



A fisherman near Sarakiniko beach in Milos, Greece. The surrounding volcaniclastic rocks could be developed for their industrial mineral applications

Exploration key to growing Greek industry

Greece is opening its doors to private investment to boost domestic industries. *Ananias Tsirambides* and *Anestis Filippidis* discuss the country's key exploration targets for industrial minerals development

Greece avoided bankruptcy with the agreement of the 17 leaders of the Eurozone on 21 July 2011 for the second aid package of €158bn. Of this, €49bn will be from the participation of individuals. Many crucial details as regards the new loan have not been clarified yet, but it is obvious that Europe has given Greece a second chance, under the suffocating pressures of the markets and fears that the debt crisis may spread to the core of the Eurozone.

Debt reduction will be aided by granting rights to exploit Greece's mineral wealth to large business groups in the US, Germany and other 'borrowing forces', for many decades, in return to the pre-collection of part of the expected revenues. Greece hosts a number of industrial minerals and rocks with good prospects for exploitation, which are discussed here.

The aid package will give the country the assistance needed to restore growth and competitiveness. The European leaders also agreed

to make the terms of the European Financial Stability Fund (EFSF) more flexible.

Privatisation, imposition of new taxes and spending cuts in the period 2011-15, totalling €28.4bn, to hold the deficit to 7.5% of gross national product (GNP), are foreseen.

In particular, the following reforms are expected: streamlining wage costs, operating cost reductions, closures/mergers of bodies, decreased subsidies, reorganisation of Public Enterprises and Entities (PEE), reduction of defence spending, streamlining of healthcare costs, reduction of costs and improvement of profits of the 32 Social Security Organisations (SSO) and combating of evasion, enhancing tax compliance with new tax measures, tax cut reductions and increase of the revenues of the Local Authority Organisations (LAO).

Besides the above, measures to enhance growth and investments can lead to high primary surpluses, so the debt will fall below 100% of the GDP (from 140% today). This may happen in 2025 with a growth rate higher than 3.5% after 2014, a primary

surplus above 5.5% and a programme of public property use and privatisations of €50bn for the period 2011-2015. Therefore, the fiscal repair and recovery of the national economy is not infeasible.

Despite the short-term costs, the reforms that have been implemented or planned will benefit Greece for many years to come, as they will raise growth, living standards and equity. A basic prerequisite of success is that the burden and benefits of reform broadly may be fairly shared. Clearly, the key to success will be in implementation, which will have to be impeccable. Although the economy is still weak and the path to recovery is lengthy, rising exports are a sign that the reforms started to bear fruits. Under the most optimistic scenario, in 2035 reduction of the debt to 60% of GDP will be attained. Prerequisite is Greece from 2015 and then to score a primary surplus of 5-6%.

The International Financial Institute (IFI), which reflects the positions of more than 400 banks, expects in 2020 the Greek public debt to have

decreased in two-digit percentage of the GDP. Specifically, it provides that the debt of Greece will be reduced to 98% of GDP by the end of 2020, taking into account the percentage and the impact from the involvement of banks in the country support plan.

Essentially, these predictions confirm the analogous estimation of the International Monetary Fund, which welcomed with great satisfaction the agreement on crisis management in the Eurozone.

The privatisation of troubled public enterprises, the reforms in the economy and the state structure, and some political consent started. It is believed that the increasing role of the private sector will gradually put an end to the respective public sinecure. Mismanagement and waste of taxpayers' money will cease permanently. We urgently need an investment plan, a plan for the restoration of Greek economy, but also substantially improvement of the business environment in the coming years.

The advantages of Greece are its geostrategic position, which allows access to markets of 170m consumers in the Balkans, the diptych sun-sea which encourages investments in tourism, where there is still much room for growth, and in renewable energy sources (RES) and the exploitation of mineral raw materials which hitherto stay unexploited (eg. oil, gas, gold, zeolites etc). The negatives of the country include the bureaucratic obstacles to establishing and operating new businesses, opacity, high taxation, and constant changes in the institutional framework. The changes in these areas are urgent.

Diamond

Areas of northern Greece, where there are metamorphic rocks of ultra-high pressure, are associated with diamond potential, including the mountainous blocks of the Prefectures of Thessaloniki and Kilkis, and a narrow zone that extends intermittently along 100 km or more from Kato Nevrokopi Drama until Evros.

Graphitic diamonds of 2-300 µm in size enclosed in garnet, quartz, amphibole and graphite of metamorphic rocks have been found in Central Macedonia (Livadi, Galarinos, Marathoussa). Also, metamorphic mineral-indices of ultra-high pressure such as coesite, diamond and garnet were detected in eclogites and gneisses in central and eastern Rhodope Massif. The diamond appears in submicroscopic crystals of <20 µm in size within garnet porphyroblasts in the regions of Pilima Xanthi, Kymi-Smigada Rhodope and Sidiro Evros.

Diatomite

Diatomite deposits in Greece, depending on the environment of formation, are located in the basins of Klidi Florina, Komnina Ptolemaida, Yannota Elassona and Megalopoli (freshwater), in the basins of Eani Kozani and Mytilinioi Samos (saline-alkaline lake), in Aegina, Milos, Gavdos and in the basins of Kastelli and Heraklio (shallow sea) and in Zakynthos (deep sea).

The indicated reserves of diatomite are 100m tonnes and their value €2.5bn. Approximately 50% of them are in the basins of Klidi Florina, Komnina Ptolemaida, Eani Kozani and Yannota Elassona with good prospects for exploitation.

Garnet

Garnets have been found in areas of contact metamorphism in Xanthi (Kimmeria, Diasparto, Thermes), Drama (Polyneri, Panorama), in Vertiskos Thessaloniki, Chalkidiki, Mount Olympus, Lavrio, Serifos, etc. The granites of Kimmeria Xanthi and Serifos are suitable as blasting materials, showing good prospects for exploitation.

Trials with the Serifos garnet made in the US showed that the material is suitable as abrasive for wooden surfaces, leather and ceramic products. Also, because of its quality characteristics it can be used as filtration media. The indicated reserves of garnets are 1.3m tonnes and their value €40m.

Graphite

Graphite has been identified in marbles, gneisses and schists of the Rhodope Massif. In particular, the garnet schists of Polyneri Drama contain an average of 3% graphite, and the occurrences in the Ypsili Rachi and Agios Panteleimonas are lower purity.

Microcrystalline (amorphous) graphite in the form of lenses has been identified in the units of Makri in carbonate formations. In the region of Diasparto and Thermes Xanthi the garnet-kyanite gneisses contain a graphite horizon with graphite leaflet crystals at rates of 3-12% and reserves in excess of 600,000 tonnes. From this horizon a graphite concentrate was produced with carbon content of 80-85%. But a graphite concentrate with >95% C is needed to allow the exploitation of these deposits.

The indicated reserves of graphite are 650,000 tonnes and their value €20m.

Table 1: Types and origin of Greek marbles

Type/colour	Region
Limestones-marbles (with >98% calcite)	
White	Kechrocampos and Vounochori Kavala, Koumaria and Kastania Imathia, Veneto Magnisia, Penteli and Dionyssos Attica, Naxos-Paros-Ikaria
Semi-white	Disvato-Elafochori-Stenopos-Filippi Kavala, Xiropotamos and Monastiraki Drama, Tranovaltos Kozani, Almyropotamos Evia, Micho Lesvos
Grey-white	Thassos, Chalkero Kavala, Panorama Drama, Zasteni and Argalasti Magnisia, Kokkinaras Attica, Parnon Arkadia, Lardos Rhodes
Beige	Ioannina, Domvrena and Martino Viotia, Kivotos Grevena, Kalythia Rhodes
Pink	Germa Kastoria, Arta, Klinovo Trikala
Grey-black	Ippio Lesvos
Black	Parnon Arkadia, Agia Rethymno
Dolomites (% mineral dolomite)	
White	Thassos (92%); Granitis (100%), Volakas (100%), Piges (92%) Drama
Semi-white	Elikonas Viotia (87%)
Grey-white	Nikissiani Kavala (87%)
Grey	Moundros Rethymno (90%)
Grey-black	Damasta Heraklio (62%)
Red	Agios Vasiliou Rethymno (80%)
Other carbonates and sedimentary units	
Breccia limestones	Karnezeika-Kantia-Lygourio Argolida, Agios Petros Arkadia, Eretria Evia, Skyros, Rodochori Naoussa
Travertines	Aridea Pella, Skra Kilkis, Vamvakofyto Serres, Pitsa Corinthia, Kapandriti Attica, Vamos Chania
Poroliths	Alfa Rethymno
Sandstones	Beige Messolongi, Gray Demati Metsovo, Gray Nestorio Kastoria
Gypsums	Sitia Crete
Serpentinities	Fytia Imathia, Tinos

Halite

Exploitation of mineral salt in Greece took place in the past (before 1900) only in Vordo Ioannina via primitive means. Today, the possibility of exploitation of mineral salt (75-90% NaCl), which has been identified in Monolithi Ioannina, intercalated with reef limestones, is being examined.

Approximately 66% of the needs of the country are covered by the production from eight salt pits operated by state company Hellenic Alykes Co. SA, founded in 1988, with a capacity of 260,000 tpa.

These pits are: Messolongi (produces approximately 50% of total), Messi Rhodope, Nea Kessani Xanthi, Kitros Pieria, Angelochori Thessaloniki, Skala and Kalloni Lesvos, and Milos. With the schedule of the medium-term financial framework for Greece's exit from the Eurozone crisis, by the end of 2015 the Greek state will allocate for sale 100% of the shares it holds in Hellenic Alykes.

The indicated reserves of mineral salt are 20m tonnes and their value is €80m.

Micas

In Macedonia and Thrace there are many acidic plutonic, pegmatitic and regional metamorphism rocks containing large crystals of mica. By 2006 only Myrtofyto Kavala (Mount Symvolos) had seen periodic extraction of sericite – the product of hydrothermal alteration of feldspar content in the granites – by Viotalk Co. The processing and the enrichment were done in Vrasna Thessaloniki. The company can reopen but modern processing equipment is required.

The indicated reserves of micas are 800,000 tonnes and their value is €20m.

Phosphate rock

The fertiliser mineral is found in three different horizons, which belong to Upper Cretaceous (Parnassos-Gkiona Zone), to Eocene, and to

Oligocene (Ionian Zone). In Parnonas phosphate has the form of crystalline fluorapatite while in Kitheron there have been small occurrences of U-V-phosphorite identified.

In the Parnassos-Gkiona Zone the occurrences are found to contact limestone with flysch in Distomo, Arachova and Antikyra and they are fragmented due to erosion. In the Ionian Zone occurrences of Miocene phosphorites have been identified in the regions of Ktismata and Argyrochori Epirus, Corfu and Kefalonia. In the same zone are Upper Cretaceous phosphate deposits mainly in Etoloakarnania, Preveza and Delvivaki Ioannina, where the deposits spread over 15km length and 2-4 m in thickness, with a P_2O_5 content of 10-25%. Because of the low P_2O_5 , the exploitation of these deposits is impossible with today's techno-economic conditions.

The indicated reserves of phosphate total 500,000 tonnes and their value is €10m.

Talc

Numerous deposits of talc have been found in Greece, some of which are of economic interest. These are usually in the form of veins and lenses in serpentinites and ophiolites that have received hydrothermal or metamorphic alteration.

The talc is accompanied by chlorite, tremolite, magnetite, calcite and quartz. Talc deposits are found in Sifnos, Syros, Evia, Larissa, Armissa Pella, Divouno Kilkis, Rhodope (Organi, Myrtiski, Chloe) etc. Exploitation of talc deposits occurred in the past in Tinos, Ierapetra Crete and Chortiatis Thessaloniki. Today, of special interest are the abundant serpentinite bodies of the units in Vertiskos (Serbomacedonian Zone) and particularly of the area Askos Thessaloniki, which are rich in vermiculite and talc.

In Askos the talc reserves (with 2.5-5.5% Fe_2O_3) are about 700,000 tonnes. Test improvements carried out reduced the iron content to 2.5-3%.

The indicated reserves of talc are 1m tonnes and their value is €20m.

Vermiculite

The deposits of vermiculite are restricted in the regions of Zidani Kozani, Askos Thessaloniki, Mountains Kroussia of Kilkis, Vavdos and Yerakini Chalkidiki. The Vertiskos Series is very interesting, which along with the talc bodies, deposits of vermiculite have identified in the region of Askos. There are 300,000 tonnes of vermiculite which contains 0-2.5% K_2O and this mineral is located at a depths of up to 30 metres.

After this depth K_2O gradually increases and deposits of hydro-phlogopite and hydro-biotite may be additional mineral resources. This vermiculite has desirable properties for the manufacture of certain construction, agricultural and horticultural products and shows a high ability to remove heavy metals from aqueous solutions.

The indicated reserves of vermiculite in Macedonia are 500,000 tonnes and their value is €20m. More encouraging are the prospects for exploitation of vermiculite found around Askos Thessaloniki.

Wollastonite

Wollastonite deposits are in Kimmeria Xanthi (with indicated reserves of 500,000 tonnes and recoverable wollastonite at 50%) and in Panorama Drama (with indicated reserves of 700,000 tonnes and recoverable wollastonite at 50%). Both show good prospects for exploitation. The indicated reserves of wollastonite are 500,000 tonnes and their value is €20m.

Zeolites

Natural zeolites are found in more than 80 types. Fibrous zeolites (eg. erionite, mordenite, scolecite, mesolite, natrolite) are avoided for the different uses. Instead it is proposed that those with a content above 70% in the ore are used, while those with lower grades could be used as aggregate or building stones.

Taking into account the reserves, the type and the zeolite content, the economical interest is focused mainly in the Evros Prefecture (Ntrista Stream and Mavri Petra of Petrota, and Kyries Toumpes and Tympano of Pentalofos), in north-east Greece, with probable reserves of 480m tonnes; 120m tonnes for each location.

Zeolite occurrences without economic interest (low zeolite content, fibrous zeolites or unknown reserves) occur in the Prefectures of Evros, Rhodope, Samos and Cyclades. In the rest of the Evros Prefecture such occurrences are found in the areas of: a) Petrota (locations Aloni-Kokkalo, Gkazomylos, Livadakis, Petrota-Lefki Stream, Fylakio Omega) containing 35-75% HEU-type zeolite, 45% Mordenite; b) Pentalofos (Palestra) containing 43-65% HEU-type zeolite; c) Metaxades-Avdella (Gourounorema-Xerovouni) containing 35-75% HEU-type zeolite; and d) Dadia-Lefkimmi-Feres (Kanalia, Xefoto, Synoro,

Table 2: Zeolite content of Greek tuff formations, north-east Greece*

Location	Average content (wt. %)	Min-max. content (wt. %)
Mavri Petra of Petrota	83 HEU	80-89
	79 HEU	74-86
	76 HEU	70-81
	65 HEU	40-90
Ntrista Stream of Petrota	89 HEU	84-95
	89 HEU	87-93
	89 HEU	87-93
Kyries Toumpes of Pentalofos	76 HEU	74-77
	65 HEU	40-90
Tympano of Pentalofos	83 HEU	70-93
	78 HEU	70-85
	77 HEU	55-95
	70 HEU	49-93
	69 HEU	68-70
	65 HEU	40-90
	59 HEU	37-81

*In Petrota (Mavri Petra and Ntrista Stream) and Pentalofos (Kyries Toumpes and Tympano), Evros Prefecture, north-east Greece. HEU: HEU-type zeolite (Heulandite-Clinoptilolite).

Vyrini, Lefkimmi, Agios Konstantinos, Aspra Chomata, Vrysi, Kavissos, Kapsala, Laka, Makrylofos, Nipsa) containing 11-70% HEU-type zeolite, 5-53% mordenite, 14-88% HEU-type zeolite+mordenite, 43% HEU-type zeolite+stilbite, 31% mordenite+stilbite, 8% laumontite+stilbite.

In the Rhodope Prefecture (north-east and north-west Skalama, Kirostatis, Voukefalo of Darneni) there are zeolites containing 18-60% HEU-type zeolite+mordenite, and 16-18% analcime.

In the Samos Prefecture (Karlovasi-Marathokampos basin) zeolites contain 57-91% HEU-type zeolite, 64% mordenite, 44-72% analcime, 66% chabazite, 78-81% HEU-type zeolite+mordenite, 55% HEU-type zeolite+analcime, and 47% HEU-type zeolite+phillipsite.

In the Cyclades Prefecture (Panagia and Kipi of Milos, Ormos Sykias and Agios Andreas of Kimolos, north-west of Polyegos, Akrotiri and Ormos Mpalou of Thira) zeolites deposits contain 33-55% of HEU-type zeolite, 23-73% mordenite, and 53-73% HEU-type zeolite+mordenite.

Natural zeolites containing no fibrous species and with a purity >70%, are suitable materials for numerous environmental, industrial, agricultural, cattle-raising and aqua-cultural applications. The Hellenic Natural Zeolite (HENZA) from Ntrista Stream, on average contains 89% HEU-type zeolite (range 84-95%). It enriches water in oxygen and adjusts the pH level to neutral.

The treatment of municipal wastewater with HENZA gave clear water with improved quality parameters by 90-95%. Also, the treatment produced a precipitate of odourless and cohesive zeo-sewage-sludge, which was produced either by mixing the sewage sludge with HENZA or as precipitate during the treatment of municipal wastewater with it.

This sludge is suitable for reclamation of agricultural soils. The treatment of industrial wastewater (from dyeing, tannery operations), gave clear water with improved quality parameters by 93-99%. Also, the treatments gave a precipitate of odourless and cohesive zeo-sludge, which is suitable for safe deposition, since the dangerous components are not leached with the rainwater.

HENZA removes cyanobacteria from waters by 51-92%. Its addition in agricultural soils increases the yield of agricultural products by 17-66%, improves the quality of the products by 4-46%, reduces the use of fertilisers by 56-100%, reduces the usage of irrigation water by 33-67%, prevents the seepage of dangerous substances into the water environment, thus protecting the quality of surface and ground waters.

The use of HENZA in farms as floor material and as feed additive increases the production (17% in the case of milk from cows, 7% in the body weight of broilers), improves the product quality, reduces the food intake, the animal diseases and medication, the neonatal mortality, and the malodour, and converts the manure to odourless fertiliser.

Today there is no exploitation of natural zeolites in Greece. Depending on the quality, grain size and degree of processing, the value of natural zeolites ranges from €10/tonne to €500/tonne. Processed in specific products (litter, nutrition supplements), prices can range from €1/kg to €48/kg.

The indicated reserves of the natural zeolites of Thrace are 600m tonnes and their value €18bn.

Critical raw materials

It is known that 70% of the necessary raw materials for the European industry are imported from non-Eurozone countries, while 70% of European industry is based on mineral raw materials. Also, while Europe consumes 30% of the global production of metallic minerals, it produces only 3%.

To ensure the supply of necessary mineral raw materials into Europe, the European mining strategy and policy is currently under redesign. In 2010 the European Union (EU) adopted the initiatives of sustainable production from domestic raw materials, sustainable consumption and recycling.

The recent Raw Materials Initiative (RMI) also restores focus to the development of mineral resources. In the content of this initiative, 14 minerals were classified as critical and of strategic importance for European industry. These were: antimony (Sb), beryllium (Be), cobalt (Co), gallium (Ga), germanium (Ge), indium (In), magnesium (Mg), niobium (Nb), platinum metals (PGE), rare earths (REE), tantalum (Ta), tin (Sn), fluorspar, and graphite.

Most of them are found in Greece, but further investigations are needed to determine the proven reserves.

Antimony

Antimony has been found in veins of the mineral antimonite mainly in Kalyntirio Rhodope, in Gerakario Killis, in Filadelfio and Lachanas Thessaloniki, Pilio, Chios and Samos with levels from 1% to 2.5% Sb. Antimony has a common presence in the sulphide minerals of Pb, Fe, Cu, Ag, Au (>1 g/tonne). From all of the occurrences of antimony, only in Gerakario has native antimony been identified. The indicated reserves of antimony are 2,400 tonnes and their value is €30m.

Gallium, germanium & indium

These metals are at the heart of the industrial applications of high-tech alloys. The mixed sulphide mineral deposits Pb-Zn-Ag constitute an ideal geochemical environment for their presence. In this sense mineralisation and deposits belonging to this category are potential sources of these metals.

The rapid improvement of analytical methods now gives the possibility for their qualitative detection and quantitative determination in selected original samples from specific areas, such as metal-bearing regions ie. Thermes Xanthi,

Polykastro Killis, Olympias Chalkidiki, Molaoi Laconia etc.

Platinoid metals (PGE)

Of particular interest are the porphyry Cu deposits containing precious metals and especially platinoids such as Ru, Rh, Pd, Os, Ir and Pt. They are very rare in nature and because they closely resemble each other usually they are in binary or triadic alloys.

The most common platinoid is platinum (Pt). The exploration goals for finding platinoid metal concentrations with economic interest are the porphyry Cu deposits of the metallogenetic arc in north-west direction from the Skouries-Fissoka Chalkidiki until Pontokerasia-Gerakario Killis. Specifically, in the exploitable ore of Skouries, economic concentrations of palladium (Pd) of 0.5 g/tonne have identified, widening further the already rich mineral potential and the value of the ore. In some cases, such as in Fe-Ni-bearing laterite deposits (eg. Vermio), elevated levels of platinoids have also been identified.

Rare earth elements

REEs constitute a group of 17 metals widely used in the production of high-tech products such as batteries, wind turbines, aerospace alloys, etc. There are great differences in the market prices of rare earth oxides. Also, their prices depend on the degree of purity determined by the specifications in the applications. In August 2011 their price ranged from \$173/kg (La_2O_3) up to \$5.880/kg (Eu_2O_3). China controls 95% of the world production.

Significant reserves of rare earths are found in alluvial deposits in the coastal environment of Strymonikos Bay between the mouth of the homonymous river and Kavala. Geological surveys estimate the reserves at 485m tonnes with an average content of 1.17% rare earths. Considerable interest for systematic economic geology exploration, present also the bauxites and lateritic bauxites of Sterea Hellas, with levels ranging from 3.275 g/tonne to 6.378 g/tonne in REE. The perceived economic interest even includes the red mud by-product from the aluminium industry.

See IM January 2012 issue for a review of Greece's industrial mineral producers and markets.

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