

## ON THE TRACE ELEMENTS COMPOSITION OF THE EGYPTIAN PHOSPHORITES: A NEW APPROACH

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### ABSTRACT

Large number of published and unpublished work was done during the last three decades on the geochemistry of the Upper Cretaceous-Lower Tertiary phosphorites of Egypt. However, the available data are certainly insufficient to reach an explicit understanding of these phosphorites as a peculiar dynamic and ever changing geochemical system. The present work provides original data on more than twenty elements, including the REE, in 106 phosphorite samples, representing almost all occurrences in the country. The analysis was performed by thermal and epithermal instrumental neutron activation techniques. The data of the present work together with previously published data have collectively been integrated to draw genetical and diagenetical conclusions. Associating facies and the prevailing chemical weathering are also among the influential factors affecting the trace elements composition of the Egyptian phosphorites.

Abnormally high content of REE was reported in 1974 for phosphorites from Abu Tartur, since then several studies confirmed this phenomenon. The present work, however, documents other abnormally high REE budget in phosphorites other than those of Abu Tartur, although with different configuration. The average REE content is estimated to be about 690 ppm for Abu Tartur phosphorites, while it exceeds the 800 level in the medium grade phosphate rocks of both East Idfu and Bahariya Oases. The bell-shape of the REE pattern of the Bahariya phosphate rocks seems to be result of an exceptional enrichment of the MREE, due to interaction with fluids that were heated by the thermal gradients prevailed during the Oligo-Miocene period. This phenomenon is analogous to that of the Eocene-Oligocene vertebral fossil bones of Fayoum.

The diagenetic uptake and remobilization of uranium explains its rather heterogeneous distribution with highest values in phosphorites occurring near to granitic exposures or their drains. The phosphorites of the Western Desert, except those of Bahariya Oasis, are markedly depleted in uranium. The mass-balance of uranium is best calculated relative to thorium. However, the high REE concentration can not alone restore the economic potentiality of any of the Egyptian phosphorites, because of the huge world reserves and the very low price of the ore, in addition to some serious mining and transportation disadvantages. The absence of an adequate cap rock for subsurface mining in Abu Tartur makes the exploitation of the ore, whether REE-rich or not, an unfeasible task. The present work provides some preliminary perception to improve the potentiality of some Egyptian phosphorites.

### INTRODUCTION

The phosphorites of Egypt belong to the extensive and commercially important sedimentary phosphate province well known as the "Mediterranean or Tethyan phosphogenic province". They occur chiefly in the Upper Cretaceous succession in southern Egypt (Fig. 1A & 1B). Customarily, they are associated with black shale, chert, glauconite, dolostone and oyster limestone. The thickest deposits of phosphorite form in areas of geosynclinal subsidence, under reducing conditions, where phosphorite is associated with carbonaceous shale and chert. The phosphorite is usually carbonaceous, pelletal and mixed with skeletal matter and phosphatic shells. The average thickness of the phosphate deposits is commonly about one meter, but may reach more than 9 meters in some occurrences such as in Abu Tartur. The phosphate occurrences in Egypt from north to south may be subdivided into three east-west trending facies belts (Hermina, 1972). The phosphorite of the northern facies belt, spread from Bahariya Oasis to Sinai. The phosphorites of this belt have no economic potential. They occur as thin layers mainly of carbonate and sand facies (Hermina, op. cit. and El-Shazly, et al. 1979). The economic occurrences are restricted to the central facies belt, which is confined to the following localities, the Red Sea coast from Safaga to Quseir; the Nile Valley between Idfu and Qena and the Western Desert between Kharga and Dakhla oases. The southern (third) facies belt lies south of latitude 22° N. The phosphate rocks of this facies are associated with iron ore accumulations among shallow water sediments.

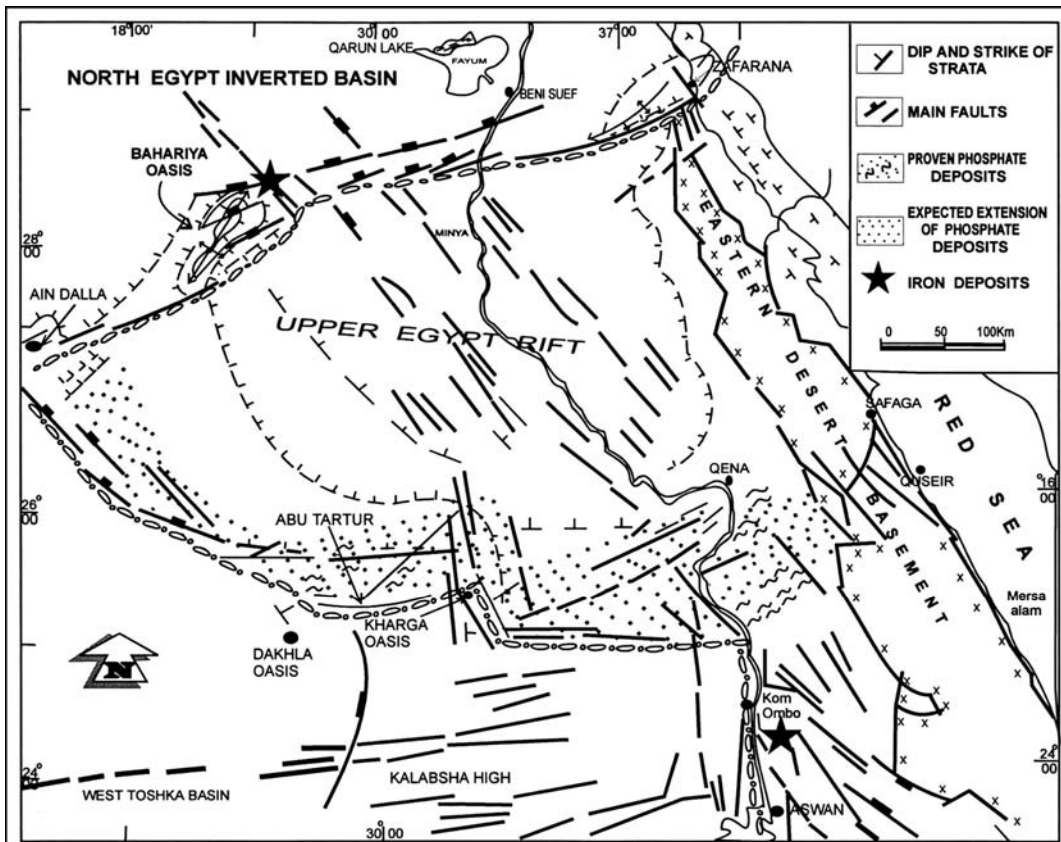


Fig.1A: Distribution of the Iron and Phosphate Deposits in Egypt (after Khalil and Denchi, 2000)

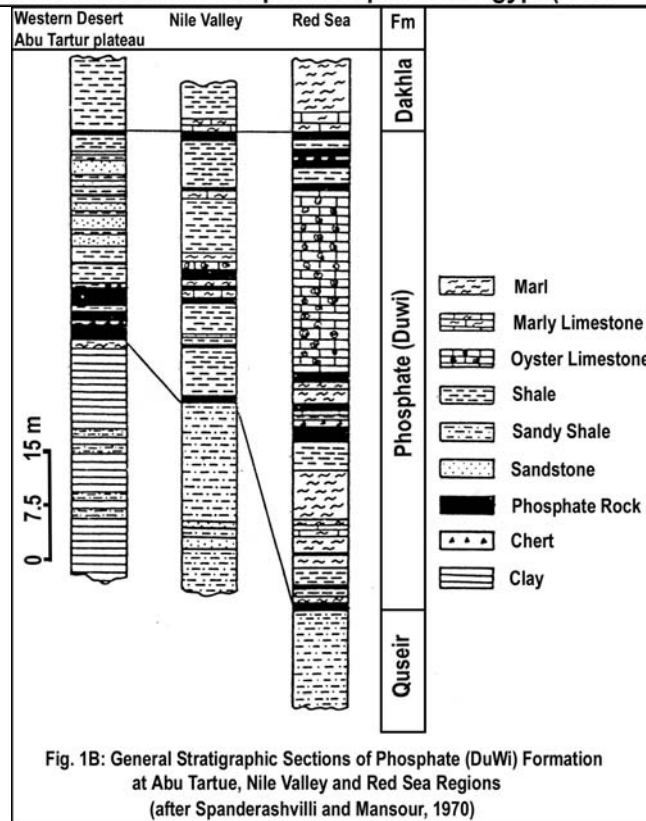


Fig. 1B: General Stratigraphic Sections of Phosphate (DuWi) Formation at Abu Tartue, Nile Valley and Red Sea Regions (after Spanderashvilli and Mansour, 1970)

The third facies is out of the scope of the present work. In the present study, the analyzed phosphorites belong to the economic occurrences of the central facies, besides the occurrences of Gebel Hefhuf in the Bahariya oasis and SW Sinai that belong to the northern facies belt.

Stratigraphically, the Phosphate (Duwi) Formation is conformably overlain by strata of Dakhla Formation and assigned as Upper Campanian to Early Maastrichtian age (Hermina, 1972). On basis of palynological studies, Schrank (1984) and Schrank and Perch-Nielsen (1985) assigned a Late Campanian to Early Maastrichtian age for the upper portion of the Duwi Formation. Richardson (1982) and Dominik and Shaal (1984) reached a similar conclusion on the basis of vertebrate fauna. Glenn (1990) correlated the Duwi lithofacies along the central belt and concluded that it attains maximum thickness in the central part that extends from the Dakhla and Kharga oases in the west to the Red Sea from Quseir to Safaga in the east. The studies by Germann, et al. (1984, 1985), Schroter (1986) and Bock (1987) concluded that the most likely phosphogentic model for Egyptian phosphorites to be one that visualize the existence of a Tethys south coast upwelling area on the North African shelf, which provided nutrient-rich waters leading to the formation of primary organic and phosphate-rich sediments.

Notwithstanding the numerous of publications on the Egyptian phosphorites during the last three decades, the available knowledge on the geochemistry of the trace elements, particularly the rare earth elements is insufficient and immature. Among the important studies, Youssef, (1957); Issawi, et al. (1969 & 1989); Philobos, (1964 & 1969); Hermina, (1972 & 1973), Hassan and El Kammar, (1975); Soliman, (1972); El-Kammar, A. (1974, 1977, 1985), El-Kammar, M. (1994); El-Shazly, et al (1977, 1984), Dardir and Kobtan (1980); Germann, et al. (1984, 1985); Dabous (1982) Dardir (1984); Glenn (1990); Saadel Din, (1990); Abdel-Rahman (1992); Al Aassy., et al. (1992); El Shishtawy, et al. (1999); Bekir and Abdel Aal, (1999), should be mentioned.

### Sampling and Methodologies

More than hundred samples were collected from the main phosphorite occurrences in Egypt. The samples were collected from the minable beds in the main phosphorite occurrences. From the Red Sea region between Quseir and Safaga, samples were collected from Hamadat, Duwi, Yonous and Wasief mines. The occurrences at the eastern flank of the River Nile between Idfu and Esna were sampled from Sharawna, Sibaiya, Mahamied, Naser mines and Hagariah. The phosphorites of the western flank of the Nile were collected from Sibaiya and Mahamied west. The phosphorites of Abu Tartur in the Western Desert were sampled from both surface exposures and the subsurface experimental mine. Phosphorites of the unexploited main beds of Shekh Abdallah and Edmonstone in Dakhla oasis, Ghanima in Kharga oasis, Gebel Hefhuf in Bahariya oasis, Abu Had near Qift at East Qena, and G. Sofrayiat SW Sinai were also sampled.

Thermal and epithermal instrumental neutron activation techniques were employed for the analysis of twenty-two elements, including the rare earth's, in 106 phosphorite samples. 200-300 mg of pulverized and well-homogenized sample was heat-sealed in polyethylene vials. The activation was done in the 2MW reactor at Inshas, Cairo. U.S. Geological Survey standards, such as BCR-1 and GSP-1, were used as reference materials and were treated precisely like samples. The geometry and activation by neutrons were almost identical for both samples and standards. The epithermal neutron activation was done for the radionuclides having very short half-life time such as F and Y, while thermal treatment, samples were activated for two hours.

A planar Ge (Li) detector with multi-channel analyzer and advanced computer system for activity correction and calculation was used. The acquiring schedule was made for 20 min after half an hour, 45 min after an hour, one hour after two hours, 4 hours after one day, 5 hours after 2 days, 7 hours after 4 days, 10 hours after 8 days, 24 hours after 24 days and finally 2 days after 40 days. Correction of data was done at different levels. The activity of iron wire was used to correct for the geometric position of vials in the irradiation capsule. Corrections were made for interference between some radionuclides, such as between  $\text{Sm}^{153}$ ,  $\text{Np}^{239}$  and  $\text{Gd}^{153}$  at the 103 keV energy peak. The obtained data are given in tables (1, 2, 3 & 4).

Table (1) Neutron activation analysis (INAA) data of phosphorites from the Red Sea Region

Locality	S. No.	%Na	%Fe	Cr	Co	Zn	Sr	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Yb	Lu	Hf	Th	U
Hammadat Area	RSH.1	0.438	1.702	63	2.7	198	2254	11.0	69	53	86	n.d.*	55	10.2	2.1	6.0	1.25	7.2	3.8	0.5	0.7	1.86	148
	RSH.2	0.501	0.308	104	0.2	287	1784	0.6	n.d.	20	34	n.d.	21	3.5	0.8	2.6	0.5	3.0	1.6	0.2	0.19	1.12	66
	RSH.3	0.426	1.253	186	10.8	95	1871	8.2	n.d.	34	106	n.d.	45	7.9	2.5	8.9	1.92	6.1	3.9	0.5	3.74	5.89	17
	RSH.5	0.413	0.939	104	3.8	183	1610	6.0	n.d.	35	71	n.d.	39	7.4	1.9	6.0	1.23	6.0	3.3	0.4	1.95	2.9	60
	RSH.7	0.298	0.594	71	1.8	168	629	5.5	n.d.	36	61	n.d.	46	8.8	2.1	7.2	1.37	8.2	4.3	0.6	3.5	3.1	22
	RSH.8	0.404	0.840	98	3.3	165	1513	5.4	n.d.	32	67	n.d.	37	6.7	1.7	5.3	1.12	5.3	3.0	0.3	1.64	2.5	46.2
	RSD.5	0.841	0.638	110	1.5	214	1189	4.1	n.d.	30	60	n.d.	33	6.6	1.9	6.5	0.97	5.7	3.9	0.6	2.42	3.4	22.8
	RSD.6	0.884	0.804	137	2.3	225	1015	5.9	n.d.	39	74	n.d.	44	8.6	2.6	8.5	1.29	7.2	5.3	0.7	3.14	4.6	20.5
Yonous Mine	RSD.7	0.798	0.471	83	0.7	202	1363	2.3	n.d.	21	45	n.d.	24	4.6	1.3	4.4	0.64	4.2	2.5	0.4	1.69	2.2	25
	RSY-1	0.529	1.245	70	14.0	50	813	12.7	n.d.	124	238	n.d.	173	34	8.4	24.0	3.65	21.0	12.4	1.4	0.29	6.24	20
	RSY-2	0.881	1.534	69	3.4	130	1650	13.9	n.d.	61	107	n.d.	59	11.8	3.3	10.9	1.62	9.6	6.2	0.9	0.2	2.5	50
	RSY-3	0.764	1.217	1185	2.4	76	1435	9.7	n.d.	56	108	n.d.	66	10	3.3	9.9	1.58	5.0	6.1	0.9	0.33	2.74	50
	RSY-4	0.433	1.020	139	1.6	192	1056	4.2	n.d.	27	35	n.d.	23	4.18	1.0	2.7	0.72	4.2	3.4	0.4	0.23	1.5	87
	RSY-5	0.652	1.254	366	5.3	112	1239	10.1	n.d.	67	122	n.d.	80	15	4.0	11.9	1.89	10.5	7.0	0.9	0.26	3.25	51.8
Wasief Mine	RSW-1	0.253	1.129	82	4.2	227	884	7.8	138	50	94	n.d.	60	8.8	3.5	11.6	1.64	10.2	5.1	0.7	2.3	3.6	20
	RSW-2	0.343	0.868	120	1.9	223	1311	6.5	135	42	72	n.d.	49	6.5	2.0	6.9	1.11	9.3	4.5	0.7	0.24	2.4	55
	RSW-3	0.446	2.108	108	3.6	247	2081	11.5	320	80	131	n.d.	81	15	4.3	13.7	2.26	16.0	8.7	1.5	0.32	3.5	60
	RSW-3b	0.370	0.958	108	2.2	185	1361	39.0	148	51	93	n.d.	57	8.42	2.5	8.5	1.31	9.4	5.1	0.9	0.59	2.17	68.8
	RSW-4	0.564	0.237	150	0.8	152	1961	4.5	100	37	78	n.d.	51	5.8	1.6	5.8	0.93	6.4	4.2	0.6	0.22	1.2	177
	RSW-5	0.286	0.329	69	0.7	175	761	2.0	103	44	85	n.d.	55	6	0.9	4.2	0.53	5.0	2.8	0.5	0.06	0.5	52
RSW-6	0.330	1.075	120	1.9	88	1166	6.6	90	52	80	n.d.	44	8.4	2.8	8.6	1.4	9.9	5.4	0.9	0.39	1.8	49	

nd. means not detected

units in ppm, unless otherwise stated

Table (2) Neutron activation analysis (INAA) data of phosphorites from East and West Nile Valley

Locality	S. No.	%Na	%Fe	Cr	Co	Zn	Sr	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Yb	Lu	Hf	Th	U	
WADI QENA Gebel Abu Had	GAH-1	0.797	1.784	61	5.9	57	1644	16.4	n.d.	96	172	n.d.	112	19.5	6.1	15.0	3.6	18	10.8	1.7	n.d.	4.2	20	
	GAH-2	1.424	1.774	75	2.5	95	1593	5.7	n.d.	30	79	n.d.	33.9	6	2.0	6.8	1	5.7	4	0.6	n.d.	1.8	79	
	GAH-2b	0.678	1.320	74	2.5	63	1041	6.3	n.d.	37	69	n.d.	40	7.4	2.2	6.9	1.2	6.6	4.2	0.7	n.d.	1.6	43	
	GAH-3	0.792	0.289	102	0.3	145	1572	3.0	n.d.	33	52	n.d.	47	5.2	1.4	6.5	0.82	5.7	4.3	0.5	n.d.	0.5	98	
	GAH-4	0.224	1.102	59	1.5	1	415	3.0	n.d.	21	32	n.d.	16	3	1.1	4.1	0.52	3	1.75	0.3	0.11	0.8	10	
	GAH-6	0.719	2.196	86	4.3	72	824	9.1	n.d.	42	77	n.d.	73	10.4	2.2	8.3	1.13	6.3	4.1	0.7	0.15	2.1	44	
EAST NILE VALLEY from Mahamied due south to Sibaiva to north	ENM-1	0.823	1.101	142	1.6	92	2372	9.7	95	56	104	n.d.	51.2	10.1	2.6	7.4	1.36	9.1	6.7	1.1	0.3	2.3	116	
	ENM-2	0.734	0.991	113	1.4	164	2548	9.1	n.d.	48	88	n.d.	58	8.6	2.4	8.2	1.34	8.8	5.4	0.7	0.15	1.8	84	
	ENM-3	0.775	1.018	90	1	158	1113	6.2	n.d.	28	53	n.d.	26.2	5	1.4	5.8	1.11	6	2.9	0.5	n.d.	1.2	54	
	ENM-4	0.941	1.001	82	1.2	157	1109	6.5	n.d.	31	53	n.d.	39	5.5	1.5	6.1	1.85	4.6	3.75	0.5	n.d.	1.4	60	
	ENM-5	0.270	1.271	67	3.5	169	752	9.8	n.d.	60	90	n.d.	74	11	2.6	9.8	1.6	9	6.45	0.7	n.d.	2	44	
	ENM-6	0.427	1.617	102	2.1	116	1058	9.0	n.d.	51	74	n.d.	65	12.2	2.1	8.5	1.25	7.5	4.75	0.6	0.14	1.4	59	
	ENM-7	0.624	1.275	150	2.2	122	2156	9.6	n.d.	49	101	n.d.	85	7.8	2.4	8.5	1.24	6.9	4.4	0.7	0.82	1.75	98	
	ENM-8	0.705	0.768	143	0.9	10.3	2105	6.0	31	30	65	n.d.	26.9	4.4	1.2	3.7	0.58	3.7	2.6	0.4	0.21	0.8	120	
	ENM-9	0.339	0.581	84	0.9	80	1518	3.0	n.d.	25	37	n.d.	19.2	2.1	0.6	2.4	0.37	2.4	1.26	0.2	n.d.	0.44	67	
	ENM-10	0.423	1.166	92	3.7	172	1381	8.5	n.d.	53	80	n.d.	66	12.9	2.3	10.1	1.25	7.8	4.9	0.8	0.22	1.5	68	
	ENM-11	0.650	7.299	16	42.9	217	1173	10.3	n.d.	103	124	n.d.	100	11.7	3.3	10.8	2	12.6	8.1	0.9	0.57	0.6	10	
	ENM-12	0.723	7.732	19	47.3	269	981	10.5	110	58	85	n.d.	65	10.5	3.0	11.4	1.95	14.1	7.3	0.8	0.69	0.6	9	
	ENM-13	0.411	4.756	29	25.5	167	1375	16.3	n.d.	90	124	n.d.	91	14.3	4.2	13.4	2.23	13.5	8.7	1.0	1.11	1.4	96	
	ENM-14	0.603	2.508	84	10.1	149	1440	9.4	n.d.	55	85	n.d.	48	9.36	2.4	8.5	1.47	8.7	5.44	0.9	n.d.	1.4	64	
	ENM-15	0.598	4.534	45	6.8	195	514	17.3	n.d.	96	133	n.d.	92	15	4.2	13.3	2.4	15.8	8.9	1.2	1.48	2.4	11	
SE Edfu	ENE-1	0.570	2.067	52	7.8	106	1679	27.7	256	186	289	n.d.	170	40	10.5	31.8	5.8	26.8	17	2.7	0.2	4.9	30	
	ENE-2	0.589	2.109	55	10.6	78	1507	28.4	297	197	306	n.d.	177	40.2	11.1	31.4	5.55	32.6	19.1	3.1	0.42	5.75	26	
	ENE-4	0.608	2.150	57	13.4	50	1334	29.0	337	208	322	n.d.	183	40.4	11.6	31.0	5.3	38.4	21.2	3.4	0.64	6.6	22	
	ENE-3*	0.599	1.468	28	3.0	74	1602	28.0	200	30	41	n.d.	20	4.5	0.7	3.7	0.56	3.8	2.43	0.4	1.44	1.7	21	
WEST NILE VALLEY	WNS-1	0.273	1.688	90	6.1	151	1173	12.1	n.d.	68	80	n.d.	41.6	9	3.0	11.0	1.9	11.2	6.3	1.0	0.33	3.9	22	
	WNS-2	0.602	3.935	26	12.6	190	2539	9.3	n.d.	29	24	n.d.	18.6	1.95	0.6	2.0	0.4	3.1	1.75	0.2	0.1	0.8	20	
	WNS-3	0.321	1.295	56	5.5	118	1557	9.2	n.d.	66	73	n.d.	42.2	8.1	1.9	6.0	1.3	7.8	4.4	0.7	0.2	2.2	40	
	WNS-4	0.621	1.610	143	5.8	171	1664	10.6	n.d.	90	76	n.d.	65.3	11.7	2.1	7.2	1.4	8.7	4.9	0.7	0.31	2.5	92	
	WNS-5	0.482	1.310	71	1.5	120	1600	7.2	n.d.	68	73	n.d.	48	7	1.8	6.6	1.1	6.6	3.7	0.5	0.21	1.7	33	
	WNS-6	0.258	1.390	30	2.6	75	1707	3.1	n.d.	16	59	n.d.	16	2.15	0.5	2.6	0.2	2.2	1.2	0.1	0.1	0.1	0.8	25
	WNS-7	0.258	0.645	58	0.6	71	1429	5.1	n.d.	20	49	n.d.	21.8	3.35	1.0	3.9	0.5	3.4	1.9	0.2	0.18	0.8	35	
	WNS-8	0.363	2.486	96	8.4	212	554	13.0	n.d.	85	118	18	74	13.7	2.9	10.6	1.96	11.5	6.9	1.2	0.66	5.3	48	
	WNS-9	0.212	0.682	97	1.9	66	274	8.0	n.d.	31	54	8	33	6.3	1.5	6.1	1.06	7.6	3.6	0.6	0.43	1.9	55	
	WNS-10	0.237	1.279	71	1.7	66	1153	9.4	n.d.	48	71	13	45	9.2	1.9	7.2	1.55	7.7	5	0.8	0.1	2.5	49	
	WNS-11	0.176	1.099	108	2.6	146	1267	10.0	n.d.	42	72	10.5	41	9.3	2.2	9.3	1.48	5.8	5.2	0.7	0.29	2.5	50	
	WNS-12	0.320	1.568	80	4	129	1372	9.0	n.d.	50	69	n.d.	38	7.7	1.8	7.0	1.22	6.8	4.3	0.7	0.27	2	46	
	WNS-13	0.158	0.896	69	1.2	69	1056	5.5	n.d.	26	43	7.5	23	4.4	1.2	4.4	0.79	3.6	2.9	0.4	0.15	1.4	43	
	WNS-14	0.269	2.085	107	3.2	195	1467	12.4	n.d.	62	90	15.3	55	11.7	2.8	10.8	1.84	10.4	6.5	1.1	0.25	3.3	58	
	WNS-15	0.256	1.556	95	2.4	150	1770	10.6	n.d.	47	82	10.4	39	9.4	2.4	10.0	1.65	6.7	5.3	0.7	0.39	2.7	75	

n.d. means not detected

ENE-3\* very low phosphate (below 8 % P2O5)

units in ppm, unless otherwise stated

Table (3) Neutron activation analysis (INAA) data of phosphorites from the Western Desert

Locality	S. No.	%Na	%Fe	Cr	Co	Zn	Sr	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Yb	Lu	Hf	Th	U
Gebel Ghanima	WKG-1	0.881	2.306	18	10.0	124	230	4.1	n.d.	25	35	n.d.	26	4.8	1.1	5.8	0.67	4.8	1.8	0.3	0.37	1.1	8
	WKG-2	1.118	3.792	43	50.0	147	422	8.7	n.d.	55	92		53	8.7	2.6	8.1	1.24	8.4	4.6	0.7	1.43	3.88	9
	WKG-3	0.874	3.851	62	102	115	589	15.2	123	101	176	n.d.	90	17.9	5.7	12.7	2.5	13.9	9.6	1.5	1.23	7.5	7
	WKG-4	1.410	6.002	77	79.2	120	593	10.8	n.d.	65	114	n.d.	69	9.6	2.5	9.4	1.31	10	4.8	0.8	3.6	4.6	26
	WKG-5	1.307	3.010	15	50.0	230	275	4.8	n.d.	29	42	n.d.	26	5.2	1.2	4.3	0.67	4.8	2.35	0.4	0.5	2.3	11
Abu Tartur Mine	WAT-1	0.629	3.288	50	10.8	72	1580	27.6	385	179	281	n.d.	153	36.9	9.9	33.5	5.3	33.8	16.2	2.4	0.3	4.2	23
	WAT-2	0.562	3.607	57	37.1	86	1584	28.2	335	175	228		157	34.3	10.0	31.0	4.84	28.7	16.3	2.2	0.67	5.8	26
	WAT-3	0.656	3.398	43	11.7	76	2143	27.8	381	183	302	n.d.	144	35.2	10.2	31.9	4.95	34	17	2.5	0.35	4	38
	WAT-4	0.632	3.316	87	12.9	91	1895	35.0	309	185	360	n.d.	180	34.4	12.4	32.3	5.05	25.6	15.8	2.1	1.8	8.5	33
	WAT-5	0.500	5.332	51	195	69	1031	28.0	286	182	279	n.d.	151	34.1	9.1	26.0	4.4	25.7	14.7	1.7	0.7	5.8	20
	WAT-6	0.435	3.131	47	7.3	58	934	23.0	350	148	220	n.d.	148	30.5	8.2	27.8	4.5	24.3	13.9	1.9	0.63	4.7	25
	WAT-7	0.508	2.984	57	12.4	158	1856	28.8	300	162	300	n.d.	158	31.0	10.7	35.0	5.2	33.5	19	2.2	0.49	6.8	21
	WAT-8	0.577	3.801	61	9.6	80	1652	27.0	333	183	273	n.d.	164	38.1	9.5	30.0	4.49	24.3	17.3	2.4	0.95	6.9	25
Gebel Sheikh Abdallah	WDA-1	0.736	8.756	50	34	13	899	15.5	553	120	170	n.d.	134	21.4	8.0	26.0	5.0	35.6	20.8	3.4	0.65	3.4	20
	WDA-2	4.131	0.642	77	0.7	75	844	3.9	56	24	50	n.d.	23	3.2	1.2	5.1	0.85	6	3.18	0.5	n.d.	1.3	27
	WDA-3	1.322	1.524	72	5.2	175	890	9.0	140	54	80	n.d.	51	6.3	2.4	8.0	0.99	9.7	4.32	0.8	0.15	1.78	30
	WDA-4	0.565	1.852	38	4.6	73	1485	3.9	132	53	51	n.d.	69	6.7	1.0	7.0	0.95	9.1	3.9	0.7	2.08	1.6	31
	WDA-5	3.106	1.729	93	5.9	144	1170	7.6	154	52	81	n.d.	53	6.4	2.6	13.0	1.27	10.2	5.4	0.9	0.21	2.7	60
Gebel Edmonstone	WDA-6	1.972	2.901	66	10.1	96	1355	8.0	207	60	87	n.d.	66	8.8	3.1	11.8	1.81	14.1	7.52	1.2	n.d.	2.16	33.6
	WGE-1	3.150	3.406	71	11	107	577	3.4	n.d.	15	35	n.d.	20	2.5	1.0	3.0	0.4	4.6	1.41	0.3	0.11	2.1	20
	WGE-2	1.990	2.570	88	6.3	116	966	22.0	n.d.	57	107	n.d.	66	9.1	3.3	11.5	1.55	10.4	6.2	1.0	0.44	4	33
	WGE-3	1.516	1.612	119	6.5	219	1223	19.1	n.d.	132	216	n.d.	145	25.2	7.2	25.5	3.4	22.8	12.5	1.6	0.53	10.9	56
	WGE-4	1.709	1.167	148	2.9	82	978	12.3	134	59	113	n.d.	68	9.9	3.5	11.3	1.77	9.8	6.2	1.0	0.22	5.4	32
Gebel Hufhuf	WGE-5	3.170	3.943	85	8.2	67	1280	98.7	186	70	150	n.d.	89	10.4	3.5	11.9	1.85	11.6	7.1	0.6	0.29	3.6	40
	WGE-6	1.203	1.477	81	3.7	98	1050	7.9	166	50	70	n.d.	43	5.1	2.1	11.0	0.94	8.1	5.2	0.9	0.18	1.7	41
	WGE-7	3.149	4.038	77	6.1	49	986	8.3	150	33	68	n.d.	35	3.2	1.7	8.1	0.84	6.0	4.7	0.7	0.42	1.5	26
	WGE-8	2.904	2.315	35	5.9	187	875	5.0	n.d.	40	94	n.d.	60	7.6	3.8	9.4	1.62	10.0	6.4	0.7	1.32	3.1	18
	WBH-1	0.210	1.790	n.d.	6.1	68	241	5.5	307	80	129	n.d.	121	26.0	8.4	35.0	7.5	37.5	8.84	1.0	4.04	3.05	100
	WBH-2	0.295	1.201	n.d.	2.5	53	110	5.8	140	61	84	n.d.	94	12.5	3.4	13.5	2.0	12.4	4.1	0.8	2.16	1.3	43
	WBH-3	0.358	1.240	n.d.	2.6	60	200	5.5	221	66	92	n.d.	51	13.4	3.4	16.7	2.8	16.6	5.9	0.8	2.5	1.4	44
	WBH-4	0.042	1.545	n.d.	7.1	88	307	4.3	654	101	215	n.d.	206	57.6	22.1	93.8	22	101	17.4	2.0	5.2	4.6	152
WBH-5	0.144	3.180	60	12.0	72	348	5.2	214	90	125	n.d.	131	20.0	4.8	16.4	3.3	20	7.96	0.9	6.3	4.9	161	

n.d. means not detected

units in ppm, unless otherwise stated

Table (4) Neutron activation analysis (INAA) data of phosphorites from Sinai and Wadi Araba

Locality	S. No.	%Na	%Fe	Cr	Co	Zn	Sr	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Yb	Lu	Hf	Th	U
Gebel	SGS-1	0.733	1.965	120	3.2	123	204	10.0	n.d.	56	76	n.d.	45	8.2	2.3	6.0	1.17	7.4	3.8	0.5	0.33	2.2	91
Sofraiyyat	SGS-2	0.141	0.821	50	1.8	257	82	4.7	n.d.	42	55	n.d.	29	7.8	2.4	13.0	1.58	7.2	2.62	0.3	1.8	1.7	37
	SGS-3	0.431	1.230	60	2.17	106	391	4.8	n.d.	31.8	44	n.d.	23	5.5	1.4	5.6	0.87	4.5	2.39	0.3	1.85	1.8	33.8
	SGS-4	0.447	1.525	40	2.1	32	476	3.4	n.d.	23	34	n.d.	14	4.8	0.8	2.8	0.55	2.6	2.34	0.3	4.13	2.6	3
	SGS-5	0.402	0.593	28	1.57	13	801	1.2	n.d.	6.1	11	n.d.	3.5	1.2	0.3	0.7	0.18	1.0	0.8	0.1	1.14	0.6	4.1
Wadi Araba	WAP-1	0.167	1.082	72	0.34	55	364	2.1	n.d.	10.8	7	n.d.	5.1	1.2	0.4	1.4	0.22	1.5	1.2	0.1	0.23	0.5	5
Phosphatized	WAP-2	0.211	3.409	320	144	66	300	4.9	n.d.	25.9	37	n.d.	21.8	4.1	1.2	3.9	0.64	3.6	2.4	0.5	1.68	0.9	50
sediments	WAP-3	0.527	1.349	191	25.1	42.1	512	5.0	n.d.	38.2	44	n.d.	29	5.3	1.5	5.5	0.87	5.4	3.48	0.5	1.39	1.4	27
	WAP-4	1.280	2.096	365	1.84	5.6	335	9.3	n.d.	90.9	150	n.d.	70	10.5	3.5	11.8	1.9	10.5	6.7	1.1	2.18	2.9	9
	WAP-5	0.123	0.164	37	0.27	15	446	2.4	n.d.	33.3	10	n.d.	22	4.9	0.8	3.3	0.41	2.4	1.6	0.2	0.9	0.7	19
	WAP-6	0.294	0.379	87	0.4	52	1106	5.4	n.d.	30.6	23	n.d.	25.6	4.8	1.6	5.6	0.96	6.0	4.1	0.5	2.18	2.1	26
	WAP-7	1.087	0.964	263	3.69	59	518	5.6	n.d.	37.4	35	n.d.	51	6.1	1.7	7.2	1.08	6.6	4.9	0.7	1.12	1.4	52

n.d. means not detected

units in ppm, unless otherwise stated

### Common Characters of the Egyptian Phosphorites

The following can be considered as common features of the Egyptian phosphorites:

- 1- Phosphorites exist as lenticular bodies (apparently bedded) with maximum thickness at troughs of the depositional basins. This phenomenon was attributed by Youssef, (1965) to be an "association with synclines".
- 2- The economic phosphorite belt in Egypt occupies a specific stratigraphic horizon, namely Campanian-Maastrichtian.
- 3- Phosphorites are regionally disturbed. The similarity in texture and composition, and their worldwide distribution suggests rather consistent depositional environments on a global scale.
- 4- Shale, dolostone, chert and glauconite are common associations of phosphorites.
- 5- The shale interbeds are always Mg-rich (e.g., smectite or smectite-illite mixed layer). According to Lucas, et al., (1979) the formation of Mg-rich shale after periods of phosphorite deposition seems to be a necessity in order to normalize the sharp increase in Mg relative to Ca. As a result of burial diagenesis of the Mg-rich clays and their transformation into the more stable illite, the released  $Mg^{2+}$ ,  $Fe^{2+}$  and silica are directly responsible for the ferroan-dolomitization of the carbonate interbeds and cementation of phosphorite by silica (McHargue and Price, 1982, and El-Kammar and El-Kammar, 1996).
- 6- Every fresh phosphorite must be drab or even black colored due to presence of organic matter and/or sulfides. The bright colors are result of diagenetic or weathering processes.
- 7- Phosphorites being clastic in nature (pelletal, skeletal or granular), they are always cemented by secondary material such as silica, carbonates, sulfates or even "collophane".
- 8- All sedimentary phosphorites, everywhere in the world, are mainly composed of carbonate fluorapatite (traditionally known as *francolite*), but the fluorine content increases with age. The *francolite* of the Upper Cretaceous-Lower Tertiary age contains 3 to 5 % F, with F/P<sub>2</sub>O<sub>5</sub> ratio of about 0.11, while in the modern human bone the F content is measured by tens of ppms. There is eminent tendency for the secondary uptake of F ion during the apatitization process (McConnell, 1973).
- 9- Sedimentary apatite has weak birefringence, but the least birefringence variety is commonly known as "collophane". Differences in birefringence are due to crystal size and mode of packing rather than to differences in lattice or space group.
- 10- Phosphorites, wherever they are, are excellent accumulators of trace elements in general and the mobile elements in particular.

The following can be considered as eligible reasons for trace elements enrichments;

- 1- They are permeable horizons bound in many cases by impermeable sediments.
- 2- They are rich in organic matter resulting from decay of collagen and soft tissues, giving rise to strong anaerobic bacterial activity.
- 3- Compaction and transformation of underlying or overlying shale produce large mass of water (trace elements-rich).
- 4- The complex structure of the carbonate-fluorapatite (*francolite*) allows substitution in different sites including  $Ca^{2+}$ ,  $PO_4^{3-}$ ,  $CO_3^{2-}$ , OH<sup>-</sup> and F<sup>-</sup>.

In spite of such remarkable similarities, the following can be considered as important peculiarities:

- 1- The thickness of the "beds" ranges from few centimeters to several tens of meters.
- 2- They display different textures, ranging from fine grained to coarse pebbly or from well sorted to conglomeratic.
- 3- The pebble: skeletal ratio varies from one bed to another, as well as from one occurrence to another.
- 4- Although "*francolite*" is the only major phosphate mineral in phosphorites, many other minerals and solid states of "uncommon" phosphate may occur in minor concentrations.

### RARE EARTH ELEMENTS (REE)

Although the discovery of phosphorites in Egypt can be dated back to the year 1888, when Zittel reported these rocks in Qift, near Qena, the geochemistry and economic importance of the REE have first been tackled by El-Kammar (1974) who reported REE abnormality in Abu Tartur phosphorites. Hassan and El-Kammar (1975) noted that the phosphorites of Abu Tartur are the least uraniferous but the highest in the REE budget. Basta and El-Kammar (1976) focused on the relationship between the REE content and the depth of the depositional basin. Dardir and Kobtan (1980) published data on the RE oxides for 101 samples from Abu Tartur area. Their results confirm the previous work by El-Kammar (1974) concerning the possible economic potentiality of REE in Abu Tartur. They evaluated the geological reserves of the REE in Abu Tartur phosphorites to be 1.742 kg/ton. Later studies on the Egyptian phosphorites by Germann, et al. (1985) reaffirmed the observation concerning the relative REE enrichment of Abu Tartur phosphorites compared to those of the Red Sea and Nile Valley. The same

phenomenon has further been confirmed by many authors e.g., Tamish (1988), Sadel Din (1990), El-Haddad and Ahmed (1991), Abdel-Rahman (1992), Ismael (2000), among many others.

The present study is based on data of 10 rare earth members of 106 phosphorite samples, representing most potential occurrences in Egypt. The average of the total 106 samples (Table 5) is used for comparison and normalization of individual occurrences in order to recognize their singularities.

The Egyptian phosphorites can generally be described as Ce and Eu deficit with marked enrichment of the LREE (Fig. 2). The average content of 10 REE is estimated to be about 280 ppm, with lower values for the low-grade phosphatic sediments. The mutual abundance of the REE reflects that about 83% of the 10 REE budget belong to only three elements, namely La, Ce and Nd (Fig. 3). In average, the LREE are about eight folds the HREE. However, the aberration in the REE parameters (Table 6), such as the sporadic positive anomalies of Ce and Eu, can be attributed to peculiarities with respect to either depositional or post-depositional controls.

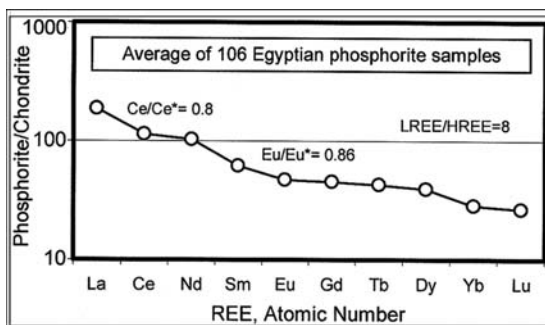


Fig. 2: Chondrite-normalized REE of average 106 phosphorite samples from Egypt

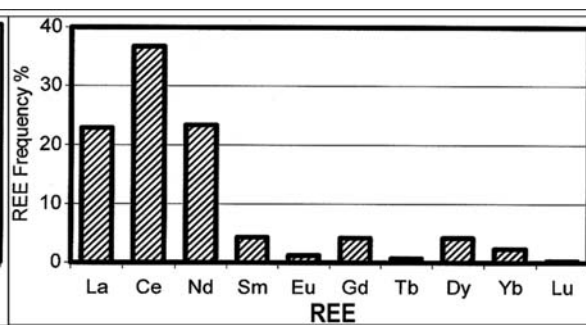


Fig. 3: The average abundance of the analyzed 10 rare earth members in the analyzed phosphorites.

Table 5: Summary statistics of REE and their main parameters

Variable	Mean (n=106)	St. Deviation	Minimum	Maximum
La	63.9	46.0	6.1	208
Ce	102.6	74.7	7.3	360
Nd	65.2	46.0	3.5	206
Sm	12.0	10.6	1.2	57.6
Eu	3.4	3.4	0.26	22.1
Gd	11.8	11.7	0.7	93.8
Tb	2.0	2.4	0.18	22
Dy	11.7	12.3	1	101
Yb	6.3	4.7	0.8	21.2
Lu	0.9	0.7	0.1	3.43
REE (10 members)	279.7	202.8	24.5	864.3
LREE/HREE	8.2	1.8	2.5	14.7
Ce/Ce*	0.80	0.20	0.17	1.86
Eu/Eu*	0.86	0.14	0.44	1.40

Table 6: Average REE parameters in phosphorites of the investigated occurrences

Parameters	Total REE	LREE/HREE	Ce/Ce*	Eu/Eu*
Hamadat	171.11	9.09	0.96	0.83
Duwi	149.35	7.48	0.94	0.90
Yonous	320.57	8.96	0.84	0.89
Wasief	236.25	8.37	0.87	0.91
Abu Had	175.44	7.96	0.89	0.92
East Nile	224.70	7.98	0.80	0.82
West Nile	186.65	8.33	0.74	0.76
SE. Idfu	821.96	7.99	0.79	0.92
Ghanima	234.34	9.18	0.83	0.95
AbuTartur	687.29	7.28	0.67	0.93
Dakhla	261.21	6.16	0.68	0.92
Edmonstone	272.97	7.91	0.88	0.98
Hefhuf	454.26	4.06	0.68	0.86
Safariate	119.28	7.68	0.75	0.79

The normalized REE patterns of the individual phosphorite occurrences to the mean of the Egyptian phosphorites (Fig. 4) reflect the following:

- 1- An almost flat pattern is the common character, except for those of G. Hefhuf (Bahariya Oasis), which show a very peculiar pattern with decisive enrichment of the middle REE and an unusually high total REE budget (up to about 840 ppm).
- 2- The phosphorites of SE Idfu and Abu Tartur are about two to three times higher than the mean values.
- 3- The low grade phosphatic rocks of G. Safariate (SW Sinai) and G. Abu Had are below the average limits.

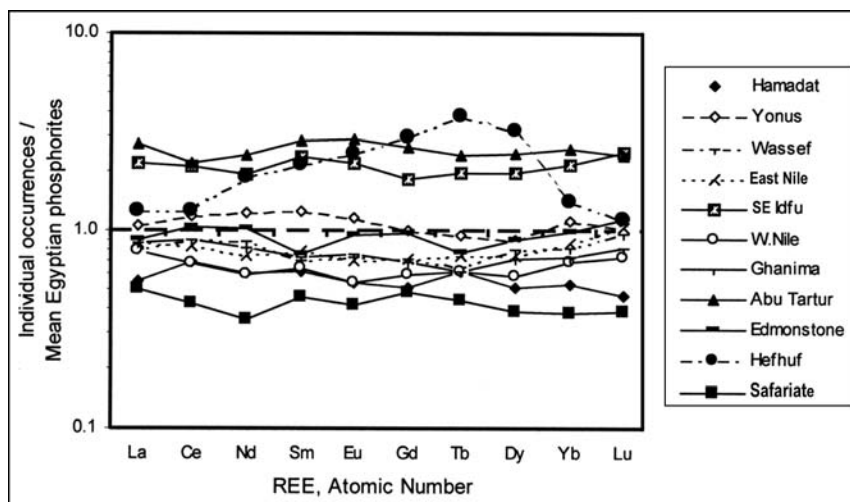


Fig. 4: REE patterns of the studied occurrences, normalized to average Egyptian phosphorites (106 samples)

The above arguments propose that an exceptionally high REE budget can be perceived in three occurrences, namely; Abu Tartur (Kharga-Dakhla Oases), Gebel Hefhuf (Bahariya Oasis), and southeast Idfu (Nile Valley). The highest content that exceeds 800 ppm is determined for those of the last area (Table 6). As far as the writers are aware, the REE abnormality in the Egyptian phosphorites, other than those of Abu Tartur, has never been documented before. Both Abu Tartur and SE Idfu occurrences are also markedly enriched in the pseudolanthanides Y and Sc.

In spite of the moderate grade of the phosphatic rocks of SE Idfu (about 16%  $P_2O_5$ , in average), their REE budget (822 ppm) is higher than those of Abu Tartur 622 ppm), which are of higher grade (about 26%  $P_2O_5$ , in average). However, the normalization of the REE to the  $P_2O_5$  content reveals that the REE content of SE. Idfu is almost two-folds that of Abu Tartur.

The third occurrence that shows relative enrichment of REE is Gebel Hefhuf in the Bahariya Oasis, Western Desert. These phosphatic rocks display a peculiar increase in the relative abundance of the MREE with increasing total REE (see Fig. 4).

There is an intimate interdependence between the REE and the two pseudo-lanthanides, namely Y and Sc (Fig. 5 a & b). It can be assumed that both Y and Sc follow the same geochemical controls of the REE in the Egyptian phosphorites, in general. However, many authors consider Y and Sc as isovalents for heavy rare earth elements, namely Ho and Lu, respectively (Pan, 1997).

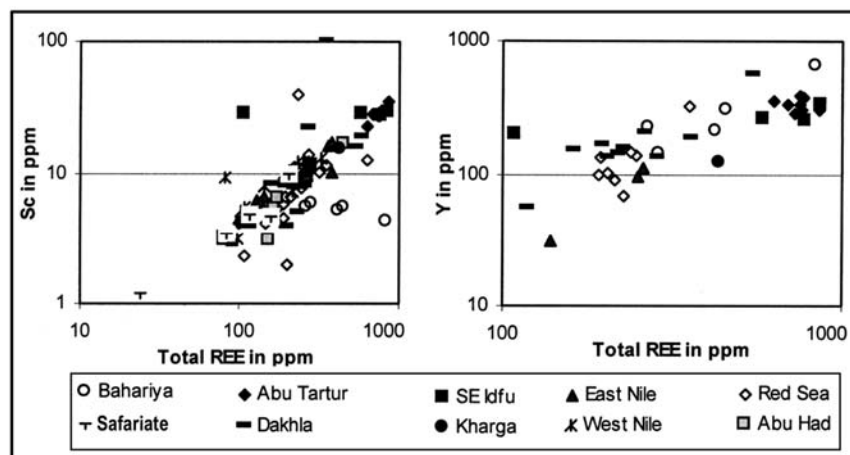


Fig. 5 a & 5b: Positive correlation between total REE and the pseudo-lanthanides.

### Chondrite-Normalized Patterns

The fossil biogenic apatite displays REE patterns which have been proposed by Reynard, et al., (1999) to reflect environmental and biological controls on past seawater composition. These patterns can be separated into two groups (1) patterns that are similar to those of open ocean and epicontinental waters, and (2) patterns that exhibit a strong enrichment in intermediate REE (bell shaped patterns). The latter can be explained by fractionation with seawater or continental fluids at low temperature, under crystal chemical control involving substitution mechanism and the context of "extensive" or "late" diagenesis. In general, the Egyptian phosphorites display pattern belonging to the first type (Fig. 6), where the LREE dominate over the HREE, and with marked Ce depletion as a signature of marine water influence (e.g., Semenov, et al. 1962, Altschuler, et al. 1960).

Nevertheless, the phosphatic rocks of Gebel Hefhuf in the Bahariya Oasis only demonstrate the second type that displays an enrichment of the MREE (bell-shape). Some authors, c.f., Kidder and Eddydelek, (1994) and Grandjeanlecuycy, et al., (1993) attributed the bell-shape REE pattern to the preferential extraction of the MREE in a manner analogous to that in which some modern algae preferentially extract MREE from water of marine composition. However, the explanation given by Reynard, et al., (1999) seems to be more convincing. Continental fluids at low temperature, preferentially enriched in the MREE, could be provided by mixing of hot fluids that dissolved REE from granitic masses (or else) under the influence of the thermal gradients prevailed during the Oligo-Miocene with meteoric water. In G. Hefhuf area, basaltic rocks appear in contact with metasomatic alteration zone with the phosphate-bearing sediments (El-Kammar, 1977).

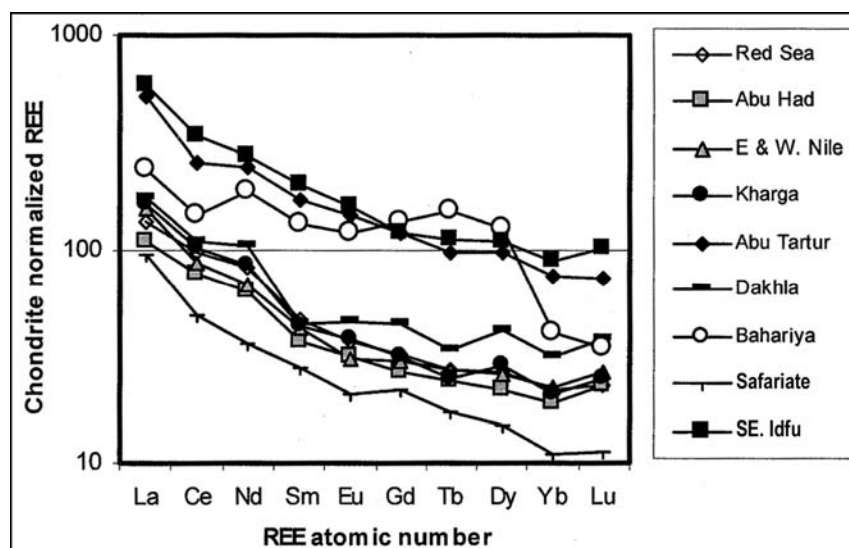


Fig. 6: Chondrite-normalized REE patterns of phosphorites from various occurrences in Egypt

### Depositional Controls of the REE

Despite of the remarkable enrichment or depletion of some occurrences in total REE, they all (except those of G. Hefhuf in the Bahariya Oasis) bear common characteristics. They have relative dominance of the LREE over the HREE and their chondrite-normalized REE patterns reflect consistent deficiency in Ce and Eu (seawater signature). The remarkable enrichment in the REE budget has long been considered as an immediate reflection to shallowing of the depositional basin (Semenov, et al. 1962). However, the phosphorites of SE Idfu and Abu Tartur that have highest REE content are petrographically fine grained and well sorted. These phosphorites were possibly deposited at the shallowest part of the Tethys, and they were deposited at the southern margin of the economic phosphate belt in Egypt.

Lately, Ismael (2000) studied the rare earth elements in Egyptian phosphorites. He concluded that the REE of Egyptian phosphorites from Upper Cretaceous-Lower Tertiary show variable degrees of relative REE enrichment, when normalized to average shale. He added that the "Black plateau"

phosphorites of Abu Tartur are substantially enriched in REE compared to those of the Red Sea and Nile Valley. This is because of their high content of Fe (pyrite), which scavenges REE from seawater and associated sediments. Indeed, the present work confirms the marked enrichment of the phosphorites of Abu Tartur in transition metals such as Fe, Co, Zn and Cr, but the explanation given by Ismael (2000) for the REE enrichment can not be accepted. Pyrite, which is mainly diagenetic as framboidal bodies, is dominant in every non-weathered low REE-phosphorites, e.g., those of Nakhiel and Bieda in the Red Sea area (El-Kammar, 1994). Moreover, the phosphatic rocks of SE Idfu are even more enriched in the REE, however, they do not contain pyrite and they are not enriched in transition metals. Moreover, the REE are not redox-dependant elements (except Ce and Eu) to be precipitated upon reduction.

### URANIUM AND THORIUM

The content of uranium varies between 20 and 177 ppm, averaging 46 ppm. The excessively low concentrations (3-20 ppm) are related to poorly phosphatic sediments rather than real phosphorites. These values (i.e., 20 – 177 ppm) match intimately with values quoted for worldwide phosphorites (Altschuler, et al., 1958; Cathcart, 1978). The uranium content varies significantly from one occurrence to another as well as in the same occurrence (Fig. 7a). Besides the remarkable heterogeneity of the uranium distribution in the Egyptian phosphorites, it is possible to draw the following observations:

1- The least uraniferous phosphorites in Egypt are those belonging to the Kharga-Dakhla area, including Abu Tartur plateau. 2- The phosphorites of Gebel Hefhuf in the Bahariya Oasis, unlike to the other phosphorites of the Western Desert, are highly uraniferous. 3- Uranium distribution is highly bifurcated in the phosphorites of the Red Sea area. Each occurrence has its own geochemical signature with respect to uranium distribution. This observation is also applicable to the phosphorites at both eastern and western banks of the Nile Valley. 4- Uranium does not show any significant coherence with the analyzed major and trace elements. Unlike uranium, thorium displays a rather systematic distribution, with highest values for phosphorites of the Western Desert and least values for those of the Nile Valley. The phosphorites of the Red Sea area have an intermediate character (Fig. 7b). Thorium is intimately correlated to the lanthanides and the pseudo-lanthanides such as Y and Sc (Fig. 8 a, b and c). It seems that these trace elements (i.e., Th, REE, Y and Sc) are coexisting and they are genetically related.

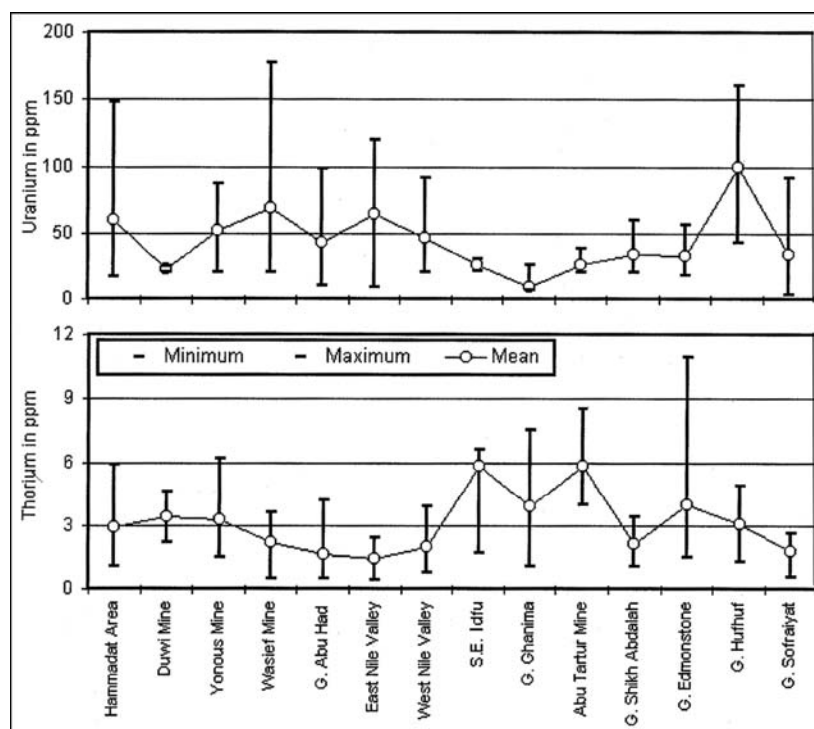


Fig. 7 (a & b): Distribution of uranium and thorium in various occurrences of phosphorites in Egypt

**Genetical-Diagenetical Controls of U and Th**

The strong heterogeneity of U in the phosphorites of Egypt, as well as everywhere else, besides the excessively low Th/U ratio suggest that the physico-chemical controls prevailed during the secondary uptake of U vary from one occurrence to another. The phosphorite, being an organic-rich medium, maintains adequate conditions for fixation of soluble uranium upon its reduction from the hexavalent to the tetravalent state. The accumulation of uranium, as such, depends mainly on its concentration in the pore water and duration of exposure to that water. The Eh of the groundwater is a controlling factor for exchange of uranium between phosphate particles and groundwater (Weinberg and Cowart, 2001).

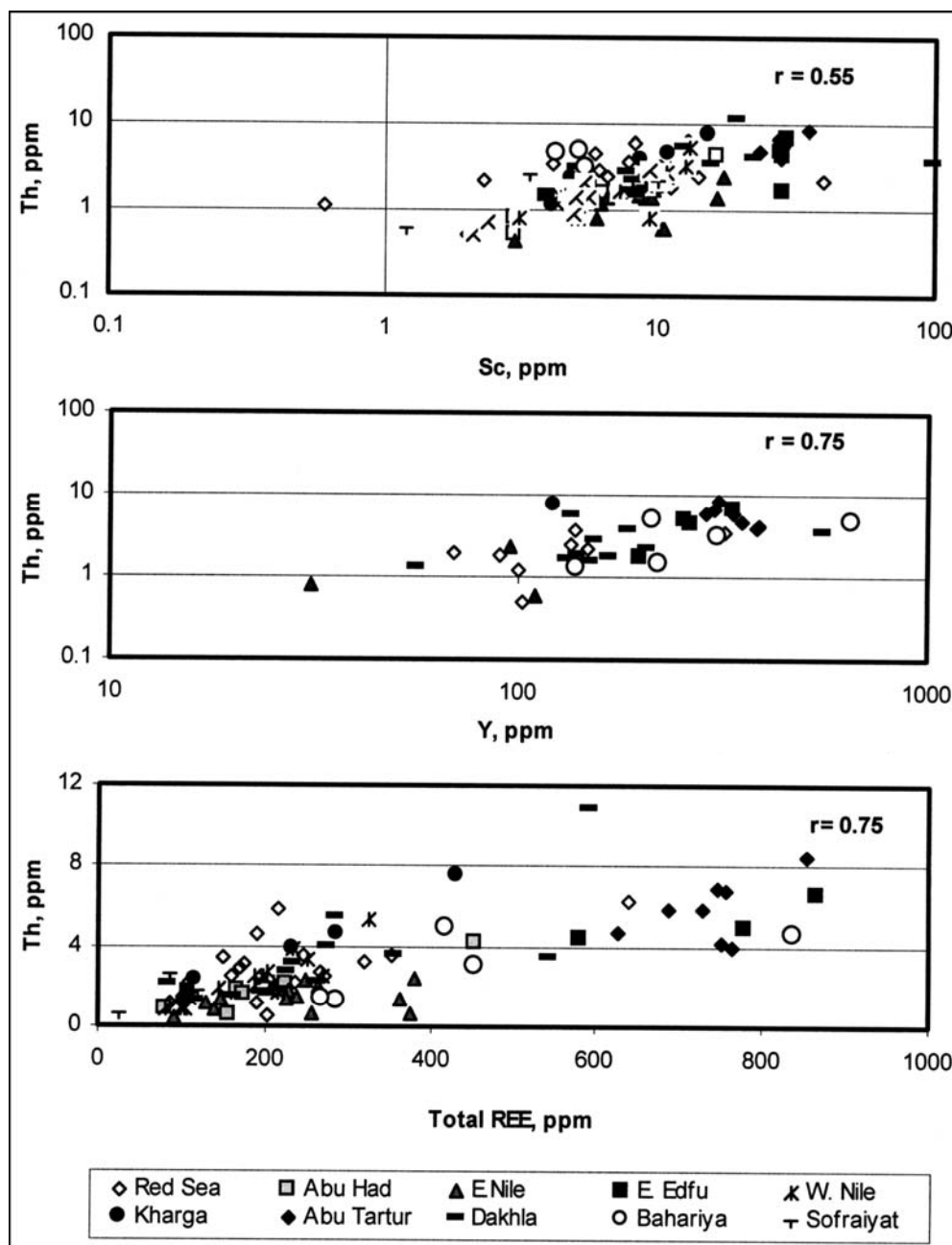


Fig. 8 (a, b & c): Relationships between thorium and REE, Y and Sc.

The diagnostically low U content in the phosphorites of the Western Desert can be interpreted to the fact that they lie high above the water table, under a very arid regime. Even during the pluvial periods (Said, 1990), the U content in the underground water must have been low owing to the absence of contact with basement rocks. The phosphorites of the Kharga-Dakhla area, including those of Abu Tartur, were considered as the shallowest depositional basins among all phosphorites of the economic belt in Egypt (Hassan and El-Kammar, 1975). Accordingly, they were receiving more accessory minerals with the terrestrial flux, and consequently higher content of the immobile elements such as Th and REE. The phosphorites of SE Idfu, being at the most southern margin of the same belt, are also shallow and consequently they are enriched in Th and REE.

The phosphate-bearing sediments of G. Hefhuf (Bahariya Oasis) can be considered as an exceptionally uraniferous with respect to those of the Western Desert. The U content (161 ppm) approaches the maximum value recorded in the present work. The authors believe that the thermal gradient that prevailed during the Oligo-Miocene time (Meneisy and Kreuzer, 1974) could be the reason of such high U. In G. Hefhuf, the basaltic rocks came in an immediate contact with the phosphate-bearing sediments. The rise of temperature of the groundwater increases the mobilization of uranium as well as most trace elements. The trace elements composition of the G. Hefhuf phosphorites refers to the fact they are very depleted in Co, Ni, Cr as well as Sr. The above argument, besides the remarkable enrichment in U, REE, Y, and Hf may all refer to mobilization of these trace elements from saturated low-Ca sources.

Under the control of the complicated structural framework (especially faults), many of the phosphorites in the Red Sea area have been in direct contact with groundwater for variable lapses of time. This may explain the high standard deviation value of U in these phosphorites.

### **Transition metals**

The used analytical technique (INAA) allows precise determination for a limited number of the transition metal such as Fe, Co, Ni and Cr. These elements are not intimately distributed in the various occurrences (Fig. 9). However, Fe and Co seem to have an intimate association, and they reach their maximum level of concentration in Kharga (Ghanima) and Abu Tartur phosphorites. El-Kammar and Basta (1983) pointed to the same observation for the phosphorites of Abu Tartur, where iron accumulates diagenetically under control of anaerobic bacteria in the form of framboidal pyrite. On weathering, pyrite is pseudomorphosed, where iron was not leached out but rather transformed into oxy-hydroxides.

The present study confirms the foregoing statement, where Kharga and Abu Tartur are the most enriched in Fe and Co, while those of the Red Sea area are the most depleted (Fig. 10). Contrary to Fe and Co, other transition metals such as Cr and Zn show decisive enrichment in the phosphorites of the Red Sea. Many authors, such as El Kammar, (1974), Germann, et al. (1984), Tamish, (1988) and Saad El-Din, (1990) quoted erratically high and strongly bifurcated data on some transition metals for the phosphorites of the Quseir-Safaga area. Although they quoted concentrations as high as a few thousands of ppm of Cr, Zn and V, they did not suggest a competent explanation. However, El-Kammar, et al., (1990) published content of higher than 0.8% of V, and almost similarly high concentrations of other transition metals such as Zn and Cu, in the black shale that strikingly overlies the economic phosphorites in Quseir area. They designate such black shale horizon as a "vanadiferous zone" enriched in all transition metals under control of microbial activity. Indeed, these authors did not provide concrete evidences on such microbial influence. However, terrestrial influx derived by erosion of sulfides precursor in the basement hinterland to the depositional basins seems to be a possibility.

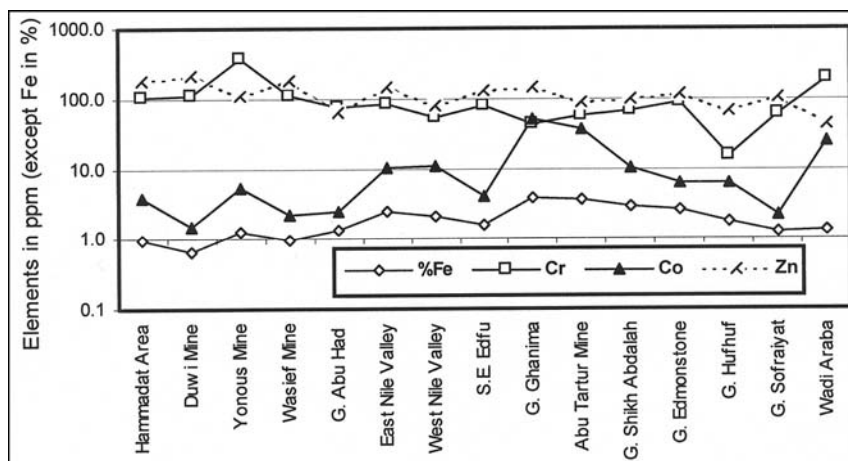


Fig. 9: Average abundance of the analyzed transition metals in the Egyptian phosphorites.

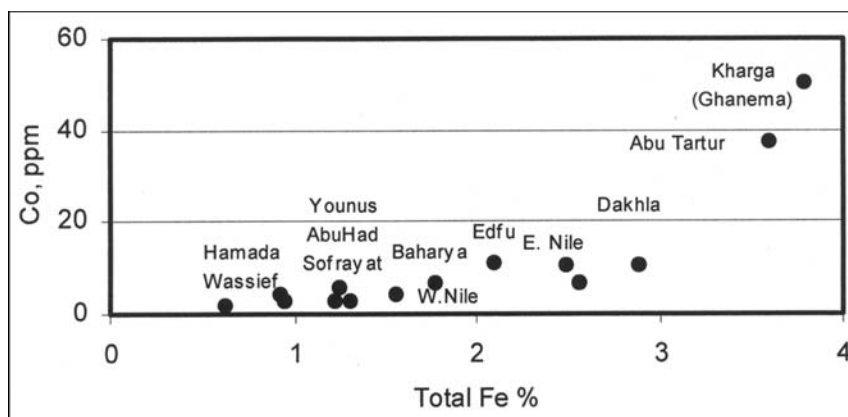


Fig. 10: The mutual distribution of Fe and Co in the Egyptian phosphorites.

### CONCLUSIONS

The present work is based on original analytical data of 22 trace elements in 106 phosphorite samples representing the various occurrences in Egypt. The available data indicate that the phosphorites of SE. Idfu are even more enriched in the REE than those of Abu Tartur. The most southern margin of the Egyptian phosphorite belt, being the shallowest depositional environment and receiving maximum terrigenous influx, is enriched in the REE and other immobile elements. The phosphate bearing sediments of G. Hefhuf (Bahariya Oasis) are markedly enriched in the MREE due to diagenetic uptake from water that washed granitic masses under the influence of the thermal gradients prevailed during the Oligo-Miocene time. The REE budget in the phosphorites of the three occurrences, namely, Abu Tartur, SE. Idfu and G. Hefhuf can be considered as potentially significant. The Oligo-Miocene thermal activity seems to be responsible for the high (161 ppm) uranium content in the phosphates of G. Hefhuf.

The phosphorites of the Kharga-Dakhla area, including those of Abu Tartur, are markedly depleted in uranium but highest in thorium. In the Quseir-Safaga area, uranium has a high standard deviation, where the content varies much from one place to another, depending on the time lapse of contact between phosphate and pore water, as well as the content of soluble uranium in that water. Phosphorites, being organic-rich medium, accumulate uranium via its reduction to the insoluble tetravalent state. The weathering of phosphorites leads to remobilization of uranium. The abundance of the transition metals in phosphorites seems to be controlled by the terrigenous influx to the depositional basins.

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