Journal of Geography and Regional Planning Vol. 5(2), pp. 21-35, 18 January, 2012
Available online at http://www.academicjournals.org/JGRP
DOI: 10.5897/JGRP11.077
ISSN 2070-1845 ©2012 Academic Journals

Full Length Research Paper

The opencast bauxite mining in N.E. Ghiona: Eco-environmental impacts and geomorphological changes (Central Greece)

Aristeidis Mertzanis

Technological Educational Institute of Lamia, Department of Forestry and Management of Natural Environment, 36100, Karpenisi, Greece. E-mail: amertzanis@teilam.gr. Tel: +30 2237023282. Fax: +30 2237024035.

Accepted 23 December, 2011

It has been observed that certain anthropogenic interventions in the form of mining activities, such as opencast bauxite mining (large artificial cavities -pits-, voluminous piles of calcareous spoils -inert materials- derived from bauxite mining, dense road network constructed in order to get access to the mine location, etc), alter "critical" parameters of the natural environment and lead to destabilization of the environmental balance of forest ecosystems as well as cause changes in geomorphological processes. The way and methods used for the mining of bauxite until the end of the 20th century in the area of Northeastern Ghiona, in combination with the deforestation, forest fires, illegal logging- wood cutting, grazing-overgrazing in the forest, opening up new dense road network constructed in order to get access to the mine locations and the uncontrollable waste disposal, resulted in a significant burden to the natural environment, especially in the cases where it covered extended parts of forests, forest areas and grasslands as well as important geomorphological formations. All the aforementioned led to the occupation or the deforestation of forests and grasslands, the interruption of natural relief continuity and the change of natural geomorphologic processes and phenomena. Despite the existing strict relevant legal system that applies in the forest areas (Laws, 998/79, 1650/86, etc) in most cases, human activity in those areas does not take into account the necessary restrictions for the protection of the environment and this leads to unfavorable effects to the relevant areas which result in alterations as far as the extend and severity, depending on the type, the extend, the function and the location of the specific activity. The aim of this paper is: (a) To locate the main opencast bauxite mining activities as well as the existing or planned other human interventions and activities in the area of Northeastern Ghiona, and (b) The determination of the impacts to the natural environment and more specifically to the hydro-geomorphological characteristics and processes of Northeastern Ghiona, both during the time of the exploitation and after the ceasing of works as far as opencast bauxite mining is concerned in the numerous mines found in the area between Kaloskopi-Kastellia-Gravia-Variani (Northeastern Ghiona).

Key words: Bauxite mining, environmental impact, geomorphology, Ghiona mountain, opencast mining.

INTRODUCTION

The presence of dense vegetation consisting mostly of forest of fir and oak and the existence of mineral resources (bauxite ores) that characterize the mountains of Elikonas, Parnassos and Ghiona in Central Greece, as well as their favorable geological, hydrological and geo-morphological and climatic characteristics, and in some cases, their accessibility, are the main factors responsible for the intense human activity in these areas. Characteristic example of these is the north-eastern Ghiona. In the mentioned area both in the zone of fir (*Abies Cephalonica*) and in the zone of oaks (*Quercus Coccifera*), the presence of human activity and especially the bauxite mining activities are intense (Mertzanis et al., 2006).

The exploitation of bauxite ores, which are found in the study area of northeastern Ghiona in Fokida, had started before the war, around 1930 and intensified greatly during the seventies. The opencast exploitation method was the primary method used for the mining of bauxite and in certain cases it was combined with the underground method of mining, in order to achieve the best yield in ore from the two main bauxite deposits, which are located in the underground of the area.

In the area under study, bauxite is mainly extracted by opencast mining, which has a variable and highly site-specific effect on the local environment and surrounding eco-systems. The primary ecological concerns connected to this activity are related to the destruction of the natural vegetation, deforestation, shrinkage of forests, forest areas and grasslands, due to the successive vegetation gaps, habitat destruction, home range de-fragmentation due to roads, effect on local flora and fauna, removal of the surface soil, soil erosion, disturbance of hydrology and water resources and changes to the geomorphology and the landscape.

Especially, the surface mining of bauxite, in the study area, led to the interruption of the natural continuity of the land relief as well as some alterations in the natural geomorphological processes and phenomena which are seen in the area, while in many cases parts of forests, particularly forest fir (*A. Cephalonica*), oaks (*Q. Coccifera*), and forest areas were overtaken. The impacts to the natural environment from the surface mining are mainly due to the stepwise mining fronts and the cavities (open pits-quarries) which are formed as a result of the works necessary to reveal the ore as well as from the large depositions of inert materials (bauxite mining spoils) which are left over after the revealing of the ore, while are intensified from the dense road network constructed in order to get access to the mine locations. These impacts differentiate in each case depending on: (a) The location and the local environmental conditions of the area where each mine is found, and (b) The characteristics of the mining activity which have to do mainly with the plan used for dealing with the mine and more especially depending on the size, location and volume of excavations and of the depositions of inert materials.

The use of improved drilling equipment as well as the use of contemporary heavy machinery which drill and handle very quickly large volumes of ores and of unusable materials contributed to the increase of the rate of deterioration of the land relief characteristics until the end of the seventies, as well as in the alteration of the rate and the direction of the development of the geomorphological processes of the area under study.

The rate of expansion of the surface exploitations was significantly limited after the implication of Laws 998/79 and 1650/86, which prohibited the development of surface exploitations, while at the same time made mandatory the environmental impact assessment studies and the imposition of environmental terms for mines located in forests and forest areas. The exploitation of the ores was mainly counterbalanced with the use of the underground method of mining. The land restoration of the abandoned mines was also considered imperative.

DESCRIPTION OF THE STUDY AREA

Geographical locations and geomorphology

This study focuses on the area of Northeastern Ghiona which have undergone intense alterations and disturbances, due to human intervention (mining activity), in the forest of fir and oak, in hydrological and in the geological characteristics and in the natural geomorphorlogical processes and phenomena. These areas are found in Greece (Figure 1).

The research concerns the sum of the surface bauxite exploitations found in the northeastern side of the Ghiona mountain and more specifically in the area between the Liritsa crest (altitude 2.007 m) and the villages Kaloskopi (altitude 1.000 m), Kastellia (altitude 430 m), Gravia (altitude 400 m) and Variani (altitude 880 m). It mainly focuses in six selected open-cast mines in the sites under the names "Kokinovrahos", "Agios Athanassios", "Kokinohoma", "Koukouvista 5", "Paliampela" and "Alefando" which constitute some of the most important sites of bauxite mining in the area (Figure 2).

The morphology of the land relief of the greater area is defined by the mountainous volume of Ghiona having as its highest point the pyramid (height 2.510 m), which is surrounded by lower crests in altitudes 2.000 to 2.300 m.

The natural banks and especially those in the north-eastern side exhibit significant morphological slopes with deep crevices alternating with rounded and deeply karstic crests and are differentiated depending on the nature and location of the geological formations going from limestone (slope 60 to 85%), to flysch (slope 20 to 60%). Lower down, we have the formation of successive calcareous elevations which end up in the alluvial areas of the plain that extends between Kastellia-Gravia and Brallos.

Climatic conditions

The mean yearly rainfall in the study area is high and ranges from 890 to 1.600 mm. More specifically, the mean yearly rainfall in the meteorological station of Lidoriki, Gravia and Kaloskopi reaches 957, 890 and 1.232 mm, respectively, while in the Ghiona crests ranges from 1.400 to 1.600 mm. The mean yearly number of rain days comes up to 100 days (Lidoriki station). The maximum 24 h rain for the same station is

Figure 1. Geographical location of the area under investigation.

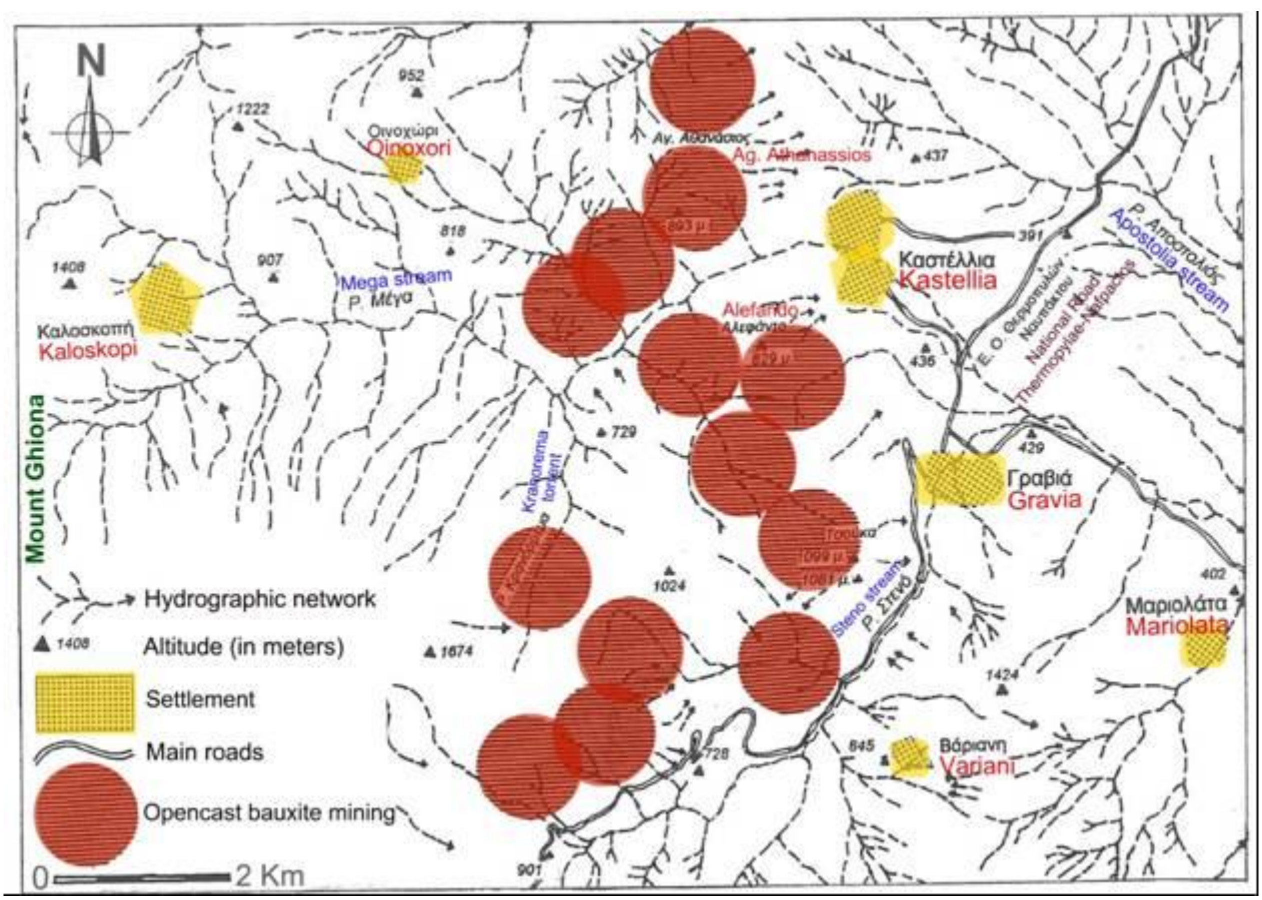


Figure 2. Geographical distribution of opencast bauxite mining activities in Northeastern Ghiona.

(a) (b)

Figures 3. (a) Bauxite mining activities (opencast mines) in the area of northeastern Ghiona. Kleisoura and Kokinovrahos bauxite mines (Mertzanis et al., 2004a). (b) Koukouvista 5 bauxite mine (Mertzanis et al., 2005a).

123.8 mm. Snowfalls are seen between October to March with 17 days of snow/year in the Kaloskopi station and 7.5 days of snow/year in the Gravia station.

Water resources

The surface water outflow forms a hydrographic network, which differs as far as density is concerned, depending on the lithology and the slopes of the banks. It is formed from the streams of Apostolia, Mega and Steno, which exhibit an intense torrential activity during the rain months, an activity with main direction in the N.E. in the North, which changes to S.E. in the lower plain part in the area of Kastellia and Gravia and which finally ends up into the Kifissos river, which flows into lake Iliki. The percolation in the karstified calcareous volumes which are abundant in the study area is high, to the order of 60 to 80% and for this reason the volume of permanently flowing surface waters is small. The underground water flow is deep and in its greater part remains unexploitable.

Vegetation

The vegetation in the study area, differentiates according to the successive altitude zones, which follow the relief, while its shrinkage compared to the past (before 1960) is significant, due to intense human interventions (bauxite mining, woodcutting, deforestation, grazing and forest fires). In altitudes of more than 800 m, the zone of fir is seen (*A. Cephalonica*), which is abundant in the area, while in altitudes of less than 700 to 800 m oaks (*Q. Coccifera*) with the occasional appearance of deciduous oaks is seen. At the locations where there is permanent surface water flow (streams, springs etc) species such as sycamores and willows is seen (Figure 3a and b).

The vegetation coverage in the excavation fronts and places of the deposits of the inert materials does not exceed 3%, with the exception of the places where land restoration has been successfully exercised, especially the inert materials deposits. These mines, which are indicatively mentioned, are "Kokinovrahos", "Aghios Athanassios", "Kokinohoma", "Koukouvista 5", "Paliampela", "Sideritis" and "Alefando". It is noted that in the areas of inert materials deposits, the restoration is accomplished mainly with the planting of acacia and rush (*Robinia pseudoacacia, Cupressus sem-pervirens, Lolium multiflorum, Phacelia tanacetifolia*), but in some sites-mine areas (Sideritis location at an altitude of 900 m), the invading indigenous species increased to a 38.4 to 62.7%, after the first three-four years of planting (Brofas and Varelides, 2000; Brofas et al., 2007) (Figure 4a and b).

MINERAL RESOURCES – EXCAVATION ACTIVITIES

Geology

The study area is mainly characterised by sedimentary formations which geotectonically belong to the Parnassos - Ghiona area while in its eastern side is seen the overthrust Eastern Greece series. The zone of Parnassos - Ghiona consists of a neritic carbon sequence (upper Triassic – upper Cretaceaous), which ends up with flysch (Eocene). This neritic sequence is not continuous but is interrupted by a number of bauxite horizons, the main

(a) (b)

Figures 4. (a) Inert materials deposits (bauxite mining spoils) on Kleisoura opencast mine, before restoration (Mertzanis et al., 2006). Inert materials deposits, in the study area, at an early stage of restoration (b) (Mertzanis et al., 2004a).

ones of which until now, as far as mining exploitation is concerned, are the following: (a) "Upper horizon of bauxite", and (b) "Lower horizon of bauxite" (I.G.S.R. 1960). Also in the same area, appear pleistocene torrential deposits in the basin of brallos and quaternary deposits, which include the colluvial deposits, talus and slope fan debris.

Bauxite production and characteristics

The common raw material for aluminium production, bauxite is composed primarily of one or more aluminium hydroxide compounds, plus silica, iron and titanium oxides as the main impurities. It is used to produce aluminium oxide through the Bayer chemical process and subsequently aluminium through the Hall-Heroult electrolytic process. On a world-wide average, 4 to 5 tonnes of bauxite are needed to produce two tonnes of alumina, from which one tonne of aluminium can be produced. In Europe, usually the average bauxite consumption is 4.1 tonnes per tonne of aluminium (U.S. Geological Survey, 2009).

Bauxite ore is a product of the decay-erosion of Al-rich carbon rocks, with simultaneous washing out of $CaCO_3$, or laterite decay-erosion of igneous rocks, mainly serpentine or even transformed ones. Bauxite is found in four types of deposit: blanket, pocket, interlayered and detrital.

More than 200 million tonnes of bauxite are mined each year. The major locations of deposits are found in a wide belt around the equator. Bauxite is currently being extracted in Australia (in excess of 60 million tonnes per year), Central and South America (Jamaica, Brazil, Surinam, Venezuela, Guyana), Africa (Guinea), Asia (India, China), Russia, Kazakhstan and Europe (Greece) (U.S. Geological Survey, 2009) (Table 1).

Despite the small percentage (2.2 million tonnes/year) of bauxite production in Greece, compared with global production (205.0 million tonnes/year), the mining of bauxite (bauxite ores) is found in total in the mountains of Elikonas, Parnassos and Ghiona in Central Greece.

Bauxite ore mineralogical and chemical composition as well as its physical properties varies. The basic minerals of bauxite are; boemite, diasporo, hidrargilite, all of which constitute the main paragenesis. The main oxides which form bauxite are: Al_2O_3, Fe_2O_3, SiO_2 and TiO_2. The mean chemical composition of higher horizon of the zone Parnassos - Ghiona are: Al_2O_3 (55 to 65%), Fe_2O_3 (2 to 25%), SiO_2 (1.2 to 25%) and TiO_2 (2 to 2.5%). The following, trace elements have also been found present: Ga, Ge, V, U, Th, La, Ce, Zr, Y, Nb, Nd, Ni, Cr, Zn, Pb, Cu, Mn, Sr, Co, B, Be, Sm, Au, Ag, and others, out of which the first eight in the list are found in significant concentrations (Papastavrou, 1986).

More specifically, as far as the elements Ni, Cr, V, Mn, Cu, Ga, are concerned, the values in the Greek bauxites range respectively from 81 to 1.300, 73 to 2.430, 125 to 3.100, 25 to 1.117, 9 to 76 and 24 m to 102 ppm (Ochenkuhn and Parissakis, 1977).

Methods used for the mining of bauxite

Bauxite is usually mined by open cast or strip mining. Rather than tunnelling into the earth these methods involves extracting minerals from an open pit. All the earth covering the minerals is removed by heavy machinery. The mining of bauxite in the study area is done:

(a) *From the surface* (opencast mines), using the method

Table 1. Breakdown of global bauxite production.

Country	Mine production in 2007 (million tonnes/year)	Mine production in 2008 (million tonnes/year)
Australia	62.4	63.0
Guinea	18.0	18.0
Jamaica	14.6	15.0
Brazil	24.8	25.0
China	30.0	32.0
India	19.2	20.0
Venezuela	5.9	5.9
Surinam	4.9	4.5
Russia	6.4	6.4
Kazachstan	4.8	4.8
Guyana	1.6	1.6
Greece	2.2	2.2
Other countries	7.1	6.8
World total (rounded)	201.9	205.2

Source: U.S. Geological Survey (January 2009).

(a) (b)

Figures 5. (a) View of Kleisoura open cast mine. (b) Detail of Kleisoura open cast mine; distinguish vertical mining fronts (Mertzanis et al., 2004b).

of "upright grades" by uncovering the deposits during which procedure vertical or step mining fronts are formed until the surface of the ore, while at the same time the inert materials are removed. Open cast mining involves the removal of the top layer of soil and rocks in order to get at the ores underneath (Figure 5a and b).

(b) *Underground mining* using the method of "room and pillar mining" during which tunnels are opened up in order to reach and obtain the ore (Figure 6a and b),

(c) In several cases a *combination* of the aforementioned methods is applied (Figure 7a and b).

The basic criterion upon which the method used for mining is chosen is economic considerations and it is determined from the ratio I = volume of inert materials (m^3) / Bauxite weight (tn). When $I < 5$, it is economic viable to use surface mining methods, while when $I > 5$ to 6, then the underground mining is preferred.

Nowadays in order to comply with environmental legislation (Laws, 998/79 and 1650/86), in deciding which method to use, amongst other things one has to seriously

Figures 6. Underground mining method (tunneling) in the study area (Mertzanis et al., 2005a).

(a) (b)

Figures 7. (a) Combination of “open cast” and “underground” mining methods, in the study area. (b) Detail of the tunnel entrance (Mertzanis et al.,, 2006).

consider environmental criteria that ensure the protection of the natural environment since land restoration is now imperative.

KARST LANDSCAPE AND HUMAN-MADE PSEUDOKARSTIC PHENOMENA

Strictly speaking, the Karstic landforms of the relief are the landforms that are formed as a result of the solvent action of water on calcareous rock. This karstic relief is characterized by valleys with closed cavities of various shapes and dimensions, due to the absence of surface hydrographic network and the presence of too many underground caves. Main conditions for the creation of karstic landforms are the presence of easily water soluble rocks and the heavy rainfall which alter the soil mechanical behaviour of the calcareous rocks. (Theodoropoulos and Zamani, 1972; Mariolakos et al., 1987; Monroe and Vicander, 1989; Papapetrou- Zamani, 1990; Castiglioni, 1997).

Monroe (1970) uses the term “pseudokarst” to define those areas that have landforms that resemble the Karstic areas which though are not the product of karstic processes. Castiglioni (1997) uses the term “parakarstic” phenomena for those processes and landforms that are created from the weathering and erosion of the non calcareous rocks, while he calls “pseudokarstic” the landforms that resemble the karstic ones but originate from quite different processes. Also the term “doline” determines the natural closed cavities of various dimensions and shapes (cylindrical, conical, bowl-or dish-shaped) which in most of the cases drain through underground ways. Usually the dolines have a diameter of 10 up to 1000 m and depths from 2 to 200 m.

As mentioned, in the under study area where we have the presence of bauxite ores and these are mined mainly using the surface and underground mining method (open cast mines), there are large areas, that show a Karst landscape and extensive Karstic phenomena in calcareous rocks. The karstification of a landscape may result in a variety of large or small scale features both on the surface and beneath. These open cast mines of the bauxite ores, which increased significantly during the decade of the seventies exhibit significant similarities to the natural karst lanforms which are called “dolines”. For this reason the term “pseudodolines” was used in order to describe these human-made – “artificial” landforms and the term “pseudokarst topography” was used in order to describe these “artificial” karst landscape which to a great extend is man controlled (Mertzanis et al., 2005a).

“Pseudodolines” are artificially formed landforms which in their entirety form the “pseudokarstic” relief and which exhibit significant similarities to the natural karstic forms of the relief that are called “dolines” but differ in the way they were created.

The main similarities of the “pseudodolines” to the natural “dolines” are:

(a) They are both closed or semi closed cavities of various forms and dimensions that exceed a height the 30 m. This height corresponds to the excavation front and the volume of the calcareous formation that is removed as unused material. In certain cases, the height of the excavation frond exceeds 200 m as it is in the case of the large mine “Koukouvista 5”. The diameter of “pseudodolines” on the top of the cone varies from 50 to 250 m.
(b) These “pseudodolines” are located on calcareous formations which constitute the roof and the floor of the bauxite mines.
(c) As far as the hydrogeological characteristics are concerned, the “pseudodolines” present significant similarities to the natural dolines due to the calcareous composition of their walls and their floors and due to the capability of these formations to show an increased permeability and thus their ability to drain the surface waters through underground karstic ways. In many cases, where we have similar underground bauxite exploitations, these tunnels facilitate the drainage of the surface waters and act as artificial drainage networks, thus substituting the natural drainage.

The main differences are:

(1) They differ in the way they were formed. The natural dolines are landforms that are created by the solvent action of water on calcareous rocks, while the “pseudodolines” are created as a result of human activity and specifically from mining activities (open cast mining).
(2) They differ from the natural dolines in the stepwise development of the slopes of their cavities, resembling a flight of stairs, which result from the artificial levels formed from excavation works and the removal of unused materials during the bauxite mining activities. It was observed that in the older mines, the angular shapes of these levels tend to become rounded as a result of the intense action of external factors which, assisted by the long periods of snow coverage during winter time, enforce the erosion-decay phenomena of calcareous slopes of “pseudodolines”. These phenomena are more intense where we have weak soil mechanic character-ristics due to existing discontinuities in the rock, or cases of serious breakage, where the rock is broken to pieces.
(3) The depositions of unused materials in or outside the cavity of the “pseudodoline” are characteristic of human-made interference.

STUDY METHODOLOGY

This study used both secondary and primary data. Secondary data collection involved review of existing reports (unpublished, gray and published reports) from libraries and documentation centers in various institutions in Athens, Amfissa and Lamia. Some reports were also made available through internet search. Secondary information was supplemented by primary data at “mine unit” level whereby small meeting were made with the “local non-government environmental organizations”.

For the depiction of the existing environmental situation in the study area between Kaloskopi - Kastellia - Gravia - Variani (Northeastern Ghiona), there were used contemporary and older topographical, geological and vegetation maps and older pictures.

Also in order to record the temporal evolution of the number of the opencast mines as well as to determine the burden and the changes to the natural environment and more especially the land relief and landscape, the natural geomorphological processes in the area and the hydro-geomorphological processes and phenomena of the forest ecosystems, aerial photographs were used obtained from the Hellenic Military Geographical Service (H.M.G.S.). These aerial photographs are of the years 1945, 1960, 1970 and 1986, in scale respectively 1: 42.000, 1: 30.000, 1: 15.000 and 1: 30.000, as well as satellite images (Google Earth, 2010).

The results from the interpretation of the aerial photographs were combined with data arising from the systematic *in situ* observations of the evolution of the phenomena relating to natural and human activities in the excavation sites, which activities are related to the formation of cavities (open pits) and elevations (embankments) from the deposition of the inert materials.

These local observations were conducted every 5 years during the months of February, June and September for the years 1989, 1993, 1998, 2003 and 2008, by means of twelve (12) "fixed points", in selected places at the mines "Kokinovrahos", "Agios Athanassios", "Kokinohoma", "Koukouvista 5", "Paliampela" and "Alefando".

The most important of the human interventions and activities which are in a position to disrupt the environmental balance of the area under study are (Mertzanis et al., 2006): (1) Bauxite mining (opencast mining - quarries - mines); (2) Bauxite mining (underground method-tunnels); (3) Wood cutting; (4) Deforestation; (5) Deforestation of riparian vegetation; (6) Grazing - overgrazing in the forest; (7) Forest fires; (8) Fire wood collection; (9) Opening up new agricultural and forest roads, (10) Opening up new dense road network constructed in order to get access to the mine locations; (11) Uncontrolled deposition of urban waste, industrial effluents, solid domestic and industrial waste; (12) Alteration of the physicochemical characteristics - deterioration of the quality of water (turbidity, etc), (13) Hunting - poaching, and (14) All sorts of disturbances to the birds and wildlife.

RESULTS AND DISCUSSION

The impact to the environment as a result of opencast bauxite mining

Woods and forests can provide a wide range of environmental and other benefits. The environmental destabilization of the forest environment in the mountainous regions, such as the study area, as far as the geomorphological processes are concerned is mainly due to certain anthropogenic interventions (bauxite mining activities, etc.) which alter “critical” parameters of the environment (artificial creation of large cavities and formation of voluminous piles of calcareous spoils - inert materials- derived from bauxite mining, deforestation, etc). The exact effects of bauxite mining are quite specific to the site. It nearly always involves some habitat destruction, soil erosion, inert materials deposition, loss of biodiversity, or water pollution and turbitity increase. These effects can be reasonably short term, and followed by regrowth, or severe and permanent. It is noted that those interventions that result in the alteration of the natural evolution of the geomorphological processes, usually lead to the creation of an “artificial” environment which to a great extend is man controlled, and which in turn in the long run resupplies and reinforces the environmental threats in the region (Brofas, 1987, 1989; Vavizos and Mertzanis, 2003; Mertzanis et al., 2004a, b, 2005a, b, 2006).

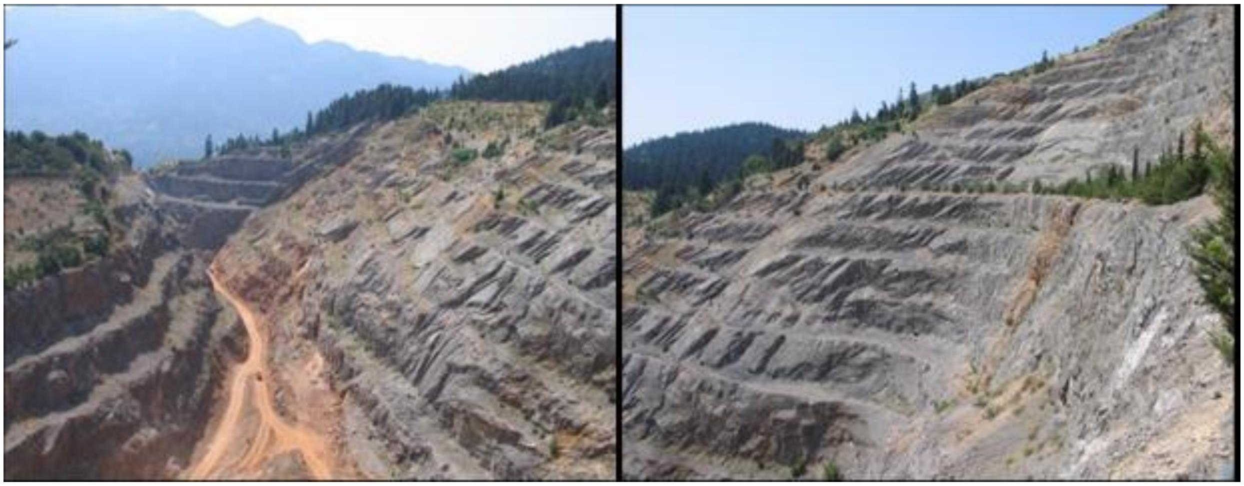
The impact to the environment is reinforced when the forest environment in the mountainous regions are burdened by human activities with the emission of pollutants or other substances, radiation or noise. This is also the case when in the area there are works or constructions of different kind and size with no prior consideration of the possibility of the destabilization of the environmental equilibrium and in general of the protection of the natural environment, the wild life and the fowl fauna of the specific area (Vavizos and Mertzanis, 2003).

The most important of these human activities in the area under study are mining activities such as opencast mines and tunnels, as well as other human interventions and activities (deforestation, grazing in the forest, forest fires, opening up new dense road network constructed in order to get access to the mine locations, etc. (Brofas, 1987, 1989; Vavizos and Mertzanis, 2003; Mertzanis et al., 2004a, b, 2005a, b, 2006).

In order to assess and evaluate the impacts to the environment that result from the mining activity, it is necessary to take into account the fact that all human activity as well as the natural phenomena, cause alterations to the environment that are in a position to cause disturbances. The term “disturbance” defines every action or row of actions that cause and affect the structure and the operations of the environment. Whether the alteration becomes disturbance, depends on the kind of natural, chemical, biological or other parameters, which are altered and on the magnitude of their alteration which in turn brings on the events which affect the structure and the operations of the environment. The transformation of “disturbances” into “impacts” depends on the ability of the environment which is subjected to the disturbances, to restore them. It is underlined that human activities (industrial plant for bauxite processing and other infrastructure areas, transportation of bauxite ore, opening up new dense road network constructed in order to get access to the mine locations, etc.) can cause environmental impacts not only as a result of the emission of pollutants (disposal of industrial wastewaters and red-mud, dust, etc.), but just as a result of their presence (US-Environmental Protection Agency, 1997, 1999; Vavizos and Mertzanis, 2003).

The mining activity of bauxite in the study area in combination with the forest fires, the illegal woodcutting, deforestation and the grazing constitute the main burden to the natural ecosystems in the Northeastern Ghiona area. The surface exploitations of the bauxite mines which was the most frequent method used in the seventies, was a method that lacked proper planning and led to the creation of a peculiar environmental entity and an human-made “artificial” environment which to a great extend is man controlled. This entity extends to large parts of forests and forest areas and is characterized by alternating excavations and mainly of stepwise mining fronts and cavities (open cast mines), which are formed when revealing the ore as well as from the voluminous depositions of the inert materials (mining spoils). The human-made characteristics of this environmental entity are aggravated by the extensive road works in the forest, that are necessary in order to make the mines accessible (Figure 8a and b).

More specifically, the main impacts (reversible or not) from the bauxite mining activities and especially from the surface exploitations (open cast mining) to the natural environment in the area, depend on the location and the size of interruption of the natural continuity of the land



Figures 8. (a) Koukouvista 5, opencast mine. (b) Distinguish vertical mining fronts (Mertzanis et al., 2004a).

relief as well as on the changes of the natural geo-morphological, hydro-geomorphological processes in the area, while in some cases there is also a very important occupation of large parts of forests and forest areas. The most important of these impacts and especially the impacts in geomorphology are described hereafter and are as follows.

Changes in the geological – hydro-geomorphological characteristics and in the natural continuity of the land relief in the area

The changes related to the interruption of the continuity of the land relief and to the change in the natural geomorphological processes in the study area are due to the use of the surface exploitation method of bauxite and more specifically: (a) In the artificial creation of stepwise excavation fronts (excavated slopes) of great heights and large cavities (opencast mine); (b) In the artificial formation of voluminous piles of calcareous spoils - inert materials- derived from bauxite mining (mining spoils); (c) In the creation of a dense road network in order to make the mines accessible (Brofas, 1987, 1989; Tsochos, 1997; Vavizos and Mertzanis, 2003; Mertzanis et al., 2004a, b, 2005a, b, 2006). It is estimated that the area taken up by the inert materials is many times over the size of the pit: It exceeds the size of the pit by an average of 3.5 times (Figure 9a and b).

These impacts, are mainly represented by the disruption or the discontinuity of the natural continuity of the land relief (opencast mines and embankments), natural geomorphological characteristics, changes in soil erosion and deposition processes, creation of acquired conditions of slope instability phenomena (creeps, land-slides, flows, rockfall, topples, debris falls, etc.), changes in the geometric layout position of the geological ore deposites as well as disruptions, shifts compactions or overlaps of the soil surface and of the geological formations.

These changes are described in detail subsequently, while is stressed that the size, the duration and the possibility of reversing of these changes are in direct correlation with location and the local environmental parameters of the area where each mine operates, as well as with the excavation characteristics and more specifically with the size, the position and the volume of excavations and the depositions of inert materials (Kaminari et al., 1989; Mertzanis et al., 2005a, 2005b, 2006):

Differentiation of the natural characteristics of water drainage: The steep slopes of the opencast mines in the excavation fronts, and the stripping of vegetation-deforestation, result in the increase of volume and speed of the surface water drainage and the limitation of percolation to the groundwater -aquifers-. The opposite phenomenon, that is the increase of percolation is observed in the artificial cavities (open cast mines) and in the planes at the bottom of the open cast mines as well as in the depositions of the inert materials, especially in cases where large areas are concerned and where it is allowed by the concentration, the soil composition, grain size and grain size distribution, permeability coefficient and hydraulic conductivity of the geological formations of the area (Papaspirou and Papapetrou,1983; Kaminari et al., 1989).

Increase of soil degradation and gully erosion rates: The large excavations in the opencast mining fronts, that have an artificial formation of upright slopes to the order of 80 to 90%, in connection with the already existing relief, and the stripping of vegetation-deforestation in combination with the construction of dense road network

Figures 9. (a) Inert materials deposits (bauxite mining spoils) on Koukouvista 5 opencast mine, at an early stage of restoration. (b) Detail of the restoration terraces construction by earthmoving machinery-excavator (Mertzanis et al., 2004a).

in order to make the sites of mining accessible, which has new road gradients (7 to 10%) and longitudinal excavation have induced changes in the direction of movement and the normal flow conditions of the surface waters that flow in the uphill parts of the drainage basins, according to the processes of laminar flow and in small scale branches of the hydrographic network. The compaction of the roads causes a serious decrease in the infiltration capacity. Therefore, the discharge of mountain torrents and the surface waters are forced to abandon their normal routes due to the condensation and the waterproofing of the road surface and either follow its gradient or overflow from the artificial banks, and the result is that the soil degradation phenomena, phenolmena of in-depth gully and retrogressive erosion on mountain pastures and in forests are intensified (Tsochos, 1997; Strunk, 2003).

Increase of the acquired phenomena of soil erosion and mass movement in the vegetation - stripped embankments of inert materials: The extended and high rising deposits of inert materials (embankments) that have resulted and that have increased bank slopes (around 70 to 90%) and low soil-mechanic characteristics, in combination with the absence of dense vegetation and special protective works, increase the possibility of creation of acquired phenomena of erosion and slope instability (creeps, lanslides, flows, topples, etc.) (Mertzanis et al. 2004a). These phenomena are of limited extend in the study area and are dealt with mainly by the formation of steps and the plantation of the deposits banks of inert materials (embankments).

Changes in the surface and underground waters

These changes are represented by the differentiation of the course or the direction of flow of the surface and underground waters, their quality and quantity, as well as by the changes in the rate of absorption of surface waters and the drainage routes or the rate and quantity of ground washing (Papaspirou et al., 1983; Kaminari et al., 1989; Mertzanis et al. 2004b, 2005a; Ezeh and Chukwu, 2011):

Increase of the turbidity: The deposition of inert materials in places different from the initial ones, and the artificial enbankments of the dense road network that make the mines accessible, favour the development of acquired erosion phenomena by the surface water and the selective transportation of the finer grain size portions (suspended particulate matter and sediments), downstream. These products bring about an increase of solids contents-turbidity in water receivers (rivers and torrents), especially during times of heavy rainfall and are directed downstream, through the hydrographic network where they are deposited in places where the morphology allows. The result of these processes is the gradual increase of the accumulation of deposits in the bank of the river Fokikos Kifissos in the area between Kato Tithorea and Kastro, where for the reasons mentioned previously and in order to avoid floods at some spots, deepening works are held in the riverbed, while at the same time, changes in the composition of the farmland of the aforementioned areas cannot be ruled out (Adamakopoulos et al., 1988; Kaminari et al.,


(a) (b)

Figures 10. (a) Dense road network constructed in order to get access to the Kokinovrahos opencast mine (Mertzanis et al., 2005b). (b) Obstruction of water courses due to deposition of inert material inside the streambed, in the Kokinovrahos opencast mine area (Mertzanis et al., 2004a).

1989; Mertzanis et al., 2004b).

Obstruction of water courses: The deposition of inert material inside the riverbed of the streams-torrents discontinues the normal mountain small turbulent streams discharge and in some cases leads to the creation of small occasional lakes. A characteristic example of this voluminous bauxite mining spoils – deposits of inert materials- inside the riverbed of the Kranorema torrent and anonymous stream that drains the "Oinoxori" drainage basin as well as the anonymous stream that drains a small drainage basin, into the stream Mega, west of Kastellia (Mertzanis et al. 2004b) (Figure 10a and b).

Deterioration of the landscape of Northeastern Ghiona

The deterioration of the landscape is a result of the differentiation of the character of the relief and of the creation of visual changes due to the destruction of its natural characteristics, which are the vegetation, the ground, and the rock formations. The destruction of the natural characteristics that existed prior to the mining activities is accompanied by the deterioration or the total disappearance of the initial visual characteristics of the natural landscape, which are the lines, texture and colour, and from its replacement with new artificial visual characteristics. These new artificial visual characteristics have deep strongly, bright colors and white spots, geometrical lines and shapes, differentiated texture and sizes which dominate in the landscape due to the removal of volume of rocks and ore from the area of the opencast mines and the deposition of inert materials in heaps, downhill or in neigbouring places (Brofas, 1987) (Figure 11a and b).

Changes in air quality

The changes in air quality are due to the creation of dust and the emission of exhausts from the heavy vehicles used for the transportation of the ore and the inert materials, while they arise during the mining activities (excavations, drillings, explosions) and they are capable of creating health problems to the people working there who are systematically exposed to them (Crounse et al., 1983). These impacts mainly concern the phase of the excavating activity and are limited to a minimum at the abandoned mines.

Changes in the microclimate

The changes in the microclimate are due to the presence of uncovered areas in the limestone excavation fronts, in the open cast mines and deposition areas of inert materials, which act as "heat collectors", resulting in very high temperatures especially at midday during summer time. This phenomenon is also considered responsible for the drying out of a fir nursery in a mine of Ghiona (Brofas, 1989).

Generation of noise and vibrations

The generation of noise and vibrations are due to the drilling of the ore, the explosions and the blowing up and more generally all the activities during the mining of the

Figures 11. Shrinkage of forests, in the under study area, due to the successive vegetation gaps which result from the opencast mines necessary to reveal the bauxite ore and from the occupation of space for the deposition of inert materials (Mertzanis et al., 2005a).

effects concern the working mines.

Changes in fauna and flora - deforestation - habitat destruction

The most important of these changes are the deforestation, shrinkage of forests, forest areas and grasslands, due to the successive vegetation gaps which result from the opencast mines necessary to reveal the bauxite ore and from the occupation of space for the deposition of inert materials (Veresoglou, 2002; Adamakopoulos et al., 1988). Another important change in fauna and flora is the home-range de-fragmentation due to dense road network constructed in order to get access to the mine locations. Note that the forests provide a wide range of environmental and other benefits. A significant impact is the disappearance of the multiple benefits of the pre-existing forest parts which were depilated for the purposes of developing opencast and underground mining for revealing bauxite ore. The most important of these benefits being the production of timber and secondary exploitation, the anti-erosion and the protection of the ground, the regulation of water economy, the supply of food and shelter to wild animals and birds as well as the control of climate and the aesthetic side of the landscape (Brofas, 1987). Together with the excavation-opencast and underground mining activities but also in quite a few cases after that, in the uphill borders of "Koukouvista 5" mine, the multiple forestfires worsened the negative impacts to the fauna of the study area, since all the nesting and food places for many kinds disappeared, drawing away also all these kinds, thus resulting in the limitation of these kinds of fauna (Adamakopoulos et al., 1988) (Figures 12a and b).

Conclusions

The impacts to the natural environment and more specifically the disruption of the morphology of the land relief as well as changes of the natural geomorphological, hydro-geomorphological processes in the area of Northeastern Ghiona, as a result of the bauxite mining activities are inevitable. Also one important change is the shrinkage of forests, forest areas and grasslands, due to the successive vegetation gaps which result from the excavations (opencast mines) necessary to reveal the bauxite ore and from the occupation of space for the deposition of inert materials. Significant is the burden to the natural ecosystem of the area from the exploitations of the bauxite mining activities, and especially the open cast mines, that were very intense during the seventies.

The mining activity in the study area and especially the surface exploitations of the bauxite was practiced without proper planning and led to the creation of a peculiar environmental entity and an “human-made” environment which to a great extend is man controlled. This entity extends to large parts of forests, forest areas and grasslands and is characterized by alternating excavations and mainly of stepwise mining fronts and cavities (open cast mines), which are formed when revealing the ore as well as from the voluminous depositions of the inert materials (mining spoils). The “human-made” characteristics of this environmental entity are aggravated by the extensive road works that are necessary in order to make the mines accessible.

(a) (b)

Figures 12. (a) Inert materials deposits (bauxite mining spoils) on Koukouvista 5 opencast mine, before restoration (Mertzanis et al., 2006). (b) Inert materials deposits, on Koukouvista 5 opencast mine, at an early stage of restoration (Mertzanis et al., 2004a).

The proliferation, the extent, the duration and the reversibility of the impacts to the environment due to mining activity, and especially to the hydrogeo-morphological characteristics and processes are in direct correlation and are differentiated in each case depending on: (a) The location and the local environmental conditions of the area where each mine is found, and (b) The characteristics of the mining activity which have to do mainly with the plan used for dealing with the mine and more especially depending on the size, location and volume of excavations and of the depositions of inert materials as well as the way of its formation.

The data and references relevant to the temporal evolution of the number of open cast bauxite mines in Northeastern Ghiona since 1945 also confirm the mechanism of operation and development of the intense, uncontrollable and non-rational exploitation of the mineral deposits (ores). Note that despite a small increase of the number of surface exploitations, the years 1970 to 2011, excluding open cast mines that have stopped functioning (slow mines), significantly increased the size of the surface occupancy (surface width) of the open cast bauxite mines.

The surface exploitation of bauxite in the study area was significantly limited after the implication of Laws 998/79 and 1650/86, which prohibited the development of surface exploitations, while at the same time made mandatory the environmental impact assessment studies and the imposition of environmental terms for mines located in forests and forest areas.

The exploitation of the ores was mainly counter-balanced with the use of the underground method of mining. The land restoration of the abandoned mines mines was also considered imperative.

ACKNOWLEDGMENTS

The author wish to thank the authorities and local governments (Fokida and Fthiotida prefectures) for the information about the environmental protection status of the areas of competence, as well as the colleagues and assistants in the field of studies for their friendship and help.

REFERENCES

Adamakopoulos T, Sfikas G, Hatzivarsanis B (1988). Evaluation and Management of the Ghiona ecosystem. Protection of National forests, p. 94 (in Greek)

Brofas G (1987). Investigation for the restoration of land in the quarrying area of Penteli. Study for the restauration of the landscape at the Penteli quarrying site. Forest Investigation, 149-186 (in Greek).

Brofas G (1989). Land restoration in mines. Conference of Geotechnical Chamber of Greece, 12-13 April, Athens (in Greek).

Brofas G, Varelides C (2000). Hydro-seeding and mulching for establishing vegetation on mining spoils in Greece. Land Degradation and Development, July/August 2000, 11(4): 375-382.

Brofas G., Mantakas G., Tsagari K and Mermiris Ch (2007). Evaluation of revegetation techniques on mining spoil slopes. Developments in Plant and Soil Sciences. Proceedings of the International Conference "Eco-Engineering: The use of vegetation to improve slope stability", 13-17 September 2004, Thessaloniki, Greece, Stokes et al. (eds), Springer Netherlands, 103: 419-427.

Castiglioni GB (1997). Geomorfologia, Torino, UTET, p. 436.

Crounse RG, Pories WJ, Bray JT, Mauger RL (1983). Geochemistry and Man: Health and Disease, 1. Essential elements. 2. Elements possibly essential, those toxic and others, in: Applied Environmental Geochemistry, ed. I. Thorton, Academic Press, London, pp. 267-333.

Ezeh HN, Chukwu E (2011). Small scale mining and heavy metal

Small scale mining and heavy metals pollution of agricultural soils: The case of Ishiagu Mining District, South Eastern Nigeria. Academic Journals. J. Geol. Mining Res., 3(4): 87-104.IGSR - Institute of Geology and Subsurface Research (1960). Geological map of Greece. Amfissa sheet, p. 1.

Kaminari M, Mertzanis A, Konstandinidou R (1989). Environmental effects from mining activities in Ghiona Mountain Conference of Environmental Science and Technology, 4-7 September, Mitilin, p. 116-130 (in Greek).

Mariolakos I, Sambo B, Fountoulis I, Logos E, Lozios S, Mertzanis A (1987). The Polgi of Poliani. First Hellenic Geographical Convention, Athens, p. 40-52 (in Greek), 103: 411-417.

Mertzanis A, Papadopoulos A, Pantera A (2004a). Acquired instability effects of the landforms, in artificially modulated banks of excavations and bankfills, along the road Thermopylae-Nafpaktos, in the area between Damasta-Skamnos (Ftiotida-Greece). International Conference "Eco-Engineering: The use of vegetation to improve slope stability", 13-17 September, Thessaloniki, Greece, 103: 411-417.

Mertzanis A, Papadopoulos A, Marabini F (2004b). Effects of mining activities of bauxite ores on the hydro-geomorphological characteristics of forest ecosystems of Mountain Ghiona. 4th Hellenic grassland Conference. Hellenic grassland Society, 10-12 November 2004, Volos, p. 517-524 (in Greek).

Mertzanis A, Papadopoulos A, Pantera A (2005a). The impacts to the environment and the creation of «pseudokarst» landforms, from the bauxite mining activity in the mountain of Ghiona (Central Greece). CD-ROM Proceedings of the 14th International Congress of Speleology. 21-28 August 2005, Athens-Kalamos, Greece.

Mertzanis A, Efthimiou G, Papadopoulos A, Papadopoulos A, Skotida A (2005b). The marble quarrying works in the Penteliko mountain, from the ancient times until today and the environmental impacts (Attica-Greece). 3rd International Symposium "Metallurgy in Southeast Europe from Ancient Times till the End of 19 th Century, 26-30 September 2005, Sozopol, Bulgaria, I: 175-179.

Mertzanis A, Papadopoulos A, Pantera A, Kalantzacos C, Alexouli-Livaditi A (2006). The surface mining of bauxite and its impacts to the natural environment of northeastern Ghiona. 2nd International Conference on "Advances in Mineral Resources Management and Geotechnics", 25-27 September 2006, Chania, Crete, Greece, pp. 665-672. ISBN 960-89228-1-X.

Monroe WH (1970). A Glossary of Karst Terminology. Geological Survey Water-Supply Paper 1899-K. U.S. Geological Survey. U.S. Government Printing Office. Washington, D.C. p. 26.

Monroe JS, Vicander R (1989). Physical Geology. Exploring the earth. Wadsworth Publishing Company. U.S.A., p. 648.

Ochenkuhn KM, Parissakis G (1977). Quantitative Untersuchungen von Bauxiten Zentralgriechenlands mittels atomabsorptions-Spektroskopie and Flammenatomemission. Microchimica acta, I: 447-457.

Papapetrou – Zamani A (1990). Notes on geomorphology. Athens, p. 176 (in Greek).

Papaspirou D, Papapetrou P (1983). A report aiming at giving information on ways of dealing with the problems between the company "Bauxites of Parnassos" and the county of Kastelia in Fokida. Unpublished report. IGME, p. 1-6 (in Greek).

Papastavrou S (1986). Greek Bauxites. I.G.S.R. edition, p. 53 (in Greek).

Strunk H (2003). Soil degradation and overland flow as causes of gully erosion on mountain pastures and in forests. CATENA, 50(2-4): 185-198.

Theodoropoulos D, Zamani A (1972). Karstic phenomena of Crete. The polges of Nida and Katharos. E.G.E Bull., 9(2): 82-92. Athens (in Greek).

Tsochos G (1997). Environmental road construction, Athens, University Studio Press, p. 270 (in Greek).

US-EPA - Environmental Protection Agency (1997). Terms of Environment: Glossary, Abbreviations and Acronyms. [online] Washington, D.C. Available from: http://www.epa.gov/OCEPAterms.

US- EPA - Environmental Protection Agency (1999). Considering Ecological Processes in Environmental Impact Assessment. National Service Center for Environmental Publications, US. p. 87

U.S. Geological Survey (2009). Mineral Commodity Summaries. p. 195

Vavizos G, Mertzanis A (2003). Environment - Studies of Environmental Impact, Athens, Papasotiriou, p. 342. (in Greek).

Veresoglou D (2002). Ecology. Larisa, Perifereiakes Ekdoseis "ella", p. 417 (in Greek).