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Determination of the interrelations between the engineering parameters of construction aggregates from ophiolite complexes of Greece using factor analysis

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HIGHLIGHTS

- The samples are grouped into: ultramafic rocks, altered ultramafic rocks, troctolites, dolerites–diorites, and trachytes.
- Factor analysis indicates a great number of interrelations between the aggregate properties.
- The correlations among the aggregate properties reflect changes in their petrographic features.
- Factor analysis contributes to a deeper understanding of the way that the properties of aggregates change in-service.
- The mafic and fresh ultramafic rocks are the most suitable for use as aggregates.

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ABSTRACT

The goal of this paper is to investigate the interrelations between the engineering parameters of construction aggregates from Greece using R-mode factor analysis. The studied samples include ophiolitic lithotypes from the Pindos, Vourinos, Koziakas and Othrys ophiolites, as well as two trachytes from the Domokos locality. They show various degrees of hydrothermal alteration and tectonic deformation. Factor analysis indicated a great number of interdependences between their physical, geometrical, mechanical and physicochemical properties. Based on the diagrammatic representation of factor scores, the samples are grouped into: (i) ultramafic rocks, (ii) highly serpentinized and tectonized ultramafic rocks, (iii) troctolites, (iv) dolerites–diorites, and (v) trachytes. The results imply that factor analysis contributes to a deeper understanding of the way that the strength properties of aggregates change in-service.

1. Introduction

The study of the engineering properties of ophiolitic rocks is of special significance, since they are used extensively as construction materials, including aggregates for highway works, concrete, mortar, railway ballast and filter media. Ophiolites are products of complex tectonic and magmatic processes that operated during the initial rifting through seafloor spreading to subduction-facilitated emplacement stages of ancient oceanic lithosphere in various tectonic settings [1,2]. A complete ophiolite suite is made up of an association of typical rocks in a clearly defined sequence. In general, it consists from bottom to top of ultramafic, mafic, hypabyssal and extrusive rocks. However, this succession is idealized and is usually disturbed as the ophiolitic complexes occur mainly in tectonic zones with superposition of numerous overthrusts. The various rock types of an ophiolite exhibit a wide range of chemical compositions, as well as of mineralogical and textural features, thus the existence of lithotypes with variable engineering characteristics is very common even in the same suite. Hydrothermal metamorphism and deformation typically obscure primary petrographic characteristics of ophiolitic rocks, leading to a modification of their physicomechanical properties [3,4].

The constituent minerals, texture, degree of chemical alteration, weathering and deformation of the various lithotypes substantially control their quality as aggregate material, as well as the

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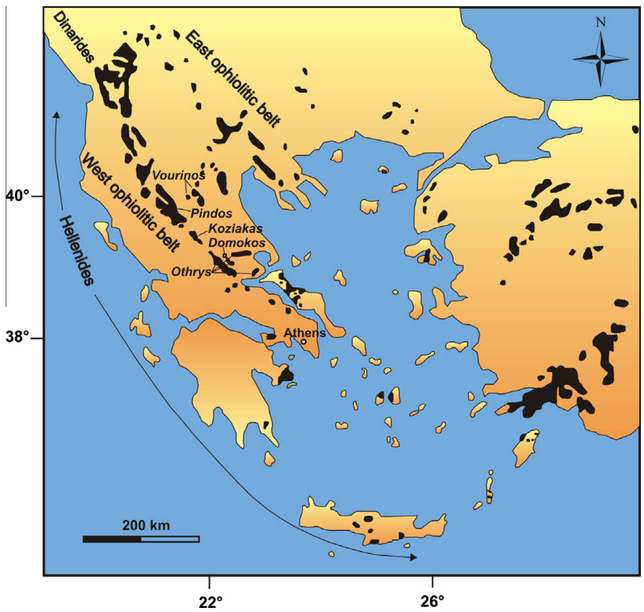

Fig. 1. Simplified map showing the sampling areas and the distribution of the ophiolitic outcrops of Greece and neighbouring countries.

interrelationships between their engineering parameters [5–9]. Fresh ophiolitic rocks have a wide range of uses in the construction industry; however, ocean-floor metamorphism variously changes their strength properties [4,10].

The most common statistical method used for the determination of the correlations between the various engineering parameters of rocks is regression analysis e.g. [9,11,12]. However, many researchers have pointed out the significance of the application of other mathematical methods in the various geological fields [13–16]. Mathematics can be of essential aid in formulating conceptual models and scientific theories to integrate diverse geological phenomena. Factor analysis may be a useful mathematical method for assessing the interrelations between rock variables, especially in the study of large data sets. It is a statistical method used to describe variability among observed variables, in terms of a potentially lower number of unobserved variables called factors. This method has been successfully applied in engineering geology [17], hydrochemistry [18,19], geochemistry [20] and environmental oceanography [21]; however, it is applied for the first time for the investigation of crushed rock aggregates.

The aim of this research is to study the interrelationships between the engineering parameters of ultramafic and mafic samples, collected from ophiolite suites of Greece. For this reason, a wide range of lithotypes were collected from the ophiolite complexes of Pindos, Vourinos, Koziakas and Othrys. Two samples of Triassic volcanic rocks were also collected from an exposure located to the north of the Othrys mountain.

2. Geological setting

The Pindos, Vourinos, Koziakas and Othrys ophiolite complexes are the most well-known ophiolites occurring within the Dinaric–Hellenic ophiolite belt of Western Greece (Fig. 1). The Pindos and Vourinos ophiolites, located in northern Greece, are thought to be continuous beneath the Cenozoic molasse of the Mesohellenic trough [22,23]. The Koziakas ophiolitic complex is situated in western Thessaly (central Greece) and is interpreted as an incomplete ophiolite sequence, thrust over the Western Thessaly Unit [24,25]. The Othrys ophiolite, located in central Greece, is a strongly dismembered ophiolite sequence and forms the uppermost tectonic unit of a series of reversely imbricated thrust sheets [26,27]. Additionally, two Triassic volcanic samples were collected 3.5 km SE of the Domokos village (Fig. 1). This exposure has been interpreted as a felsic constituent of the rift-related Agrilia Formation [28,29].

Table 1
Petrographic characteristics of the investigated samples.

No.	Sample code/ locality	Lithotype	Texture	Primary minerals	Secondary minerals
1	PKZ1/Pindos	Dunite	Granular, porphyroclastic	Ol, Opx, Sp	Serp, Tc
2	PKZ2/Pindos	Ol-rich harzburgite	Granular, porphyroclastic	Ol, Opx, Sp	Serp, Tc
3	PKZSR1/Pindos	Harzburgite	Cataclastic, mesh, ribbon	Ol, Opx, Cpx, Sp	Serp, Tc, Chl, Tr/Act, Cc, Ox
4	VVD1/Vourinos	Dunite	Mylonitic, porphyroclastic	Ol, Opx, Sp	Serp
5	VVD2/Vourinos	Ol-rich harzburgite	Mylonitic, porphyroclastic	Ol, Opx, Sp	Serp
6	VKOR1/Vourinos	Dunite	Granular, cataclastic	Ol, Opx, Sp	Serp
7	VKOR2/Vourinos	Ol-rich harzburgite	Cataclastic, porphyroclastic	Ol, Opx, Sp	Serp
8	VRZ1/Vourinos	Dunite	Granular, cataclastic	Ol, Opx, Sp	Serp
9	VRZ2/Vourinos	Dunite	Cataclastic, porphyroclastic	Ol, Opx, Sp	Serp, Cc
10	VAET1/Vourinos	Dunite	Mesh, granular	Ol, Sp	Serp, Chl
11	VAET2/Vourinos	Dunite	Mesh, granular	Ol, Sp	Serp, Chl
12	VVDSR1/Vourinos	Harzburgite	Cataclastic, porphyroclastic, mesh, ribbon	Ol, Opx, Sp	Serp, Cc, Ox
13	KOZ1/Koziakas	Pl-bearing lherzolite	Granular, porphyroclastic, interstitial	Ol, Opx, Cpx, Pl, Sp	Serp, Tc, Chl, Tr/Act, Ox
14	KOZ2/Koziakas	Harzburgite	Cataclastic	Ol, Opx, Sp	Serp, Tc, Chl, Ox
15	PKD1/Pindos	Troctolite	Granular	Ol, Opx, Cpx, Pl, Op	Serp, Chl, Ep, Qz
16	PKD2/Pindos	Troctolite	Granular	Ol, Opx, Cpx, Pl, Op	Serp, Chl, Ep, Qz
17	OTH1/Othrys	Diorite	Granular, porphyritic	Pl, Hbl, Cpx, Op	Ep, Qz, Chl, Czt, Act, Ser
18	OTH2/Othrys	Diorite	Granular, porphyritic	Pl, Hbl, Cpx, Op	Ep, Qz, Chl, Czt, Act, Ser
19	PVN1a/Pindos	Dolerite	Subophitic, porphyritic	Pl, Cpx, Op (Acc: Tit)	Act, Chl, Qz, Ep
20	PVN1b/Pindos	Dolerite	Subophitic, porphyritic	Pl, Cpx, Op (Acc: Tit)	Act, Chl, Qz, Ep
21	PVN2a/Pindos	Dolerite	Subophitic, porphyritic	Pl, Cpx, Op (Acc: Tit)	Act, Chl, Qz, Ep
22	PVN2b/Pindos	Dolerite	Subophitic, porphyritic	Pl, Cpx, Op (Acc: Tit)	Act, Chl, Qz, Ep
23	B4/Vourinos	Dolerite	Subophitic	Pl, Cpx, Op (Acc: Tit)	Act, Chl, Qz, Ep, Cc
24	B5/Vourinos	Dolerite	Subophitic, porphyritic	Pl, Cpx, Op (Acc: Tit)	Act, Chl, Qz, Ep, Cc
25	DMK1/Domokos	Trachyte	Porphyritic, glomeroporphyritic	Kf, Hbl (Acc: Zr, Ap)	Act, Chl, Ep, Cel, Ox
26	DMK2/Domokos	Trachyte	Porphyritic, glomeroporphyritic	Kf, Hbl (Acc: Zr, Ap)	Act, Chl, Ep, Cel, Ox

Acc: accessory minerals, Act: actinolite, Ap: apatite, Cc: calcite, Cel: celadonite, Chl: chlorite, Cpx: clinopyroxene, Czt: clinozoisite, Ep: epidote, Hbl: hornblende, Kf: K-feldspar, Ol: olivine, Op: opaque minerals, Opx: orthopyroxene, Ox: Fe-oxides, Pl: plagioclase, Qz: quartz, Ser: sericite, Serp: serpentine, Sp: spinel, Tc: talc, Tit: titanite, Tr: tremolite, Zr: zircon.