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# Investigation of the High Radiation Levels in Plio-Quaternary Volcanic and Pyroclastic Rocks Used as Building Raw Materials in Isparta Volcanic Area, SW Turkey

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**Abstract**
Available natural radioactivity ($^{40}K$, $^{238}U$, $^{232}Th$) measurements on Plio-Quaternary volcanic and pyroclastic rocks, which are usually used as building raw materials, from the Isparta region of SW Turkey, released that their radium equivalent activity values are close to the internationally accepted upper limits and a potential radiation risk. In this study, the relationship between their magma and source characteristics has been investigated to reveal the reason of the high radiation values in these volcanic materials carrying value by more than three times the equivalent materials in Turkey. Recent volcanological studies have shown that potassic-ultrapotassic magmas governed the genesis of the Isparta volcanism. Potassium-rich characters and elevated concentrations of radiogenic (e.g.,Th and U) and total rare earth elements (∑REE) are their most diagnostic features. These characteristics are also similar to some mantle-derived carbonatites (e.g., Norwage and Kenya) with high radiation levels. To support this, recent investigations also revealed that the origin of Isparta potassic volcanism is associated with a common and enriched mantle source, which were interacted with carbonatite melts. Accordingly, carbonatitic melts left their geochemical imprints into their mantle sources, and partial melting of this mantle source produced K, REE, Th, and U-rich volcanic materials with high radiation levels in the region. These results indicate that the carbonatite-influenced mantle source were played a key role for not only enrichments in distinct elements (e.g., Th, U and REE) but also high radioactivity levels in Isparta volcanic and pyroclastic rocks. In this study, attention is drawn to the fact that a potential risk of high radiation in volcanic and pyroclastic rocks used as building raw materials can be expected for a given volcanic region, which include potassic magma derived from a carbonatite-modified mantle source.

**Keywords:** Isparta, potassic volcanism, carbonatitic affinity, high radiation, building materials

# Isparta (GB Türkiye) Volkanik Alanında Yapı Malzemesi Olarak Kullanılan Pliyo-Kuvaterner yaşlı Volkanik ve Piroklastik Kayaçlardaki Yüksek Radyasyonun İncelenmesi

**Öz**
Isparta bölgesinde (GB Türkiye), genellikle yapı hammaddesi olarak kullanılan, Pliyo-Kuvaterner yaşlı volkanik ve piroklastik kayaçlarda belirlenmiş olan mevcut doğal radyoaktivite ($^{40}K$, $^{238}U$, $^{232}Th$) ölçümleri, radyum eşdeğer aktivite değerlerinin, uluslararası kabul edilebilir üst limitlerine ve potansiyel bir radyasyon riskine yakın değerler olduğunu açığa çıkarmıştır. Türkiye'deki eşdeğer materyallere göre üç kat fazla değerler taşıyan bu volkanik materyallerdeki yüksek radyasyon seviyelerine neyin sebep olduğunu çözümlemek için, burada, onları üreten mağmalar ve türedikleri kaynak arasındaki ilişki araştırılmıştır. Son güncel volkanolojik çalışmalar, Isparta volkanizmasının jenezini potasik ve ultrapotasik mağmaların kontrol ettiğini göstermiştir. Potasyumca zengin karakterleri ve yüksek konsantrasyonlardaki radyojenik element (örn., Th ve U) ve toplam nadir toprak element (∑NTE) içerikleri, onların en tanımlayıcı özellikleridir. Bu karakteristikler aynı zamanda, yüksek radyasyon seviyeli bazı karbonatitlerin (örn., Norveç ve Kenya karbonatitlerinin) karakteristiklerine benzerdir. Bunu destekleyecek şekilde, son zamanlardaki araştırmalar, Isparta potasik volkanizmasının orjininin, karbonatit

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eriyikleriyle etkileşmiş olan yaygın ve zenginleşmiş bir manto kaynağıyla ilişkili olduğunu açığa çıkarmıştır. Bunun bir sonucu olarakta, karbonatitik eriyikler, manto kaynağına jeokimyasal etkilerini bırakmış ve bu manto kaynağının kısmi ergimeside, bölgede K, NTE, Th ve U'ca zengin, yüksek radyasyon seviyeli volkanik materyalleri üretmiştir. Bu sonuçlar, karbonatitlerle etkileşmiş bir manto kaynağının, Isparta volkanik ve piroklastik kayaçlarının sadece belirgin elementlerce (örn, Th, U, NTE) zenginleşmelerinde değil aynı zamanda yüksek radyoaktivite seviyelerinde de anahtar bir rol oynadığına işaret etmektedir. Burada ayrıca, yapı malzemesi olarak kullanılan volkanik ve piroklastik kayaçlardaki yüksek radyasyonun potansiyel bir riski, karbonatitlerle modifiye olmuş bir manto kaynağından türemiş potasik mağmaların yüzeylendiği herhangi bir volkanik bölgeden beklenebileceğine de dikkat çekilmektedir.

**Anahtar kelimeler**: Isparta, potasik vokanizma, karbonatitik affinite, yüksek radyasyon, yapı malzemeleri.

## 1. Introduction

During the last decades, there is an increasing interest on radiological safety of rocks, due to their common usage as building raw materials, and effects on environmental pollution and human health. The specific levels of environmental radiation are related to the contents of thorium, uranium and potassium in the rocks and soils [1]. The most significant natural radionuclides are potassium ($^{40}K$), uranium ($^{238}U$), and thorium ($^{232}Th$) and their decay products. Igneous rocks from which building materials produced, commonly include these radionuclides, and are one of the sources of direct radiation. Information on their radionuclides concentrations and dispersions also provide useful information for monitoring natural radioactivity and environmental pollution [2]. Accordingly, the natural radiation is the main contributor to the external dose of the population and important to assess the gamma radiation dose from natural sources [3]. The concentrations of natural radionuclides in building raw materials (e.g., cement, bricks, concrete) are also measured to establish dose criteria [4-6]. In this regard, plenty of radioactivity measurements in magmatic rocks and in building raw materials from different localities of Turkey have been researched and reported by several workers [1-3,7-16]. From the natural radioactivity assessments in construction materials in Elazığ, Turkey [11], highest radiation value obtained in gas concrete (as 405.2 Bq/kg), which is higher than global values (370 Bq/kg). Similarly, mean activity concentrations in cement in Turkey [15] are lower than international standart values. Amongst the activity measurements in magmatic products from different localities in Turkey, the most remarkable values, which are close to the internationally accepted upper limit and enriched three times more than those of the other Turkish magmatic products, were obtained from the Isparta volcanic field. In this study, to better understanding of the reason for the high radioactivity levels in Isparta volcanic and pyroclastic rocks, a specific research have been performed on the relationship between their magma styles and source characteristics.

## 2. Volcanic Setting in Isparta Region

During Pliocene to Quaternary period of historical volcanic activity in Isparta region (SW Turkey), Gölcük explosive volcano and concomitant volcanic eruptions produced various types of volcanic (e.g., trachyte, trachyandesite, phonolite, leucite ankaratrite, lamprophyre) and pyroclastic products (e.g., ignimbrite, tuff, pumice) (Figure 1) [17-19]. Such volcanic products widespreadly exposed at surrounding areas of Isparta city centre, and overlies the pre-volcanic units (Figure 1). From these volcanic products, pumice is used to make lightweight building materials such as concrete and concrete block and for plastering the buildings made of bricks [16], and trachyandesite (locally known as andesite stone) is used as pavement stone.

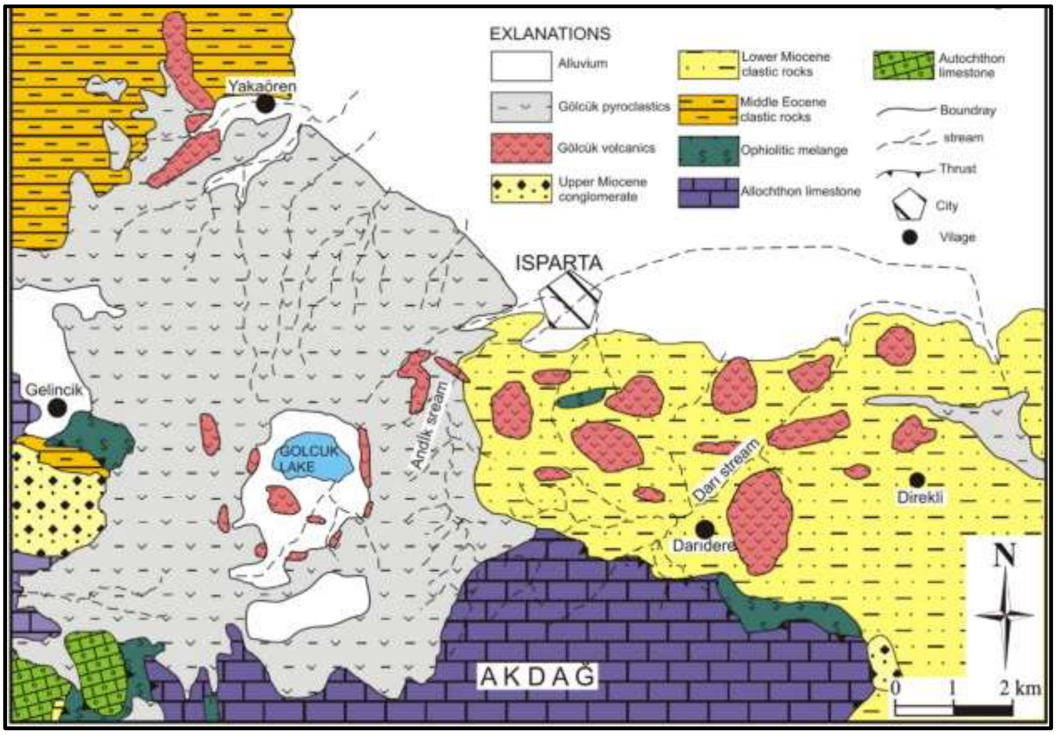


**Figure 1.** Simplified geological map of the Isparta region. Modified from [24].

## 3. Results

### 3.1. Th, U and REE Geochemistry of Isparta Potassic Volcanism

Potassic nature's and elevated concentrations of radiogenic elements (e.g.,Th and U) and total rare earth elements (∑REE) are the most diagnostic feature of the Isparta volcanism (Table 1). These characteristics also show a geochemical similarity to those of some carbonatites (e.g., Norway and Kenya carbonatites, [20,21]). Isparta volcanites were derived from two magma types; potassic-shoshonitic magmas and ultrapotassic magmas [17-19]. Average $K_2O/Na_2O$ ratio of potassic-shoshonitic magmas, from which trachytes, trachyandesites, phonolites, ankaratrites, pumices, tuffs and ignimbrites produced, is ≈ 1, and $K_2O$ contents almost range between 3 – 6 wt.% (Table 1). In ultrapotassic magmas, from which lamprophyres produced, average $K_2O/Na_2O$ ratio is greater than 2, and $K_2O$ contents can reach up to 10 wt.% [17,19]. All volcanic and volcanoclastic rocks are characterized by enrichments in distinct elements, e.g., ∑REE (up to 1325 ppm in phonolite; 733 ppm in trachyandesite; 805 ppm in ankaratrite; 695 ppm in lamprophyre), radiogenic Th (up to 138 ppm in pumice; 128 ppm in trachyandesite; 103 ppm in phonolite) and U (up to 37 ppm in pumice; 28 ppm in trachyandesite, 22 ppm in phonolite) (Table 1). Highest concentrations of Th (145 ppm), U (249 ppm) and ∑REE (32012 ppm) found in ultramafic xenoliths, which are represent to an enriched mantle source (Table 1).

### 3.2. Measured Radioation Levels in Magmatic Products from Turkey and in Some Carbonatites

Available radioactivity measurements of $^{226}$Ra, $^{238}$U, $^{232}$Th and $^{40}$K (Bq/kg) in tuffs, granites and pumice samples from different regions in Turkey, together with those of Isparta volcanic and pyroclastic rocks, are given in Table 2. Results show that except for Isparta samples, measured radiation levels of magmatic rocks in Turkey are low, and below the international accepted limits (370 Bq/kg). In contrast, Isparta volcanic and pyroclastic rocks contain enhanced concentrations of natural radioactivity, with respect to the other Turkey magmatic products. For example, in Isparta pumice, $^{226}$Ra values reach up to 256.2 Bq/kg. In Isparta volcanic rocks, $^{238}$U values reach up to 444 Bq/kg, $^{232}$Th values reach up to 408 Bq/kg and $^{40}$K reach up to 1959 Bq/kg (Table 2). As mentioned before, Isparta volcanics also carry the typical geochemical characteristics of carbonatites, and high radioactivity levels also reported from some carbonatite occurrences (e.g., Norway and Kenya carbonatites; [20,21]). In Norway carbonatites [20], $^{226}$Ra values reach up to 300 Bq/kg in rauhaugite, $^{232}$Th values reach up to 5900 Bq/kg in rödberg, and $^{40}$K reach up to 1500 Bq/kg in fenite. In Kenya carbonatites [21], $^{238}$U values reach up to 909 Bq/kg and $^{232}$Th values reach up to 4247 Bq/kg and $^{40}$K reach up to 1166 Bq/kg.

**Table 1.** Th, U and REE concentrations in Isparta potassic volcanics and in mantle xenoliths found in pyroclastics

| | Rock Type | | Th (ppm) | U (ppm) | $K_2O$ (wt.%) | $K_2O/Na_2O$ | ∑REE (ppm) | References |
|---|---|---|---|---|---|---|---|---|
| ISPARTA | Potassic Volcanic Rocks | Phonolite | 103 | 22,2 | 4,4 | 1,0 | 1325 | [19] |
| | | | 70 | 10,6 | 6,5 | 1,1 | 1274 | [18] |
| | | trachyte-trachyandesite | 128 | 28,0 | 6,5 | 1,0 | 635 | [22] |
| | | | 98 | 25,0 | 6,0 | 1,1 | 733 | [23] |
| | | ankaratrite | 38 | 9,8 | 4,4 | 1,5 | 713 | [24] |
| | | | 33 | 8,8 | 4,0 | 1,8 | 805 | |
| | Ultrapotassic Rocks | lamprophyre | 35,6 | 9,5 | 4,4 | 2,5 | 489 | [19] |
| | | | 33,8 | 6,2 | 5,4 | 2,0 | 695 | [17] |
| | Xenoliths | Ultramafic | 145 | 29,0 | 3,6 | 0,6 | 1366 | [23] |
| | | mafic, felsic | 132 | 249 | 7,0 | 11,8 | 32012 | [25] |

**Table 2.** Radioactivity measurements in magmatic rocks in Isparta and in other locations of Turkey

| Location | Rock type | $^{226}$Ra (Bq/kg) | $^{238}$U (Bq/kg) | $^{232}$Th (Bq/kg) | $^{40}$K (Bq/kg) | References |
|---|---|---|---|---|---|---|
| Central Anatolia | Tuff (average) | 17,8-97,2 (50,4) | | 17,4-96,0 (58,6) | 229-1036 (717,6) | [13] |
| Turkey (Isparta not included) | Tuff | 2-108 | 3-129 | 8,0-89,0 | 99-1147 | [8] |
| | Granite (average) | 0,7-186 (69,4) | | 0,5-249 (83,19) | 166-1923 (1234) | [12] |
| | Pumice (average) | 12,7-166,7 (80,9) | | 12,3-161,7 (80,5) | 445-1847 (1254) | [16] |
| Western Turkey | Granite (average) | 15,6-139,7 (60,5) | | | 297-880 (632) | [14] |
| Eastern Mediterranean | Pumice | 15,7 | | 16,11 | 403 | [2] |
| Isparta | Volcanic | | 204-444 | 234-408 | 1608-1959 | [1] |
| | Trachyandesite | | 351 | 261,4 | 1460 | [10,26] |
| | Pyroclastic | | 172-280 | 192-278 | 1261-1555 | [1] |
| | Tuff | 146-197 | 211-356 | 159-366 | 940-1290 | [8] |
| | Pumice (average) | 235,9-256,2 (244,4) | | 224,4-237,9 (231,4) | 1613-1840 (1743) | [16] [7] |

## Discussion

The origin of Isparta Plio-Quaternary potassic-ultrapotassic volcanism is associated with a lithospheric mantle source metasomatized by slab derived melts/fluids and asthenospheric melts [19,24,27]. Recent petrological studies also demonstrated that the asthenospheric carbonatite melts were played a key role on the mantle lithosphere of Isparta Plio-Quaternary volcanism, and they interacted and modified the wall-rock peridotites [24,27]. Hence, carbonatite melts left their geochemical imprints into these mantle metasomes. Partial melting of carbonatite- and slab melts-modified lithospheric mantle produced the several types of volcanic and pyroclastic products in the region. Thus, high Th, U and REE concentrations in Isparta volcanic and pyroclastic rocks can be explained by observed carbonatitic affinity, since carbonatites are the main carrier of REE and some radiogenic elements (e.g., Th and U). Presence of highest concentrations of Th, U and REE in ultramafic xenoliths found in pyroclastic rocks support this arguement (see Table 1). Accordingly, measured high radioactivity levels in some carbonatites (e.g., Norway and Kenya) [20,21], also can provide an evidence for elevated radiation ratios of Isparta potassic volcanics. These petrological inferrence also suggest that since their usage of building and industrial raw materials, a potential risk of high radiation in volcanic and pyroclastic rocks can be expected for a given volcanic region, which include potassic magma derived from a carbonatite-modified mantle source.

## 4. Conclusions

Obtained radioactivity measurements in magmatic products in Turkey demonstrated that Isparta volcanic field carry values by more than three times the magmatic products in other locations. In this study, a spesific geochemical research on potassic magmas and source characteristics of volcanic and pyroclastic products in Isparta volcanic field have been realised to clarify the reason for their high radioactivity levels. Results are given below:

1. High radioactivity ($^{40}K$, $^{238}U$, $^{232}Th$) levels in Isparta volcanic and pyroclastic rocks are related to the high elemental concentrations of K, Th and U in these volcanic products.
2. High REE concentrations in Isparta potassic volcanic products derived from a carbonatite-modified mantle source, together with high Th and U, are typical characteristics of those of some mantle-derived carbonatites (e.g., Norway and Kenya).
3. Presence of high radiation levels in mantle-derived carbonatites (e.g., Norwage and Kenya) indicates that high radiation levels in Isparta volcanic products are related to role of carbonatitic melts in the genesis of Isparta volcanics.
4. Carbonatite melts left their chemical effects in the mantle source, and partial melting of this carbonatite-modified mantle produced several types of volcanic products with high radiation levels in the Isparta region.
5. It is also concluded that a potential risk of high radiation in volcanic and pyroclastic rocks used as building raw materials can be expected for a given volcanic region, which include potassic magma derived from a carbonatite-modified mantle source.

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