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# The Contribution of Geological Maps and Mapping to Industrial Scale Design †

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**Abstract:** The aim of this work is to highlight the contribution of geological maps and mapping to industrial scale design. To achieve this goal, the site selection of a new quarry area is used as an example. For the development of a new quarry, the materials to be mined must meet specific requirements, mainly acceptable quality, adequate reserves, environmental restrictions, and economic viability. Geological maps of various scales were used in all stages of this research project. Initially, geological surveillance maps (1:50,000), which formed the basis for the sampling, were used. Finally, this research project was completed with the detailed mapping of two candidate areas for the development of the new quarry.

**Keywords:** geological maps; geological mapping; aluminosilicate composition; cement industry; TITAN S.A.



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## 1. Introduction

The alkali content of cements influences the properties of the end products: for example, high content of alkalis in clinker generally results in a decrease in final strength, or, the effects of increased alkali content on the hydration processes are manifested in the engineering properties of cement pastes and the produced concrete [1]. Alkali–aggregate reaction (AAR) is a deleterious chemical reaction that occurs in concrete structures. AAR involves two different reactions: the alkali–silica reaction (ASR), which occurs primarily with aggregates containing reactive silica ($SiO_2$), and the alkali–carbonate reaction (ACR) with carbonate minerals such as dolomite ($CaMg(CO_3)_2$). In 1957, ACR was identified as another type of AAR, where alkalis in the pore solution react with dolomite from the aggregates to form expansive phases, which induce cracking. ASR is the most common form of AAR and has been identified as the cause of volume expansion and cracking in many concrete structures worldwide [2,3]. For this reason, low alkali aluminosilicate raw materials acquired special value in the cement industry. The aim of this work is to highlight the contribution of geological maps and mapping to industrial applications, in the context of the search for low alkali raw materials. A typical application of geological maps and mapping is the process of locating an area of interest for quarrying purposes (industrial minerals). The new quarry area should fulfill all the necessary pre-conditions and restrictions (in terms of quality, reserves, environment, critical distances, economy, etc.) in order to supply low alkali aluminosilicate raw materials in the existing cement production line of the TITAN CEMENT Company S.A. in Drepano, Achaia, Greece. In addition to the other criteria, chemistry and distance were the other primary considerations for determining the design of the project. Existing geological maps (which formed the basic layer for the sampling campaign) played a decisive role in the design and implementation of the project, and also factored into determining the appropriate scale of the final geological mapping of the candidate areas (Figure 1).

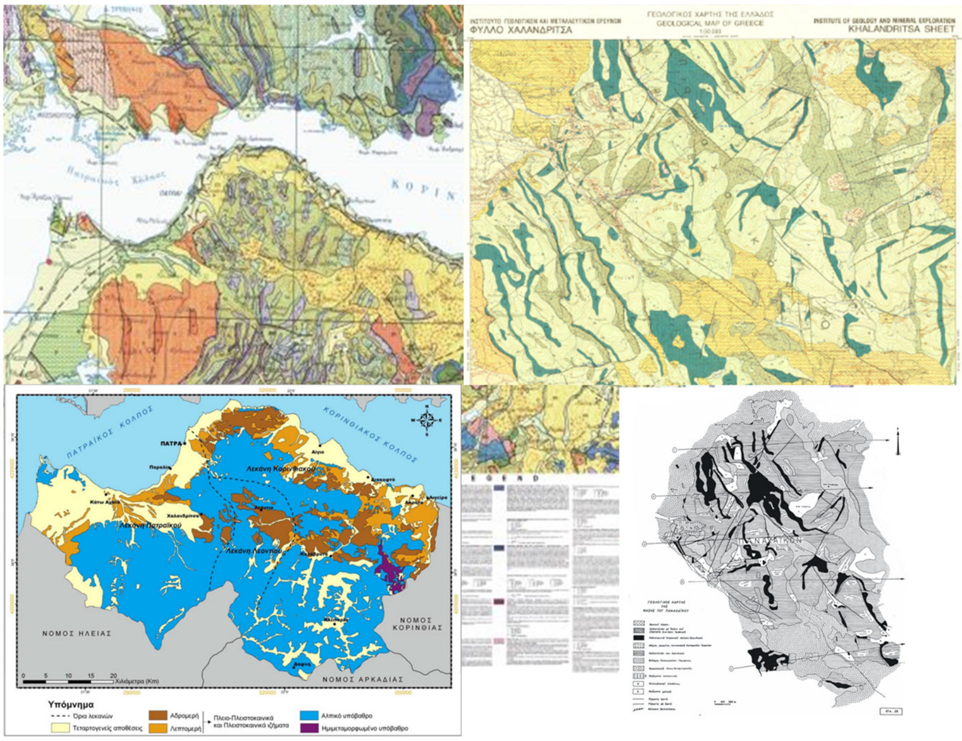


**Figure 1.** Different kinds of geological maps used for this study. Explanations are provided in text.

## 2. Background

For the development of a new quarry, the materials to be mined must meet specific requirements, mainly acceptable quality, adequate reserves, environmental restrictions, and economic viability. More specifically, the chemistry of the material to be searched must be within the limits, as illustrated in Table 1.

**Table 1.** Percentage limits of the oxides of the searched raw materials.

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O + Na_2O$ |
|---|---|---|---|---|---|
| >65% | 8–12% | 4–5% | <3% | <1% | <2% |

A search without criteria for targeting a new location would lead to the collection of several hundred samples from the wider area and different lithologies formations. The quality of raw materials needed is directly related to the chemistry and homogeneity of rocks in adequate quantities (in-situ reserves), which in turn depends on the lithology, stratigraphic structure, spatial distribution, and the tectonics of the formations. Additionally, the environmental criteria that the new quarry zone must meet are essential and therefore crucial for the selection or rejection of sites/areas.

Most geological maps record the regional distribution of rocks belonging to different formations. However, such maps reveal far more than where rocks belonging to a given formation can be found. The geometrical shape of the different formations on the geological map can also be interpreted in terms of the geological structure and geological history of the region concerned. Accurate geological maps form the basis of most geological work, even at the laboratory scale. They are used to solve problems in earth resource exploration (minerals and hydrocarbons), civil engineering (roads, dams, tunnels, etc.), environmental geoscience (pollution, landfills), and hazards (landslides, earthquakes, etc.) [4]. In order to search for possible sites, all accessible data were collected and studied: from the extract of the supervisory/reconnaissance geological map of Greece for the area [5], the main geological sheets that cover the potential research area around the cement plant in Drepano (Patras and Khalandritsa sheets), as well as maps from doctoral theses [6,7] concerning the spatial distribution of alpidic and post-alpidic rocks in the area.

## 3. Procedure

The procedure's starting point is the adequate and detailed knowledge of the raw materials to be sought after, in order to sufficiently restrict the number of the geological formations that would potentially supply the raw materials in need.

As previously mentioned, the raw material to be searched must fulfill the following pre-conditions: it must be an aluminosilicate mineral, low in alkali content and at the same time free of high concentrations of calcium and magnesium oxides, located at a distance of less than 50 km from the cement factory in Drepano, and not be located in protected areas such as Natura 2000 (Figure 2).

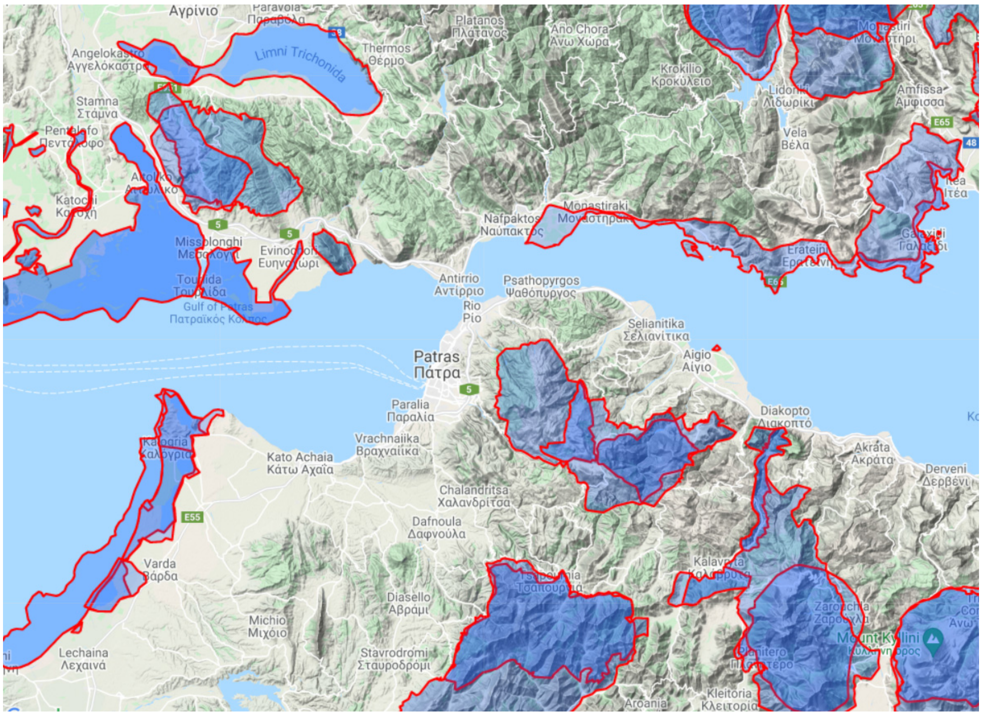


**Figure 2.** Map with Natura 2000 areas distribution in wider area of interest [8].

Based on these criteria, the rock formations of the geological area of interest within the prefecture of Achaia were examined, initially based on their basic geochemical characteristics. According to the above data, Table 2 was prepared, which concerns the formations/deposits of the zones of Olonos-Pindos and Gavrovos-Tripoli as well as of the post-alpine sedimentary rocks. This classification is the first surveillant approach for the spatial distribution of chemically suitable/unsuitable raw materials with data that were easily extracted from existing geological maps. As becomes obvious in this case, the geological maps, in addition to the spatial distributions of the rocks and their structures, also provide supervisory data on their chemistry.

The first conclusion drawn from the analysis of Table 2 data is that a specific formation of the Olonos–Pindos zone is of special interest, which in the aforementioned geological maps (sheets "Patrai" [9] and "Khalandritsa" [10], scale 1:50,000) is referred to as "radiolarites". In the purely scientific sense of the word, "radiolarites" are a rock that emerged from radiolaria that were zooplankton and created in geological time a bio-clastic sediment and then a rock of silicate composition. In the geological maps of the Greek Institute of Geology and Mineral Exploration (IGME), however, this term is used not as an absolute paleontological definition, but as a characteristic horizon that can be mapped. However, this formation in its physical appearance in the field (and therefore in its appearance on geological maps), also includes in places, apart from the core silicate composition, material alternations with limestones, clay minerals, and tuffs. As for its chemistry, there are noticeable differences between the pure radiolarite in nature and the "radiolarite" that is mapped/characterized as such on geological maps. In our case, the "radiolarites" of the Pindos zone are of crucial interest, as they develop in the wider study area, but also due to the fact that they are basic components of the post-Alpine sediments and rocks (Figure 3), as shown in Table 3. These chemically heterogeneous formations were approached geochemically by targeted two-stage sampling, which was also based on geological maps.

**Table 2.** Classification of the geological formations that appear in the wider area of the Prefecture of Achaia, in terms of their suitability as raw materials for the production of low alkali cement. Stratigraphic column homogenized based on the geological maps of IGME (sheets "Patrai" [9] and "Khalandritsa" [10], scale 1:50,000).

| | | |
|---|---|---|
| Quaternary deposits | Polygenetic breccio-conglomerate, with terra rossa, red loam, and chert fragments, which are weathering products of radiolarites. In places high alkali values. | Suitable Materials Under Conditions |
| Neogene deposits | Marls, clays, calcareous marls, coarse-grained sands, sandstones, conglomerate. In the areas of Chalamdritsa, Kataraktis, and Leodio, the top of Pliocene deposits is covered by cohesive conglomerate. In places, high alkali values. | Suitable Materials Under Conditions |
| Paleocene–Oligocene deposits | Flysch of Tripolis and Pindos zone. (alternation of clay and sandstone layers). High alkali values. | Unsuitable raw materials for cement production |
| Upper Cenomanian—Paleocene deposits | Limestone and flysch. High values of calcium oxides and alkalis. | Unsuitable raw materials for cement production |
| Jurassic–Lower Cretaceous deposits | Radiolarites, clays, and tuffs. In places, high alkali values. | Suitable Materials Under Conditions |
| Upper Triassic deposits | Limestone, cherts, and flysch. High values of calcium oxides and alkalis. | Unsuitable raw materials for cement production |

These different lithostratigraphic formations that appear at an acceptable distance from the cement factory are groups of rocks of different ages and different stratigraphic and tectonic evolution, which belong to more than one geotectonic zone and appear with different lithological and mineralogical compositions, all of which, ultimately, delimit and also determine their chemistry.

**Table 3.** Distribution of oxides from selected areas.

| Oxides | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | (sum) | LOI |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 65.15 | 14.91 | 7.63 | 1.3 | 1.35 | 1.66 | 0.07 | 0.11 | 92.18 | 6.65 |
| B | 25 | 2.07 | 1.46 | 42 | 0.14 | 0.55 | 0 | 0.09 | 71.31 | 28.17 |
| C | 61.75 | 12.1 | 6.77 | 4.48 | 2.37 | 2.45 | 0.73 | 0.11 | 90.76 | 8.17 |
| D | 92.4 | 2.16 | 2.01 | 0.72 | 0 | 0.39 | 0 | 0.12 | 97.8 | 1.45 |
| Limits | >65 | 8–12 | 4–5 | <3 | <1 | <2 | | | | |

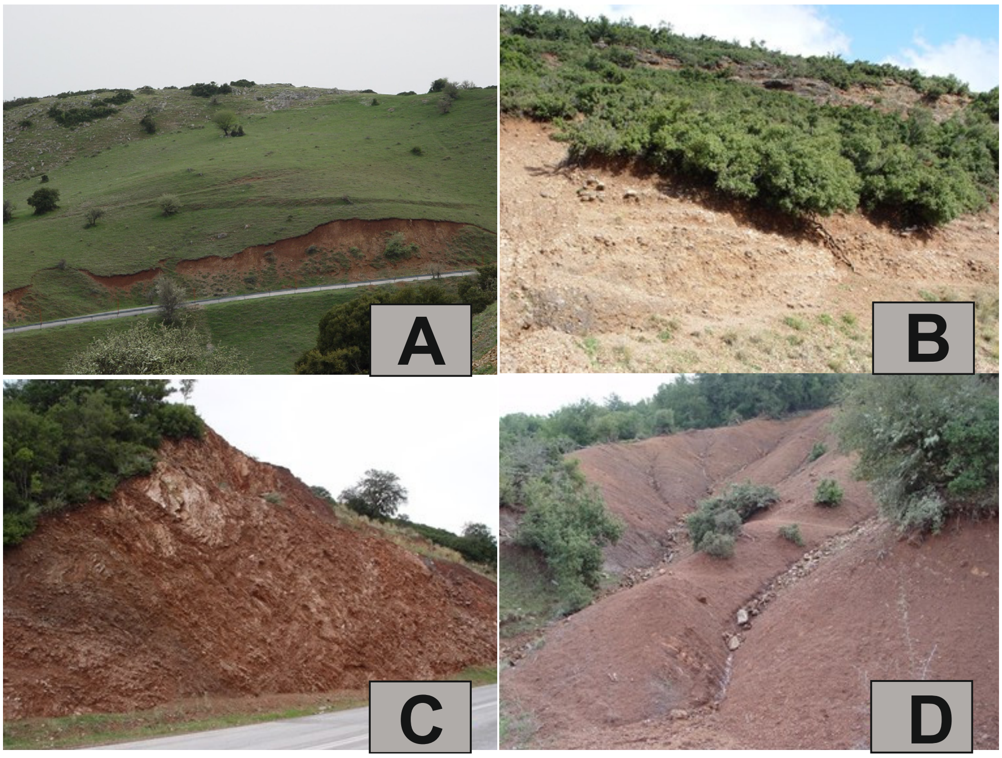


**Figure 3.** (**A**): Transition from radiolarites to terra rossa, on the regional road network Aigio—Fteri—Petsaki, Prefecture of Achaia, (**B**): Plio-Pleistocene conglomerates between the settlements Lagadi—Kalanistra, (**C**): Radiolarites before the settlement Kataraktis, (**D**): Radiolarites in the area Rachi Striglou, Panachaiko mountain.

## 4. Results and Conclusions

By using as background information the existing geological maps of the wider area, among dozens of outcrops investigated, a group of ten areas of potential interest were identified and focused upon. From these ten focus areas, the first sampling was performed, in order to characterize the chemistry of the host rocks.

Next, based on the results of the initial geochemical evaluation, a detailed geological mapping of the outcropping structural formations was performed in the most promising three areas of interest.

Finally, based on the collected data (spatial distribution, geometric characteristics, geologic type, chemistry, etc.), a spatial valuation and an initial reserves evaluation was performed with the aim of producing a preliminary design of a new quarry in the most promising area. The calculation and the targeting were conducted with respect to the expected needs in aluminosilicate raw materials for the next few decades by the cement factory, in such a way that a low alkali cement can be produced without any scarcity of raw materials. In order to minimize the drilling costs of reserves evaluation in the development area of the new quarry, the method of surface sampling at pre-specified grid sites could be used, parallel with a detailed mapping. This is a method that has already been applied by the company in another quarry area.

## 5. Conclusions

Geological maps are static representations of the spatial distribution of three-dimensional geological bodies with special physical and chemical characteristics. Geologists and engineers become acquainted with geological maps during the first years of their studies. Geologists in the last years of their studies will have to construct a geological map while engineers will have to prove that they are able to use a geological map effectively. The wider geoscientific literature lacks examples of the use of geological maps and geological mapping. This gap is being filled by this work. Geological maps and mapping were effectively and systematically applied in order to address the long-term planning needs of TITAN CEMENT S.A., cement plant in Drepano, Patras, Greece. The end result was a final proposal for a new quarry site, with sufficient reserves with low alkali aluminosilicates and of in-specs quality.

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