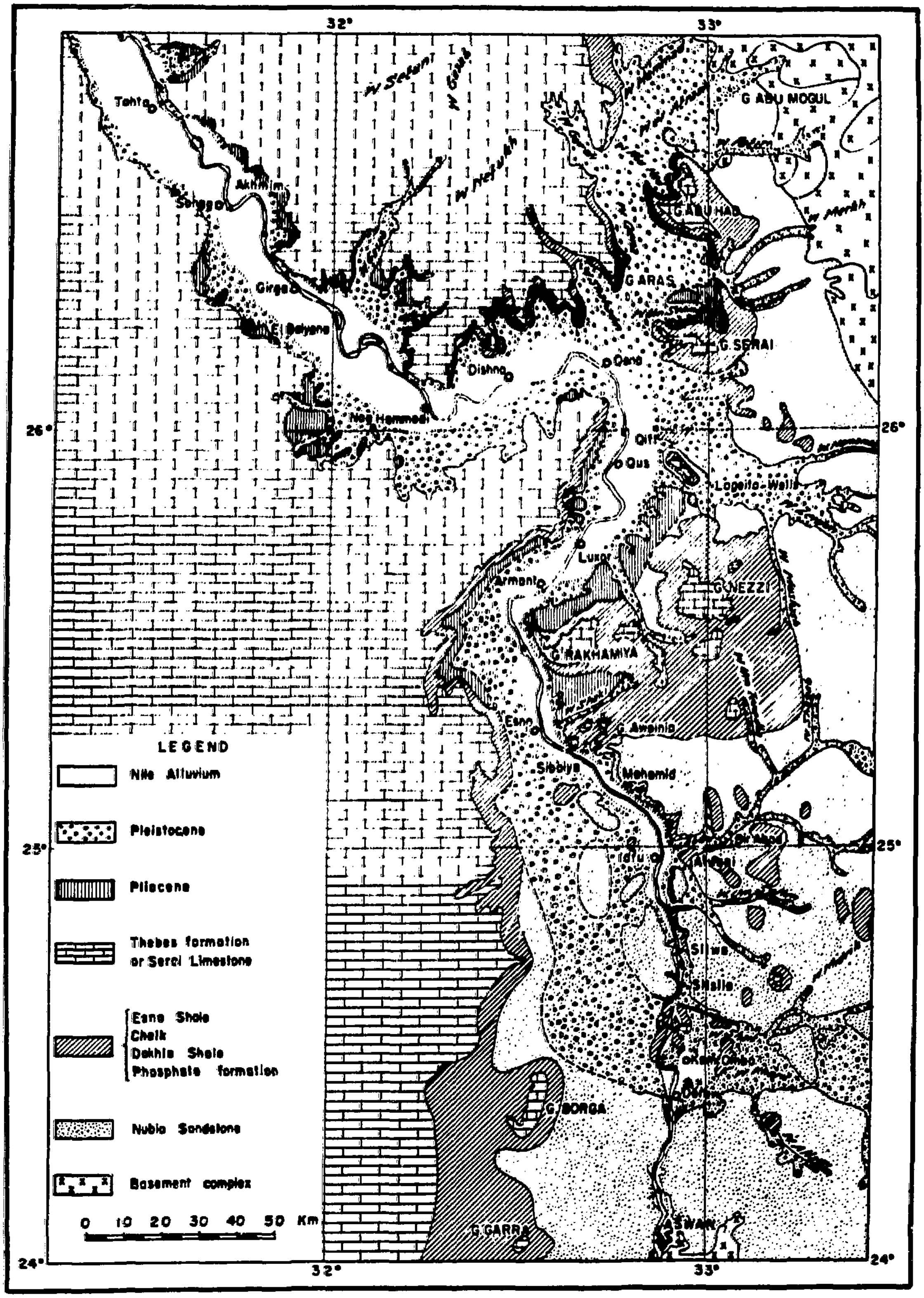
*Pottery Compositional Group 1.

Figure 1. Geological Map of the Nile Valley in Upper Egypt (Reproduced from The Geology of Egypt by R. Said, with the kind permission of Dr. Said.)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33°
26°
25°
24°
W Selemi
W Gash
W Hetukh
W Ahmar
W Atlon
W Mereh
G ABU MOGUL
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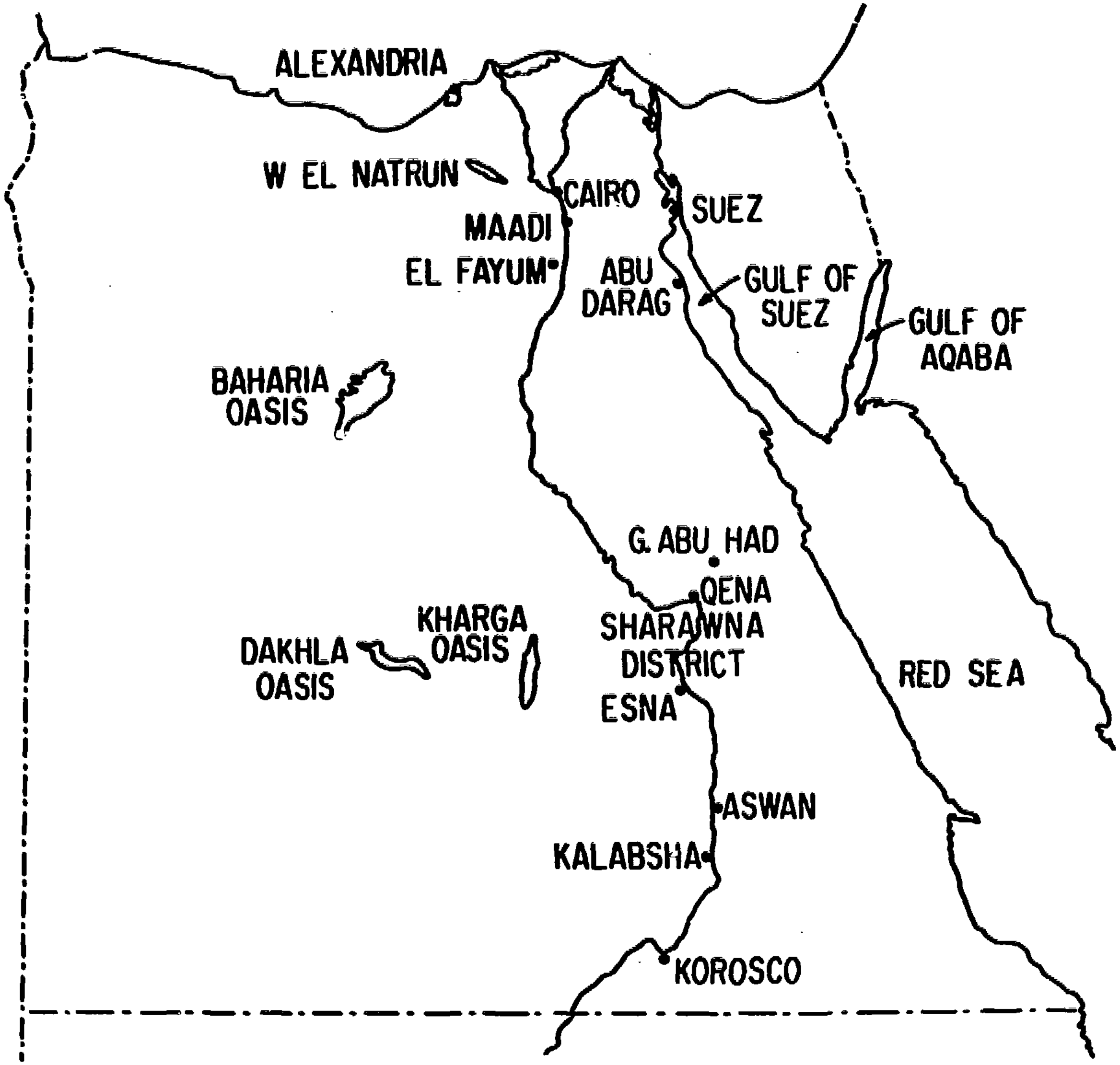
G ARAS
G SERAI
Tahta
Akhmim
Sohag
Girga
Nag El Balyana
Nag Hammadi
Dishna
Qena
Qift
Qus
Logeita Wells
Luxor
Armant
G NEZZI
G RAKHAMIYA
Esna
G Awainia
Sibaiya
Mehamid
Idfu
Silwa
Shalla
Kom Ombo
Daraw
G BORGA
G GARRA
ASWAN
LEGEND
Nile Alluvium
Pleistocene
Pliocene
Thebes formation or Serai Limestone
Esna Shale
Chalk
Dakhla Shale
Phosphate formation
Nubia Sandstone
Basement complex
0 10 20 30 40 50 Km

Figure 2. Sample Source Locations in Egypt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W EL NATRUN
CAIRO
SUEZ
MAADI
EL FAYUM
ABU DARAG
GULF OF SUEZ
GULF OF AQABA
BAHARIA OASIS
G. ABU HAD
QENA
SHARAWNA DISTRICT
KHARGA OASIS
DAKHLA OASIS
ESNA
RED SEA
ASWAN
KALABSHA
KOROSCO

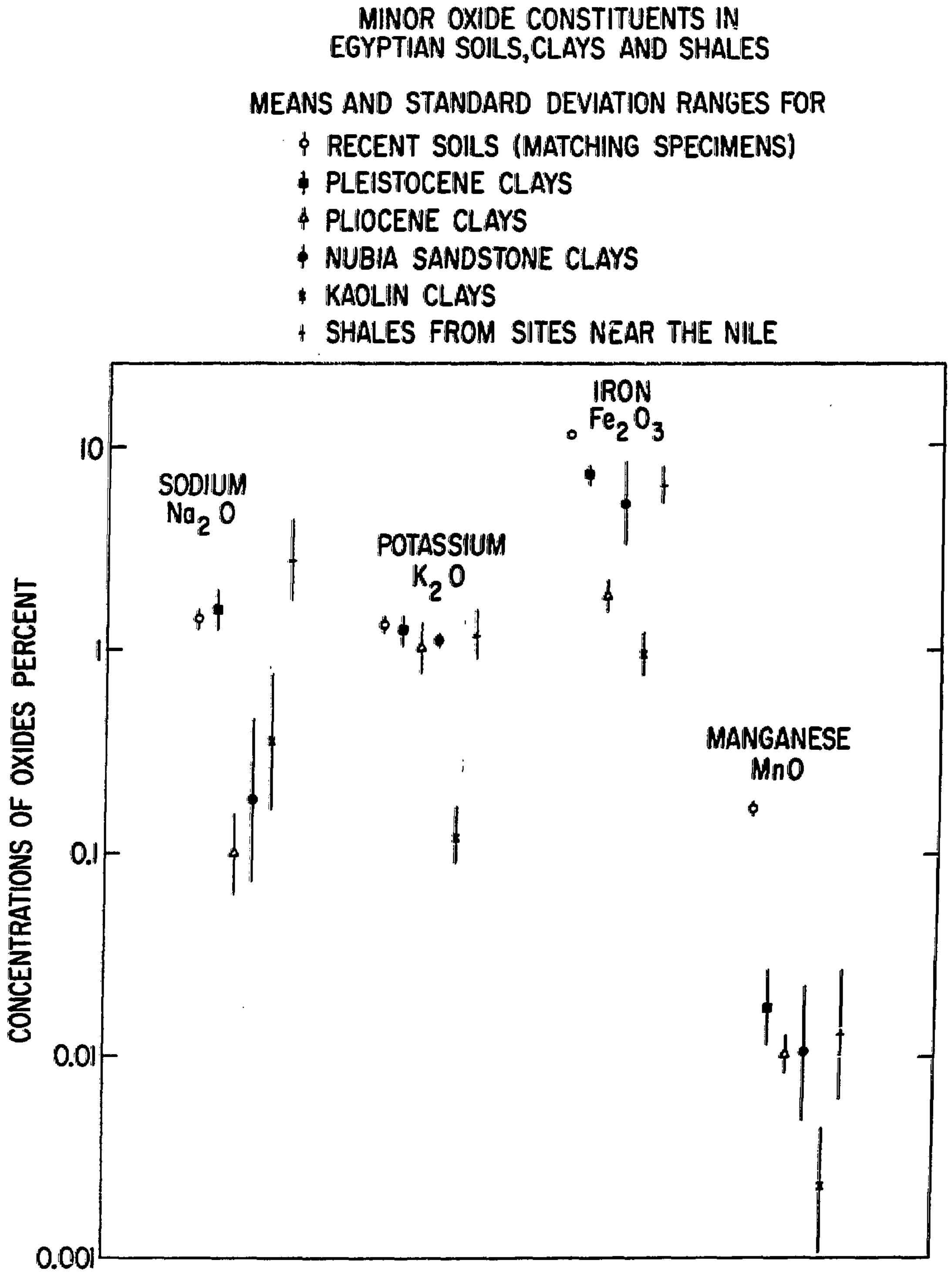
MINOR OXIDE CONSTITUENTS IN EGYPTIAN SOILS, CLAYS AND SHALES
MEANS AND STANDARD DEVIATION RANGES FOR
RECENT SOILS (MATCHING SPECIMENS)
PLEISTOCENE CLAYS
PLIOCENE CLAYS
NUBIA SANDSTONE CLAYS
KAOLIN CLAYS
SHALES FROM SITES NEAR THE NILE
SODIUM
Na2 O
POTASSIUM
K2 O
IRON
Fe2 O3
MANGANESE
MnO
10
1
0.1
0.01
0.001
CONCENTRATIONS OF OXIDES PERCENT

Figure 3

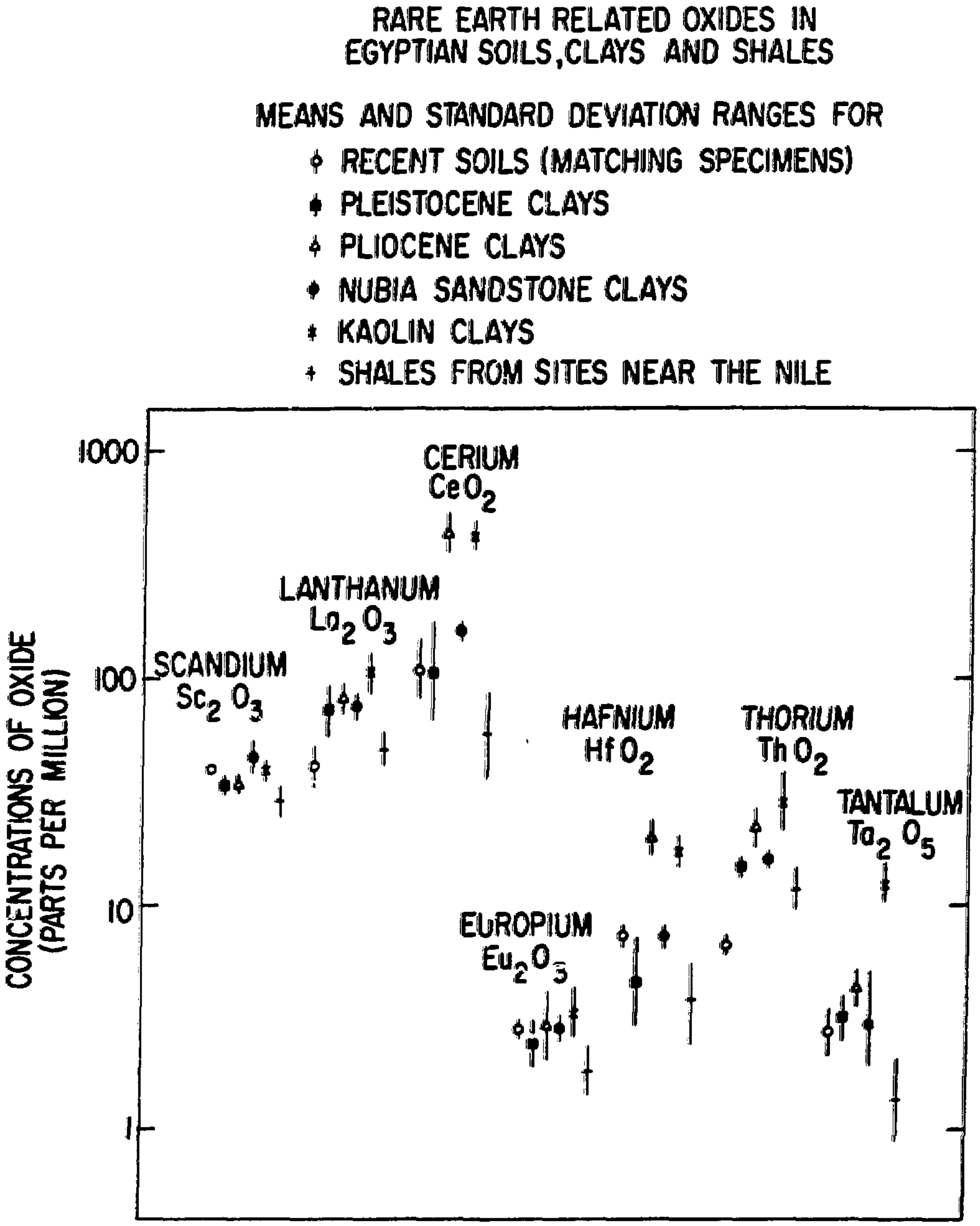
RARE EARTH RELATED OXIDES IN EGYPTIAN SOILS,CLAYS AND SHALES
MEANS AND STANDARD DEVIATION RANGES FOR
RECENT SOILS (MATCHING SPECIMENS)
PLEISTOCENE CLAYS
PLIOCENE CLAYS
NUBIA SANDSTONE CLAYS
KAOLIN CLAYS
SHALES FROM SITES NEAR THE NILE
CONCENTRATIONS OF OXIDE (PARTS PER MILLION)
1000
100
10
1
SCANDIUM Sc_2O_3
LANTHANUM La_2O_3
CERIUM CeO_2
EUROPIUM Eu_2O_3
HAFNIUM HfO_2
THORIUM ThO_2
TANTALUM Ta_2O_5

Figure 4