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A forward look into rare earth supply and demand: a role for sedimentary phosphate deposits?

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Abstract

Rare earth elements, key to many high-technology applications, are regularly making headlines, even in general public newspapers. Will the word run short of rare earth elements and of the many applications that rest on their use?

In support to French and European Union policy making, as well as in support to industrial clients, BRGM is monitoring rare earth markets from the supply and the demand sides, as well as for technological shifts that drive them. Not every rare earth element is effectively rare and there are well over 400 ongoing rare earth exploration projects worldwide. Nevertheless, some rare earth elements such as dysprosium, europium and terbium are rare, in high and fast growing demand; as they either are indispensable to the production of Fe-B-Nd (Dy) permanent magnets, the highest performance magnetic material currently being available at industrial scale, or to the production of phosphors essential to the production of fluorescent compact, energy saving, light bulbs and video displays. At the current 10% compound annual growth rate of the demand for these elements, the question arises of their the future availability. Among the many rare-earth bearing minerals apatite is of particular interest as a potential source of rare earth elements, as it is a widespread mineral, forming huge deposits such as the sedimentary and magmatic phosphate deposits. An overview of the potential of sedimentary phosphate deposits as an important source for future rare earth production is presented and discussed.

In addition to knowledge about the distribution and concentration of individual rare earth elements in sedimentary phosphate deposits, it is also necessary to understand the partitioning of the individual elements between phosphogypsum and phosphoric acid in the fertilizer production process, as well as available technologies to recover and separate individual rare earth elements from these materials. This could pave the way to the generation of extra added-value for phosphate producers, and to the broadening of the international production base of rare earth elements in high demand by the global economy.

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Keywords: rare earth; phosphate; phosphoric acid; phosphogypsum; economy

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1. The many applications of rare earth elements

According the International Union for Pure and Applied Chemistry (IUPAC), rare earth elements (REE) are a group of 17 elements with closely related physical and chemical properties, the 15 lanthanides plus scandium and yttrium. As scandium occurs in different ore deposits than the other REE, only the 16 other elements are further considered and discussed here. Those 16 elements are commonly divided into two groups [1]:

- the light rare earth elements (LREE) : lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm) and samarium (Sm);

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- the heavy rare earth elements (HREE) : (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu) and yttrium (Y).

Promethium only exists as an unstable, radioactive, isotope of which the total naturally available quantity available in the Earth's crust is estimated to be 21 grams [2]. Therefore it has no economic significance.

Although cerium was the first rare earth element identified, in 1803, rare earth elements in pure elemental form, and as derived compounds meeting strict user specifications, became only available in larger quantities during the second part of the XXth century, thanks to the independent work of Austrian, French and American chemists. In Austria, Carl Auer von Welsbach separated neodymium and praseodymium in 1885, by fractional crystallisation, noticing the strong luminescence of some rare earth elements, he developed the cerium/ thorium oxides soaked “Auer” gas mantles that revolutionized Europe’s urban lighting of the first part of the XXth century. In 1903, he invented the modern lighting flint, still widely used in today’s cigarette lighters, a ductile cerium-iron alloy.

In France, Georges Urbain also worked on the separation of individual rare earth elements by means of fractional crystallization, which led him to the discovery of the last rare earth element to be discovered, lutetium (1907). In 1919, he was among the founders of the “Société des Terres Rares”, an enterprise devoted to rare earths and radioactive materials, producing gas mantles and lighting flints in the rare earth processing plant at Serquigny, in Normandy. In 1947, the rare earth part of the plant was transferred to a new plant located in La Rochelle, where it is now operated by Solvay-Rhodia, as one of the world largest rare earth separation and purification plants located outside China (10,000 tons per year total rare earth production capacity, the largest one now being the Lynas advanced materials plant located near Gebeng, in Malaysia, with a 11.000 t/ year capacity, to be expanded to 22,000 t/ year in 2013/14). In 2012, the La Rochelle plant also became active in recycling rare earth from phosphors in lighting devices (compact fluorescent lamps and neon tubes) and from end-of-life nickel-metal hydride batteries.

In the US, Frank Spedding and his team, working for the Manhattan project at the U.S. AMES Laboratory, located in Iowa, made an essential breakthrough in 1956, in developing the ion-exchange based process to separate individual rare earth, a process much more efficient to separate individual rare earth elements than fractioned crystallization.

The parallel small-scale mining of the rare earth minerals (bastnaesite) bearing Mountain Pass carbonatite mining started in the USA, at Mountain Pass (California) in 1952. This activity was considerably upscaled in the 60’s to meet the demand for europium used for the production of the phosphors needed by the rapidly growing colour TV market. It is only in 1966 that the world REE production exceeded the 10,000 metric tons total rare earth oxides (TREO) threshold[†], to be compared with today’s production of 110,000 tons TREO [3].

In China, rare-earth production started in 1957 [4] at the Bayan Obo iron (rare earth) mine, in Inner Mongolia and, at an unspecified date in the southern China Jiang Xi and Guandong provinces. In 1985, China surpassed the US as the world largest REE producer, although at that time the total REE production, as expressed in metric tonnes of total rare earth oxides (TREO), was only 43,500 t TREO, to be compared with 111,000 t in 2011 [3].

The demand for REE is driven by technological innovations. Among the main ones, in terms of impact on the TREO demand are:

- the discovery of the Nd_2-Fe_{14}-B alloy, separately patented in 1983 by General Motors, Sumitomo and the Chinese Academy of Sciences, the most powerful magnetic material so far manufactured at industrial scale, allowing the production of high performance, miniaturized, permanent magnets. For a similar magnetic flux density these magnets have a volume of only about 1.5% of their Al-Ni-Co ancestors of the 40’s; leading the way to product miniaturization in many areas from automobile, aircraft, mobile computing and telephony, defence, satellites, wind turbines and many other areas;
- the use of rare earth, essentially Eu, Tb, Ce, La, Lu, Y in phosphors [5];
- the use of rare earth for catalysis, either for the production of light fuels (essentially La and Ce), such as car and aircraft fuel, or for the cleaning of the automotive exhaust in automobile catalytic converters (essentially Ce).

[†] Data on global rare earth production, use and trade needs to be considered with caution and are indicative in nature, as there are no fully reliable statistics available regarding Chinese production and trade. According to various authors there may from 10 to 30% illegal exports on top of the official exports indicated by the Chinese authorities. In addition, there is limited or no data available on resources and reserves owned by private equity financed projects, or projects financed out of a company’s cash reserves. Only companies listed on main Western stock markets and financing part or all of their exploration projects through the floating of shares to the public are obliged to report their resources and reserves in compliance with specific national reporting codes, such as the JORC (Australia) or NI 43-101 (Canada).

Goonan (2011) [5] provides a detailed overview of the manifold uses of REE. Table 1, derived from a presentation by Dudley Kingsnorth to the German (public) Raw Materials Agency (Deutsche Rohstoffagentur) [6] provides data on the quantities of TREO that were required in 2011 by the main REE applications, as well as a tentative evaluation of the 2020 TREO demand for these uses.

Table 1 - 2011 TREO consumption by the main market segments and scenarios for 200 consumption, based on current Compound Average GGrowth Rates - Derived from D. Kingsnorth [7]

			2011 Production	2020 demand scenario
			Metric tons	Of rare earth
Permanent Magnets	Nd, Dy, Pr	Windmills, hard-disk drives, automobile, defense and many more	21 000	42 000 – 69 900
NiMh batteries	La, Ce	Batteries, especially in hybrid vehicles	21 000	30 000 – 50300
Phophoros	Eu, Tb, Y, Ce, Dy, Gd, La, Pr	Videoscreens (TV, computers) ; compact fluorescent lightbulbs, LEDs, banknotes	8 000	12 000 – 20 000
Catalysts for the oil & gas industry	La, Ce, Pr, Nd	Cracking of larger hydrocarbon molecules into light products for the production of fuels	20 000	22 300 – 37 100
Polishing powder	Ce, La, Nd	Polishing powder for automobile winshiels	14 000	16 300 – 27 100
Catalysts for the automotive industry	Ce, La, Nd	Reduction of particulates, SOx and Nox in exhaust gas	7 000	10 100 – 16 800
Glass industry	Ce, La, Nd, Er, Pr, Eu	UV filtering (Ce in winshields), La for optical glass (cameras), other for colouring	8 000	8 900 – 14 900

2. A look to rare earths economics

Before discussing the issues related to the future supply of HREE, it is necessary to understand the distribution of REE in their deposits, underlining the fact that the individual REE elements do not occur as specific deposits but are always mixed together in the same ore mineral(s), this making it necessary to use complex separation technologies to recover individual REE and further process them into the products required for specific end-uses.

Further to the obligations enforced by the main Western stock markets supervisory authorities, where junior exploration companies are listed (Johannesburg, London, Toronto, Vancouver …), financing their projects by the emission of shares, these have to report their exploration results according to national reporting codes such as JORC (Australia), NI 43-101 (Canada), SAMREC (South-Africa) or PERC (Europe). Further to this obligation quality data on resources and reserves of the deposits owned by such companies are available since about a decade. For REE, the Technology Metals Research blog (http://www.techmetalsresearch.com) regularly compiles and updates the compliant resources and the reserves reported by the companies operating in REE exploration and development. On December 21st, 2012 there were resources, and in some cases reserves, data reported for 49 REE projects in 14 different countries, operated by 43 companies.

This data does not cover China, for which data related to mineral resources is generally scarce and of questionable reliability. Nor does it include data related to projects that are not financed via the emission of shares on the stock markets, for instance through private equity or from a company's cash reserves. The 49 reported projects are likely to represent a major share of the new Western World REE potential production projects, but there could well be future announcements of production from other sources, which do not report their resources and reserves such as the Kringlerne deposit in in Groenland (Tanbreez) or the Mabounié Nb-REE deposit in Gabon (ERAMET), or from the recovery of REE from by-product apatite from LKAB's iron ore mines in northern Sweden.

Table 2 provides an estimate of the new or accrued REE production anticipated up to 2016, based on published company reports, located outside of China, that are either already producing REE (Mountain Pass, USA and Mount Weld, Australia), or for which the expected production start year has been announced, together with resources and, for the most advanced projects, reserves data, together with the average content of the ore in individual REE elements.

Table 2 - New or accrued rare earth oxide mine production over the 2010 - 2016 period, in metric tons - Compiled from company reports

Production start year	Ore deposit name	Owner	Country where the deposit is located	Production start year	Total yearly production (metric tons TREO)	Total resources in metric tonnes ore	Grade in% REO	Capital expenditure in millions US $
2 012	Mountain Pass Phase I	MolyCorp	USA	2 012	7 000	16 692 000	6,57%	645
2 013	Mountain Pass Phase I	MolyCorp	USA	2 012	13 000			
	Mount Weld Central Lanthanide Deposit (CLD) Phase I	Lynas	Australia	2 013	17 333	14 949 000	9,70%	673
2 014	Mountain Pass Phase I	MolyCorp	USA	2 012	19 050			
	Mount Weld CLD Phase I and II	Lynas	Australia	2 013	22 000			
	Dubbo Zirconia Project Phase I	Alkane Resources	Australia	2 014	1 840	73 200 000	0,89%	927
	Nolans Bore	Arafura Resources	Australia	2 014	20 000	47 161 720	2,62%	1 983
	Wigu Hill	Montero Mining and Exploration Ltd.	Tanzania	2 014	5 000	3 300 000	2,59%	not determined
	Zandkopsdrift	Frontier Rare Earths Ltd. & Korea Resources Corp.	South Africa	2 014	20 000	42 480 000	2,23%	910
2 015	Mountain Pass Phase I and II	MolyCorp	USA	2 012	40 000			
	Mount Weld CLD Phase I and II	Lynas	Australia	2 013	22 000			
	Dubbo Zirconia Project Phase I	Alkane Resources	Australia	2 014	1 840			
	Nolans Bore	Arafura Resources	Australia	2 014	20 000			
	Wigu Hill	Montero Mining and Exploration Ltd.	Tanzania	2 014	5 000			
	Zandkopsdrift	Frontier Rare Earths Ltd. & Korea Resources Corp.	South Africa	2 014	20 000			
	Bear Lodge	Rare Element Resources Ltd	USA	2 015		28 020 000	3,75%	334
2 016	Bokan Dotson Ridge	Ucore Rare Metals Inc.	USA	2016 ?	24 327	3 669 000	0,75%	221
	Kvanefjeld	Greenland Minerals and Energy Ltd.	Greenland	2 016	40 800	619 000 000	1,05%	2 295
	Nechalacho Upper Zone	Avalon Rare Metals	Canada	2 016	10 000	177 730 000	1,14%	807

Fig. 1 to 4 provide an estimate of the production of Ce, Nd, Dy and Eu oxides from 2010 to 2016, as well as an estimate of the 2016 demand range for these elements, as published by D. Kingsnorth in a 2012 presentation [6]. The supply estimate considers that China's production will remain at the 2010 level, as the country's industry is undergoing an in depth restructuring that includes curtailing environmentally problematic operations. China's supremacy in the global rare earth industry has so far been partly based on poor environmental performance, including radioactive pollu Journal of Environmental Radioactivity 87 (2006) 52e61tion [7, 8].

The future trends of the global REE industry are underlain by many unknowns and the figures in table 2 as well as figs. 1 to 4 need to be considered as merely indicative due, inter alia, to the following important unknowns.

- **The technology driven demand for each individual REE**. Demand is driven by the technologies requiring the specific functionalities made possible by each REE unique properties. There is no such thing as a single rare earth market. How much of which specific REE will be needed in the future is a difficult to reply question, as demand is driven by rapidly evolving technologies that in turn are influenced by the REE prices and public policies, such as the quest for renewable energy sources. An example of the technologies of great importance to the REE market is the rapidly growing production of rare-earth permanent magnets (REPM). These are made of neodymium-iron-boron sintered or bonded magnetic material, to which dysprosium is added to enhance magnetic performance, where magnets are exposed to higher operating temperatures, up to 220° C (the higher the dysprosium content the higher the maximal use temperature of the REPM). These high-performance, extremely compact magnets, are found in a wide-range of applications [9], such as electric motors (25.5% of the REPM used in 2010), hard disk drives (13,1%) or direct-drive wind-turbines (2,1%). The compound annual growth rate for the total REPM market up to 2016 is estimated to be a whopping 9% for Nd and 12,5% for Dy.

One important growth sector is the use of REPM for the production of direct drive, large (frequently 3 MW and more capacity) wind turbines used in off-shore wind farms. Data published by S. Constantinides [9] shows that REPM based direct drive wind turbines need about 600 kg of such permanent magnets per MW power generation capacity. Their magnets contain 27.5% Nd and 4.1% Dy, the latter being needed as an additive in order to safe keep the magnet's properties at higher operating temperatures. The same author [10] anticipates that from 2010 to 2020 the Nd and Dy demand from the wind energy industry will respectively grow from 895 metric tons Nd and 133 tons Dy to 1,859 and 277 tons, considering that better design will allow to reduce the need for magnetic material to 400 kg per MW and, accordingly, the need for dysprosium.

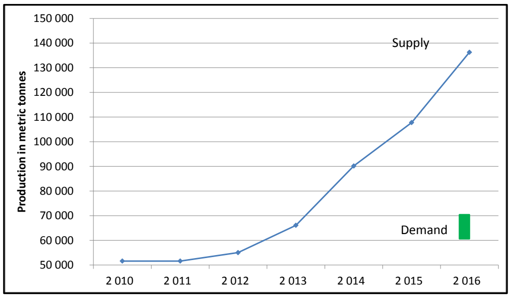

Figure 1 - Ce oxide production scenario 2010-2016 and 2016 demand estimate

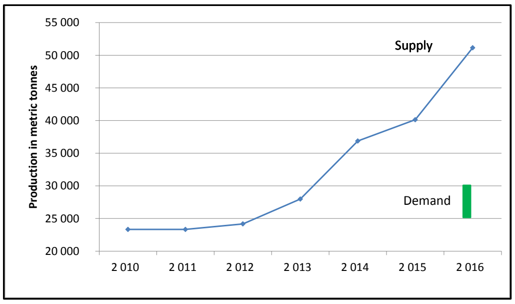

Figure 2 - Nd oxide production scenario 2010-2016 and 2016 demand estimate

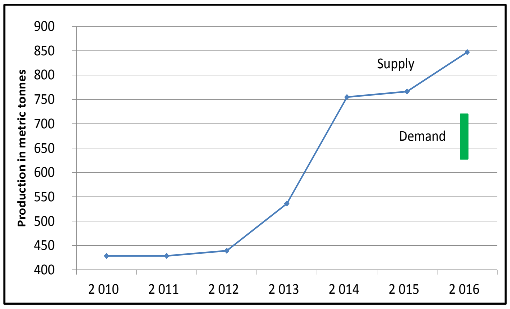

Figure 3 – Eu oxide production scenario 2010-2016 and 2016 demand estimate

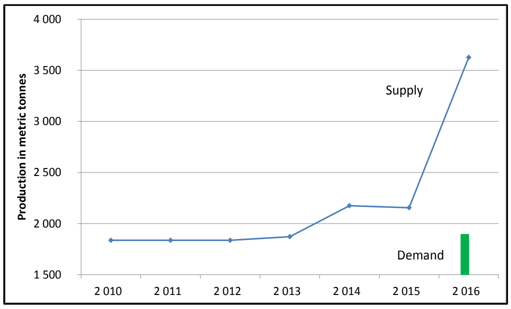

Figure 4 - Dy oxide production scenario 2010-2016 and 2016 demand estimate

The coupling of REE production. One of the particularities of REE markets is that all REE elements occur jointly in each deposit. This means that, in average, each time 1 ton of a much wanted heavy REE such as dysprosium, europium or terbium will be produced, a much larger quantity of cerium and lanthanum will become available too. For instance, in average, the production of 1 ton of dysprosium will result in the coupled production of about 20 tons of lanthanum and 35 tons of cerium. This may result in a situation where undersupply of heavy REE could happen simultaneously with oversupply, and resulting low prices, of light REE.

The development of substitutes to the use of REE in some applications. Substitutes may develop further to the ongoing research efforts in several industrialised countries, but theirpossible impacts remain unknown. Rare-earth free high-performance magnetic materials such as amorphous iron or iron nitride are known. In 2012, Hitachi, for instance, presented a 11 kW prototype electric motor using amorphous iron [11] magnetic material instead of REPM. Some day, supraconducting materials may revolutionize the way wind turbines are built, phasing out the need for REPMs; solid state technology, such as flash drives, may challenge the conventional REPM using hard-disk drive technology; the replacement of compact fluorescent energy saving lamps, requiring cerium, europium, lanthanum, terbium and yttrium in the 1.1 to 1.5 g phosphor needed to produce light bulbs suiting consumer tastes [12] by LED lighting requiring much less REE may significantly reduce the need for the very rare elements europium and terbium.

Doing more with less: the REE related issues fostered a considerable rise in the awareness of companies of their exposure to risk factors related to the technology metals, including REE, they need to manufacture their products. This, and high metal prices, triggered research that is likely to result in new approaches in designing high-performance materials, reducing the intensity of use of the most critical raw materials. This is part of the remit of many research programmes at the international level.

The real and future production of REE in China. Its exact current production is unknown, but on the basis of the USGS Commodity Summaries (2012) edition, it represented 97% of the global, statistically recorded REE production, in 2011. In addition, there is unrecorded production that is illegally exported. The Chinese State Council, in its white paper titled 'Situation and Policies of China's Rare Earth Industry' [8] estimates that, in 2011, 20% of the rare earth produced in the country were illegally exported. The monopoly of China over REE mining will be growingly challenged by production in other countries, which already started with the re-launch of REE production at the Mountain Pass mine in the USA (2012) and the start of the production, expected early 2013, of individual REE by Lynas, from its Australian Mount Weld Mine and its Malaysian REE separation plant. If the Chinese government effectively enforces higher environmental standards in its REE industry this may reduce its future production capacity, especially for the much needed heavy REE extracted by environmentally destructive in-situ leaching of very low-grade ionic clay deposits in Southern China..

The future production outside China. This depends:

- **On the award of the administrative permits required to start the mining and processing operations on one hand and the REE separation/ purification plant on the other hand**. Due to existence of radioactive by-products, at concentration levels that vary from about 10 to over 10,000 ppm for ThO_2 [13], public concern related to the handling and the storage of radioactive waste from certain REE mines and processing plants may considerably delay permitting procedures and harm the project's feasibility;
- **On the readiness of investors to invest in the development of all the new mines**. While the rare earth market is a technology driven, complex, niche market, it will take at least 9 billion US $ in capital investments up to 2016 inclusive to put into production all the projects listed in table 2. This is to be compared with the value of the 2010 rare earth production. This value is about 8 billion US $, at spot market rare earth prices FOB China listed by Metal Pages on 29/01/2013. Rare earth price could further decrease as the figures 1 to 4 indicate that there would be oversupply if all the projects listed in table 2 would really start production at the announced dates. It appears likely that investors will be wary in their funding allocations, possibly favouring investment in deposits located in jurisdictions with the lowest associated risks and limiting their investment to the deposits with a high heavy REE/ total REE ratio. Seen from the demand side, the production of at least some of the deposits listed in table 2 is essential to meet the fast growing demand for most REE, as can be seen in the scenarios depicted in figs. 1 to 4. China may well be a key investor in the development of REE production outside of its borders, as one of its strategic priorities is to continue developing high value-added industries needing REE is sectors as diverse as defence, electronics, energy production and storage or lighting.

It will also depend on the capacity of the well over 400 junior companies active worldwide to find new deposits attractive to investors and to secure the continued financing of their activities. This is doubtful in quite a number of cases.

This means that the future REE production shown in table 2 needs to be considered with caution. The very narrow REE market is likely to yield many future surprises.

3. Sedimentary phosphate deposits as a source of rare earth

While much of the international exploration effort goes to conventional deposits of REE relateds to carbonatites and hyperalcaline intrusives, there are relatively few mentions about sedimentary phosphate deposits as one potentially important future source of REE supply to the world economy. While it is widely known that apatite, the phosphate bearing mineral, may also contain REE, V, U, F, Ag, Cd, Cr, Mo, As, Se, Sr, Te, Zn and other elements, detailed analysis of phosphate ore from sedimentary deposits appear limited to a few deposits, and the representativeness of these analyses is not well established.

Table 3 provides detailed REE analysis from several sedimentary phosphate deposits around the world. In addition to these, a personal communication indicates that ~~a~~ at least on one sample TREO content of a Moroccan sedimentary phosphate deposit is 900 ppm and one sample from the Boucraa deposit has 415 ppm TREO, values that are well in line with these detailed on table 3. TREO contents exceeding 1,000 ppm (0.1 %) are reported from the Abu Tartur deposit in Egypt as well as from British Columbia, Canada. The example from Israel documents the existence of significantly REE-enriched layers of mechanically reworked granular phosphates as compared to pristine laminitic facies. This example shows that there is much scope for detailed paleogeographic studies to assess the existence of REE enriched zones in known sedimentary phosphate deposits. This will require comprehensive geostatistical modeling of these deposits.

Table 3 - Detailed REE composition of selected rare earth elements from sedimentary phosphate deposits

		All grades are expressed in %															
Phosphate deposit	**Source**	**La2O3**	**CeO2**	**Pr6O11**	**Nd2O3**	**Sm2O3**	**Eu2O3**	**Gd2O3**	**Tb4O7**	**Dy2O3**	**Ho2O3**	**Er2O3**	**Tm2O3**	**Yb2O3**	**Lu2O3**	**Y2O3**	**Total (TREO)**
Abu Tartur, Egypt	Aly M. M. et al. (1999) [14]	0,020	0,040	N.D.	0,021	0,005	0,001	0,005	0,006	0,005	N.D.	0,001	N.D.	0,002	0,000	0,036	0,141
Fernie formation, British Columbia, Canada	Simandl J. et al. (2011) [15]	0,020	0,014	0,004	0,017	0,003	0,001	0,004	0,001	0,004	0,001	0,003	0,000	0,003	0,000	0,049	0,125
Whistler member, Sulfur mountain formation, British Columbia, Canada	Simandl J. et al. (2011) [16]	0,019	0,011	0,004	0,015	0,003	0,001	0,004	0,001	0,003	0,001	0,002	0,000	0,001	0,000	0,040	0,105
Mishash phosphorites - Negev Desert, Israel - Pristine phosphorites	Soudry D. et al. (2002) [17]	0,001	0,001	0,000	0,001	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,006
Mishash phosphorites - Negev Desert, Israel - Recycled granular phosphorites	Soudry D. et al. (2002) [17]	0,005	0,003	0,001	0,003	0,001	0,000	0,001	0,000	0,001	0,000	0,001	0,000	0,001	0,000	0,014	0,030

The value of the REE they contain could yield a significant economic bonus. Using the REE spot prices available on 29/01/2013 from Metal Pages, the value of the REE content of the Abu Tartur sample would be about 150 $/ ton of phosphate ore, assuming that 70% of the amount shown on table 3 could be recovered. This is only slightly less than the price of 185$/ metric ton for Moroccan Bou Craa 70% BPL phosphate rock, free alongside ship at Casablanca, quoted by Index Mundi for December 2012.

The additional cost of extracting REE from the phosphate rock could be relatively low compared to the costs incurring from mining, and then separating REE from conventional bastnaesite or monazite bearing deposits, as the REE would be recoverable during the production of phosphoric acid or from existing waste phosphoric acid and phosphogypsum, with limited additional investment and operating costs. It would be much easier for a mining company producing REE as a by-product to enter the REE niche market, than for a new mining company producing only REE to succeed (see Wellmer [18]).

The processing technology needed to recover the REE from both the phosphoric acid and the phosphogypsum appears to be existing, judging from the literature available, moreover it appears as economically affordable, for instance [14], [17], [19], [20], [21], [22]. KEMworks, a US engineering company specialized in phosphate ore processing, indicates on its website (http://www.kemworks.com/process-technology.htm) that 'for K09 Moroccan phosphate the value of the REE content is over $50 / t of P2O5 treated and the recovery cost is about $10 (prices at November 2011)' This would be quite below the 40 $/ kg. TREO production cost reported by Lynas for its Central Lanthanide Deposit (CLD) at Mount Weld, Australia mining and for its Malaysian separation plant operating costs.The CLD is considered as one of the best deposits outside China, so far.

Further research is needed to better understand the partitioning of individual REE between phosphoric acid and residual phosphogypsum resulting from the sulfuric acid process route used in the phosphate industry, and to characterize the mineralogical bearers of REE elements in the phosphogypsum residue. According to Bourgier [21] heavy REE migrate to the phosphoric acid, while 60 to 80% of the total REE content of phosphate rock, essentially the light REE, would go to the phosphogypsum.

Pereira et al. [22] highlight that the sulfuric acid route has many inconveniences, inter alia for the effective recovery of REE. They recommend the development of the hydrochloric treatment of phosphate rock coupled with liquid-liquid extraction of the phosphoric acid, to both get rid of the production of phosphogypsum waste and to ensure the easy recovery of REE.

In March 2011, the OCP and Wallonia Regional Investment Company (Belgium) co-owned Prayon Technologies company, a global phosphate chemistry and technology leader with chemical plants in Belgium, Canada, France, India, Morocco and the US, announced talks and technical cooperation with Hydromet, a Belgian company in which Payon indirectlly owns shares, and cooperates on REE extraction from phosphoric acid produced by Prayon. On 30/10/2012 PhosAgro, a global Russian leader in phosphate-based fertilisers and the production of phosphate rock, and Prayon signed an agreement on the transfer to PhosAgro of Prayon's technology for extracting rare earth elements from phophogypsum.

In conclusion, there are many signs that OCP not only has amazing phosphate rock resources, making Morocco the world second largest (after China) sedimentary phosphate and fertilizer producer with a 28,000,000 tons/year produced rock phosphate ore, but it also shows that OCP has access to innovative processing and hydrometallurgical technologies that could help it to become one of the world class producers of many rare metals, that nowadays are by-products of the phosphate ore, with associated environmental problems. These rare metals are needed for an ever growing range of innovative technologies, for instance in photovoltaics, energy storage green cars, defence (for instance the production of drones), aircraft industries, agriculture and health. This could help the phosphate industry to turn environmental problems in sustainable development supportive, profitable, solutions.

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