The phosphate deposits of Israel – Overview

The phosphate deposits of Israel belong to the Late Cretaceous-Early Eocene (90-45 m.y. B.P.) Mediterranean phosphate belt which extends from Turkey to Morocco. A number of exploitable wide-scale phosphate deposits are located along this belt, including the deposits of Egypt, Middle East (Israel, Jordan, Syria, Iraq), Saudi Arabia, and North Africa (Tunisia, Algeria, and Morocco). To this belt also belong the Colombian and the Venezuelian phosphate deposits (south America) which formed in the same paleogeographic system. These phosphorites all deposited in the southern edges of the Tethys Ocean (the ancestor of the present Mediterranean Sea) along the north continental shelves of the Arabo-African craton. The paleolatitude of this entire area (8 - 15º N), together with the creation of a circumglobal (E-W) equatorial oceanic circulation, and a northward Eckman offshore transport of surface waters arising from easterly winds, resulted in upwelling of nutrient-rich waters onto the southern Tethys shelves. The high productivity regime which established in this area at different Cretaceous-Eocene tome intervals led to the deposition of an organic and P-rich sequence formed by carbonates, phosphorites and biosiliceous sediments.

In Israel, the deposition of this P-rich sequence occurred during the Upper Campanian (approximately 80 to 72 m.y. B.P) and mostly in the Negev area. It is known as the Mishash Formation. An important factor which also contributed to the development of phosphorites in the Negev is the Late Turonian tectonics (~ 90 m.y. B.P) which shaped this area into a series of gentle highs (the present Negev "anticlines') and semi-confined lows (the present Negev "synclines"). This special configuration caused restricted marine circulation and contributed to trapping of abundant organic-rich detritus in the Negev basins. Degradation of the organic detritus together with important activity of microbial mats on the seafloor and suitable redox conditions led to formation of discrete apatite (phosphate) bodies in bottom sediments. These, subsequently, were mechanically concentrated by bioturbation and bottom currents and redeposited as granular phosphorite strata.

The economic phosphate section of the Negev (mostly a few meters to 10 m.-thick) is generally composed of alternating P-rich granular phosphorite beds and "sterile" (P-poor) interlayers (mostly carbonates). Its phosphate fraction mainly consists of sub-millimetric ovoid grains (peloids), some amounts of bone fragments, phosphatized foraminiferid shells, and many rounded fragments of phosphate-coated remnants of mat-forming microorganisms (fungi, bacteria and cyanobacteria). As in other sedimentary phosphorites elsewhere, the phosphate mineral of the Negev phosphorites is carbonate-fluorapatite (CFA). P concentration of the economic phosphorite beds (conventionally expressed as % P_2O_5) mostly varies from 23 % to 30 % P_2O_5. This concentration is dependant on a variety of factors, among others the diagenetic history of the phosphorite, its sediment fabric, the mineralogy of the CFA phase, the nature of the intergranular fraction, and the structural and paleogeographic setting of the phosphate section. However, others components (other than P content) also control the marketability of the phosphorites. For example, a higher CaO/P_2O_5 ratio causes more sulfuric acid consumption during phosphoric acid production, high levels of magnesium (Mg) contribute to “blinding” of filters, silica (SiO_2) causes filtration problems, sodium (Na) and potassium (K) results in equipment scaling, organic matter (O.M.) causes foaming during phosphoric acid manufacture, chlorine (Cl) causes excessive corrosion, and high levels of toxic elements,e.g., cadmium (Cd), selenium (Se) and arsenic (As) make the phosphorite unsuitable for fertilizer production. Therefore, a detailed knowledge of the geochemistry of the phosphorite is a necessary condition to assess its economic viability and to decide about the appropriate beneficiation and the processing techniques that should be adopted.

Main GSI activities in phosphorite research

One of the most important activities of the Geological Survey of Israel (GSI) in the field of phosphorite research is geological exploration of phosphate deposits in the Negev. This, to get a complete knowledge as to the entire geological phosphorite resources of Israel, to evidence new economic phosphate deposits which could be exploitable in the near future, and to enable a rational national planning of the Negev areas taking into account other needs and uses. Exploration of phosphorites in the Negev by the Israel Geological Survey started in the early fifties and continued by intermittence and at different intensities over the last five decades. So far, some 20 phosphate deposits were discovered by different GSI teams in various areas of the Negev (northern Negev, ‘Arava, central Negev) during successive exploration campaigns. Three of these deposits (Oron, Zin and Rotem) are presently mined and produced the totality of crude phosphate rock now extracted in Israel (approximately 8 millions tons per year). Mining is done by the Rotem Amfert Negev (the Negev Phosphate Co. in the past) which is the sole company which today exploits phosphate in Israel. Before and during the mining operations, a detailed prospection of the phosphate deposit is performed by the Rotem Amfert geologist teams to get a more complete knowledge of the structure of the deposit and of its variations in space. This also enables reserve calculation and rational mining and processing of the deposit.

Exploration strategy includes several stages: first, preliminary reconnaissance of the phosphate field based on outcrop studies, then, detailed geological mapping of the deposit, followed by opening of trenches in the phosphate section and drilling in the deposit area including collection of cores. A variety of analyses are performed on the phosphate samples: total chemistry (ICP-AES and ICP-MS) of bulk and separated (carbonate-free, after laboratory TAC treatment) phosphorite samples, X-ray diffraction (XRD) analyses of total samples and of the CFA phase (measurement of structural CO_2), petrographic studies, scanning electron microscope (SEM) and electron probe analyses, and Fourier transform infra-red (FTIR) spectroscopy on separated CFA fractions. Preliminary beneficiation tests (performed in the Rotem Amfert Co. laboratories) are also made on the phosphate samples.

These phosphate exploration campaigns conducted by the GSI contributed to a better understanding of the phosphate potential of Israel and its geographic distribution. Resources of approximately 1600 millions tons were determined in the various phosphate deposits of the Negev; this, including a wide-scale and high-grade phosphate deposit in the Arad area (unfortunately, of problematic exploitation due to environmental problems) and a very large field in central Negev near En Yahav (Har Nishpe deposit) with huge phosphorite resources. Approximately some 220 millions tons of the total Negev resources are considered as today marketable (data from Rotem Amfert).

However, exploration of phosphate rocks cannot be rationally conducted without a good knowledge on the palaeoceanographic and palaeoenvironmental conditions which prevailed during the formation of phosphorites. Intensive research on various aspects of the Mishash sequence during the two last decades (together with data from areas of Recent phosphate formation) provided important information on the physical, chemical and biological processes that control the precipitation of apatite and the genesis of the Negev phosphorites. These include many studies on the paleogeography, the lithostratigraphy, and the biostratigraphy of the Mishash sediments, the petrogenesis of cherts, carbonates and phosphorites, mineralogical research on the CFA phase, and various geochemical studies including the geochemistry of organic matter in phosphorites, the geochemistry of cadmium (Cd), fluorine (F), uranium (U) and rare-earth elements (REE), and various isotopic studies ($\delta^{13}C$, $\delta^{18}O$, $\delta^{34}S$) in different Mishash mineral phases. The results of these researches greatly helped to better constrain the chemistry of the Mishash phosphorites and the environmental factors that cause compositional changes through space. For example, study of the paleosettings of economic phosphates in the Negev allowed to better understand the distribution of these rocks and yielded useful geological guides for phosphorite exploration. Similarly, geostatistical analysis of thousands of geochemical and petrological data from various Negev deposits enabled to explain the diagenesis of Cd during phosphate deposition and the controls of its distribution. It also permitted to predict the geological settings that could be associated with high Cd contents, thus allowing a more rational exploitation of the Negev phosphorites. A recent multi-element (U, REE, Cd, Zn, F, structural CO_2) geochemical study of the Negev phosphorites also enabled to show how these chemical components are inter-related, and what regulates their distribution during phosphate sedimentation. A bi-national (US-Israel) research (GSI and University of Hawaii), combining extensive, multi-element, strontium (Sr), neodymium (Nd), calcium (Ca), organic carbon (C_{org}), and organic nitrogen (N_{org}) isotopic analysis, together with quantification of P and Ca accumulation rates and systematic elemental geochemistry, is now conducted to better clarify the controversial question of global fluctuations of phosphogenesis through time.

Industrial phosphate products

To become a suitable product for delivery to conversion plants (conversion into phosphorite acid and phosphate fertilizers) the mined phosphate ore (~ 8 millions tons per year in total from Zin, Oron, and Rotem) has to undergo beneficiation (extraction of the P-rich granular phosphate fraction). Beneficiation processes in the Negev plants include washing/disliming, flash calcination, and flotation. Following beneficiation, the P content of the phosphate ore (recovery ~ 40 in average) is at least 32% P_2O_5 . About a quarter of the beneficiated phosphate ore is traded on the international market (Europe, India, South Eastern Asia). The remaining is converted to phosphoric acid and fertilizers (including direct application) in Rotem plant. Part of these products is domestically used and the other (the major part) is exported to various countries (Western Europe, Australia, South America, South Eastern Asia).